POST-OPERATIVE

WOUND INFECTION

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(1) Special measures to overcome the difficulties of skin sterilization.

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The most striking of these were:-

In the wards:

(1) A completely inadequate dressing technique;

(2) Failure to use accepted dust-suppressive measures on the floors and on the blankets, leading to a considerable pollution of the ward air by staphylococcus pyogenes, many strains of which were resistant to penicillin.

In the theatre:

(1) A completely inadequate masking system,

coupled with a high incidence of nasal carriers of staphylococcus pyogenes in the operating personnel.

(2) Increased contamination of theatre air resulting from failure to wear overboots, as proved by a specially designed experiment.

The commonest wound infector was staphylococcus aureus.

There was a high incidence of staphylococcus aureus nasal carriers amongst surgeons and anaesthetists.

The air of the theatre and the wards invariably contained staphylococcus aureus.

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CHAPTER 6.

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PART ONE

CHAPTER ONE

INTRODUCTION

INTRODUCTION

There can be no possible doubt that the practical application of Surgery depends for its success primarily upon the employment of an aseptic technique which is rigid and meticulous to the extreme.

At first sight, a statement of this nature would appear out of place in this age of modern surgical achievement, where the aseptic technique has become exceedingly elaborate, and where it has become a routine procedure in the operating theatre.

In the same light, it would appear that a thesis devoted to the problem of wound infection would be a mere repetition of what has now become common knowledge, for the surgeons discussed this problem 70 and more years ago, and the literature from that time onwards abounds with articles and treatises dealing with the cause, the treatment and the prevention of post-operative wound infection.

Up to a point, all this is true, but the fact remains that even in this day of modern surgical achievement, and in spite of the remarkable advances in medical science during the past decades, the best run hospitals all over the world still show evidence of a considerable incidence of infection in clean operation wounds. In

an analysis of the figures given by various authorities in recent times, it is found that the incidence of infection in clean operation wounds is in the neighbourhood of from 5% to 15%. (171, 100). Deryl Hart reported on infection occurring after major surgical procedures in a hospital where "every step of the aseptic technique was subjected to critical analysis", and in spite of which no less than 17 deaths occurred from infection over a period of 5½ years, and of which 6 deaths occurred within a period of 3 months. (83, 84). Following intra-cranial operations, Cairns found that in one year, 25% of the operative fatalities were due to operative infection. (32). Siddall & Mack reporting on a large series of hysterectomies as recently as this year, found that post-operative infection was numerically and proportionately the greatest contributing factor to mortality in the whole series. (167).

Most observers have found that the average surgeon is ignorant of his infection rate, and that even the honest surgeon usually imagines it to be exceedingly small, or else negligible, but when a careful investigation is instituted, it is invariably found to be quite considerable. (125).

Meleney (122) says: "I must confess, we go blissfully on our way using operating room technique

handed down for several decades in the firm conviction that it could not be improved upon".

Post-operative wound infection remains to this day one of the major problems in surgery, and it is responsible not only for an occasional death, but for a much greater percentage of invalidism, pain and suffering. These sequelae are all unnecessary and they are all preventable, and until such time as infection in the clean operation wound has been brought to an irreducible minimum, the problem of wound infection remains unsolved, and the subject must therefore remain open for discussion.

Both the surgeon and the scientist must continue in their efforts to improve on those procedures of the present day aseptic technique which still have their deficiencies, and every contribution, no matter how small, which leads to a further reduction of wound infection, brings us a step nearer the attainment of the ideal in surgery.

Above all, it will always remain the duty of the operating surgeon, every time a human life is placed in his care, never to deviate for a moment from the path of carefully and rigorously planned aseptic technique which he knows will enable that life to recover from his surgical interference under the optimum conditions.

Moynihan said: "Every operation in surgery is an experiment in Bacteriology, and the success of the experiment

depends not only on the skill, but also on the care exercised by the surgeon in the ritual of the operation." (132)

The introduction into surgical practice in recent years of a large number of powerful antiseptics and antibiotics has brought with it a very real danger - a danger that there may result a slackening in the carefully planned ritual of our aseptic technique, and that the surgeon may begin to lose that respect for pathogenic organisms on which the aseptic principle was founded.

The value of these substances can never be over-estimated, but they were never intended to clear the conscience of the operator.

This thesis aims at the application of present day knowledge of the causes and prevention of post-operative wound infection to a large South African Hospital. This has resulted in some interesting and important findings, but the main object of this work is to impress on the surgeon the paramount importance of a rigid and meticulously applied aseptic technique.

In addition, a major surgical operation has been devised for the study of such infection in the laboratory animal.

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CHAPTER TWO

HISTORICAL NOTE

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It is interesting to note that from the time when wounds were first described in surgical literature in the Papyri of ancient Egypt (1600 B.C.), right up to the time of Lister, knowledge in regard to the cause of infection and the treatment of infection had made very little progress.

The ancient Egyptians used the oil extracted from castor oil seeds for their wounds; Hippocrates (460 B.C.) used tar and wine dressings; Celcus in his De re Medicina (A.D.30), described the use of myrrh, nitre, saffron and iris; Galen (A.D. 130-200), spoke of pus being laudable; the surgeons in the middle ages used on their wounds dressings which promoted the production of pus; and in the time of Lister, thick creamy "laudable" pus poured from every operation wound that stood any chance of recovery.

For may centuries it was believed that disease was a form of punishment from a supernatural source, and very gradually this gave way to the theory that the air carried in it some ill defined miasma or a vapour which had a special affinity for certain people. This theory was first postulated by Hippocrates, and for a very long time it was believed that the air and the wind were carriers of disease, and in fact as late as the 16th

century, the pandemics of the Justinian reign were regarded as a result of vitiation of the atmosphere from putrefaction of animal substances. In 1665, William Baghurst, one of the heroes of the Great Plague of London, wrote: "Plague or pestilence is a most subtle, peculiar, insinuating, venemous, deleterious exhalation arising from the maturation of the ferment of the faeces of the earth, extracted into the aire by the heat of the sun, and difflated from place to place by the winds, and most tymes gradually but sometymes immediately aggressing apt bodyes."

More than a hundred years previous to this, however, in 1546, Fracastorious had theorised in a remarkable manner on the existence of seeds or germs of disease, which were transported in the air, but his theory of "contagium animatum" lay dormant until it could be placed on a sounder footing by the discovery of the microscope at the beginning of the 17th century. It would seem that theearliest reference to the microscope was made somewhere between the years 1590-1610, although the real discoverer "of a world of living creatures" was Anthony van Leeuwenhoek (1632-1723), but it was not until more than 200 years later that Cohn established the vegetable nature of bacteria in 1853, and that Ehrenberg (1854) wrote a treatise on micro-organisms.

In the meantime, in 1836, three different

observers, Schwann, Kützing, and Latour, showed independently that fermentation, which until that time was considered a simple chemical reaction, was really a biological process due to yeast which they showed was a living organism.

Although a great number of different scientists of that time contributed materially to the discovery that the air contained bacteria, the credit for establishing the fact that the so-called putrefactive changes and the fermentations in organic matter were caused by these bacteria has usually gone to Louis Pasteur (1860).

The story is well-known how 7 years later, Lister, as a result of hearing of the work of Pasteur and encouraged by his efforts to understand and to reduce the appalling conditions of hospital gangrene in the surgical wards, applied Carbolic to a compound fracture of the femur. Lister's paper, "On the Antiseptic Principle in the Practice of Surgery" in 1867 marks the turning point in the history of surgery, and the beginning of the aseptic technique as we understand it to-day. (104).

Lister did not discover carbolic acid, nor was he the first to indicate the contagious nature of surgical fever or puerperal fever. (This had been done as early as 1843 by Holmes and in 1847 by Semmelweiss.) Furthermore, he had not contributed to the knowledge that bacteria were the cause of infection in wounds; but the credit goes

to Lister because he was able to formulate a principle, the application of which has resulted in the amazing progress of surgical science which has occurred in the last 60 years.

It was not until three years after Lister's paper that Pasteur announced the discovery of the staphylococcus and the streptococcus, and in 1881, Ogsten demonstrated the presence of staphylococci in abscesses.

Up until this period, the surgeon was limited in his scope to amputations, lithotomy, vascular surgery, and the drainage of abscesses, while the abdomen, the thoracic cavity, the cranial cavity and the spinal cord remained virtually untouched. The mortality following amputations was considered normal when it did not exceed 50%, but after the work of Lister, there began an immediate improvement in the post-operative fatalities. With this improvement other fields began to be explored, and this applied chiefly to the Continent where Lister's principles were more readily accepted than in England. From that time onwards, progress became very rapid indeed, so that within the space of a few decades there was no part of the human body which was not explored by the surgeon.

At the time of Lister, great stress was laid on the organisms which were in the air and special measures in the form of carbolic sprays were adopted to cope with these, but it soon became to be realised that by far the

most important source of infection was by direct contact, and in view of the great improvement in the post-operative infection which occurred as a result of dealing with this aspect, the theory of air-borne infection became to be overlooked.

The hands, the instruments, and anything else which came into direct contact with the wound were therefore subjected to a process of sterilization. In 1891, Halsted introduced the use of rubber gloves for all those taking part in an operation, but it was a long time after this before gloves came into general use. Originally they were used only by the instrument nurses to protect their hands from corrosive disinfectants, and gradually they came to be worn by the surgeon as well. Cotton gloves had been in use on the Continent as early as 1880 but chiefly for the purpose of obtaining a better grip.

In 1897, C. Flügge demonstrated the danger of droplet spread from the surgeon's mouth into the operation wound and in the same year he suggested the use of a mask to Mikulicz. Here too there was a great deal of opposition from the contemporaries of the time, so that it was not until some years later that masks became to be used. In 1900, William Hunter advocated the use of masks for surgeons and nurses, and from that time onwards numerous articles appeared in the journals advocating various types and modifications.

The importance of the air as a carrier of

infection was limited to the droplets which Flügge had described, but apart from this, the air was not considered of any consequence, and in fact, scientists went to great length to show that the air could be disregarded as a vehicle for the spread of infection. This is well borne out by the very emphatic statements of C. V. Chapin in 1912, and the result was that it was not until about 15 years ago that this view was exploded by the work of Wells.

By this time, the field of surgery had been extended considerably. As a result of improvements in the administration of anaesthesia, and improvements in the pre- and post-operative care of patients, more lengthy and more difficult operations were performed, and these often meant the exposure of large raw surfaces to the air for long periods of time. With this advance, there came also an increase in post-operative infection, and this was found to occur in spite of an aseptic technique which was exceedingly rigid. This infection was shown to be due to droplet nuclei in the air of the operating rooms, and it was shown that by sterilizing the air of these rooms, the incidence of infection was reduced to a small fraction of what it was previously. This work of Deryl Hart in connection with the use of Ultra-violet radiation in the operating theatre, marks another important step in surgery. Within the last decade, other important contributions to the aseptic principle have been added to the already

formidable list, and these include the reduction of air contamination in the wards by the oiling of blankets and floors, by van den Ende, Lush, Edward, et al., and the sterilizing of the air of wards by means of aerosol vapours, by Douglas, Hill and Smith in 1928, and later by a number of other observers. (30, 118, 174, 181, 182, 67, 69).

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CHAPTER THREE

THE CAUSES OF POST-OPERATIVE WOUND INFECTION

THE CAUSES OF POST-OPERATIVE WOUND INFECTION.

Today, the field of surgery knows few limits, and it is probably safe to say that the one factor which has contributed more than most to the successful application of our present day major surgical procedures, is the appreciation and understanding of the complex methods involved in the production of wound infection. In spite, however, of the amazing progress which has occurred in the first half of this century, we are still faced with the problem of post-operative wound infection, and in those hospitals where a careful study has been made, it has been found to be quite considerable. Following clean operations, the incidence (as indicated before) has been shown to be between 5% and 15% in modern, well run hospitals, and it is higher in accident wards.

Post-operative infection varies in degrees from a condition of slight delay in healing, to a condition of fulminating septicaemia and death. The following sequelae, taking place in a clean surgical wound, which in the normal course of events, should have healed in the optimum time and by complete resolution, constitute infection:-

(1) Stitch abscesses: excessive redness of the suture line accompanied by an undue elevation of temperature; certain cases of phlebitis and

thrombosis; cellulitis of the surrounding tissues ; and finally, suppuration in the wound.

(2) In more severe cases there is sloughing of the wound; or there may be septicaemia and death.

(3) Included here are also those cases where there has been no severe local disturbance, but a chronic inflammatory process has resulted in a wide scar, a heaped up bluish scar (some of the keloids may be included here), and a certain percentage of peritoneal adhesions.

(4) As a later sequel to these inflammatory processes, herniation of the wound is a common complication.

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The present day system of aseptic surgical technique has become very elaborate, each individual step in the system having as its one object the prevention of bacterial access to the wound, and it has become elaborate as a result of the discovery of the many devious paths by which bacteria may find their way into a wound. A surgical wound is constantly in danger of becoming infected from the moment of the initial incision until its final resolution, and this infection may be brought to the wound either in the operating theatre, or in the ward, or in both.

IN THE THEATRE:

The wound may become infected from one or more of the following sources:-

(1) The patient's skin.

(2) The surgeon and his assistants.

(a) Their hands;

(b) Their noses and throats;

(c) Their clothes and shoes.

(3) The instruments and equipment.

(4) The theatre air.

IN THE WARD:

The wound may become infected from one or more of the following sources:-

(1) The patient himself.

(2) The dresser.

(a) Her hands;

(b) Her nose or throat;

(c) Her clothes.

(3) The instruments and equipment.

(4) The ward air.

Thus we find that similar mechanisms operate both in the theatre and in the ward, but it is obvious that the relative importance of each must differ to a certain extent depending on whether we are dealing with the ward or with the theatre. To facilitate the

description and at the same time to obviate unnecessary repetition, the discussion will be limited to the following items:-

(1) The patient.

(2) The patient's skin

(3) The surgeon, assistants and dresser:

(a) Their hands;

(b) Their noses and throats;

(c) Their clothes.

(4) The instruments and equipment.

(5) The air.

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(1) THE PATIENT

It happens occasionally that the patient is the source of his own infection, and this infection in the wound, when it occurs, is usually due either to the streptococcus pyogenes or staphylococcus aureus. The patient is a carrier of this organism without being aware of the fact, and the organism is found either in the nose or in the throat, or in both. It has been shown that 40% to 50% of all normal people harbour staphylococcus aureus in the anterior nares (77,78), and that a varying number of normal people give positive throat or nose swabs for streptococcus pyogenes, different authors giving figures from 5% to 30% (126,77). This high carrier rate pertains

chiefly to the colder climates, and the incidence is found to be higher in the winter than in the warmer weather.

10% to 20% of the staphylococcal carriers harbour the identical organism on the skin of the hands, wrists and other parts of the body. In a similar way, the streptococcal carriers harbour the identical organisms on the skin of the hands, face, upper trunk, in the hair, and invariably in the clothes as well.

These people infect their wounds by the following mechanisms:-

(a) The organism may be already on the skin in the vicinity of the wound, and thus can easily get into the wound;

(b) The organism may be brought to the wound by the infected hands of the patient;

(c) In the process of talking, laughing, coughing and sneezing, infected droplets are deposited on the blankets of the patient and in the immediate vicinity. The latter may include the dressing trolley with its exposed instruments and dressings, and from here the organisms may later be deposited into the wound. The bacteria deposited on the blankets are disturbed when the blankets are handled, and are liberated into the air, but they may also infect the hands of the nurse who is attending to the blankets. From the air, the organisms later sediment out on the dressing trolley or even directly into the wound when this is exposed.

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(2) THE SKIN OF THE PATIENT.

The skin of every human being harbours an enormous number of bacteria. These are of two types:-

(a) The resident bacteria;

(b) The transient bacteria.

(a) THE RESIDENT BACTERIA:

These are the normal inhabitants of the skin and they consist chiefly of staphylococcus albus, and staphylococcus citreus. They are to be found living on the surface of the skin embedded in the horny fat, in the skin creases and crevices, in the hair follicles, and more deeply in the skin - in the sebaceous glands. Studies of sections of the skin incubated for a period of 6 hours all show the presence of these organisms deeply in the pilonidal follicles and sebaceous glands, and embedded in sebaceous material.(112). On the other hand, a careful study of the sweat glands has failed to find organisms in them. Bacteria have not been demonstrated in the excretory ducts; in the coiled portions as they pass through the epidermis; and in the secreting tubules.

All the resident bacteria are situated outside the body, and they are never found inside the cells or between the cells, either of the epidermis or the cells lining the pilonidal follicles.

The resident flora remains remarkably constant both as regards numbers and composition for long periods of time. When the skin has become partly sterilized by vigorous mechanical and chemical means, the flora returns to the original figure both as regards size and composition within the space of about a week. At first the return is rapid, but slows down after a few days. (140).

These bacteria are found all over the body, being more numerous as a rule on the covered parts of the body than on the exposed parts, and their numbers and composition vary with different individuals and their habits.

(b) THE TRANSIENT BACTERIA.

These are the contaminating organisms, and, as will be readily appreciated, they may be of numerous kinds, both pathogenic and non-pathogenic. Amongst the more common and important pathogenic bacteria of surgical importance, which are likely to contaminate the skin, are the following:-

Staphylococcus aureus,
Streptococcus pyogenes,
Escherichia coli,
B. proteus,
Ps. pyocyanea.

These organisms are more loosely attached to the

skin, adhering to it through the medium of the grease and dirt which are on the skin, and they are found chiefly on the exposed parts of the body, and especially those parts that are liable to come in contact with infected material. The hands therefore play an important part in this respect. Conditions on the skin are usually not very favourable for the growth and multiplication of these extraneous organisms, but it does happen not infrequently, and especially with repeated contact, that they become adapted to the new conditions, and then they become resident bacteria along with the normal residents. In those people who are nose and throat carriers of pathogenic organisms as mentioned before, these organisms become residents, and they are therefore found deeply in the skin.

REMOVAL OF BACTERIA FROM THE SKIN.

The methods adopted for this purpose are mechanical and chemical. The surface bacteria are embedded in the horny fat, dirt and other foreign material. These bacteria consist of the transient flora in addition to a certain percentage of the resident flora. Mechanical means of cleansing, consisting of the use of brush, soap and water, removes the surface bacteria along with this horny fat and dirt, but the more deeply placed bacteria are not affected. Chemical cleansing consists of the application of antiseptic solutions, and these are not

effective on the surface bacteria until the horny fat and dirt have been removed. The deeply placed organisms are embedded in sebaceous material which is a highly insoluble substance and for this reason they are protected from the action of most antiseptics which may be used on the skin without causing damage to the skin. These deeply placed organisms are our greatest difficulty in the process of skin sterilization, and there is so far no known antiseptic which has sufficient penetrating power to attack them, without at the same time causing injury to the skin. (110).

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After thorough mechanical and chemical cleansing of the skin, negative swab cultures can often be obtained, but after a short while, the deeply placed bacteria, as a result of multiplication, rise to the surface and so contaminate it again. Warmth and perspiration of the skin will hasten this process. This does not mean that the organisms are brought to the surface in the sweat, (the sweat glands are sterile) but sweating increases the surface tension on the skin and this assists to bring the deeper organisms to the surface. Sweat is sterile until it reaches the skin, but there it becomes a favourable medium for the growth of bacteria.

Swabs taken of the wound after it is made, and after thorough skin preparation, usually are positive for

resident bacteria. These are introduced into the wound by the knife which must necessarily pass through a large number of infected hair follicles and sebaceous glands.

At the end of an operation, swab cultures are always positive for a much greater number of organisms and these are a result of multiplication of those originally introduced into the wound, in addition to those that have escaped from the cut edges of the wound, and those that have been carried into the wound with the perspiration on the surface of the skin. This happens even in the presence of lining swabs attached to the edges of the wound. (112).

Most of these organisms are residents, and the number of pathogens amongst them will depend firstly on the thoroughness of the original skin preparation, and secondly on the pathogenicity of the resident flora. (This excludes for the present those organisms which have acquired access to the wound from other sources.)

The presence of a moderate number of these resident bacteria in a wound does not necessarily imply that suppuration will follow. Assuming the tissues to be in a healthy condition, and assuming that the operative technique was not faulty, in the great majority of cases the local and general tissue reactions are in a position to cope with these organisms, so that repair proceeds to a normal resolution. All these factors, however, are not always present, and in addition, the susceptibility of

different people to different organisms varies considerably, so that not infrequently, the presence of these bacteria in the wound constitutes a real danger.

The presence of skin infection in the neighbourhood of the operation site will naturally increase the chances of infection entering the wound, and this applies equally in those cases where the incision passes through the lymphatic drainage from an infected area situated more distantly.

Where a wound has to be reopened for a second stage operation, the presence of slight infection in this wound will greatly increase the chances of the new wound becoming severely infected.

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(3) THE SURGEON, THE ASSISTANTS and the DRESSER.

(a) THEIR HANDS:

This will apply to all those persons whose hands come in contact either with the wound at the time of the operation or after the operation, or with instruments and equipment which may be used in or on the wound.

It concerns chiefly the surgeon and his assistants at the time of the operation, and the dresser later on in the ward.

The statements in the previous pages in connection

with skin bacteria naturally apply equally to the hands, but here it is important to note that the question of transient bacteria, and pathogenic bacteria which have become residents, play a very important part in the bacterial flora. It is natural that the people who come in contact with wounds a great deal are the ones who are most likely to get their hands contaminated with various strains of micro-organisms. These are the same people who are chiefly concerned in the production of fresh wounds, or in the dressing of fresh wounds. It has been shown (140) that repeated contact with pathogenic organisms is very liable to result in the establishment of these bacteria as residents along with the normal residents. From the surgeon's point of view, this is a very serious matter because it means that even with thorough cleansing of the hands prior to an operation, these new residents remain in the deeper layers of the skin and they emerge during the course of the operation, being especially encouraged to do so on account of the rubber gloves he wears. From the dresser's point of view, these new residents constitute an excellent source for cross infection in the ward.

In this connection it would be important to stress the danger which arises from the pernicious practice employed by both surgeon and dresser of inspecting wounds by raising the edge of the dressing with the bare hands or fingers. It has been shown that even in those cases where

the outer dressing does not appear to be soiled, the infecting organism can nevertheless be demonstrated in these dressings, and furthermore, the same organisms can be shown to be transferred to the fingers as a result of such a procedure. (127).

Normal carriers of pathogenic organisms in the throats and noses are found to an equal extent amongst members of the medical and nursing professions, and it is clear therefore that a certain percentage must harbour these organisms on the hands as well. These organisms are residents on the skin of the hands and they present the same difficulties of removal as the other residents.

These pathogenic residents constitute one of the most important causes of wound infection, and one of the most difficult to deal with. (55, 127). Despite thorough cleansing of the hands prior to an operation, these pathogens re-infect the surface of the surgeon's skin after a very short time, and it means that damage to his gloves during the course of the operation, immediately constitutes an opportunity for these bacteria to gain entrance to the wound. In a careful examination of gloves after operations, Miles and Devenish (55) found that in an analysis of 6965 gloves, between 15% and 24% were punctured after different operations. In the case of a surgeon who was a staphylococcal carrier, they were able to demonstrate that at the end of an operation, if

the outsides of the gloves were sterilized, and a small puncture made in the glove at the finger tip or over a knuckle, light pressure of this part of the glove on to an agar plate invariably prodduced a good growth of staphylococci. In the same way, they were able to obtain good growths of the organism from swabs of the outsides of the operating gown sleeves. (55).

Price (140) has calculated that the number of resident bacteria on the skin of the two hands and arms as far as the elbows may be anything up to 8,000,000 or 9,000,000, and that this number remains remarkably constant for one individual for many years.

Vigorous scrubbing of the hands and arms with brush, soap and running water, reduces the basic flora at a constant logarithmic rate, roughly by half every six minutes, or two-thirds every ten minutes. It would therefore require about 2½ hours' continuous scrubbing to sterilize the skin completely. (140).

Soap is useful for the removal of the transient bacteria because these are attached to the grease on the skin, but it can be shown that the resident bacteria require for their removal, chiefly mechanical scrubbing, and that they are removed at a faster rate when the hands are scrubbed with a brush and water only, than when soap is used as well. The soap in this case acts as a lubricant and reduces friction. The use of sterile water has no

advantage over tap water.

The wearing of rubber gloves increases very rapidly the return of the basic flora, and in fact it increases the number of organisms which are finally on the skin. Beginning with 3,000,000 bacteria on the hands and arms after cleansing, it was found that after wearing gloves for a period of 2 hours and 40 minutes, the count was increased to 26,000,000 organisms. (140).

Putting on gloves with mercuric chloride, boric acid, or 4% alcohol solutions, made no difference to the final counts; nor did dry hands with powder make any appreciable difference to the final counts. (140).

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As far as the surgeon is concerned, he may be the cause of infecting his wounds by means of his hands in the following ways:-

(a) Imperfect cleansing of the hands prior to an operation.

(b) If he is a carrier, the organisms may escape, in spite of thorough cleansing, through tears in the gloves during the operation, or by penetrating the sleeves of his gown, especially if these are wet.

This will apply to his assistant and to the nurse who handles his instruments.

As far as the dresser in the ward is concerned,

the hands play a very important role in the process of cross-infection for the following reasons:-

(a) The average surgical ward contains patients with clean surgical wounds; patients with infected wounds; patients with discharging sinuses; and patients with extensive burns which are invariably infected with a variety of different organisms.

(b) The dresser on her dressing round must necessarily come in contact with infected material, and therefore her hands in due course harbour pathogenic bacteria which have become established as resident bacteria.

(c) The dresser's scrub-up is not as thorough as that of the surgeon, and therefore she must leave considerable numbers of organisms on her hands - both resident and transient.

(d) The dresser usually performs her dressings with the bare hands. This leads in the first place to possible infection of the clean wound from her hands, or in the second place it may lead to infection of her own hands from an infected wound.

The danger of pathogenic organisms becoming established as residents on the hands of surgeons and dressers has been stressed, but it is equally important to realise that it has been shown that once these pathogens become residents, it is a matter of considerable difficulty to remove them as such.

It cannot be stressed sufficiently, therefore, how important it is for the operating surgeon and the dresser to avoid at all costs contamination of the hands with infected material.

.....

(b) THEIR NOSES AND THROATS:

In 1897-1899, C. Flügge (64) drew attention to the fact that in the normal acts of talking, laughing, sneezing and coughing, small particles of saliva were projected from the mouth, and that these particles contained micro-organisms which were normally present in the mouth and throat. In his investigations and those that followed, it was shown that these particles were projected for a short distance only and were deposited within an area of two or three feet from the individual. Flügge stressed the importance of these droplets as a possible cause of wound infection by the surgeon, and he persuaded Professor Mikulicz to test out various methods for the reduction of this mode of infection. As a result of these findings, considerable stress was laid on the dangers of talking while an operation was in progress, and in fact, several surgeons of that time actually prohibited talking in the operating theatres. As it was necessary to make the occasional comment, Mikulicz suggested

the use of a bandage to be worn over the mouth. After a short period it was found that the nose also had to be covered.

Apart, however, from the actual deposition of infected droplets into the wound, it was taught that the air was not a carrier of infection, and this view was held until it was proved by Wells (199) in 1933-1934, that bacteria were suspended in the air of semi-enclosed spaces and that these were a constant source of infection. Cruickshank in 1935 (49) made the observation that most third degree burns after admission to hospital became infected with organisms which were infecting wounds in the ward, and this soon led to intensive study of the air as a source of infection both in the theatre and in the ward. It was soon found that the bacterial pollution of a room was proportional to the number of people in the room, and further it was demonstrated that the organisms which were in the air were identical with those present in the noses and throats of the occupants of the room. (3, 71, 73, 87, 125). Still more important, it was found that when all the occupants of an operating room wore masks over the mouth and the nose, the air still became contaminated by the organisms harboured by these people (8, 84), and that the degree of contamination of the air was proportional with the number of people in the room. (83, 84, 85). These are extremely important findings, and they are facts which are

not appreciated fully enough even today.

...

Droplets expelled from the mouth and nose during the acts of talking, laughing, coughing and sneezing are of different sizes, and the ultimate fate of these droplets depends on their size. The larger droplets are projected a short distance from the mouth and immediately proceed to fall to the ground, describing a curve in their descent. The smaller ones evaporate very rapidly and almost as soon as they have left the mouth; leaving a minute particle of organic matter and salts, to which may be attached organisms coming from the throat. These latter are droplet nuclei, and on account of their size they remain suspended in the air for long periods of time.

When a stream of air is passed over the surface of a liquid at a high velocity, small particles of the liquid become detached and pass on with the stream of air in the form of droplets - producing what is called atomization. The size of the droplets produced will depend on a number of factors, including:-

1. The velocity of the air stream.
2. The surface tension of the liquid.
3. The viscosity of the liquid.
4. Its chemical composition.
5. Particulate inclusion in the liquid.
6. Evaporation.

For practical purposes we know that the higher the velocity, the smaller will be the droplet; and the greater the viscosity of the liquid, the larger will be the droplet. Castleman in 1931 (33) showed that when an air stream is passed over water at a speed of 100 metres per second, the minimum droplet size produced was 10 μ in diameter.

In talking, coughing and sneezing, a process of atomization takes place, but here the velocities of the air current are usually much less than 100 metres per second, and in addition the saliva or mucous in the mouth or throat have a greater viscosity than water. The resulting droplet is therefore greater than 10 μ.

Strauss, in 1922, (172) found that in loud speaking air velocities of 16 metres per second were attained while enunciating the letters "p" and "t". Chaussé and Magne (38), 1916, estimated the velocity of air past the glottis in coughing at 40 to 48 metres per second, and that it may even reach 100 metres per second (i.e., 328 feet per second). Various authors since then have shown by various methods that the diameter of these droplets is anything from 20 to 2000 μ and that the majority are in the neighbourhood of 100 μ to 500 μ. (1, 95, 196). Wells (196, 197), who did a great deal of pioneer work in this direction, showed that droplets of 100 μ in diameter evaporate and remain suspended in

the air before falling the distance of the height of a man. Droplets larger than this fall to the ground before they have evaporated.

The rate of fall of a droplet and the rate of its evaporation will depend largely on its size. The velocity of a large droplet in its downward journey increases as it descends, as shown by the formula:-

$$V = Vo + gt$$

where Vo is the initial downward velocity
g is the acceleration due to gravity
t is the time of fall.

The small droplets behave differently. It can be shown that particles of 0.1 mm in diameter and less have a constant rate of fall because of the greater air resistance relative to their size. The downward velocity of such a particle is expressed by the formula:-

$$V = \frac{2\,r^2\,gp}{9n}$$

where r is the radius of the droplet
g is the acceleration due to gravity
p is the density of the particle
n is the coefficient of viscosity of the air at a given temperature and pressure.

Assuming no evaporation to take place, droplets will take the following times to fall a distance of two metres:-

Diameter	Time
1 mm	less than 0.6 seconds.
0.1 mm	6 seconds.
0.001 mm	16.6 hours.

Evaporation, however, plays a big part in the fate of droplets, and the smaller a droplet is, the greater is its surface area in relation to its volume, as shown by the formula:-

$$\frac{\text{area}}{\text{volume}} = \frac{4\pi r^2}{4/3\pi r^3} = \frac{3}{r}$$

As evaporation takes place from the whole of the surface of the droplet, it is clear that the smaller the droplet becomes, the more rapidly it diminishes in size relative to its volume than a larger one. In addition, the rate of evaporation is further increased for small droplets because of the increase in vapour pressure with decreased radius of curvature. (90).

Wells, (196) found that water droplets evaporate at the following rates in unsaturated still air and at a temperature of 22° Centigrade:-

Diameter (microns)	Seconds
2000	515
200	5.2
50	0.31
25	0.08
12	0.02

(1 micron = 1/1000 mm)

The rate of evaporation, however, depends on a number of physical factors such as:- surface tension,

viscosity, velocity of the particle, air movement, temperature, humidity and so on; and Wells came to the conclusion that: "Since respiratory droplets are not the same physically and chemically as water, somewhere between 0.1 mm and 0.2 mm lies the droplet size which identifies droplets of mouth spray that reach the ground within the life of the droplet, as against droplets that remain in the air as droplet nuclei with attached infection." (196).

Droplets, then, of 0.1 mm and smaller evaporate so rapidly after expulsion that they have no time to sediment out of the air. They now behave like particles of smoke and depend for their movement on the air currents in the room. In still air they remain suspended in the air for long periods of time.

...

In talking, coughing and sneezing, small and large droplets are expelled from the mouth and nose, but the mechanism and the velocities of the air streams are different in each case, so that the end results are also different.

A great deal of important work has been done by M. W. Jennison (95) in connection with droplet expulsion, and by using stroboscopic light photography of the acts of talking, coughing and sneezing, he was able to make very important findings. The photographs

on the following pages are reproductions from an article published by Jennison in Aerobiology, 1942 (95).

TALKING:

Atomization is produced usually only with enunciation of the letters "f", "p", "s" and "t", and as the air speed in the process is not very great, a large percentage of the droplets expelled is on the large side. These are projected as a rule not further than a foot from the speaker.

Some people are "wet" talkers, and they produce a greater number of droplets. In loud talking, more droplets are usually expelled than in quiet talking.

Enunciating the letter *f*. Consonants are more difficult than vowels to pronounce without forming droplets. Droplets produced in speaking are larger than those from sneezing.

COUGHING:

The mouth being open, the highest air velocity and the area of maximum droplet formation is probably in the pharynx, and here the secretions are mucoid. A large percentage of the droplets are large on account of the viscosity of the secretions, and also because of the fact that the surfaces from which atomization takes place are fairly wide apart, so that the velocity of the air stream at this point is not very great. It is of course possible that considerable numbers of smaller droplets are produced but that these do not get further than the mouth, and that they evaporate before they leave the mouth.

Droplets resulting from a cough. Only a few hundred droplets are produced in a cough compared with thousands in a sneeze.

Photography has shown that the majority of droplets are large, and also that the numbers are comparatively low, being in the vicinity of from a few dozen to a few hundred. These droplets are projected as a rule not further than two or three feet.

SNEEZING:

A considerable air velocity is produced in the act of sneezing on account of the fact that air is forced between wet surfaces at the anterior end of the mouth, which are almost in apposition. The maximum air velocity occurs at this point, and this is where the maximum atomization takes place. In this situation, the secretions consist chiefly of saliva which is considerably less viscid than mucous. In the act of sneezing, a large number of droplets is produced, and the great majority of these are very small. Jennison found that the numbers varied in different sneezes from 20,000 to 40,000, and by means of the special photographic methods it was possible to show that these particles became as small as from 7 to 10 μ in diameter. The distance of expulsion is usually not greater than from 2 to 3 feet. An interesting point in connection with the small droplets is the speed of disappearance as shown on a motion film. It was found that within a fraction of a second all the small droplets had vanished, leaving only the larger ones, which immediately proceeded to fall downwards to the ground.

A violent sneeze completed. Over 40,000 particles are here shown. The eyes are characteristically closed. A few droplets may be seen coming from the nostrils.

...

In a series of experiments on the expulsion of droplets from the mouth, Hare (78) arranged a number of blood agar plates in a semicircle in a vertical plane and with the subject's mouth at the centre of the circle. The position of the plates on the circumference of the circle was marked in degrees, beginning with 0 vertically below the mouth, and 90 degrees on a horizontal plane with the mouth.

In quiet talking it was found that most colonies were grown on the plates placed at 0 and 22.5 degrees.

No colonies were grown on the plates placed at 90 degrees and at a distance of one foot from the mouth. (This plate was on a horizontal level with the mouth.)

In coughing, most colonies were obtained on the plates placed at 45 and 67.5 degrees at a distance of one foot. It was found that in speaking the droplets did not proceed further than 18 inches in a horizontal plane, and in coughing they did not move further than two feet. These experiments show that droplets, once they have left the mouth, begin to drop downwards, and are deposited in the immediate vicinity.

It has been shown that a droplet of 1.0 mm in diameter, projected at a velocity of 152 feet per second from a man in the erect position, will reach the floor at a distance of approximately 15 feet, provided the air of the room is perfectly still (77).

...

It was shown previously that a considerable number of normal people carry staphylococci and streptococci which are pathogenic, in the mouth and in the nose. These organisms are common surgical wound infectors. It does not necessarily follow, however, that all the droplets expelled by these people will contain these organisms. Hamburger carried out an investigation of the streptococcal content of saliva of people with positive throat cultures. (72). Here it was shown that 68% of

positive throats were saliva positive as well, and in all these cases the type of streptococcus found in the saliva was identical with the one isolated from the throat.

It is clear that an exposed wound, not more as a rule than 18 inches from the mouth of the surgeon, is in an ideal position to become infected by droplets expelled from his mouth. But this is not the only danger. Potentially infected droplets are being expelled by all the inhabitants of the theatre all the time; they are expelled by the nurse who sterilizes the instruments; and they are being constantly expelled by the nurse attending to the dressings of the wounds in the ward.

The wearing of a mask will prevent the dissemination of the larger droplets provided the mask is impermeable, and provided it is large enough. No mask so far designed, however, is capable of preventing contamination of the air by the organisms carried in the exhaled air. This could be possible only if all the exhaled air could be filtered as soon as it left the mouth or the nose. Large droplets expelled from the mouth will stick to the fabric of the mask, but droplets which have evaporated before reaching the mask will merely be deflected as droplet nuclei round the sides of the mask and so infect the air of the theatre. The small droplets become droplet nuclei almost immediately they leave the mouth or the nose, and this explains the findings that

theatre air remains contaminated in spite of the wearing of impermeable masks. (8, 83).

...

In the theatre, the expulsion of infected droplets may affect the wound directly; or the wound may become infected indirectly through instruments and other equipment which have become contaminated.

In the ward, infected droplets are being expelled all the time not only by the staff, or by the dresser while she is attending to a dressing, but by all the patients in the ward. It is possible, therefore, that infected droplet nuclei are constantly in the air of the ward, but these are probably not a great danger to the wounds in the ward. The wounds are covered most of the time, and the short time that they are uncovered for the purpose of dressings, is not sufficient to allow of contamination from this source.

Larger infected droplets, however, are deposited on the blankets of patients, and from these the dried organisms are later distributed into the air when the blankets are handled, and from the air the infected particles may sediment out on to an exposed wound or else on to the exposed instrument trolley near the bed.

The dresser at the time of dressing may deposit infected droplets onto the wound, or else she may deposit

them on to the instruments while she is arranging her dressing trolley in the sterilizing room.

.....

(c) THEIR CLOTHES:

Nasal and throat carriers of pathogenic bacteria are constantly depositing these organisms, through the medium of droplets, onto their clothes; chiefly the upper part of the coat, the shoulders and lapels. The pocket handkerchief is usually heavily infected, and as a result of this, the pockets are usually infected as well, and so are the sleeves. In these carriers, the lower garments are usually not infected. (77).

Numerous observers have shown that the dust of wards contains the organisms which are causing infection of wounds in the ward, and also organisms which are present in the throats of the inmates of the ward.

This dust may infect the shoes of the surgeon on his ward round, and this may later be shaken off in the theatre.

The common wound infectors are as a rule not to be found in the dust of the streets and the countryside, and because of this, it is exceedingly uncommon to find an accident wound, or a war wound, no matter how dirty it is,

to be infected with either streptococci or staphylococci on admission to hospital. (77, 78). Infection with these organisms, should it occur, is more often than not acquired secondarily in the hospital.

The most important wound infector which may be carried from the street or the country-side to the operating room or the ward is the tetanus bacillus. That the transfer of such infection to the operation wound is a real danger has been amply demonstrated by the work of Robinson, McCleod and Downie, and others. (147,214).

Bacteria are easily liberated from infected textiles by means of shaking, when these are dry. Gentle handling of an infected wound dressing on which the discharges have dried liberates showers of organisms into the air. Gentle handling of blankets does the same thing. (126, 128).

The clothing of individuals who are carriers of infection, and those who are constantly in contact with infected material, behaves in a similar manner to blankets and dried dressings when these are shaken or gently crumpled. Such individuals when moving about in a theatre "shake off" considerable numbers of their organisms into the air of the theatre, and from which they are later deposited on the sterile field. Others fall on the floor of the theatre from which they are later stirred up with the movement of the personnel.

In the ward, the dresser whose clothing is

infected may shake off organisms, either on the exposed wound or else on the instruments on the dressing trolley.

Organisms which have been accumulated on the shoes, either in the ward or in the street, are, in a similar way, shaken off in the operating theatre, and distributed into the air of the theatre. These may later find their way into the wound along with the other pathogens in the theatre air.

In a specially designed experiment, which will be described in chapter 5 of this thesis, it was shown that the uncovered shoes caused a pollution of the theatre air three times that when the shoes were covered, and when ten people took part in the experiment.

.....

(4) THE INSTRUMENTS.

Under this heading are included all the equipment and instruments employed in the operating theatre and in the ward which in any way come into direct or indirect contact with the wound. This then includes a great number and variety of items, such as instruments, gowns, masks, gloves, towels, sheets, mackintosh sheets, swabs, suture material, drainage tubes, lotions and all those receptacles which hold or support these various items.

In the normal course all these are subjected to a process of sterilization, so that if the technique employed is faultless, the chances of any of these causing a direct infection of the wound becomes very small indeed.

The majority of pathogenic organisms are killed by a few seconds' immersion in boiling water. Prof. Andrew Fleming has shown that Streptococcus pyogenes, staphylococcus aures, enterococci, Ps. pyocyanea, and Proteus vulgaris are all killed by 5 to 10 seconds' immersion in boiling water. (63). These are the common wound infectors in the surgical wards. Heat resisting sporing organisms require a more prolonged treatment, and it has been shown that some spores will resist 16 hours' boiling, and longer. (96). For these, autoclaving is the ideal method of sterilization.

With regard to all these items, it is important to bear in mind that the ordinary methods used for sterilization are usually sufficient to render them sterile, but this does not mean that they will be sterile by the time the surgeon uses them at the operation.

It often happens that the surgeon is ready "scrubbed up", but has to wait for the anaesthetist to render his patient sufficiently insensible, and he also may have to wait while the patient is adjusted into the correct position for the operation. During this time,

there is usually considerable activity in the theatre so that considerable numbers of organisms are stirred up into the theatre air, and these now are deposited on the whole of the sterile field, which includes the surgeon's gown and gloves, the sterile towels and instruments (if these are uncovered), and the lotions which the surgeon uses for his hands.

Recently-sterilized instruments may become contaminated before being used by the surgeon, by the uncovered mouth and nose of the instrument nurse, or by the air on the way from the sterilizing room to the theatre.

Fortunately, however, in the modern operating room, the chances of instruments and equipment being the cause of infection in wounds is very small. This is one link in the chain of aseptic technique which is comparatively easily dealt with, and there should be no excuse for it to provide bacterial access to a wound.

In the ward, the danger of instruments becoming contaminated after sterilization is much greater than it is in the theatre because the air of the ward has a much higher bacterial content. Here the instruments are particularly liable to become contaminated when left exposed in the neighbourhood of a bed. The arranging of blankets prior to a dressing, and the removal of bandages and dressings all send showers of organisms into the air of the immediate vicinity and from here they are readily deposited on the sterile field.

.....

(5) THE AIR.

The recognition of the air as a vehicle of infection is a comparatively recent development, as was indicated in a previous chapter. Wells (199) in 1933 described an apparatus, called the Wells' centrifuge, which collected dust and bacteria from the air by means of suction and then, by centrifugal force, these were deposited on a cylinder of agar. This cylinder was incubated, after which the colonies which had grown on it were counted, it being assumed that each colony began from a single organism.

Since this apparatus was described, other methods of air sampling have been devised, such as filtering the air through sand, sintered flass or cotton wool; or collecting the bacteria in a fluid medium through which the air had been bubbled; or the method of Hollaender and Dalla Valle, where air was drawn through a funnel on to the surface of an agar plate.

All these methods gave reasonably good results for the larger particles, but they were found to be much less efficient when it came to sampling the smaller ones.

The machine which has proved to be the most accurate so far invented for the purpose of sampling the air, is the slit sampler perfected by Bourdillon, Lidwell and Thomas. (19).

Air is sucked through a narrow slit 0.25 mm

wide, 27.5 mm long and 3 mm deep, on to the surface of an agar or other culture plate, which is revolving just below the slit. By experiment, it was found that the ideal distance between slit and culture medium was 2 mm. The apparatus is constructed so that air is drawn in at varying speeds from 1 cub foot per minute up to 20 cubic feet per minute, the speed of the revolving plate carrying the culture medium being regulated to describe a complete revolution in ½, 2 or 6 minutes.

With the aid of these adjustments, it is possible to collect air from rooms where the air is comparatively clean, and from rooms where there is considerable contamination.

The machine has been found to have a high degree of efficiency, and is particularly efficient in the collection of single bacteria, whereas other devices are capable of collecting only the larger particles.

...

The air of semi-enclosed spaces which are inhabited by human being is contaminated by organisms which are both pathogenic and saprophytic.

In the operating room and in the ward the air may become contaminated from the following sources:-

(a) The noses and throats of the occupants, expelling droplet nuclei which remain in the air.

These may consist of single bacteria, or else the bacteria may be attached to small particles of organic matter, the residue of the evaporation of small droplets.

(b) The dust of the floor and the furniture.

(c) The dust and fibres from the blankets (chiefly in the ward), and also the dust shaken off the clothes of the occupants.

The ultimate source of the infection of this particulate matter in the air is always a human reservoir. There are only two such sources:-

(1) The nose and throat;
(2) An infected wound.

The study of air contamination has been greatly simplified, and it has been put on a proper scientific bases as a result of the work of Lancefield and Griffiths (3), which has made possible the accurate typing of the numerous strains of streptococci which are pathogenic to man and lower animals. Most of the work in connection with air-borne infection has been done in connection with streptococci as a result of this, and the scientist now has accurate and infallible means of tracing cross-infection.

(1) <u>THE NOSE AND THROAT</u>:

The air contamination which takes place when a room is occupied can be shown to correspond exactly with

the flora obtained from the throats of the occupants. (4, 51). In the same way, the streptococci infecting the dust of the ward, and the blankets of the ward, can be shown to be identical in type with those infecting either the throats or the wounds of the patients in the ward. (73).

The infection of the air, the dust and the blankets by means of expired droplets is particularly easy to trace in wards where scarlet fever patients are nursed, but this applies equally to any type of streptococcal throat infection, including the sub-clinical carrier. It has been shown that the air, the dust and the blankets all become infected exceedingly rapidly after admission of the patient, and the organism isolated always corresponds identically in type and group with the one infecting the throat. Hamburger et al (73) showed that the bed-clothing and blankets of a patient suffering from a streptococcal throat may become infected with the same organism within six hours of his admission to the bed. A patient admitted to a scarlet fever ward, and infected by a certain type of streptococcus, may, after a week or longer, become infected with another type of streptococcus, which can usually be identified as coming from another patient in the ward who is also suffering from scarlet fever. In multiple bedded wards, it has been shown that between 50% and 70% of the patients become infected with another

type of streptococcus during their stay in the ward. It is interesting to note in passing that this reinfection was formerly looked upon as a relapse. It is now known that infection with one type of streptococcus does not confer immunity against other types. It is also interesting to note that any type of streptococcus may be the cause of a sore throat or a wound infection, and the appearance of a rash in conjunction with a sore throat (or even a wound infection) which labels the disease, scarlet fever, is merely a fortuitous occurrence, and it depends on the coincidence of two variable factors; a Dick positive patient, infected by an organism with a high Dick toxin content. (22).

Although the susceptibility of different people to infection by streptococci varies greatly, it nevertheless can be shown that widespread infection can occur in a ward where only one or two of the patients are carriers of the organism, and this can be shown to occur where there is no possibility of direct contact. (4,48.)

By means of air sampling it has frequently been shown that the air of a ward containing a patient with a streptococcal throat infection is heavily infected with the identical organisms, but that this contamination disappears very soon after the patient is removed from the ward. When this patient is transferred to a room where there is no streptococcal contamination of the air, the

air there becomes contaminated within a short space of time (73).

Brown and Allison (25) and many other observers have found that the dust of wards, and especially in the vicinity of infected patients, contains the same organisms that are infecting the patient. During sweeping and dusting, it is shown that the air of these wards becomes heavily laden with the particular infecting organisms. (186, 187). This added contamination during sweeping falls to the normal level again as soon as the dust in the ward has settled.

Examination of blankets and bed-clothing of patients harbouring streptococci in the throat have been shown by many investigators to contain the identical organism. It has usually been shown that these organisms are attached to the heavier particles of fibre and dust on the blankets, and that they can be removed or shaken off comparatively easily. (73, 186). During the process of bed-making it has been shown over and over again that the air contamination by these infecting organisms rises immediately to a remarkable extent, and that it is reduced to normal levels within a half to one hour after bed-making. (190, 191).

In the operating theatre where the bacterial content of the air is insignificant before the theatre becomes occupied, it has been shown by numerous observers

that the aerial pollution rises immediately the operating team enters the theatre. Meleney (125) showed that there were ten times more bacteria in the air of the operating room when the room was being used than when it was empty. Drets and Diago (215) found that when the operating team came into the theatre, the normal air contamination was raised no less than 32 times. A great part of this contamination comes from the noses and throats of the occupants in spite of the fact that they are all wearing masks, and the degree of contamination of the air by pathogenic organisms is found to be proportional to the number of carriers in the room. Furthermore, these contaminants are identical in type to the flora cultured from the throats of the occupants of the theatre. (83).

In connection with the aerial contamination of wards where carriers of these organisms are being nursed, it is still a moot point what percentage of this contamination comes from droplet nuclei, and what percentage comes from the dust on the floor or the blankets. (73). All these contaminants originally come from the throats of the patients, the droplet nuclei remaining suspended in the air, while the heavier droplets fall to the ground or else fall on the blankets. On the floor and on the blankets these droplets soon dry, and they are later distributed into the air in the dried state as indicated above. These particles of dust and

blanket fibre are comparatively heavy so that they settle out from the air fairly quickly and it has usually been found that after bed-making and sweeping, the air of the ward is back to normal as far as its bacterial content is concerned within the space of an hour after cessation of these activities. In sedimenting out of the air after these operations, the infected dust particles again fall on the floor, on the furniture, on the blankets, and anything else which is exposed in the room, and all these now become contaminated. In addition, such particles may be inhaled by the occupants of the ward, resulting, if the infecting dose is heavy enough, in a new throat infection, clinical or sub-clinical.

The incidence of streptococcal throats always increases in the winter months, and in this connection it must be pointed out that many attacks of so-called common cold or mild sore throat are accompanied by the presence of pathogenic streptococci. (77) What is more important, is the fact that, in many cases, the organism which was the original cause of the mild sore throat may be cultured from the throat many months after the patient has recovered from his sore throat. (77, 78)

(2) THE INFECTED WOUND:

Wounds are a prolific source of bacteria. Some wounds containing numerous organisms show little evidence of infection, and not only inflamed and purulent

wounds are a potential source of pathogenic bacteria. (126, 127). Bacteria which do no harm to one patient may prove to be exceedingly pathogenic for another. The skin around an infected wound harbours the same organism up to a distance of 2 to 4 inches from the margin of the wound, and in many cases where the infection in a wound has cleared up entirely, the same organism may still be found in the periphery. (126)

All parts of a wound dressing become infected with the organism which is in the wound, and this applies not only to the soiled dressings, but also to the outer unsoiled layer of cotton wool, the bandages, and in fact the whole bed becomes contaminated by the same organism. (73). It has been shown that as long as the infected pus or exudate on the dressing remains wet, no dissemination in the air is likely. When these discharges have dried, and the dressings are kept perfectly still, there is also no aerial contamination. But the merest handling of such a dressing will release large numbers of bacteria into the air, and even in an almost imperceptible breeze, these infected particles can be shown to travel a distance of at least 3 metres. Most surgeons and nurses are ignorant of this fact.

The air of a ward, the dust on the floor and on the blankets, all can be shown to be contaminated by the same organisms that are infecting the wounds in the ward.

Cruickshank (49) found that this applied in burn wards where most of the burns were infected with streptococci. He studied 100 severe burns bacteriologically from within a few hours after admission to the burn wards. All were cultured immediately on admission and it was found that 11 of the 100 were infected with streptococci on admission, and 46 cultures were sterile. On the day after admission, not one culture was sterile. On admission 5% of the patients had positive throat swabs. After a week in hospital this rose to 25%. Ten cases developed scarlet fever, the burn being the primary infection and not the throat. Two nurses working in the burn wards developed scarlet fever, the infection having been traced to burns in the wards.

In a careful study of the bacterial flora of burns, Colebrook et al (43) used an exceedingly rigid technique for their dressings which were all executed in a specially prepared dust-free room separate from the ward. In spite of the extra precautions, it was found that a considerable percentage of the burns acquired an added infection. It was shown that this was definitely not due to faulty dressing technique, and the added infection was not acquired in the dressing station. In almost every case the added infection occurred in a burn which, on account of its position or extent, was not always adequately sealed off from the ward air.

Most of the work in the literature relating to the contamination of the air, the dust and the blankets from wounds in the ward, has been done in connection with streptococci. In the investigations described in Chapter 5 of this manuscript, it will be seen that it was possible to trace penicillin resistant staphylococci in the air of the ward, in the blanketsand in the outer dressings of wounds, to wounds infected by the identical organisms, on several occasions.

...

VIABILITY OF DUST-BORNE ORGANISMS:

There is no evidence that the virulence of organisms is in any way altered by drying in the air or in dust. Drying in vacuo is now the most reliable method of maintaining both the virulence and viability of stock cultures in the laboratory. (96)

Various kinds of organisms suspended in the air in the form of fine mists have been shown to be viable after two days. Staphylococci will remain viable in this form for 3 days. (27). Organisms when dry, however, will survive longer periods of time, and Colebrook (45) has shown that streptococci will survive in dust for a period of 10 weeks. Different organisms will survive these conditions differently. (96). It has been shown that respiratory organisms from the human throat are

particularly resistant to drying. This applies especially to streptococci and pneumococci. (7)

Light plays a very important part in the survival of bacteria in the dust and in the air. (68) Garrod has shown that in streptococcal wards, the dust from lighted areas of the ward was much less infected than that obtained from under the beds and in dark corners. Haemolytic streptococci in dust will survive over 6 months in the dark. Even ordinary diffuse daylight, whether coming through glass or not, is bactericidal to streptococci.

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CHAPTER FOUR

THE PREVENTION OF POST-OPERATIVE WOUND INFECTION

THE PREVENTION OF POST-OPERATIVE WOUND INFECTION.

The success of our aseptic technique depends on the rigid application of each and every procedure in the process, and the neglect of even an apparently minor step may result in the breakdown of the whole system. Because it is so complicated, it presents a large number of loop-holes, only too readily discovered by the ubiquitous micro-organism, and it therefore requires constant and careful survey and analysis to ensure its efficiency. It is perfectly true that a comparatively lax or faulty technique may proceed reasonably smoothly for a time, and without any serious consequences, but this is no excuse for employing a lax technique. Disaster in the shape of a serious infection can come only from employing a technique which is faulty; and in the knowledge of the routes of such complication together with a knowledge of the means at our disposal to prevent such complication, the occurrence of serious wound infection usually implies carelessness in the application of the technique.

The ideal aseptic technique would be one which prevented the entrance of even a single organism into the wound at any time from its inception to its final resolution. This is what we aim at but we have not reached this stage of perfection, there being a number of

steps in the technique which have not been completely mastered. This means that even in the presence of meticulous attention to detail, some organisms will still gain access to the wound. Fortunately the local and general tissue reactions are usually able to deal with these contaminants with the result that healing takes place in the minimum time. To assist these reactions, it is necessary for the surgeon to employ an operative technique which is not faulty, and it is necessary that attention be paid to the patient's general condition. These details will include the following:-

General:

The patient's blood and tissues must not be deficient in haemoglobin, protein, salts, water and vitamins.

Local:

The following will assist the growth of bacteria in the wound:

(a) Unnecessary and rough handling of tissues.

(b) Inclusion of large amounts of tissue in ligatures.

(c) The use of excessive amounts of ligature material.

(d) Non-obliteration of dead space.

(e) Poor haemostasis.

(f) The use of drainage tubes, etc., where not necessary.

(g) The application of sutures under too great tension.

The surgeon, in making a wound, must be ever mindful of certain elementary yet important facts:-

(1) Micro-organisms are naturally prevented from access to the human body by virtue of the continuity of the skin. A wound breaks this continuity and immediately provides access for them.

(2) A wound is the ideal culture medium for a large variety of pathogenic organisms.

(3) A wound is constantly in danger of becoming infected from the moment of the initial incision, and until it is completely healed.

(4) The persons who are most likely to infect the wound are those who produce it, and those who attend to it later on. These are:-

(a) The surgeon.
(b) The dresser.

...

In a discussion of the methods employed in preventing wound infection, it will be convenient to deal with the various items in the same order as presented in the previous chapter:

(1) The patient;
(2) The patient's skin;
(3) The surgeon, assistants, and dresser.
    (a) Their hands.
    (b) Their noses and throats.
    (c) Their clothes.
(4) The instruments and equipment;
(5) The air.

(1) THE PATIENT.

Being a carrier of pathogenic micro-organisms, there is a possibility of the skin harbouring the same organism; of droplets being distributed in the neighbourhood and on to the wound; and of infected hands contaminating the dressing or the edge of the wound. All these are possibilities which can usually be prevented, and should not apply in the face of a technique which is being properly employed. The question of the organisms on the skin and those disseminated in droplets will be discussed under their appropriate headings. The possibility of the patient handling his wound, or interfering with the dressing, is readily overcome by applying adequate and secure dressings.

...

(2) THE SKIN OF THE PATIENT.

No antiseptic has so far been discovered which will sterilize the skin completely, and which will keep the skin sterile for the duration of an operation. Lovell (110) says: "The sterilization of the skin is the weakest link in our chain of aseptic technique."

Skin preparation prior to an operation has as its object the destruction of all the organisms living on and in the skin. It consists of mechanical and chemical

cleansing, the mechanical part of it being designed to remove the surface bacteria along with the dirt, grease and desquamated epithelium. Soap and water are necessary for this operation, and in those parts where scrubbing with a brush is possible, this assists in the cleansing considerably. In parts of the body where there is hair in the region of the operation site, this is removed by close shaving. After mechanical cleansing, the area in question is subjected to successive applications of some fatty solvent such as ether, and then an antiseptic solution such as alcohol, acetone or iodine. The part is now covered with a sterile towel, and the skin preparation is repeated immediately before the patient is sent to the theatre. Before the surgeon makes his incision, he applies an antiseptic solution to the skin.

Apart from the value of the mechanical cleansing which removes the surface grease and dirt, it is doubtful whether the antiseptic measures adopted in the ward contribute much to the actual sterilization of the skin. No method of skin preparation will destroy the deeply placed organisms, and within a short space of time, they always reinfect the surface. The application of antiseptic by the surgeon immediately prior to his incision is probably the only one which is really of value, and in this connection it is interesting to note that it has been demonstrated on many occasions that there is no greater incidence of wound infection following emergency operations

than there is following operations where elaborate skin preparations have been employed. On the contrary, these excessive pre-operative measures are very liable to damage the local skin resistance.

As regards the efficiency of antiseptic solutions on the skin, it is generally agreed that the antiseptic of choice is Iodine. In many institutions, a 3.5% solution of Iodine is used followed by alcohol to prevent blistering of the skin. (216). In a careful investigation, Gardner and Seddon (217) found that 2% Iodine in 70% alcohol was effective in sterilising the skin surface in 15 to 20 seconds, and that there was no other antiseptic as good. CTab was effective against staphylococci in high dilutions, but ps. pyocyanea required considerable concentrations for their removal. Ethyl alcohol was also an efficient antiseptic but required a much longer period of action to be effective. Dettol and Chlorine derivatives were disappointing in their action.

The scalpel at the conclusion of the skin incision is infected, and therefore the surgeon discards it and uses a fresh blade for the deeper dissections.

After the skin incision, the surgeon applies lining swabs to the edges of the wound because he knows that the skin surface will not remain sterile for long. To be of value, these skin towels must be of sufficient thickness or texture not to allow contaminants from the skin to come through to the upper surface.

At the end of the operation, the wound is always infected with a variety of organisms; those that have come in from the skin of the patient, and those that have come in from the air of the theatre. In addition, the skin surface adjacent to the wound is no longer sterile.

To render the wound as germ free as possible before closing it, the surgeon washes the wound with considerable amounts of saline solution, or else he applies a mild antiseptic solution such as Carbolic 1/40. (94). Since the first World War, when Carrel and Dakin introduced Sodium Hypochlorite as a wound irrigant, a variety of different suggestions have been brought forward, including those of Orr in 1925 who condemned irrigation and chemical application in favour of immobilization, but the majority of opinion is still in favour of washing of the wound prior to closing. Mason (1937), Kock (1941), Karrigan (1942), and many others were all strongly in favour of washing the wound with soap and water, usually green soap. In a specially controlled experiment, Peterson (139) showed that soap actually produced damage to the tissues, and he came finally to the conclusion that the best results were obtained in experimental wounds, and that these healed in the optimum time, when they were flushed with 1000 cc of normal saline solution.

Before the skin sutures are applied, the skin adjacent to the wound is re-sterilized by application of

antiseptic solution.

As the Bacteriologist prevents contamination of his culture media be means of a plug of cotton wool in the top of his test-tube, so the Surgeon prevents infection from getting to his wound after the operation by applying adequate cover of dressings and cotton wool, and these are securely fixed by means of adhesive strapping.

In passing, it is interesting to note what Rutherford Morison wrote on the subject of cotton wool in 1881. (130). He referred to an article by Dr. Marion Sims suggesting the use of cotton wool as an antiseptic dressing, and expresses astonishment that Mr. Lister, who had found it so useful as a filter for atmospheric germs, should not have thought it worthy of a trial for surgical purposes.

...

(3) THE SURGEON, ASSISTANTS and DRESSER.

(a) THEIR HANDS:

The operating surgeon takes care at all times not to get his hands contaminated with infected material. Should he develop a skin infection of the hands or fingers, he refrains from operating, until the infection has subsided completely. To assist the sterilization of his hands, he keeps his finger nails trimmed as short as possible.

Sterilization of the hands consists of mechanical and chemical cleansing. The mechanical consists of vigorous scrubbing with a hard brush, soap and plenty of running water. The scrubbing is performed in a methodical manner so that all parts of the fingers and hands and arms are dealt with systematically over and over again. As the surface bacteria are removed at a logarithmic rate, it is helpful to rinse the hands at frequent intervals, followed by reapplication of soap. The fingertips receive special attention. In studying the effects of mechanical cleansing, Price (140) established the following interesting details:-

To remove dirt	about 1 minute's scrubbing.
To remove almost all the transient bacteria	3 minutes.
To remove all the free fat from ordinary clean hands	6-8 minutes.

For practical purposes, he recommends a 7 minute scrub-up for the surgeon. This scrub-up will remove about half of the resident bacteria as well.

After scrubbing, an antiseptic solution is applied to the hands, usually in the form of spirit (70%), after which the hands are dried, and then the gloves are put on. The deeply placed organisms in the skin are not affected by this treatment.

Bearing in mind the possibility of the gloves becoming contaminated during the course of the operation, the surgeon frequently rinses his gloves hands in antiseptic solution.

The rapid return of the skin flora as a result of wearing gloves makes it important for the surgeon to handle his gloves with care, and to change into a new pair, the moment they become damaged.

...

The dresser in the ward presents a different problem and as her hands are a very important potential source of cross-infection, a special technique is employed for wound dressings.

The ideal dressing team consists of three people working together. One is concerned with changing of lotions and re-sterilizing instruments. The second one removes and applies bandages, and adjusts mackintoshes, blankets and screens. The third is concerned with the actual dressing of the wound. (163). On account of staff shortages it is not always possible to employ three nurses for this purpose, but the work can be done very efficiently by two dressers.

Here the team consists of a dresser and her assistant. The assistant arranges the screens, the dressing trolley, the blankets, and the outer dressings and bandages. For the removal of the dressings she employs a special pair of long forceps which are kept in

antiseptic solution. She never touches a dressing with her hands.

In the meantime, the dresser washes her hands, but regards her hands as unsterile all through the dressing, taking care not to touch the wound or any part of an instrument or dressing which is going to come in contact with the wound. For the dressing of the wound, she employs a "no-touch" technique throughout.

At the completion of the dressing, her assistant helps her to apply the bandages.

After the blankets are adjusted, and <u>before</u> the screens and dressing trolley are moved to the next patient, both the dresser and her assistant wash their hands. As the bandages and blankets have been handled by both nurses, their hands are contaminated by the organisms on them, and the hands are therefore washed to prevent contamination of the screens and the handle of the dressing trolley.

WASHING THE HANDS BEFORE A DRESSING PROTECTS ONE PATIENT. WASHING THE HANDS AFTER A DRESSING PROTECTS THE WHOLE WARD.

In those cases where a wound is badly infected, and where the dressing is complicated and cannot be done efficiently by means of the "no-touch" technique, the dresser scrubs-up thoroughly as for an operation and she then puts on sterile gloves. This allows her to use her hands in the wound and at the same time it protects her

hands from becoming contaminated. Where several badly infected wounds have to be attended to, the gloves are left on, but after each dressing the gloved hands are washed with soap, water and brush for 1 minute, and then immersed for 3 minutes in a strong antiseptic solution, such as Biniodide in spirit or Carbolic 1/20. The hands are then rinsed in sterile water before attending to the dressing. (119). Price (140) showed that when the outside of sterile rubber gloves are infected with a known number of test organisms, and allowed to dry for 2 minutes, these are removed to the extent of 99% by scrubbing with soap and water for a period of one minute. The antiseptic solution referred to above will remove the remainder.

Whenever there are badly infected wounds in a ward, along with clean wounds, the former are attended to at the end of the dressing round.

The attitude adopted by many dressers that a badly infected wound does not require the same rigorous aseptic preparation and precautions as a clean wound is a dangerous one.

TO INFECT A CLEAN WOUND IS A SERIOUS MATTER.

TO IMPART AN ADDED INFECTION TO AN INFECTED WOUND MAY HAVE DIRE CONSEQUENCES.

...

(b) <u>THEIR NOSES AND THROATS</u>:

The prevention of infected droplets and droplet

nuclei from infecting the wound at the operation and afterwards in the ward, and from infecting instruments and other materials used on the wound, is the second weak link in the chain of aseptic technique. (192).

Meleney (125) in a bacterial study of the flora in the air of his operating rooms came to the conclusion that from 35000 to 60,000 bacteria fell on the sterile field during the course of one hour. Davis (53) says that apart from wearing rubber gloves, and the gentle handling of tissues, adequate masking is not only essential, but the most important precaution the surgeon can personally take to prevent infection in the clean operative wound.

Meleney (125) describes an interesting case of a severely infected post-operative wound by a certain strain of streptococcus. Two doctors and the instrument nurse, who were present at the operation, in addition to the patient himself, all had beta haemolytic streptococci in their throats. By means of agglutination tests, it was found that the infecting organisms were identical with those cultured from the throat of the nurse. She had contaminated the instruments.

In a similar way, three cases of infected thyroidectomy wounds occurred in rapid succession. These were traced to the anaesthetist who refused to wear a mask on account of the discomfort it caused him. (125)

The object of the mask is to prevent the passage of infected droplets from the mouth and nose from entering

the wound. Most materials used in the construction of masks are permeable and they allow larger droplets to pass through. The denser a mask is made by increasing the number of layers of material it contains, the more uncomfortable it becomes for the wearer. Kellog and McMillan found that in testing all-fabric masks, the efficiency seldom exceeded 50%. (98). Arnold was convinced that even if all the expired air was prevented from passing through the mask, that which escaped at the sides of the mask was still infected. He then devised a mask consisting of cellucotton which acted as an air filter. The difficulty, however, was the escape of air at the sides of the mask. (8).

The position today is still what it was ten and more years ago. We still have not found the efficient surgical mask.

The best we have been able to do so far is to use an impermeable mask which prevents the projection of infected droplets directly through the mask and thus on to the wound or sterile field. The photograph (by Jennison), on the next page, demonstrates the inadequacy of a thick fabric mask in dealing with the larger droplets.

To increase the efficiency of the impermeable mask (i.e. on constructed of two layers of gauze with a sheet of impermeable material, such as cellophane, between the layers) the mask must be worn as closely as possible to the mouth and the nose. This will assist wet expired

droplets to adhere to the fabric of the mask, leaving relatively sterile air to pass out at the sides of the mask. The smaller droplets evaporate very quickly after leaving the mouth and as dried droplet nuclei, they are merely deflected by the mask with the air stream and so add to the contamination of the air of the room.

Sneezing test of an all-fabric face mask. This mask was comparatively dense, having an air-permeability less than one-fifth as high as that of the most permeable mask tested.

To prevent fogging of the surgeon's glasses, a strip of lead sheeting or aluminium is sewn into the centre of the upper margin of the mask and this is moulded to the shape of the nose, thereby preventing exhaled air from passing upwards.

...

Masks are worn by all people entering an operating room whether an operation is in progress or not. At the conclusion of the operation, these masks are not removed until the theatre has been vacated.

Masks are worn by all people engaged in the sterilization of instruments and it is as important for masks to be worn at all times in the sterilizing room as it is in the theatre.

Masks are worn by all people concerned in the dressing of wounds whether these are clean or infected.

The wearing of masks does not prevent contamination of the air of the theatre by organisms present in the throats of the occupants. Davis (53) found that when patients were operated upon in the presence of a crowd of spectators, either on the floor or in the stands, they frequently had a stormy convalescence from wound infection, as opposed to those where no spectators were present, in spite of the fact that everyone in the theatre wore a mask.

A slight respiratory tract infection immediately increases very greatly the numbers of organisms that are expelled from the mouth and the nose, and for this reason every person suffering from such infection should be debarred from entering an operating theatre until the infection has subsided completely.

The part of the mask which is in contact with the mouth and nose becomes highly contaminated after a short

while. For those who wear the same mask over a prolonged period, it is important to bear this point in mind, and to see to it that the infected side of the mask is always replaced towards the mouth and nose.

All masks, after use, are infected, and must therefore be re-sterilized.

...

(c) THEIR CLOTHES.

In the modern hospital, the surgeon and his assistants change from their normal clothes into special theatre garments before entering the scrub-up room. Here, sterile caps and masks are put on, and over-boots to cover their shoes.

After the scrub-up, a sterile gown is put on by all those immediately concerned with the operation.

Anaesthetists, spectators, and nurses who enter the theatre are all required to wear over their own garments sterilized gowns and over-boots, in addition to the caps and masks.

In the wards, the dressers, prior to dressing round, put on caps, masks and gowns.

...

(4) THE INSTRUMENTS.

The aseptic technique demands that all instruments, and all other materials used for the purpose of an operation or for the purpose of wound dressings, shall be completely free from micro-organisms. This fortunately is one link in the aseptic technique which can be guaranteed to be faultless provided it is carried out properly.

For sterilization purposes, we use two methods chiefly, viz., moist heat, and disinfectants.

The lethal effect of heat on bacteria is markedly influenced by the amount of moisture present. Moist heat is much more effective than dry heat, but the resistance of different species of bacteria varies, the pathogenic forms being in general a little less resistant.

Spore formation in a given species leads to marked increase in resistance to heat, and we find that some forms of spores will resist boiling water upward of 16 hours. (96). The vegetative forms of most bacteria are killed by ten minutes' exposure at 55° to 58° C., and most of them are killed by a few seconds' immersion in boiling water.

The pH of the liquid in which they are suspended influences considerably the speed with which they are killed. Thus, any appreciable change in the pH in one direction or

another, will immediately increase the susceptibility of the bacteria to destruction by heat. For this reason, the addition of washing soda to the water in the sterilizer greatly increases the efficiency of the sterilization process. At the same time, it is beneficial in preventing the rusting of instruments.

The vast majority of pathogenic organisms met with in civilian practice are purely vegetative, and for practical purposes, boiling of instruments for a period of 1 to 3 minutes is quite sufficient to render them sterile provided all organic matter has been removed previously, by means of brush, soap and water.

The only really important pathogenic sporing bacilli of surgical interest are Clostridium Tetani, Clostridium Welchii, and possibly Bacillus Anthracis. Gram positive sporing bacilli are exceedingly common in nature, but fortunately they are mostly saprophytic.

The tetanus spore will resist 100° C. of steam for 60 minutes, while various antiseptics will destroy it as follows:-

5% Phenol	... 10 to 12 hours.
" plus 0.5% HCl ..	... 2 hours.
Mercuric Chloride 1/1000 .	... 2 to 3 hours.
" plus 0.5% HCl ..	... 30 minutes.
1% silver nitrate	... 1 minute.

The anthrax bacillus will resist 140° C. of dry heat for at least 3 hours but is killed by 10 minutes'

boiling. 4% potassium permanganate will destroy it in 15 minutes.

Moist heat at temperatures higher than boiling water becomes increasingly lethal against bacteria, the higher the temperature.

At 15 pounds pressure, the temperature rises to 121.3° C.

At 20 pounds pressure, it is 126.2° C.

This is the principle used in the autoclave, which is part of the routine equipment of all well-run hospitals, and is used for the sterilization of such articles as sheets, caps, masks, gowns, gloves and suture material.

As a rule, exposure to 15 pounds pressure of steam for a period of 15 minutes is sufficient to kill all vegetative and spore forms of bacteria. Very occasionally very resistant forms of spores are not killed by this exposure.

DISINFECTANTS:

These are not commonly used for the sterilization of instruments. Alcohol has for a long time and still is commonly used for the purpose of sterilizing syringes, but it has been shown that it is not a method to be relied upon, and this applies especially to glass-metal syringes. The germicidal action of alcohol is

slow, and is not complete for some considerable time. In addition, it cannot be guaranteed to penetrate into the crevices and corners of a syringe in which bacteria may lodge.

Alcohol is probably the only antiseptic which is suitable for syringes, when other methods are not available, and for this purpose it is necessary to use freshly prepared 70-75% v/v alcohol. (121). It should be used only for all glass syringes, and after these have been carefully washed in clean water with a test-tube brush.

Lysol and other phenol derivatives are used for the purpose of sterilizing objects which cannot be boiled, and they are therefore used for baths, arm baths, bowls, bins, dishes, rubber draw sheets and mackintoshes, trolleys, tables and jars for instrument forceps.

...

(5) THE AIR.

The methods at our disposal for the purification of the air of the ward and the theatre are as follows:-

(a) Ventilation;
(b) Dust suppressive measures;
(c) Antiseptic mists;
(d) Ultra-violet Radiation.

(a) VENTILATION:

By using the exposed plate method, and by sampling the air with a suitable air-sampler, it can be shown that the air of a room can be rendered relatively sterile by passing all the incoming air through a system of mechanical filters, consisting of glass or steel wool treated with a viscous oil, or else by washing the incoming air. Various experimenters have found that commercial filters designed on these lines will remove from 40% to 80% of the bacteria in the air. (211).

The degree to which such air conditioning will improve the bacterial content of the air depends, amongst other things, on:-

(1) The velocity and direction of the incoming air;
(2) The cleanliness of the room;
(3) The number, and the amount of movement of the occupants.

..

(1) It has been shown that air entering a room at a velocity of 50 feet per minute or less will, as a result of stirring up the dust on the floor and the furniture, reinfect the room. If the entering air stream be directed towards the floor of the room the resulting air contamination is very much greater than when the air is directed upwards or sidewards. (157,211). Under these conditions then, the clean air entering the room has the effect of

actually polluting the atmosphere.

(2) Should the floor and the furniture of the room be dusty, then again the clean air entering the room will merely stir up this dust and thus increase the aerial pollution.

(3) It has been shown that in clean rooms, provided with a so-called efficient air filtering system, the effectiveness of such filtration in reducing air pollution when the room is occupied is very small and often nil. Yaglou and Wilson (211) found that when there were 9 people in the room, there were from 5 to 11 times as many bacteria in the room as when there were 2 persons present.

By itself, air conditioning is not an effective means of reducing the contamination of the air of rooms which are occupied.

...

(b) DUST SUPPRESSIVE MEASURES:

As a result of intensive studies, first in England and later in America, by a number of different workers (107, 108, 109, 153, 185, 186, 187), effective means have now been devised for the suppression of dust both on the floor and blankets. As long ago as 1909 (Heise) and 1910 (Butler), the value of oils in suppressing dust on the floors of Printing Works, and in the class room

respectively, was effectively demonstrated, but it appears that no reference was again made to this subject in the literature until the work of van den Ende, Lush and Edward (185) was reported on in 1940. In this report it was shown that a 90% reduction of aerial contamination followed the application of a crude liquid paraffin to the floors, when these were swept, as opposed to those floors which had not been oiled. Then followed a series of articles describing the use of these oils on the floors of hospital wards, and also the application of this oiling principle to the blankets and linen of these wards. Most of this work was done in connection with wards where patients suffering from various kinds of streptococcal infections were being nursed, and where the dust was shown to contain a high percentage of the infecting organisms.

Spindle oil was used for the floors, and this oil (a crude liquid paraffin) was also used for the blankets. These were immersed in a solution of 30% oil in white spirit, after which the excess oil was spun off in a hydro-extractor, leaving a small fraction of the oil adherent to the blankets. These blankets were now found to possess marked bacteria holding properties, and that in spite of vigorous handling during bedmaking, there was no pollution of the air of the ward as opposed to the marked pollution which occurred when the blankets were not treated. (186, 187).

The method involved in the application of the oil, and also the fire hazard associated with the solution

which was first used, were both serious drawbacks, and as a result of further work, a number of other oils and combinations of various chemicals have been recommended. One of the most recent developments has been the use of an oil emulsion base called T-13 consisting of the following ingredients:-

Heavy Mineral Oil (Fractol A) ... ... 87 parts

Triton NE ... ... 13 parts.

(Triton NE is a 30% water solution of a substituted phenyl ether of polyethylene glycol.)

This mixture is milky white in appearance and has the consistency of face cream. It mixes spontaneously with water in any desired concentration, and is added to the final rinse of the usual laundry procedures, after which the textiles are dried, and ironed in the usual way. Cotton and woollen fabrics treated in this way, and containing from 2% to 5% of oil, are claimed to be indistinguishable from untreated materials, in appearance, texture, touch and odour. (107).

It is further claimed that this emulsion base is completely non-toxic, and that after numerous applications over a long period of time, no skin reactions have been noted.

Treated articles retain their bacteria holding properties for many months without retreatment, and in fact, ordinary washing does not remove the oil. In

addition, there is no fire hazard associated with its use.

So far, it has been shown that these oils have no bactericidal effect, and their value depends only on their property to cause dust to adhere to the blankets and clothing which have been treated. It follows, therefore, that when such articles have been used in infectious cases, they must be sterilized in the usual way. Efforts are now being directed to the incorporation of disinfectants with these oily substances, which will then serve the two-fold purpose of laying the dust and at the same time of destroying the bacteria contained in the dust. (153)

In the treatment of floors, spindle oil or any other oil of similar nature is used. According to Government regulations, this oil must have a flash point of 300° F. or more; a viscosity of 70 to 110 seconds at 100° F; a pour point not higher than 30° F; and it must be of a pale lemon colour. The oil must be clear, well refined, and with no objectionable odour. (107) The amounts of the oil required for floors depends on the nature of the floor and the duration of effectiveness required. In the case of wooden floors, as little as 1 gallon per 1000 square feet is sufficient to hold dust for a few days, but with repeated application, the effectiveness lasts longer. When large amounts of oil are applied to wooden floors, the dust holding properties may last as long as six months. (107, 153). In the case of smooth and polished surfaces, a very small amount of the oil is required, but

this has to be applied more frequently. Too much oil on these surfaces will increase the risk of slipperiness.

Different observers have found that with oiling of floors in hospital wards, the reduction of the aerial contamination as a result of sweeping was anything from 70% to 90%. (153, 175, 176).

...

(c) ANTISEPTIC MISTS:

The use of bactericidal mists and vapours for the destruction of bacteria in the air began with the carbolic spray of Lister, and since that time various agents have been used for this purpose but most of them have been found to be toxic and irritating to the respiratory passages or to the conjunctivae.

The first really important work in this direction was that of Douglas, Hill and Smith (1928), who, using a fine spray of electrolysed sea water, (containing NaOCl and about 1% of available chlorine), demonstrated a remarkable reduction of colon bacilli which had been suspended in the air of a room. In 1938 Trillat and Masterman, working separately, reported on the properties of germicidal aerosols and vapours (159) and on the effectiveness of hypochlorite solutions when sprayed into the air as a means of sterilizing the air.(114).

Trillat made the interesting observation that certain antiseptics which killed bacteria in the test-tube in dilutions of 1/200, were capable of destroying air-borne bacteria in aerosol form, in concentrations of 1 gram of the substance in 5,000,000 cc of air. His explanation for this was that each minute droplet of the aerosol, no matter how small, still contained the same concentration of the effective antiseptic and therefore produced its maximum effect on whatever bacteria it came in contact with. (159).

Masterman's work showed the remarkable degree of sterilization of the air which occurred with the atomization of very small quantities of Sodium Hypochlorite. He was able to effect complete sterilization of the air when using a test-organism, by atomizing 1 gram of 1% NaOCl in 40,000,000 cc of air. (114). His view was that when this substance is atomized, hypochlorous acid gas is liberated, and that this is the bactericidal agent. In other words, it is not a true aerosol. To produce this degree of effectiveness with so small an amount of hypochlorite, he used a "Dynalysor", which was capable of producing droplets of 1.0 μ and less in size. When these concentrations were used, it is claimed there was no irritation of mucous membranes, and there was no disagreeable odour. In addition, this method has the advantage that the substance in question is readily obtainable and is cheap.

Twort, Baker, Finn and Powell (184) used a misture of Hexylresorcinol in propylene glycol, and they, and later Andrewes et al (108), came to the conclusion that this substance was the ideal and the most effective under laboratory conditions. These substances, however, are not readily obtainable.

More recently a great deal of work in this connection has been done by the Americans chiefly in connection with propylene glycol and triethylene glycol vapours. (107, 109).

Using propylene glycol as the sterilizing agent, and staphylococcus albus as the test-organism, O.H.Robertson et al (160) found that by using a concentration of one gram of propylene glycol aerosol in 2,000,000 cc of air, there was complete sterilization of the air when it contained as many as 500,000 organisms per litre. This sterilization occurred within the space of seconds of the introduction of the aerosol. Hamburger et al (75), working with triethylene glycol in army wards where a concentration of 0.003 to 0.012 mgms/litre of air was maintained for long periods of time, found that there resulted a reduction of streptococci in the air of from 65% to 95%, and a reduction of total bacteria of 32% to 75%. These latter were not only more resistant to the action of the glycol, but in addition they were attached to particles of dust and were therefore not affected in the

same way as bacteria not attached to dried particles. It had been shown by other workers as well that the efficiency of highly bactericidal substances as aerosols was much increased by using a hygroscopic substance as the vehicle instead of water. (159). For this reason, the glycols, though not efficient bactericidal substances in themselves, are very efficient when in the atomized state. The mode of action of the aerosols has been a debated point with different observers. It would appear, however, that the view now held is that the atomized substance becomes converted into its gaseous form, and when a sufficiently high concentration of the gas is obtained, the desired germicidal effect is produced. It had been observed, for instance, that when the glycol had been atomized in coarse droplets, the lethal effect was markedly diminished, and its efficiency, and the efficiency of other substances as aerosols depended on the smallness of the droplets produced. (70, 74, 159).

The various substances used for the production of bactericidal mists, are not necessarily effective as antiseptics when used in solution. Hexylresorcinol is effective in concentrations of 1/15,000. Sodium hypochlorite is effective at about 1/20,000, and the glycols are not bactericidal until a concentration of 80% to 90% is reached.

With regard to the use of these substances in

the sterilizing of the air of occupied rooms, it becomes an important matter to determine what toxic effects these substances will exert when inhaled over a long period of time. A normal adult inhales over a period of 24 hours roughly from 12,000 to 14,000 litres of air. If this air is charged with a high concentration of the bactericidal vapour, it is possible that a considerable amount of the substance will be retained in the respiratory passages. Unfortunately there is no reference in the literature to the effects of inhalation over long periods of time of substances like hexyl-resorcinol and sodium hypochlorite. Tests on mice over a period of 6 and 7 months have shown no ill effects when these have been subjected to an atmosphere containing a high concentration of propylene glycol, but here too there is no concrete evidence of the possible toxic effects on other animals or on human beings. (159).

Sodium hypochlorite sprays have been used in factories for a number of years, as well as in offices and in densely populated spaces. It is claimed that the reduction in bacterial contamination of the air is marked, and that there has been a reduction in the incidence of respiratory infections as a result of these aerosols. (34, 114).

These aerosols exert their maximum effect on organisms that have been sprayed into the air of rooms.

When the organisms are attached to dried particles of dust and other organic matter, the effect becomes very much less marked.

It has been found that the best results have usually been obtained when the humidity of the atmosphere has been over 70% at temperatures of 54° to 72° F. (34). Baker and Twort (10) showed that the number of bacteria able to survive an aerosol in a given time, decreased many fold by raising the relative humidity from 40% to 60%.

Puck, Hamburger, et al report an interesting investigation of the effect of an aerosol and dust suppressive measures on the Beta haemolytic streptococci in a hospital ward. When dust prevention and glycol were used in conjunction, the air became almost completely streptococcal free. There was a reduction of 98% during the quiet periods, and 96% during bed-making. When only dust prevention was used, there was a reduction of 86% of the streptococcal count during bed-making, but no reduction at all during the quiet periods. (145).

...

(d) ULTRA-VIOLET RADIATION:

Ultra-violet radiation has a limited field of usefulness as a bactericidal agent, but when applied under ideal conditions to certain bacteria, it has extraordinary lethal effects.

This property was first recognised about 70 years ago, but it was not until about 25 years ago that systematic work on the subject was described. The really important work in this connection is, however, much more recent and it followed the introduction of specially selected filters allowing isolated regions of the spectrum to be studied individually. This resulted in the discovery that limited bands of the spectrum emanating energy of a certain wavelength were highly bactericidal, whereas others again which were not lethal to bacteria produced erythema of the skin. This is an important point because it means that lamps which are designed for the purpose of killing air-borne bacteria in the operating room must be specially selected, otherwise they will be quite ineffective in their action, and will lead to a false sense of security.

The emission line at 2537 A is taken as the standard of homogeneous, ultra-violet radiation, required for germicidal lamps, whereas wavelength 2967 A is the standard for therapeutic purposes.

Ultra-violet radiation has no penetrating power and therefore will not kill bacteria if these are shielded in any way. For instance, bacteria suspended in clear water are killed by radiation, but as soon as the water becomes the slightest bit turbid, the suspended matter in the water will protect them. For this same

reason, bacteria which are suspended singly in the air succumb quickly while those attached to particles of organic matter are protected from the action of the rays. Different types of bacteria vary relatively little in their response to radiation whether spore forming or vegetative, and in this respect they differ from their reactions to heat. The sensitivity of bacteria to this radiation is not altered by variations in temperature over a range from 5° to 37° C. (42, 92, 152).

The efficiency of ultra-violet radiation in a room will depend to an extent on the movement of the air in the room. Those bacteria nearest to the source of radiation will naturally be affected most, while those at a greater distance and not subjected to the same exposure may survive the action of the rays. It is interesting to note in this connection, that those bacteria which have survived the action of ultra-violet radiation are usually more susceptible to the action of other antiseptic measures than normal bacteria. This is an important practical point.

The application of ultra-violet radiation to the destruction of air-borne bacteria has been studied in great detail by Deryl Hart, and was first described by him in 1936. He emphasized the use of radiation from a monochromatic source, and having the highest bactericidal, and the least erythermal effect. A wavelength of 2537A was found to meet this requirement.

In his operating theatres he used a cluster of 8 tubes, five feet away from the table, and he found that the intensity of the radiation was sufficient to kill bacteria in less than one minute at 54 inches. The radiation produced only a transient erythema in a blond subject after 80 minutes' exposure. (81).

Working in the Duke Hospital, and reporting on an organised survey of the post-operative wound infection over a period of 11 years, during the first half of which period an exceedingly rigid aseptic technique was followed in the theatres, but without the use of ultra-violet radiation, and during the second 5½ years of this period when the same technique was accompanied by the use of this radiation in the theatres, Hart found that the incidence of infection had been reduced in the second half period to from 1/20 to 1/100 of what it had been in the first half period. (83). These infections in the first 5½ years were called unexplained infections for the reason that every step in the aseptic technique had been rigidly overhauled and tightened up, but in spite of which, the infections continued.

Hart found that the contamination of the theatre air varied directly with the following:-

(a) The number of occupants in the theatre;
(b) The duration of occupancy;
(c) The percentage of nose and throat carriers;
(d) The amount of activity and talking;
(e) The efficiency of the ventilating system. (85).

It was found that the conventional gauze mask did not prevent air contamination, and did not prevent bacteria from being atomized through the mask. (84)

Hart came to the conclusion that pathogenic bacteria given off from the noses and throats of the occupants of the modern well-run operating room, floating in the air and sedimenting on to the sterile field, comprise the greatest breach in our present-day aseptic technique. This applies especially to the large wounds, where haemostasis is not adequate, trauma is inevitable, and other conditions ideal for wound healing are not possible to attain.

The work of Hart has become a landmark in surgical history, and his findings have been substantiated by a large number of other observers.

The value of ultra-violet radiation has, however, been demonstrated not only in the operating room, but also in children's wards, school rooms and elsewhere. (24, 157, 162).

The view is held by some authorities that ultra-violet radiation actually stimulates the tissues, and thereby promotes more rapid healing. Whether this is so or not has not been definitely established, but it is possible that prompt healing is due to the complete absence of organisms in the wound which results when radiation is used in the theatre.

It has been shown that when cells are damaged by this radiation, they produce a substance which stimulates cell proliferation and growth. (103). This substance is thought to be in the nature of a hormone.

The exact nature of the processes involved in the destruction of bacteria is not fully understood, but it is thought that the rays produce a coagulation of the protein of the bacterial cells.

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CHAPTER FIVE

POST-OPERATIVE WOUND INFECTION IN THE GROOTE SCHUUR HOSPITAL

POST-OPERATIVE WOUND INFECTION IN THE GROOTE SCHUUR HOSPITAL.

When this investigation began, there had been for some little time, amongst some of the hospital authorities, a certain degree of concern regarding an unduly high incidence of post-operative wound infection in one of the surgical wards.

This fortuitous circumstance was a most fortunate one from the point of view of the present study, and it was decided forthwith to make this ward the base for the investigations.

To make the study more complete, it was decided to investigate at the same time the incidence of such infection in another and similar ward as a control, and then to investigate the possible causes of this infection, both in the wards and in the operating theatres concerned.

For the convenience of description, the results of the findings will be classified under two headings:-

(1) A SURVEY OF THE WARDS.

(2) A SURVEY OF THE OPERATING THEATRE.

...

(1) A SURVEY OF THE WARDS.

The application of an investigation of this nature to all the surgical wards of the hospital would have been beyond the bounds of possibility for one person working single-handed. It was felt that a survey of two large wards in the hospital, over a reasonable period of time, would, however, give a fair indication of the incidence of infection in clean operation wounds in the hospital generally. The control ward had not been credited with an unusual percentage of wound infection, so that in view of this it would be interesting to determine whether there really was a higher incidence of infection in the one ward than in the other.

The ward under consideration was Ci.

The control ward was Bi.

The reason for choosing Bi as a control was not only that no comment had been made about its incidence of infection, but also because it had a number of points in common with Ci, and it seemed therefore to be a suitable control.

(a) Both are European general surgical wards, and both consist of male and female sections of equal proportions.

(b) Both are constructed on identical lines, and on the same plan.

(c) Both are situated in the same wing of the hospital,

ward Ci being on the floor immediately above Bi.

(d) In view of their position, both wards are subjected to the same conditions of sunshine, prevailing winds, and other atmospheric variations.

(e) The methods of administration and routine are more or less identical in the two wards.

The main points of difference between the two wards are as follows:-

(1) The surgical staffs.

Bi is served by one surgical team consisting of:-

1 Senior surgeon;
3 Assistant surgeons;
3 Registrars.

Ci is served by two other surgical teams consisting of:-

2 Senior surgeons;
4 Assistant surgeons;
2 Registrars.

Thus it is seen that two different sets of surgeons operate in the two wards, so that the possibility of one particular surgeon having patients in both wards does not arise.

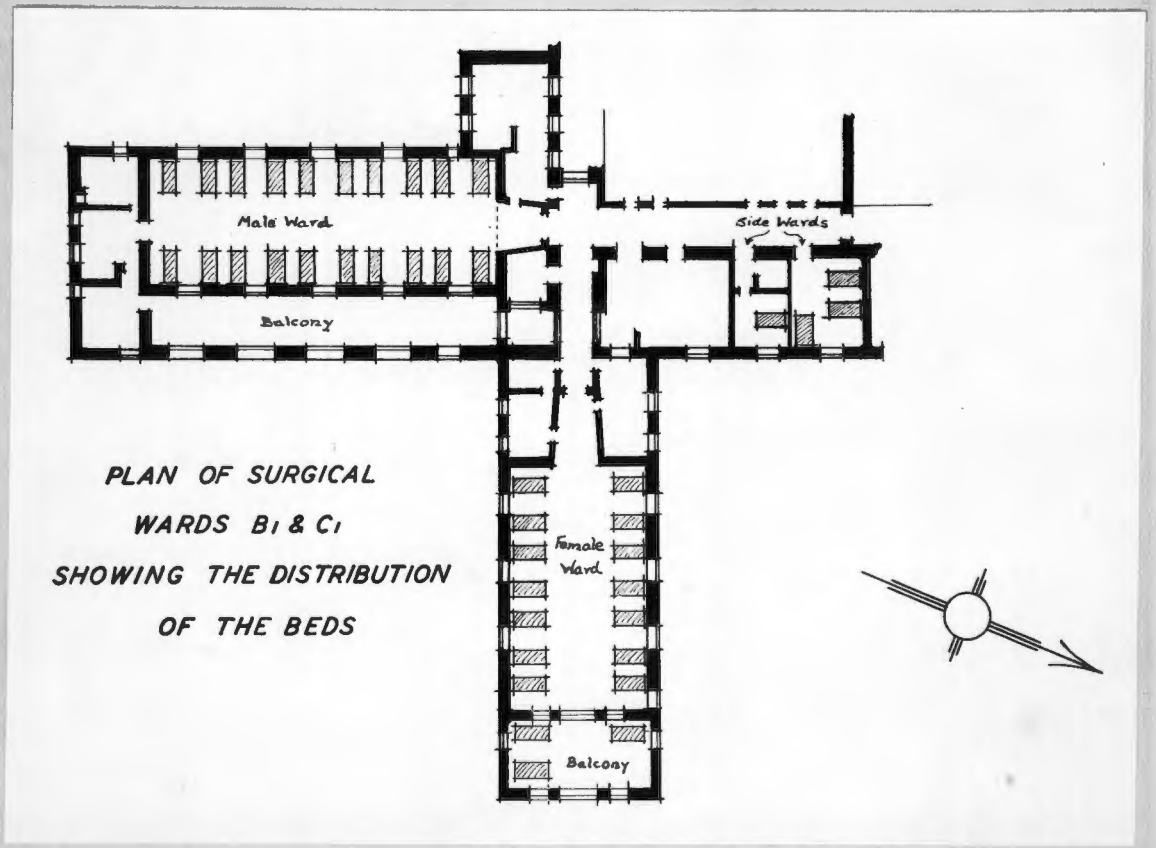
(2) The case turn-over in Ci is somewhat greater than it is in Bi, so that should the incidence of post-operative infection be more or less general in the hospital, one would expect to find a greater

number of infected cases in those wards handling a greater number of patients.

...

THE WARDS:

Each unit consists of a large male ward containing 20 beds, a large female ward containing 14 beds, and small side wards. In the case of Bi, the side wards are three in number, each accommodating one, two and three beds respectively. In the case of Ci, there are only two side wards, a three bedded, and a two bedded ward. The large wards are spacious and airy, well supplied with windows and large doors, giving excellent illumination and ventilation. Windows of equal proportions are situated in opposite walls of the large wards, allowing for suitable ventilation in the face of adverse weather conditions. On the next page is a true to scale diagram of the original plans of the wards, kindly lent by the Superintendent of the Hospital. The diagram is included chiefly to indicate the position and arrangement of the beds. It shows also the positions of the windows and doors in relation to the beds. The bed spacing is adequate, and there is a large balcony attached to each large ward, used by convalescent patients.



PLAN OF SURGICAL WARDS B1 & C1 SHOWING THE DISTRIBUTION OF THE BEDS

The floors of all wards and corridors leading to the wards are covered with a rubberoid compound, thus eliminating cracks and crevices for the accumulation of dust.

From this description it will be seen that the conditions for the nursing of sick patients would appear to be ideal. It will be noted, however, that no provision is made for the separate nursing of clean and infected cases.

...

The work in the wards has been grouped under two headings:-

(a) General observations related chiefly to the ward routine and procedure.

(b) Special observations.

(a) GENERAL OBSERVATIONS:

Naturally, only those points will be discussed here which may have a bearing, directly or indirectly, on this study, and they indicate the procedure which applied during the first half of the period under investigation. At the end of this half period, and with the consent of the hospital authorities, a change of routine was instituted in ward Ci, and these new procedures were more or less rigidly followed for the second half of the period of investigation. Meanwhile, the procedure in Bi remained as before. The purpose of this change was to establish whether or not improvement in the dressing technique would result in an appreciable improvement in the wound infections, in this instance ward Bi again serving as a control.

It would perhaps be fair to mention at the outset that the advent of an investigator in the wards and in the theatre produced an undesirable reaction on the part of the nursing staff. The impression gained was that the purpose of the investigator was to determine the

efficiency or otherwise of the nursing staff, with the result that each sister in charge took it upon herself to improve her ward to the best of her ability. Be this as it may, it nevertheless must be recorded that there was complete co-operation at all times from the nursing personnel, and also from the honorary visiting staff of the hospital.

...

GENERAL WARD ROUTINE:

(a) Bed-making	.....	7 to 7.45 a.m.
(b) Sweeping	.....	7.45 a.m. and again at 10.30.
(c) Dusting	.....	9 a.m.
(d) Dressings	.....	9 a.m. to about 11.30 a.m.
(e) Ward round	.....	during dressings.
(f) Student clinics	.....	during dressings.

The above times are given to indicate when the dressings were done in relation to the other activities in the ward. Of particular interest is the fact that one sweeping operation always occurred in the middle of the dressing round.

BED-MAKING:

No special comment is necessary here in regard to the making of beds, but it is necessary to mention the blankets and the linen.

Blankets: On the discharge of a patient, his blankets are placed for airing on the balcony for a period of about 24 hours, after which they are stored in the linen cupboard for further use. No system was in force by which blankets were routinely sterilized. Only in special cases were they sent for special treatment.

The ward blankets accompany the patient on his way to the theatre, but before he is actually wheeled into the theatre, his blankets are changed in the anaesthetic room for theatre blankets, which then accompany him on the remainder of his journey to the table. Usually, however, while waiting in the anaesthetic room, the ward blanket is placed on top of the theatre blanket as the latter does not afford sufficient cover. The ward blanket does not, however, go into the theatre.

Linen: For those patients who are in the ward for a long period, there is a change of linen varying from one to three weeks, depending apparently on the stocks in hand. When supplies run short, draw sheets are substituted for sheets. New patients on arrival are supplied with fresh linen.

DUSTING AND SWEEPING:

It will be noted that dressings began usually when dusting began, and, in addition, when the dust in the ward from the recent sweeping had not yet settled.

The wards were always swept again during the middle of the dressing round. Sweeping and dusting was always dry, and no methods were employed to prevent production of dust in the wards during these operations.

DRESSINGS:

The following important points were noted:-

(a) It was the exception to find the windows and doors closed while dressings were being done.

(b) It was the exception not to find the ward orderly-boy busy sweeping the ward while dressings were in progress, and it was noted on numerous occasions that his operations were allowed to proceed undisturbed in the immediate vicinity of a bed where an exposed wound was being dressed by the nurse.

(c) It was the exception not to find all sorts of activities going on in the ward simultaneously with the dressings, such as the arranging of flowers, distribution of books to patients, ward clinics to students, ambulant patients walking freely about the ward, and so on. In fact, the impression gained was that everyone was free to come and go as he pleased, whether dressings were being done or not.

THE BATH:

Mention is made here of the bath because it was noted on several occasions that patients with severe

burns were placed in the bath at regular intervals as part of their treatment. It has been shown (126) that the sterilization of a bath is a difficult process, and that a large number of organisms always adhere to the bath and especially along the grease line in spite of washing and scrubbing the bath. As far as could be ascertained, there was no special method adopted to sterilize these baths, after the burn patients had used them.

TRAINING OF DRESSERS:

The general impression gained was that the average nurse was quite inexperienced in wound dressings. Her theoretical training in this respect was gained in the classroom, while her practical training was invariably dependent on what she was taught by the previous dresser, whose place she had taken. Apparently it is the duty of the Sister in the ward to supervise the dressings and to train the nurses, but it became quite clear that her many duties prevented her from paying as much attention to this aspect as was necessary.

SEGREGATION OF PATIENTS:

The surgical wards accommodate patients with clean wounds, infected wounds, and of course patients with no wounds. Infected and clean wounds are often nursed side by side, and no special methods are employed to segregate them.

...

(b) SPECIAL OBSERVATIONS:

These include the following:-

(1) A study of all the wounds.

(2) The skin of the patient.

(3) The dressers:
  (i) Their noses and throats;
  (ii) Their hands;
  (iii) The dressing technique.

(4) The instruments.

(5) The air of the ward.

...

(1) A STUDY OF THE WOUNDS.

Records were kept of all patients admitted to the two wards over a period of approximately 7½ months, beginning on 14th January, 1947. A card was used for each patient, bearing on one side the name and age of the patient, his complaint and operation, and a few notes concerning his treatment and progress. On the reverse side was noted the nature of the organisms cultured from the wound. The cards were all numbered, and the cultures made were numbered correspondingly, for the purpose of classification and identification at a later stage.

The laboratory procedures were almost all carried out in a room conveniently placed in the hospital

and equipped with all the necessary apparatus, most of which was supplied by the Department of Bacteriology of the University of Cape Town.

At the beginning of the investigation, the dressers were accompanied on all the dressing rounds each day, and all wounds inspected with them. Swabs were taken of all wounds that looked infected. The daily inspection of all the wounds became, however, a serious time-consuming undertaking and to obviate this, charts were posted in the wards on which the dressers could indicate what wounds needed inspection and swabbing. On the next page is a photograph of a portion of such a chart. It indicated, at the same time, when the patient was admitted and when the wound became infected in relation to his operation. To ensure that all the infected wounds were properly recorded, a personal inspection during the dressing round was conducted at least twice weekly.

For the purpose of this study, the wounds in the wards were classified into primary and secondary. Primary wounds included those patients admitted with infection, while the secondary ones consisted of those that had become infected following a clean operation.

...

WARD B1 SEPTIC WOUNDS

NAME	MAY 5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
v.d. Westhuizen	+	+	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-
Mc Gregor	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Jordaan	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Henze	+	+	+	+	-	-	-	-										
Paxton	+	+	-	-	-	-	-											
Beukes	+	+	+	+	+	+	-	-	-									
Kendar	+	+	-	-	-	-												
Black	-	+	+	+	+	+	+	+	+	+	+	-	-	-				
Wickham	-	-	+	+	+	+	+	+	-	-	-	-						
Abrahams	-	-	+	+	+	+	+	+	+	-	-	-						
Vermeulen	O	-	-	-	-	+	+	+	-	-	-							
Hobbs	O	-	-	-	-	+	+	+	+	+	-	-						
Greenbaum				A	-	-	O	-	-	-	+	+	+	+	+	+	+	-
Nys				A+	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Marais										A	-	O	-	-	-	+	+	+

A ADMITTED
O OPERATION
+ INFECTED

LABORATORY PROCEDURES:

All swabs taken were plated immediately on 2% and 6% sheep's blood agar plates and incubated for 24 hours at 37° C. Swabs taken from patients who were receiving penicillin, or had recently been given penicillin, were first immersed in a solution of sterile penicillinase for 10 minutes, and then plated in the ordinary way.

After incubation, cultures were examined with

a hand lens, and all suspicious pathogenic colonies were picked off and subcultured on Hartley's agar slopes, and incubated for another 24 hours. These were then stained with Gram's stain and examined microscopically and classified into groups of Gram positive cocci, Gram positive bacilli, and Gram negative bacilli. These were then stored for identification later.

The Gram Positive cocci:

(a) The Staphylococci: Only the suspicious pathogenic colonies showing haemolysis and yellow pigmentation were kept for further examination.

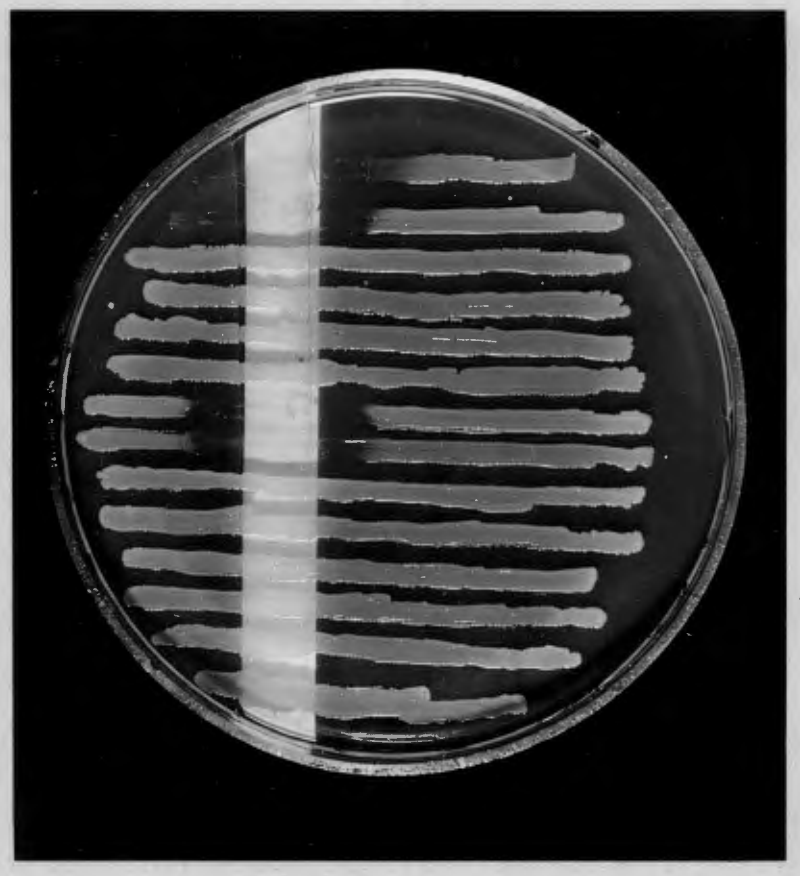
Coagulase Test: 2.25 cc of Hartley's broth was mixed with 0.25 cc of human plasma, and inoculated with a loop-ful of the subculture, and incubated for 24 hours.

All coagulase positive cultures were subcultured again for the penicillin sensitivity test.

Penicillin Sensitivity: A large petri dish containing Hartley's agar was used for this purpose. Across the centre of the medium, a gutter of half an inch wide was cut with a sterile knife, and into this was poured molten agar containing the required concentration of penicillin. For these tests, the usual 4 units per cc. was used, and then all the resistant strains were later tested against 10, 100 and 1000 units per cc.

Using a platinum loop, each culture to be tested was streaked across the gutter in a straight line,

and then the plate was incubated for 24 hours. The photograph shows a plate of this type inoculated with 14 strains of staphylococci. For the purpose of the photograph, a strip of white paper was placed behind the plate showing the position of the penicillin gutter. It will be noted that 10 of the strains were completely resistant to the penicillin, i.e., they grew right across the penicillin agar.



(b) The Streptococci: Very few beta haemolytic colonies were cultured in this survey, and most of these came from the throats of nurses. These were kindly identified for me in the Department of Bacteriology.

The Gram Negative Bacilli. These are subcultured on McConkey's medium to determine lactose fermentation. From here, isolated colonies were inoculated into peptone water and incubated for 24 hours. This culture was then tested for motility by the hanging drop method, after which a drop of the culture was inoculated into tubes containing dextrose, lactose, mannite, urea, gelatine and lead acetate. The indole test was performed on the remains of the peptone water culture. These tests were usually sufficient to identify the organisms.

The Gram Positive Bacilli. These were mostly diphtheroids and sporing bacilli and were not of sufficient importance to justify further identification. Where necessary, sugar fermentations were carried out.

...

THE RESULTS :-

(a) For the first half of the period of study.

WARD Bi

Total number of patients.....	220
Primary infected cases.....	20
Number of operations.....	137
Number of post-operative infections.....	25
Percentage of post-operative infection.....	18.24%

Organisms cultured from the wounds.

Staphylococci : Coagulase positive	26
Penicillin resistant	5
B. Coli	7
B.proteus	16
Diphtheroids	30
B. subtilis	5
Ps. pyocyanea	6

...

WARD Ci.

Total number of patients	300
Primary infected cases	40
Number of operations	191
Number of post-operative infections	40
Percentage of post-operative infection	20.9%

Organisms cultured.

Staphylococci : Coagulase positive	33
Penicillin resistant	9
B. coli	25
B. proteus	25
Diphtheroids	15
B. subtilis	2
Ps. pyocyanea	6

...

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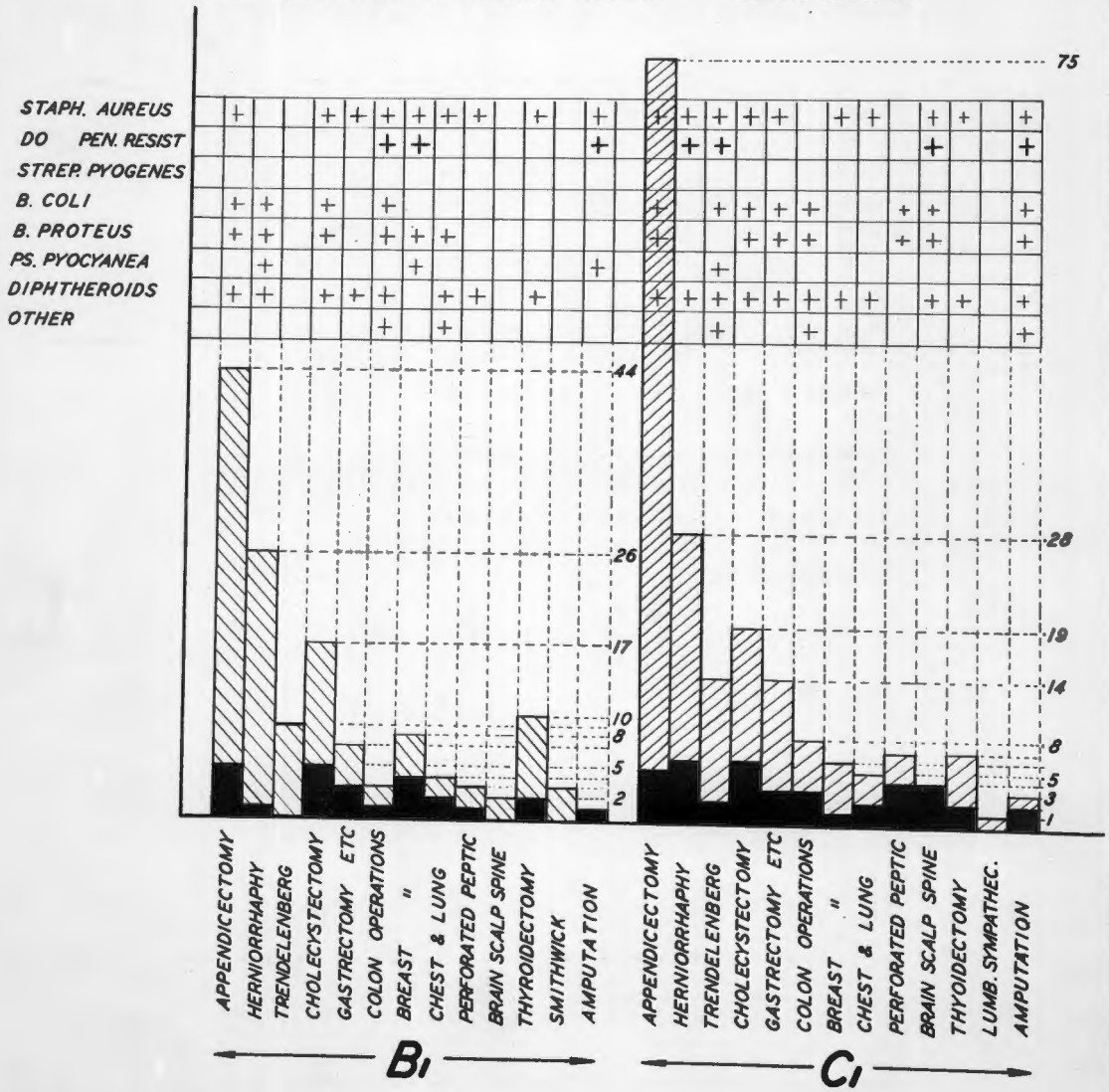
POST-OPERATIVE WOUND INFECTION

WARDS B_1 & C_1

JANUARY - APRIL 1947

SHOWING TOTAL NUMBER OF CLEAN OPERATIONS — SHADED COLUMNS
AND TOTAL NUMBER OF INFECTED WOUNDS — BLACK COLUMNS



For the second half of the period, radical changes in the dressing technique were introduced into ward Ci, the conditions in Bi remaining as before. The nature of these changes will be indicated later.

(b) For the second half of the period of study.

WARD Bi.

Total number of patients	142
Number of primary infections	15
Number of operations	98
Number of post-operative infections	28
Percentage of post-operative infection	26.55%

Organisms cultured.

Staphylococci : Coagulase positive	24
Penicillin resistant	6
B. coli	16
B. proteus	5
Diphtheroids	11
B. subtilis	3
Streptococci (Beta Haemolytic)	1

...

WARD C1:

Total number of patients	260	
Number of primary infections	23	
Number of operations	151	
Number of infected wounds	24	
Percentage of post-operative infection		15.89%

Organisms cultured:

Staphylococci: Coagulase positive	27	
Penicillin resistant	7	
B. coli	12	
B. Proteus	4	
Diphtheroids	15	
B. subtilis	3	

...

The charts on pages 113 and 116 show the types of operation that were recorded, the numbers of each type of operation, and in black columns the proportion of infected cases. In addition, it will be seen at a glance what types of organisms were responsible for the infections in each group of operations.

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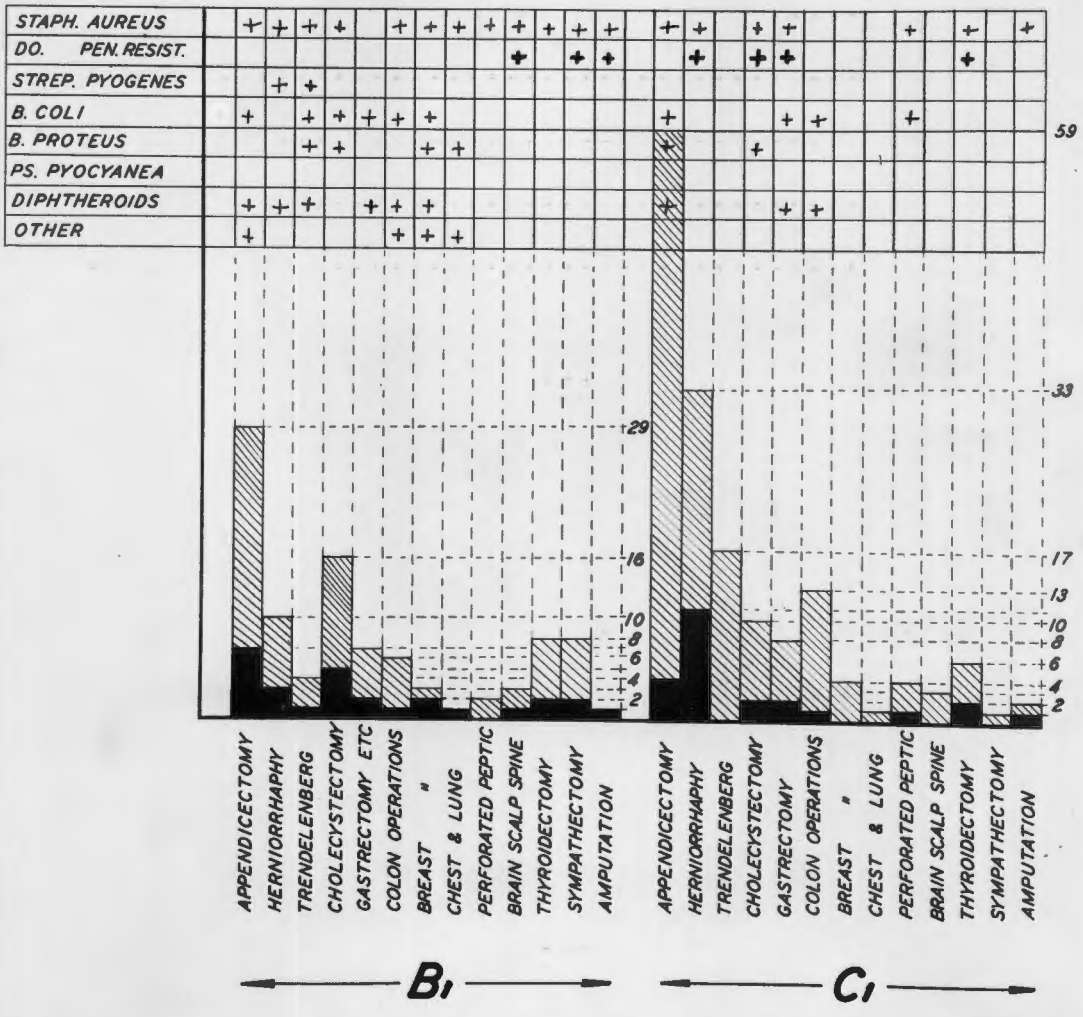
POST-OPERATIVE WOUND INFECTION

WARDS B1 & C1

MAY - JULY 1947

TOTAL NUMBER OF CLEAN OPERATIONS — SHADED COLUMNS
TOTAL NUMBER OF INFECTED WOUNDS — BLACK COLUMNS



Thus by far and away the commonest wound infector in the two wards for the whole of the period was the staphylococcus aureus.

During this period, 922 patients were admitted to the two wards. Of these, 215 had infected wounds, both primary and secondary, and of these, no less than 110 were infected with staphylococcus aureus.

Of these 110 coagulase positive staphylococcus aureus strains, 28 were resistant to penicillin, i.e. 25.45%. All these latter were resistant to 4 units of penicillin per cc. and with further testing they were all found to be resistant to 1000 units as well.

The types of wounds infected with these resistant strains were as follows:-

1	Scalp operation for circoid aneurysm.
4	Amputations.
6	Hernias.
1	Trendelenberg operation.
1	Halstead.
1	Abdomino-perineal.
1	Lumbar sympathectomy. (This patient died from his infection.)
1	Thyroidectomy.
1	Cholecystectomy
1	Gastrectomy
18	TOTAL

The following were not after clean operations:-

2	Burns
1	Gun-shot wound necessitating amputation of the leg.
2	Cases of osteitis.
1	Pilonidal sinus.
2	Chronic ulcers of the leg.
1	Abscess near knee joint (? bursitis).
1	Scalp wound (street accident)
10	TOTAL

...

For the purpose of this report, it would be superfluous to describe each of these cases in detail, but a few interesting facts arise which would be worthy of recording:

The CIRCOID ANEURYSM case was first seen 13 days after his first operation when he was having penicillin and sulphadiazine. Staphylococcus aureus was cultured which was penicillin sensitive. Two weeks after the wound had healed, he was subjected to another operation, and the wound became infected within the third day. The organism was penicillin resistant, and it took many weeks before the wound healed. A great slough occurred by the end of the first week.

Most of the AMPUTATIONS in the two wards seemed to become

infected. There were 7 during this period, of which 5 became infected, and in four of these, penicillin resistant staphylococci were obtained from the wounds. One patient with senile gangrene of two toes (Mrs. M.L.R., No.15, 14/1/47), had her foot amputated. The wound became infected and penicillin in 20,000 unit doses was given 3-hourly. This was continued for nearly a month, by which time the wound had not healed and a further amputation was performed, this time above the knee. Again the wound became infected and it was more than two months before it had healed. The staphylococci were resistant to penicillin before the second operation, and those cultured after the second operation were also resistant.

HERNIA: This operation was followed by an unusual amount of post-operative infection. One surgeon, as a routine, prescribed sulphadiazine to his patients post-operatively. Mr. G.L.S., No.1040, 13/5/47, had a bilateral herniorrhaphy. On the sixth post-operative day, there was a large bulge over the left inguinal scar, and eventually three days later, a sinus forceps inserted deep to the external oblique, evacuated about ¾ pint of pus. This was resistant to penicillin, although no penicillin had been given. In another case, Mr. H.S., No.1180, 1/7/47, infection occurred in the wound, where the organism was resistant to penicillin and where no penicillin had been administered. In the case of the LUMBAR SYMPATHECTOMY,

extensive cellulitis of the surrounding skin of the abdomen and the thigh appeared on the third day after the operation and by the eighth day, enormous quantities of pus were evacuated. Penicillin was given in 50,000 unit doses from the commencement, and the organism was resistant to penicillin. A month after the operation, the patient died from his infection. (Patient: Mr.v.d.W., No.618, 30/6/47.) In the case of the THYROIDECTOMY (Mrs. R.L., No.1217, 13/7/47), there was extensive discoloration of the skin over a wide area from the wound, due to imperfect haemostasis. From the sixth day onwards there was considerable discharge of pus from the wound. The organisms were penicillin resistant, although no penicillin had been administered.

In both BURN cases, the resistance of the organism was established only after the treatment with penicillin had begun.

The GUNSHOT WOUND (Mr. B.E., No.59, 29/1/47), had penicillin resistant organisms two days after the amputation. The penicillin therapy was begun immediately after the operation. PILONIDAL SINUS (Mr. P. McG., No.360, 3/2/47):- This patient had a discharging sinus on admission, and 17 days after treatment with penicillin, the sinus was excised, the wound Bipped, and then closed, a drain being left in. Pus discharged freely from the wound from the fourth day onwards, and the wound remained open for more than two months. The organisms were

resistant to penicillin, but this resistance was established only some time after the therapy had begun.
LEG ULCER. (Miss K.P., No.384, 20/2/47):- The patient had an ulcer on the lateral part of the leg for more than a year. She had Poliomyelitis as a child, affecting that leg. The original culture gave staphylococci which were sensitive to penicillin. In spite of prolonged treatment with penicillin, the ulcer showed no signs of healing, and then the ulcer was grafted, the graft being taken from the thigh. The graft failed, and swabs taken from the ulcer at this stage, and from the donor area, both gave cultures of penicillin resistant staphylococci.

...

In the majority of the cases it appeared that the resistance to penicillin was acquired after treatment was instituted, and the question arose whether this resistance was due to inadequate dosage. It is, however, quite clear that in quite a number of the cases, the organism was resistant from the start. This applies to the three cases mentioned where no penicillin had been given, and it seems very probable indeed that the lumbar sympathectomy case, which received massive doses from the beginning, was infected with a resistant strain at the time of the operation. In the case of the gunshot wound, the strain was found to be resistant on the second day

after the operation. Swabs were not taken before the operation, or before penicillin was started, but it seems very unlikely that the strain could have become resistant as a result of treatment in this short time, so that it must be assumed that the wound became infected either in the theatre or in the ward, with the resistant strain.

...

It has been shown by many observers that resistant strains of staphylococci and streptococci, as well as pneumococci, can be cultivated in vitro, on media to which increasing concentrations of penicillin have been added. The sensitive strains are destroyed, leaving the more resistant ones, so that by a process of mutation, a highly resistant strain is eventually developed. (102) This resistance is not a permanent characteristic, as it is in the case of organisms which have been made resistant to sulphathiazole in vitro. (151)

Lyons, Schmidt and Sesler, Rammelkamp and Maxson (113, 150, 164), have all showed that acquired resistance develops in vivo, and that this is due to penicillin therapy. The resistance which has been acquired in vivo is a permanent characteristic of the organism. (191)

Of all the organisms sensitive to penicillin, staphylococcus aureus probably shows the greatest variation in its sensitivity to penicillin, and at the same time

shows the greatest percentage of strains that are naturally resistant. (102).

Rantz and Kirby (151) found that of 70 strains of staphylococci cultured from wounds, no less than 24% were penicillin resistant. Galardo (65) in a study of 112 wounds of the extremities, found 108 strains of staphylococci, and of these, 22.2% were either naturally resistant, or became resistant during the course of treatment. He found that 9.4% of the pathogenic strains became resistant during the course of treatment, and that the period taken to become resistant varied from 5 to 40 days. The resistance of staphylococci acquired as a result of treatment is thought to be due to the production by the organisms of a substance called penicillinase, which is in the nature of an enzyme, and has the property of inactivating penicillin. Resistance resulting from in vitro cultivation is not due to the capacity to produce penicillinase. (102)

Penicillinase is produced by a variety of different organisms, both pathogenic and saprophytic. The commonest and the most important of these organisms are the gram negative bacilli found in the gastro-intestinal tract such as the paracolon bacilli, Esch. coli, B. megatherium, and B. mesentericus. Saprophytes such as B cereus and B subtilis are also capable of producing penicillinase readily. (102)

The paramount importance of this fact arises in connection with wounds infected by penicillin sensitive organisms, which are in addition contaminated by organisms which are capable of producing penicillinase. For instance, this arises each time a staphylococcal wound becomes contaminated by B. coli. In this case the penicillin immediately loses its potency because it is inactivated by the penicillinase before it is able to attack the penicillin sensitive organisms.

With regard to the effect of penicillin resistant strains of staphylococci on wounds, North, Christie and Rank (134) have reported on a series of 59 infected war wounds. They came to the conclusion that "the presence of penicillin resistant strains did not retard the clinical progress of the wounds. Their healing was not a primary function of antiseptic treatment or absolute bacteriological sterilization. These wounds were only healed after natural processes and time-honoured surgical methods ultimately brought them into the category of simple uncomplicated wounds, and then they healed rapidly".

In this connection it is interesting to note that Spink and Vivino (168) have shown that penicillin resistant strains of staphylococci are more susceptible to the bactericidal action of the blood than the penicillin sensitive strains.

It was shown earlier that penicillin resistance

in vivo was due to the production of penicillinase by these strains. It can be shown that if conditions are such in a wound that these penicillinase producing staphylococci cannot accumulate and produce an abundance of penicillinase, then penicillin, if administered freely, should prove to be efficacious. Inadequate drainage in a wound, and the presence of large amounts of necrotic tissue capable of harbouring an accumulation of penicillinase, are naturally destined to interfere with the action of the penicillin. (134)

Out of this then arises the important fact that in the treatment of staphylococcal infections, penicillin must not be relied upon to replace well established surgical principles. If penicillin is to be of value, it must be used judiciously in conjunction with these principles.

...

(2) THE SKIN OF THE PATIENT.

The pre-operative skin preparation of the patient is more or less identical in the two wards, with the exception that in Ward Bi two skin preparations are performed, as opposed to one only in the case of Ward Ci. The preparation is as follows:-

On the afternoon before the operation, the

patient has a bath, after which the part to be operated upon is shaved. A nurse who has scrubbed up, now washes the part thoroughly with spirit soap, and then applies, with the aid of sterile cotton wool swabs, first ether, then alcohol, and then acetone. After this, a sterile towel is applied to the area and a bandage to keep this in place.

On the following morning, the skin preparation is repeated prior to the patient's being taken to the theatre.

In Ward Ci the patient has a bath on the afternoon before operation, but the rest of the preparation is performed on the morning immediately before the operation, this preparation being identical with that described above.

In the theatre, the surgeon again applies antiseptic solution to the area.

More details of the skin flora will be discussed in the chapter dealing with the investigations in the theatre.

...

(3) THE DRESSERS:

(i) Their Noses and Throats:

It is customary in the two wards that nurses do dressings for a period consisting of from two weeks to a month, after which time another set of dressers takes over.

Swabs were taken, at varying intervals, of the noses and throats of all the nursing staff in both wards. Each ward consisted of one sister, two staff nurses and seven junior nurses.

The results of these swabs were as follows:- For the first half of the period under investigation:

WARD Bi:

	Percentage
Staphylococci	40
Coagulase positive ...	20
Penicillin resistant .	nil
Streptococci:	
Viridans	70
Pyogenes	nil

WARD Ci:

Staphylococci	50
Coagulase positive ...	30
Penicillin resistant .	nil
Streptococci:	
Viridans	60
Pyogenes	nil

For the second half of the period, the percentage of the personnel harbouring pathogens in the nose and throat was as follows:-

	Percentage
WARD Bi:	
Staphylococci	70
Coagulase positive ...	50
Penicillin resistant .	30
Streptococci:	
Viridans	100
Pyogenes	20
WARD Ci:	
Staphylococci	40
Coagulase positive	40
Penicillin resistant ..	10
Streptococci:	
Viridans	60
Pyogenes	40

Of the Beta Haemolytic streptococci cultured, one nurse in Ward Bi had Group C streptococci, and all the others belonged to neither Groups A, B or C. It was not possible to trace cross infection in the wards through streptococcal infections. During the whole of the period under investigation, on only one occasion was a Beta haemolytic streptococcal culture obtained. This was grown from a Trendelenberg operation wound (Mrs. G.G.B., admitted 24/5/47, No.553.) The organism in this case belonged to Group A. No other infection of this type was found, and in addition the patient's throat was negative for streptococcus pyogenes.

A point of interest in connection with the figures given on the two previous pages is the fact that during the winter months there was a distinct increase in the number of pathogens. The other interesting feature is the presence, in several of the throats, of penicillin resistant staphylococci, but in this connection it must be pointed out that an entirely different set of nurses and sisters operated in the two wards in the two time periods. This is the result of the method adopted whereby a nurse works in a particular ward for a short period and then is transferred to another. Therefore no record could be kept of the change of flora in any particular throat.

For the purpose of dressing of wounds and the sterilization of instruments, masks were not worn in any of the wards of the hospital. At the end of the half period, masks and gowns and caps were worn by dressers in Ward Ci, but no in Bi.

...

(ii) Their Hands:

Gloves were not worn for dressings; the hands were scrubbed for a short period only; the "no-touch" technique was not employed; and all dressings in the ward were performed by one nurse working single-handed.

In view of these observations, it was decided

to demonstrate, if possible, contamination from the wound being transferred to the hands of the dresser, and from here to the handles of the dressing trolley. A considerable number of these experiments was carried out, but needless to say, it was not always possible to demonstrate this contamination. In most cases, the experiments were performed in conjunction with patients whose wounds contained organisms that were easily identified.

It will be sufficient to give a brief summary of the findings without having to burden the reader with a list of all the cultures obtained in every swabbing.

EXPERIMENT G : 8/3/47.

Patient: Mrs. M.L.R., No. 15. Amputation stump.

Bacteriology: Penicillin resistant staphylococcus.

Swabs taken:

(a) Dresser's hands after scrubbing.
(b) Dresser's hands after dressing the wound.
(c) Wound.
(d) Skin of patient's abdomen.

Air Samples: (e) Before blankets had been disturbed.
(f) While wound was being dressed.

Cotton Wool : (g) A small portion of the outer cotton wool dressing was placed by means of sterile forceps into a test-tube containing nutrient broth. This wool did not appear to be soiled.

RESULTS:

The same strain of penicillin resistant staphylococci were obtained from:-

The dresser's hands after the dressing;

The wound;

The skin of the patient's abdomen;

The second air sample (while the wound was being dressed);

The cotton wool from the dressing.

EXPERIMENT J : 9/3/47.

Patient: Mr. W. v.N. No.30. Abdomino-perineal.

Bacteriology: (a) Penicillin resistant staphylococci.

(b) B. coli.

CULTURES:

(a) Dresser's hands after scrubbing;

(b) Dresser's hands after dressing the wound;

(c) The wound;

(d) Handle of the instrument trolley;

(e) Part of the screen touched by the dresser after the dressing;

(f) Air sample before the dressing;

(g) Air sample during the dressing.

RESULTS:

B. coli was found in the cultures of:- The wound; the dresser's hands after the dressing; the handle of the trolley; and the screen.

Penicillin resistant staphylococci were found in:-
The wound; and in the second air sample.

EXPERIMENT L : 27/3/47.

Patient: Mr. M.B. No.418. A : Laparotomy for carcinoma of stomach.
B : Cut-down on each ankle infected.
C : Pressure sore infected.

Bacteriology: From the abdominal wound: Diphtheroids and B. proteus. From all the other wounds, the growth of B. proteus was so heavy, that even after repeated subculture on 6% plates, all were completely overgrown.

CULTURES:

(a) Dresser's hands before dressing;
(b) Dresser's hands after dressing;
(c) All the wounds;
(d) Skin of the patient's thigh;
(e) Ants running around at the foot of the bed, attracted by the discharges on the dressings. A few of these were transferred to nutrient broth and incubated.

RESULTS:

All the cultures excepting the first, i.e. of the dresser's hands before the dressing, were completely overgrown with proteus.

EXPERIMENT S.H. : 30/5/47.

Patient: Mr. L.S. No.1014. Bilateral herniorrhaphy. (Local anaesthetic)

Bacteriology: Pure cultures of penicillin resistant staphylococci.

The dressing was done by two dressers. One arranged the blankets of the patient and his bandages. The other performed the dressing. Air samples were taken at intervals from before the dressing, until it was completed.

CULTURES:

(a) Dresser's hands before dressing;

(b) Dresser's hands after dressing;

(c) Assistant's hands before arranging blankets and bandages;

(d) Assistant's hands after;

(e) Skin of patient's leg;

(f) Skin of patient's arm;

(g) Wounds;

(h) Air samples:- Before dressing;

(i) While blankets were being turned down;

(j) While bandages were being removed;

(k) During the dressing;

(l) Later on when the dressing had been completed.

RESULTS:

The only cultures which did not give penicillin resistant staphylococci were those taken from dresser and

assistant before they commenced their duties, and the first and last air samples. The greatest number of colonies of these organisms was obtained in the cultures from the assistant's hands after handling the blankets, and in the air sample taken when the blankets were turned back (excepting the cultures from the wounds and the patient's skin, which were heavily infected).

EXPERIMENT H : 16/4/47.

In this experiment, conducted in ward Bi, the dresser's hands were swabbed before she commenced her dressings, and then swabs were taken of all the wounds she dressed during the morning; and at the end of the round, swabs were taken of her hands again and also from the handle of the instrument trolley.

The wounds gave the following cultures:-

No. 476: B. subtilis.
Gram positive cocci: coagulase negative.
Gram positive cocci: coagulase negative.

No. 490: B. proteus.
Gram positive cocci: coagulase negative.

No. 489: B. proteus.
Diphtheroids.

No. 467: Diphtheroids.
B. subtilis.

No. 356: Ps. pyocyanea.

No. 384: Diphtheroids.
Gram positive cocci: coagulase positive and penicillin resistant.

The dresser's hands at the beginning gave:- coagulase negative cocci, gram negative bacilli which were probably Alkaligenes, and B. subtilis.
At the end of the dressing round, she had in addition on her hands, Staphylococci which were resistant to penicillin.
On the handle of the trolley one was able to get a profuse growth of Ps. pyocyanea.

It seemed very probable that the dresser's hands became contaminated from the wounds containing these staphylococci and also Ps. pyocyanea, although it was not possible to demonstrate the latter on her hands. She must, however, have transferred this infection to the handle of the trolley.

...

(iii) The Dressing Technique:

The methods described here were universal in the hospital. A few general points in connection with the ward routine were mentioned at the beginning of this chapter.

Dressings were conducted by one nurse working single-handed; one nurse doing the dressings on the male side and the other on the female side.

Masks, caps and gowns were not worn.

Gloves were not worn.

The instrument trolley was prepared in the sterilizing room, the top shelf containing the instruments, bowls, dishes, sterile dressings, and towels. The bottom shelf had a receiver for soiled dressings, and bottles of antiseptic solutions. The trolley was covered with a sterile towel until the dressings were commenced.

Having placed the trolley next to the first patient, the dresser placed the screens, turned down the blankets, removed the bandages and dressings with her hands. She then washed her hands, removed the towel from the trolley and proceeded with the dressing, using her hands all the time in the wound. Instruments that had been used directly in a wound were discarded, but several instruments on the dressing trolley, such as scissors, and dissecting forceps were used time and time again during the whole dressing round, always being replaced on the trolley after use, amongst the other instruments on the trolley. The dresser obviously failed to appreciate that these had become contaminated from her hands. The trolley was invariably left uncovered for the whole duration of the dressing round. At the completion of the dressing, the bandages were reapplied and then the blankets were adjusted. The screen and the trolley were then taken to the next bed, where the blankets, bandages and dressings were turned

down as before, and only then were the hands washed again.

From this it is quite obvious that the contaminated hands from the previous dressing were spreading infection from that wound to the screen, the handles of the trolley, the blankets of both patients, and the bandages and dressings of both patients. In addition, the wound was invariably left exposed to the ward air while the dresser was washing her hands.

...

(4) THE INSTRUMENTS:

No experiments were performed to determine the efficiency of the sterilizer. It is intended merely to record a few observations regarding the possible contamination of instruments used on the dressing round.

Masks were not used by nurses in the sterilizing room while attending to the sterilization of instruments and setting of the dressing trolley.

Once the trolley was in the ward, it was left uncovered for the duration of the dressing round. This meant that the sterile equipment on the trolley was exposed for several hours to the air of the ward, which was contaminated at each bed where the trolley was placed, by the handling of the blankets and the dressings. It is

very probable that considerable numbers of organisms sedimented out of the air on each occasion, on to this sterile equipment.

In addition, as mentioned before, it was noted that certain instruments were used for such purposes as cutting pieces of gauze, removing swabs and gauze from their containers, and removing strips of "tulle gras" from their container. These were always replaced on the trolley after use amongst the other instruments. In many cases these particular instruments were used towards the end of a particular dressing when the hands of the dresser were most infected.

...

(5) THE AIR OF THE WARD:

For the investigation of the air, a SLIT AIR SAMPLER was used, being one of the first models manufactured in England on the lines of the instrument originally perfected by Bourdillon, Lidwell and Thomas. The machine is the property of the Department of Bacteriology at the University of Cape Town.

In order to obtain the necessary suction of air, an Electrolux Vacuum cleaner was obtained and this was housed in a specially constructed box lined with a thick padding of "Acousti-Cellotex" on the inside, to eliminate

noise. At each end of the box a circular hole of about three inches in diameter, allowed for the passage of the hose of the vacuum cleaner, on the one hand, and escape of air on the other. Casters were attached to the base of the box, and fittings on the lid allowed the machine to be fixed securely to it. Thus, the apparatus with its attachments was made very compact, and at the same time, was easily transported from place to place.

A photograph of the complete unit is shown here.

The sampler was provided with two chambers, one being used for the collection of air at a rate of 1 cubic foot per minute, and the other allowing for sampling at 20 cubic feet per minute. In the photograph, the latter chamber is in place.

The speed of the turntable is adjustable so that it makes a complete revolution in ½, 2 or 6 minutes. Thus when using the large chamber and air being drawn in at 20 cubic feet per minute, volumes of air amounting to 10, 40 and 120 cubic feet respectively, may be sampled on one plate.

The turntable is rotated through a train of gears and a worm wheel by a gramophone motor, and it may be lowered or raised by manipulating a turn-buckle in the verticle shaft which supports it.

Air is drawn in through a short tube seen at the top of the sampler, through a narrow slit (0.013 ins. wide) on to the surface of the culture medium contained in a petri dish, which is placed on the turntable. The latter is housed in a chamber provided with a glass door which is clamped down on to the chamber and which is then air tight. The turntable with its petri dish can be screwed up so that the surface of the medium is exactly 2 mm distant from the slit. The length of the slit is placed radially to the surface of the medium, and is so positioned that a circular space in the centre of the

plate never passes under the slit.

The manometer at the side of the apparatus indicates the correct suction pressure, which may be adjusted if necessary.

The electrical connections are so arranged that suction of air, and rotation of the turntable commence at the same moment, and an automatic switch stops both these at the completion of one revolution of the turntable.

The culture medium used for the experiments was 3% blood agar in small plates for the small chamber and in large plates for the larger chamber.

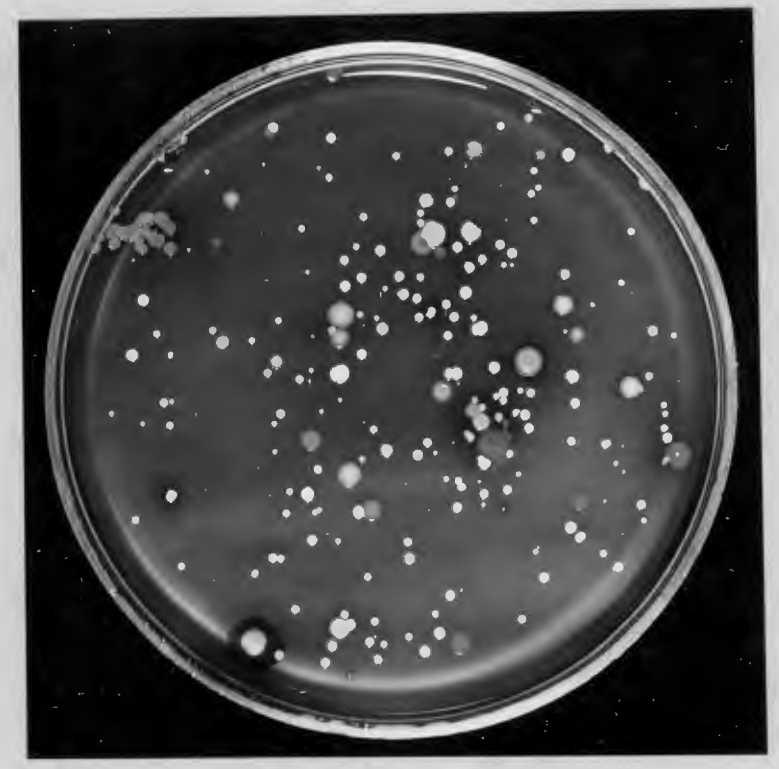
For the routine samplings of air, in the ward and in the theatre, the small chamber was used, and as a rule, 6 cubic feet of air were collected at a time. (6 min.)

For special purposes, such as collecting samples of air while a dressing was being done, the larger chamber was used, collecting 10 cubic feet of air in half a minute.

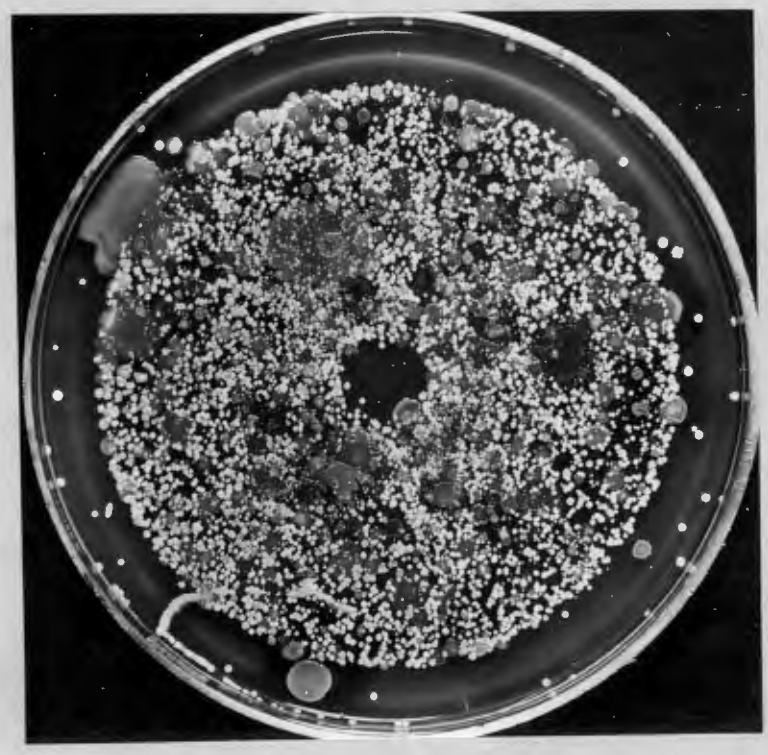
...

Samples of ward air were taken on many occasions in both wards, beginning at 6 a.m., and continuing until 11 a.m. and in some cases, 12 noon. These were taken at 15 minute intervals and therefore gave a survey of the contamination of the ward air from a quiet period, through the activities of bed-making, sweeping, and until the ward was quiet again.

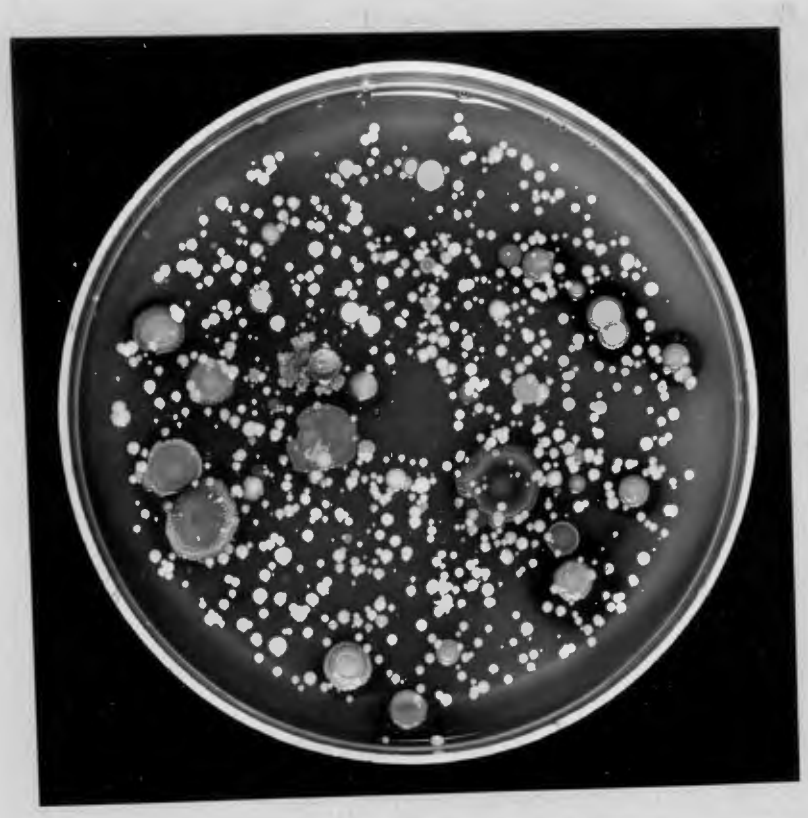
After exposure, the plates were incubated for 24 hours at 37° C. and then the colonies were counted,



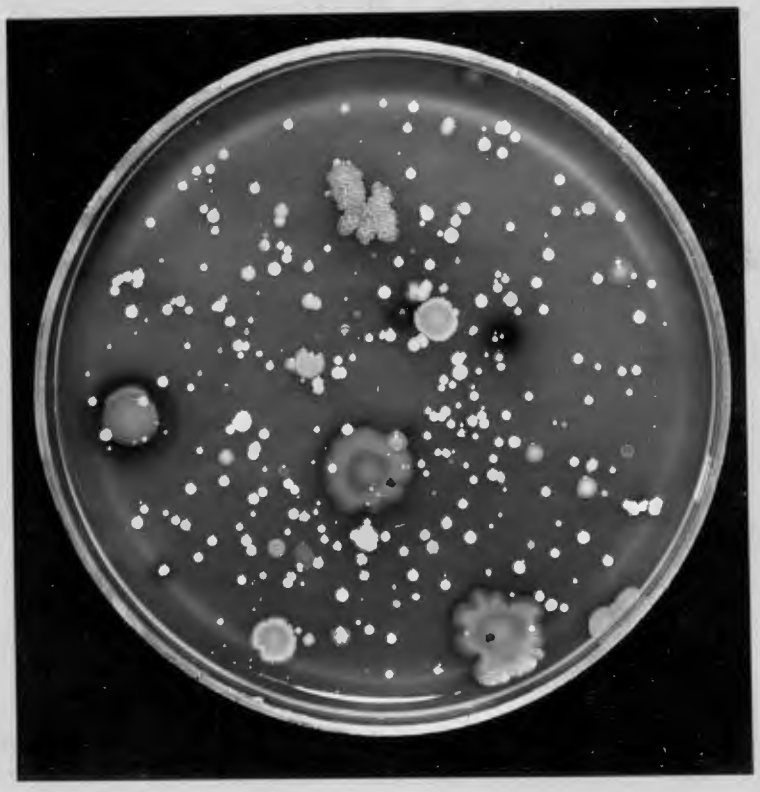
All quiet.



During bed-making.



During sweeping.

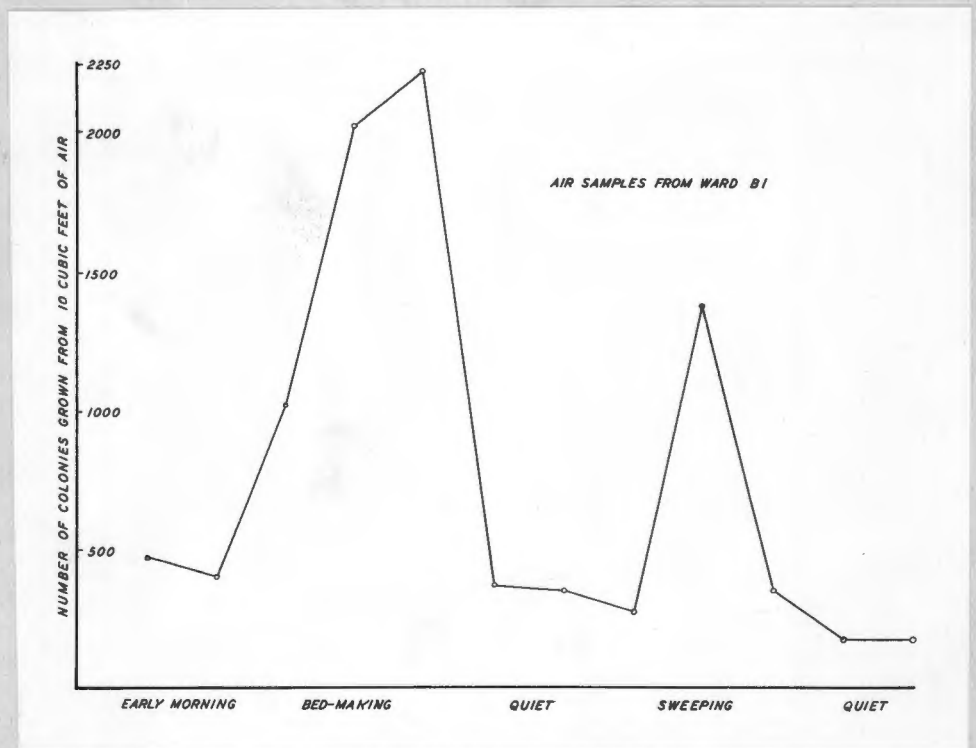


1 hour later.

it being assumed that each colony on the plate began from a single organism deposited on the plate. Suspicious pathogenic colonies were picked off and sub-cultured for further identification. The photographs on page 142 and 143 are of representative plates taken at different times of the day as indicated.

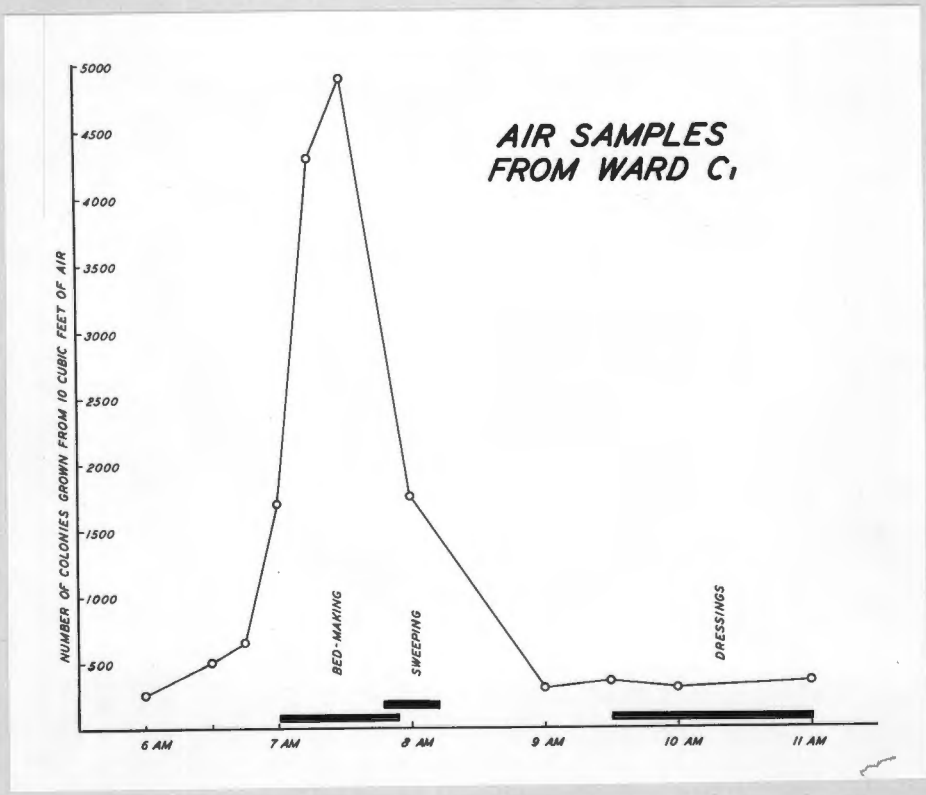
Immediately bed-making commences, there is a tremendous increase in the bacterial content of the air, and this falls fairly rapidly once the beds are made.

During sweeping, it was always found that the pollution was never as much as it was during bed-making.



It was usually found that within three-quarters to an hour after these activities, the ward air bacterial content was down to practically where it was in the early morning. On page 144 is a chart which is typical of all the samplings done in the wards, during the first half of the period of study.

On this page is a chart representative of a series of samplings after the change in routine. In the new routine it was insisted that dressings should not commence until at least one hour after the completion of sweeping and dusting operations, and that there should be no activity of any kind in the ward during the time of dressings.



The chart illustrates very well the enormous pollution of the air during bed-making, and also the rapidity of its return to normal. It will be noted that during dressings the aerial contamination was normal.

In an examination of these colonies from the air samples, it was found that the great majority were saprophytes, but pathogenic organisms were always found amongst the colonies on each plate. These were usually staphylococcus aureus, and in a large percentage of the cases, the organisms were both coagulase positive and resistant to penicillin.

In the routine air samplings done in ward Bi, it was found that in almost 100% of the plates, it was possible to pick out staphylococcus aureus colonies. Of these plates, no less than 65% had colonies where the staphylococcus was coagulase positive and at the same time resistant to penicillin. In ward Ci it was found that the percentage of plates carrying penicillin resistant staphylococci was no less than 72%.

These are indeed very high figures, but when it is borne in mind that there was a relatively high incidence of infection by penicillin resistant strains of staphylococci, and that no special methods were adopted to sterilize the blankets or to lay the dust in them, it is not surprising that it was possible to collect these organisms from the ward air. There seemed no doubt that

a large percentage of these aerial contaminants came from the blankets and that they were distributed into the air as a result of bed-making.

To ascertain whether the ward blankets did actually harbour these organisms, a simple experiment was performed.

Swabs were moistened with sterile broth and then rubbed lightly over the surface of a dozen blankets in each ward. The blankets were chosen at random from the linen cupboard, so that there was no way of knowing when they were last used and on whom. An area of approximately six inches square was swabbed on each blanket, and the swabs were then plated out on 2% agar

plates in the usual way.

In every one of the 24 plates, staphylococcus aureus colonies were identified and of these in no less than thirteen cases were they coagulase positive and resistant to penicillin. In most of the cases the growth was very profuse. On the previous page is a photograph of two such plates.

In view of these findings it must be assumed that a considerable proportion of the ward blankets were contaminated with pathogenic strains, and that the treatment which the blankets received after discharge of patients was not sufficient to remove these. It is also possible that uncontaminated blankets in the ward became contaminated as a result of bed-making, when the organisms released by contaminated blankets were distributed into the air of the ward. It is also possible that the mixing of blankets in the cupboard caused a certain amount of transfer from one to the other.

.....

(2) A SURVEY OF THE OPERATING THEATRE.

This investigation included all the possible causes of wound infection which might occur in the theatre, as described in Chapter 3 of this manuscript.

The results of these findings are therefore classified under the same headings:-

(1) The patient's skin.

(2) The surgeon and his assistants:

- (a) Their hands;
- (b) Their noses and throats;
- (c) Their clothes and shoes.

(3) The instruments.

(4) The air of the theatre.

(1) THE PATIENT'S SKIN:

Swabs were taken of the operation wound immediately after the skin incision, and again towards the end of the operation immediately prior to closure of the wound.

In a number of cases, lining swabs were not used and in these cases, swabs were also taken from the patient's skin immediately adjacent to the wound, and just before closure of the wound.

Altogether, ten wounds were swabbed in this way, and in four, swabs were taken of the skin as well.

In every case, it was possible to obtain positive cultures from the wounds at the beginning of the operation, and in every case it was possible to obtain a heavy growth from swabs taken at the end of the operation.

The organisms cultured from the wounds immediately after the incision were chiefly:-

Staphylococcus albus

Diphtheroids

B. subtilis.

The organisms cultured at the end of the operation were the same as above, but in addition, pneumococci and streptococcus viridans were found. Normal wound infectors were not isolated from any of the wounds.

The last two mentioned organisms came from the nose and throat of surgeon or assistant and therefore do not interest us here.

It is only possible to say that the cultures obtained at the end of the operations were always greatly in excess of what was obtained at the beginning, and it is assumed that this increase was an increase of the normal inhabitants of the skin of the patient, in the great majority of cases, although it is not possible to exclude those organisms which had dropped into the wound during the operation from the theatre air or from droplets and droplet nuclei.

In each of these experiments, the surgeon was requested to wash the wound with normal saline or with Carbolic 1/20 before closing up. After this washing, swabs were again taken.

The latter two swabs, i.e. the swab of the wound at the end of the operation, and the one after the washing, were both plated out on the same plate for the purpose of comparison.

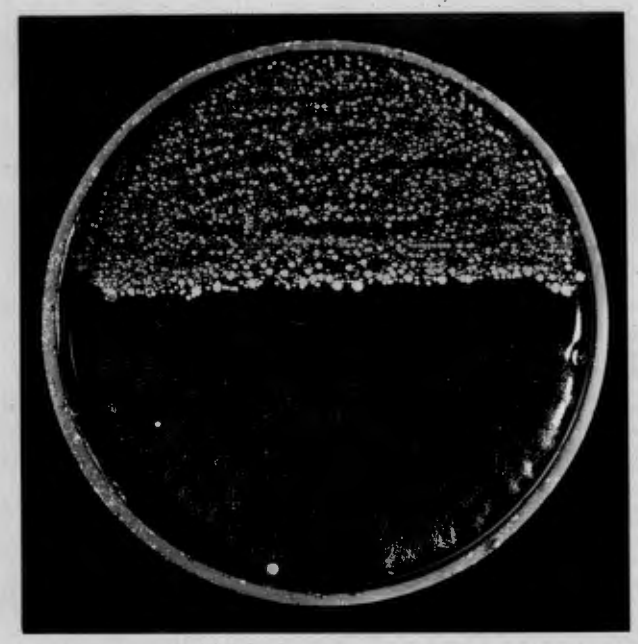
The difference in the growths obtained was always the same: a heavy growth from the first swab, and either no growth at all, or at the most 3 or 4 colonies from the other.

In one case there was a heavy growth of pneumococci on one side of the plate, whereas on the other side representing the swab after saline washing, there were only three colonies.

After washing with carbolic lotion, the swabs were always sterile.

After washing the wound with saline, the swabs produced a few colonies in each case but the number never exceeded four colonies.

On the next page is a print of such a plate showing on the one side the culture from the wound at the end of the operation, and on the other no growth at all as a result of washing the wound with carbolic solution 1/20.



Swab of wound at end of operation.

After swabbing with Carbolic 1/20.

In every case where a swab was taken of the skin of the patient at the end of the operation, there was always a heavy growth of organisms, and the organisms cultures in these cases were always staphylococcus albus and diphtheroids.

...

(2) THE SURGEON AND HIS ASSISTANTS:

(a) Their Hands.

On a large number of occasions, swabs were taken from the hands of surgeons, assistants and theatre sisters, after scrubbing and before putting on gloves.

In addition, in about thirty cases, the surgeon, assistant and theatre sister were requested at the conclusion of the operation, to remove the gloves very carefully, turning them inside out in doing so, and to press the part of the glove which was in contact with the palm of the hand, on to the surface of an agar plate.

These plates were then incubated in the usual way.

The results were as follows:-

Hands before operation and after scrubbing:

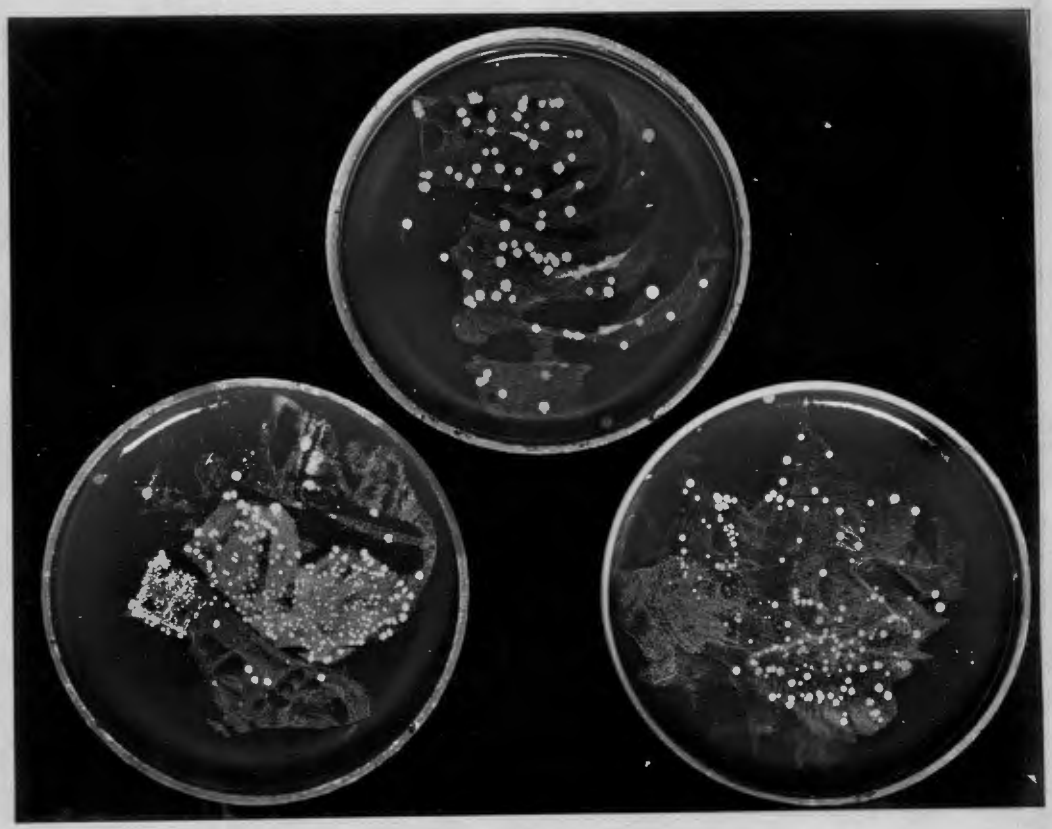
In all these cases, spirit had been applied to the hands after the scrubbing and before swabs were taken. In a small percentage of cases, sterile cultures were obtained, and in every case the swab was from a surgeon. In the majority of cases, positive results were obtained and in most of these cases, the swabs were from the hands of house surgeons and sisters. In the case of one surgeon, haemolytic staphylococcus aureus was obtained from the hands at this stage. In the same surgeon, there was a heavy growth from the hands at the end of the operation.

The fact that the cultures from the house surgeons and the sisters were always heavier than those from the surgeons, suggested that the former probably came more in contact with infected material than the surgeons, who were probably also more careful to prevent their hands from becoming infected.

Press Plates at the end of the operation:

These were positive in 100% of the cases, the numbers of colonies on the plates varying from 5 to 460.

The great majority of these colonies always were staphylococcus albus but in 50% of the plates there were haemolytic albus colonies, and in 20% of the plates there were haemolytic staphylococcus aureus colonies. 5% of the plates had coagulase positive staphylococcus aureus cultures and in one case, the organism was resistant to penicillin. This culture came from a house surgeon. Below is a photograph of press plates from a surgeon, his assistant, and the theatre sister. The plates in each case are marked by the powder from the gloves.



Cultures from inside of gloves:

As a rule it was found that when the insides of the gloves were wet, the cultures obtained were always heavier than when the gloves were dry.

In view of these results, it was decided to investigate the condition of the gloves at the end of a series of operations.

All gloves used at operations by surgeon, assistants and theatre sisters were carefully examined under water, over a period of two weeks.

The investigation showed that in the different series, the percentage of gloves that were pricked or damaged varied between 36% and 91% and an average for the whole period of 50.3%.

Taking into account, therefore, this incidence of damaged gloves, and the incidence of contamination of the insides of gloves at the end of an operation, it would seem probable that a considerable number of operation wounds become infected from the hands of the operating team.

...

(b) Their Noses and Throats:

To the casual observer in the operating theatre, it would suggest that the system of masking practised in the theatre must be the source of considerable post-

operative wound infection.

In the first place, the mask used was shown to be completely inadequate. In any case, it has been shown that for an all-fabric mask to be efficient in preventing direct transmission of droplets, it must be constructed of 16 layers of gauze which consists of 48 strands to the inch. (8)

The mask used in the operating theatre was found to be made of <u>two</u> thicknesses of gauze of 44 strands to the inch.

In the second place, it must be pointed out that in not one single instance was a surgeon, or his assistants, observed to wear a mask over the mouth and the nose. In every case, the masking was confined to the mouth only, and in many cases, the diminutive size of the mask (average 4½ by 5 ins.) resulted in even the mouth being improperly covered. In view, however, of the permeability of the mask, the importance of this fact falls away. It must be recorded, however, that all the surgeons who were consulted on this point were agreed that the masking was inadequate and there was wholehearted support from every surgeon, with one exception, regarding the investigations which were carried out in this connection.

The investigations consisted of a determination of the incidence of carriers amongst the surgical and

anaesthetic staff (i.e., nose and throat carriers of pathogenic organisms); the efficiency of the mask in use; and some experiments to determine contamination of the wound from organisms lodged in the nose of the operator or his assistant.

INCIDENCE OF CARRIERS.

It was possible to obtain swabs from all surgeons, house surgeons, and anaesthetists connected with the theatre, with one exception.

In no case was streptococcus pyogenes isolated. A considerable proportion were positive for streptococcus viridans.

The important organism cultured was staphylococcus aureus, and in many cases was isolated in pure culture. The results were as follows:-

(All the staphylococci mentioned here were coagulase positive.)

	Staphs.	Penicillin Resistant
Surgeons:	54.5%	Nil
House surgeons:	50%	33.3%
Anaesthetists:	71.4%	28.5%

The interesting feature here is not only the very high incidence of nasal infection, but the very high incidence of resistant strains occurring in people who had had no penicillin therapy.

THE EFFICIENCY OF THE MASK.

The general consensus of opinion was that the mask in use was unsatisfactory. A new mask was then designed, consisting of a double layer of gauze measuring 7 inches by 9 inches, and open at one end to allow for the insertion of a sheet of cellophane the same size as the mask. For the convenience of those surgeons who wear glasses, and to prevent fogging of the glasses, a small strip of lead sheeting was sewn into the centre of the upper margin of the mask. This strip of lead could be moulded to the shape of the nose of the wearer and thus eliminate exhaled air from passing upwards and clouding the glasses.

An experiment was then designed to test the efficiency of these two masks. At first it was decided to test the mask on human subjects who had rinsed the mouth with a culture of Chromobacterium prodigiosum, the subject being placed in the position of a surgeon at an operating table, and exposed culture plates being placed on the table to represent the patient's wound. The subject would then be encouraged to talk at intervals.

The exposed culture plates would indicate the degree of droplet infection of the wound, and an air sampler in the theatre at the time of the experiment would indicate the degree of droplet nuclei infection.

Unfortunately, the culture which was going to

be used for the test, on inoculation into a series of animals was found to be unsafe for use in this way.

As an alternative it was then decided to construct a plaster cast of a human head and neck, and to use this for the experiment.

The case was hollow, and apertures were provided for the nostrils and the mouth. A de Vilbiss type of atomizer was fixed into the interior of the model so that the nozzle was situated half an inch from the opening of the mouth. A portion of the vault was detachable and this portion had an opening in its centre into which was plugged a tightly fitting rubber stopper carrying a short piece of glass tubing. The inner end of this glass tubing was connected to the rubber tubing of the atomizer, while to the outer end was attached a piece of pressure tubing leading from a compressor.

The atomizer having been charged with a suitable concentration of the test culture, the detachable portion of the vault was replaced, and fixed securely by means of adhesive strapping. This made the joint air tight.

The model was now placed on a suitable stand 18 inches above and 12 inches distant on a horizontal plane from two exposed plates containing a culture medium.

The slit air sampler was placed two feet laterally from the model so that the inlet of the sampler was on the same horizontal plane as the exposed plates.

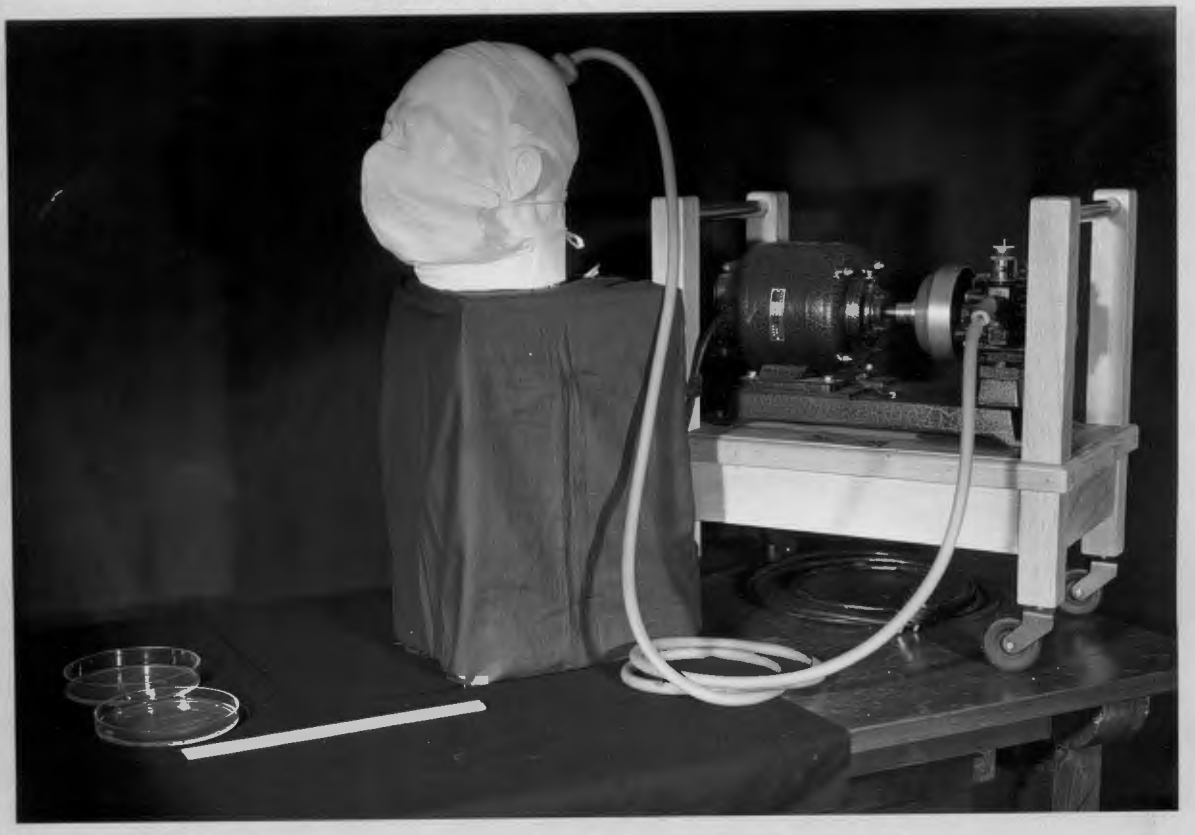
The air sampler was adjusted to collect ten

cubic feet of air in 30 seconds.

Hartley's agar was used as the culture medium, the organism used being Chromobacterium prodigiosum.

Experiments were then conducted to determine the degree of contamination of the two exposed plates placed beneath the model, representing infection of the wound by droplets; and contamination of the air in the vicinity, this representing the degree of droplet nuclei infection of the air. The experiments were repeated under identical conditions:-

(a) With no mask in place;
(b) With the old mask in place;
(c) With the new mask in place.



The photograph on the previous page gives an idea of the "set-up" which has been described.

Immediately before each experiment, three successive air samples were taken to determine the contamination of the air of the room.

For the actual experiment, the compressor and the air sampler were set in motion at exactly the same moment, and both for exactly half a minute. This meant that 10 cubic feet of air were sampled.

After the experiment, the room was thoroughly ventilated, and another three samples of air taken before the next experiment.

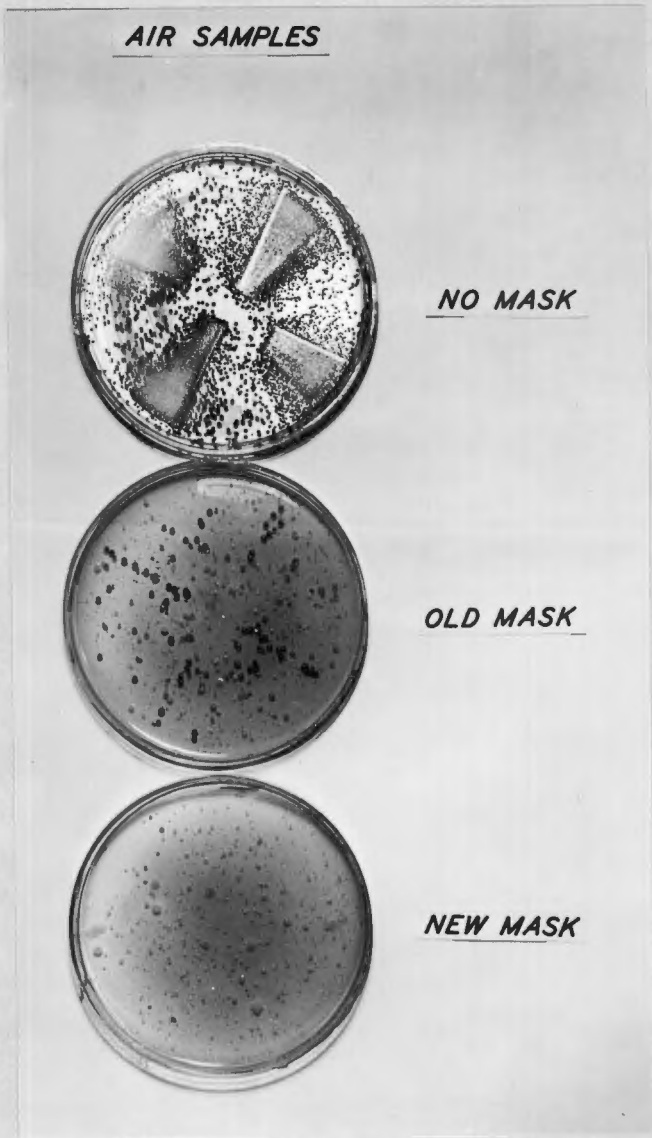
To ensure that the conditions of atomization were more or less the same in each mask experiment, it was decided to carry out a test without mask before each mask experiment.

The results obtained were as expected, namely, that while the old mask was in place there was definite contamination of the exposed plates by large "droplets", while there was no such contamination when the new mask was being used.

The air became contaminated with the test organism in both experiments, but to a very much greater extent when the old mask was in place.

Photographs of these plates are seen on the following pages, the test organisms showing up as dark shiny colonies.


EXPOSED PLATES
NO MASK
OLD MASK
NEW MASK


AIR SAMPLES
NO MASK
OLD MASK
NEW MASK

WOUND INFECTION FROM THE NOSE:

In a previous chapter, attention was drawn to a case of Lumbar Sympathectomy which became severely infected with a penicillin resistant Staphylococcus. The patient died from the infection about a month after the operation, and massive doses of penicillin had been administrated from the beginning. The view held was that the organisms were resistant to penicillin from the commencement, and the interesting feature of the case is that examination of the nasal cultures of the surgeon and the assistant who were present at the operation showed that the surgeon had Staphylococci in pure culture but these were not penicillin resistant, whereas the house-man's swab gave a pure culture of penicillin resistant staphylococci.

EXPERIMENT Ch. : 6/6/47.

OPERATION: Herniorrhaphy.

During this experiment there were only three people in the theatre who had masks covering only the mouth. All the others had mouth and nose covered. The three people were the surgeon, the assistant and the anaesthetist.

SWABS TAKEN:

(a) Hands of surgeon, assistant and theatre sister before the operation.
(b) The wound after the skin incision.
(c) The wound at the end of the operation.
(d) Nasal swabs of the surgeon, assistant and anaesthetist.

AIR SAMPLES:

These were taken before the operation, at the beginning of the operation, at regular intervals during the operation and then at the end of the operation. The duration of the operation was 1½ hours.

The results were as follows:

HANDS BEFORE OPERATION:

Surgeon: Gram positive cocci - coagulase negative.

Assistant: Gram positive cocci - coagulase negative.

Sister: Gram positive cocci - coagulase negative. Alpha haemolytic streptococci.

WOUND SWABS:

Before operation: A few colonies were grown which were white and opaque in appearance and non-haemolytic. They were diphtheroids.

After the operation: A profuse growth of minute transparent colonies showing marked alpha haemolysis. These were also diphtheroids.

NASAL SWABS:

Surgeon: Profuse growth of minute transparent colonies with alpha haemolysis. These were diphtheroids. There were also a number of white opaque colonies, found to be Staphylococcus albus.

Assistant: Gram positive cocci and gram positive bacilli. The cocci were coagulase -ve.

The bacilli were diphtheroids, though morphologically quite different from those found in the wound.

Anaesthetist: Haemolytic staphylococcus aureus in pure culture, both coagulase positive and penicillin resistant.

AIR SAMPLES:

All air samples excepting the first one taken before the operation and the one taken at the conclusion of the operation had colonies of haemolytic staphylococcus aureus which were coagulase positive and penicillin resistant.

The diphtheroids obtained from the wound at the end of the operation, and those obtained from the nose of the surgeon, proved on further testing to be identical in every respect. There was therefore no doubt about the fact that the surgeon had contaminated his wound from his nose.

The presence of penicillin resistant staphylococci in the theatre air, and in the nose of the anaesthetist, suggested that the latter probably was the cause of the contamination.

EXPERIMENT Lo. : 24/6/47.

OPERATION: Appendicectomy.

Swabs were taken from the wound at the end of the operation, and from the skin near the wound, no lining swabs having been used. The wound was washed with saline

and another swab was taken of the wound.

Swabs were also taken of the noses of assistant and surgeon, and finally, press cultures were taken of the insides of the gloves at the end of the operation.

RESULTS:

Wound at end of operation:

Amongst other colonies there were 96 pale haemolytic colonies morphologically pneumococci.

After washing with saline:

Three colonies only of colonies identical with above.

SKIN: Profuse growth of staphylococcus albus.

NOSES:

Surgeon: Diphtheroids, staphylococcus albus, streptococcus viridans, and a large number of colonies of pneumococci.

Assistant: Diphtheroids, and streptococcus viridans.

HANDS:

	No. of Cols.	No. of Staph. Aureus.
Surgeon	7	Nil.
Assistant	125	26
Sister	7	4

The pneumococci obtained from the nose of the surgeon and from the wound at the end of the operation, and those left after washing with saline were all identical. The surgeon had contaminated his wound.

At one stage during the investigations it was noted that in one of the wards, no less than six cases of

wound infection by staphylococcus aureus occurred in fairly close succession. In each of these cases, a house-man who had coagulase positive staphylococcus aureus in the nose, had been the assistant at the operations. The operations included a thyroidectomy, hernia operations and appendicectomies. This finding seemed more than a mere coincidence, and it may be assumed that the organism was transmitted to the wound in each case from the nose of the assistant.

...

(c) Their Clothes:

In view of the fact that no special precaution was taken in the theatre regarding the shoes of those who operated and those who came into the theatre as spectators, it was decided to perform a series of experiments in an endeavour to demonstrate the necessity for wearing some kind of cover for the shoes.

Two different theatres were used on three different occasions. In each case, the theatre was washed down on the evening before the experiment, and then locked for the night and until the experiment began. A series of air samples were then taken in the theatre before anyone had been in the theatre.

Exposed blood agar plates were then placed in several places on the floor of the theatre and on the

operating table. The air sampler was in the middle of the room near the table.

Ten volunteers, including nurses and doctors, were then attired completely as for an operation, with caps, gowns, masks (covering noses and mouths), and overboots. These ten people were then required to walk quietly around the theatre for a period of two minutes without talking, and during this period the air sampler collected the air of the theatre at the rate of 20 cubic feet per minute.

After the experiment, the theatre was again locked, and air samples were taken at half-hourly intervals after the experiment.

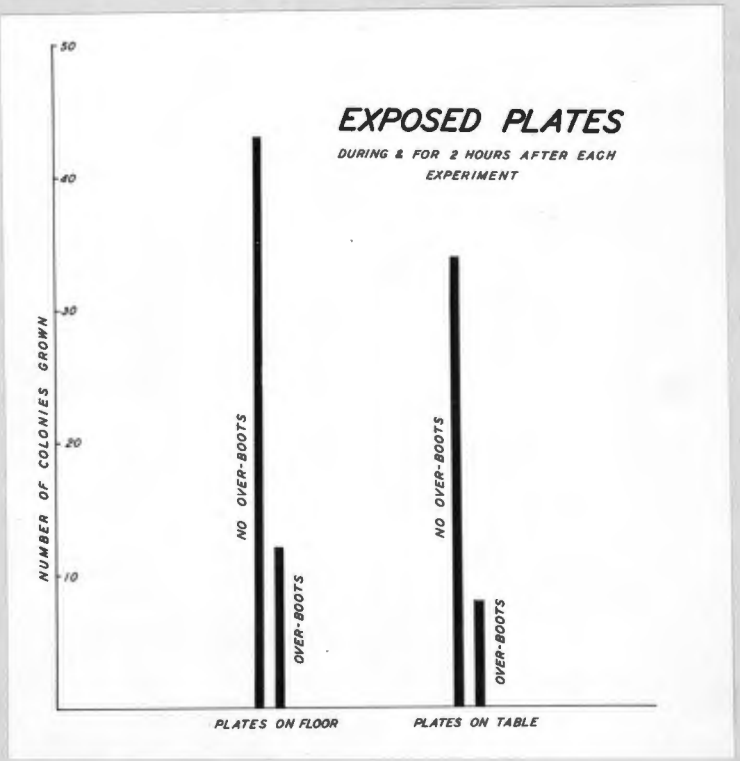
The identical experiment was then repeated in the other theatre immediately after this experiment, but in this case, no overboots were worn.

A week later the same two experiments were repeated under identical conditions except that the conditions were reversed in the two theatres, thus making allowance for any differences in ventilation in the two.

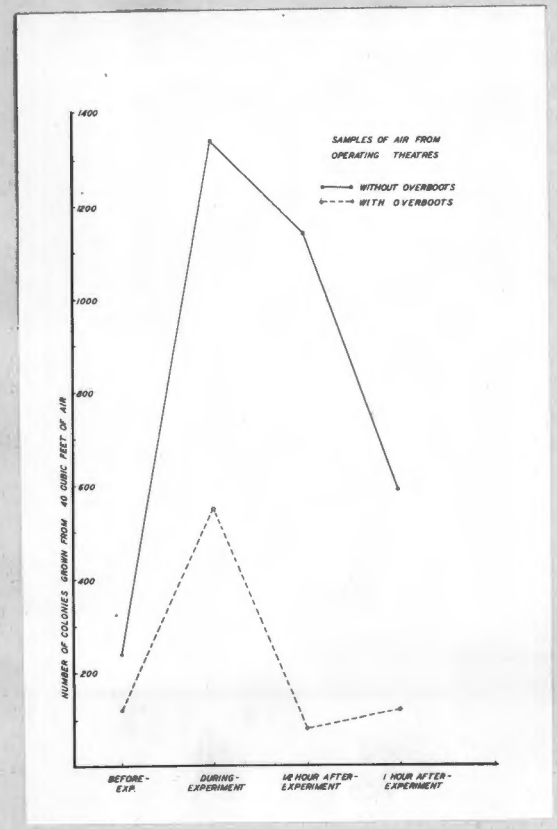
In the third experiment, a team of ten volunteers repeated the routine in both theatres, and in this case, both experiments were performed in both theatres, the overboots being worn for the first experiment, and then after an interval of an hour, the

process was repeated without overboots.

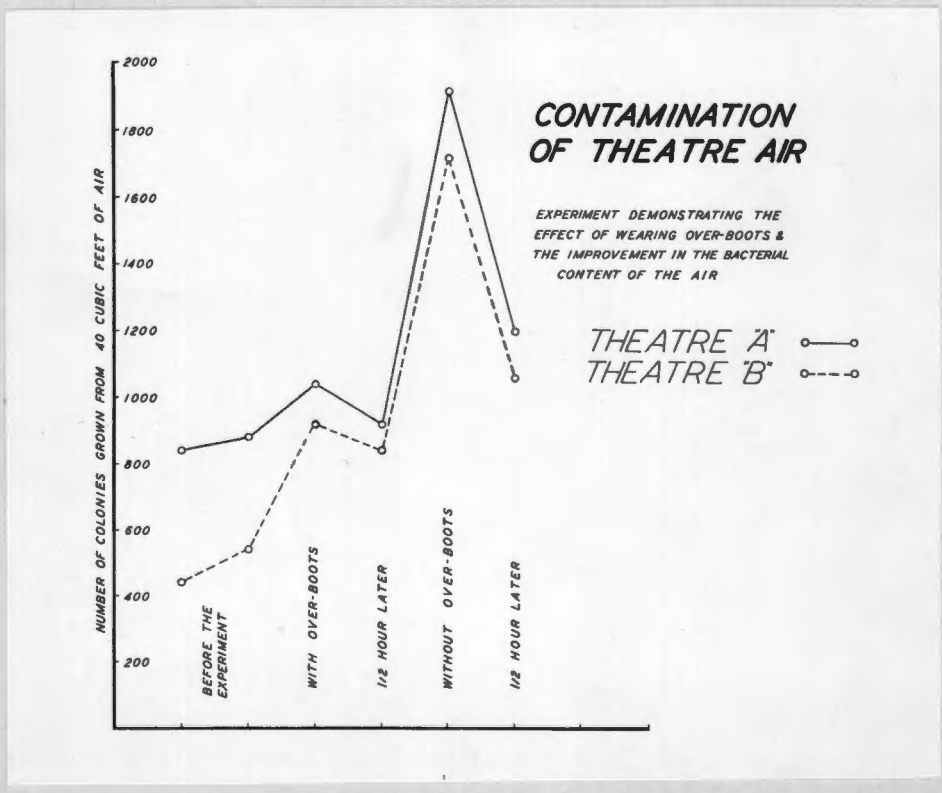
The charts which follow indicate clearly the much greater contamination of the theatre air when no overboots are worn as opposed to the experiments when overboots were worn. This increased contamination is shown not only by the air samples but also very well by the exposed plates placed on the floor and on the operating table. These indicate the number of bacteria which have sedimented out of the air, and in this connection it is interesting to note the extent of the contamination of the plates placed on the operating table in view of the fact that only ten people were in the theatre for each experiment, and the fact that, as mentioned before, they were required to move about quietly in the theatre during the experiment.



The number of colonies indicated here is the average from all the plates exposed.

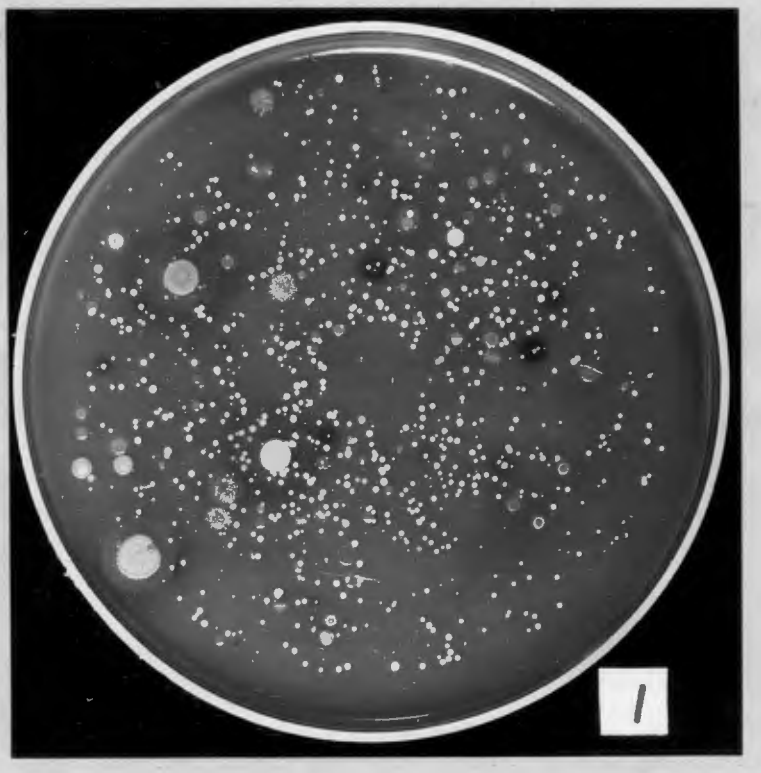


This chart shows the figures obtained in two different theatres, but similar figures were obtained when the experiments were repeated with conditions reversed.

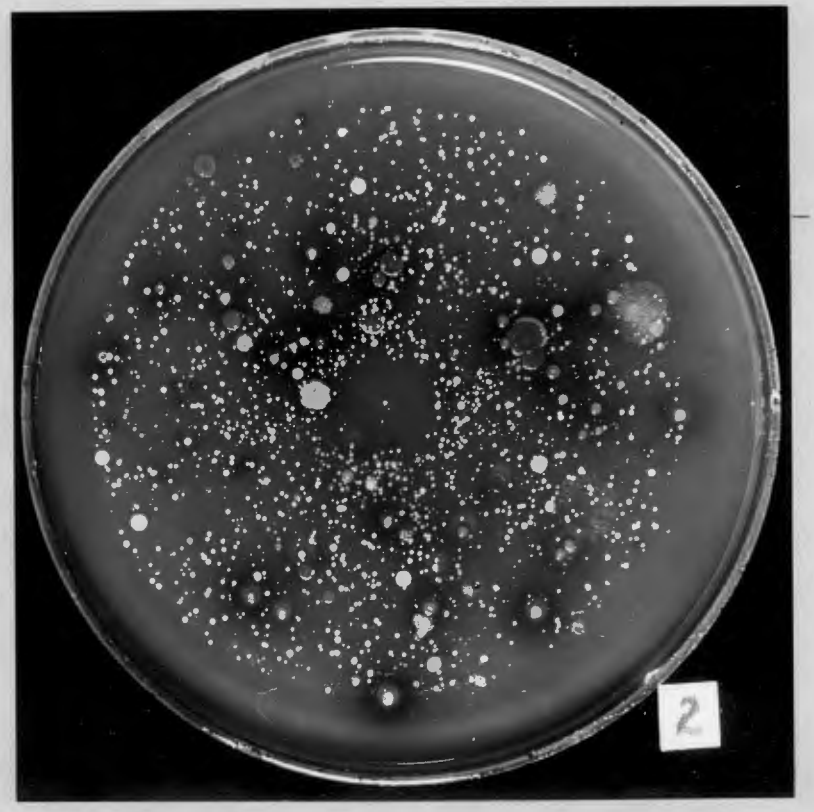


Both experiments in both theatres.

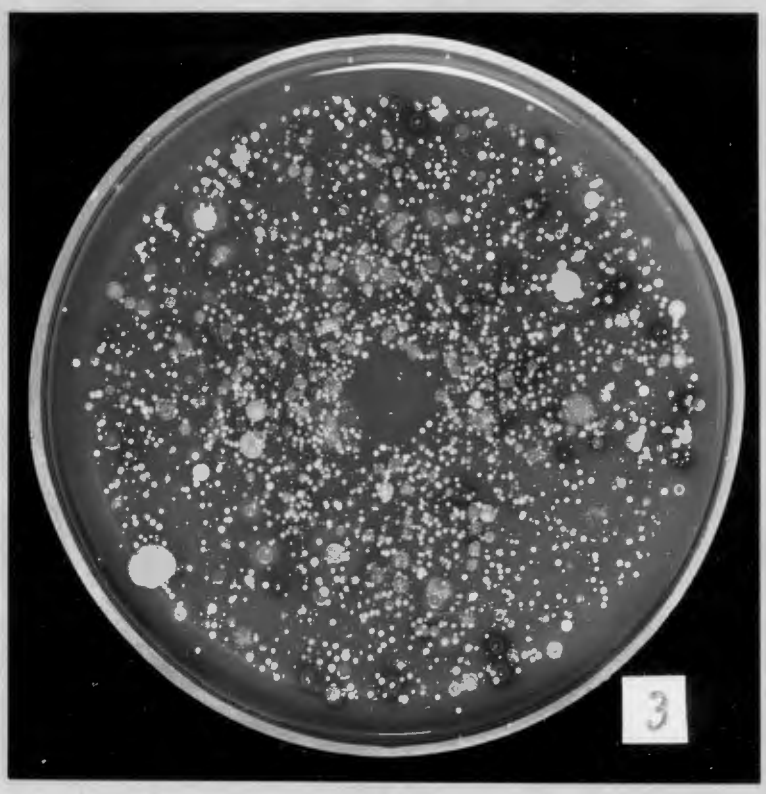
AIR SAMPLES FROM "OVER-BOOTS" EXPERIMENTS.



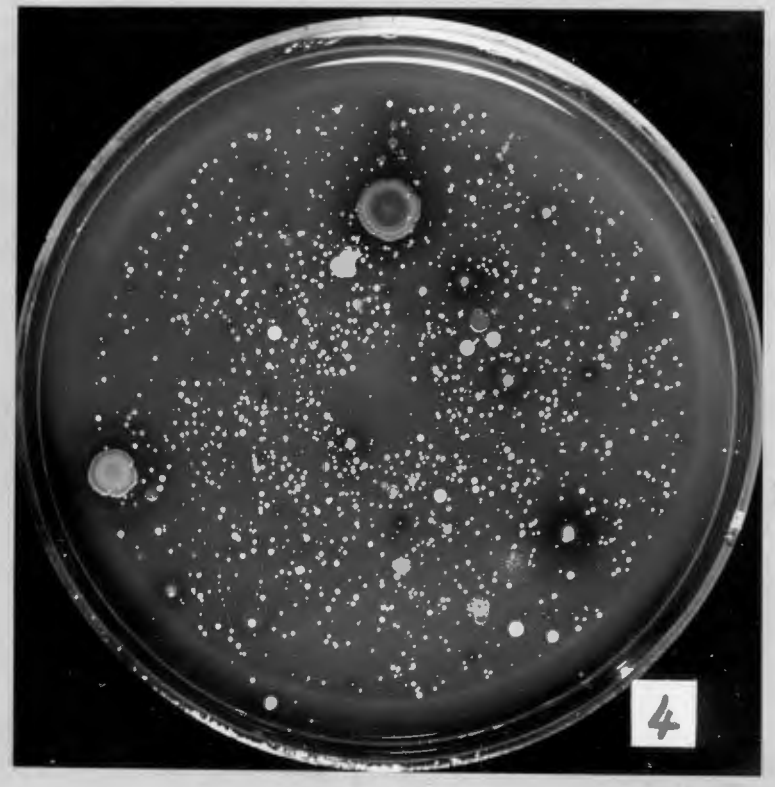
Before experiment.



With Overboots



NO
Overboots

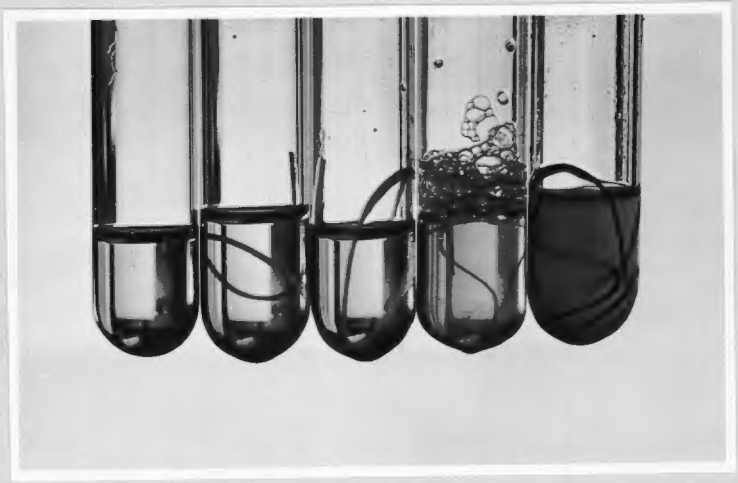


After
Experiment

(3) THE INSTRUMENTS:

No special investigations were done to determine the sterility or otherwise of the instruments used for operations, but a few interesting cultures were obtained from various kinds of ligature and suture material.

In the first experiment, short pieces (about 1½ inches) of cat gut, chromic gut, black silk, and linen thread were placed in sterile broth and incubated for a period of 24 hours. These samples were taken under strictly bacteriological conditions from the exposed impedimenta on the instrument table at the end of an operation. The object was to determine whether these materials had become contaminated from the air of the theatre during the course of the operation.



The results were very interesting, as the photograph of the broth cultures on the previous page will indicate.

From left to right these tubes contain:-

Plain broth, as a control;
Broth plus catgut;
Broth plus chromic gut;
Broth plus linen thread;
Broth plus black silk.

It will be seen that the first three tubes are quite clear, whereas the last two are distinctly turbid, indicating bacterial growth.

A loopful of each tube of broth was then plated out on blood agar in a petri dish and incubated for 24 hours. The photograph on this page shows three petri dishes showing no growth at all, and they are photographs

of cultures from the first three tubes after 24 hours' incubation.

The pictures on this page are the result of incubation from broth from the last two tubes, the well defined white colonies being obtained from the linen thread, the pale colonies from the black silk.

The white colonies proved to be Staphylococcus aureus, the pale colonies, gram positive sporing bacilli.

In view of these findings, it was decided to repeat the experiment, this time using material which had not been exposed to the air of the theatre, but which had not been used. Here again, the cat gut and the chromic gut were found to be quite sterile, but both the linen thread and the black silk were found to be contaminated.

The photograph on this page shows the cultures obtained from linen thread and black silk, after these had been sterilized in the usual way and prior to being used in the theatre. In both cases, the organisms were found to be gram positive sporing bacilli, but not pathogenic.

One surgeon suggested that this ligature material was not being properly sterilized on account of the fact that it was tightly wound round a small spool and suggested that the thread should be wound on a frame about seven inches long, thus allowing for better exposure of the thread to the sterilizing process. This was done, and the materials were boiled for 20 minutes, after which specimens were again taken for incubation. The results

were exactly the same. The materials were now sterilized in the autoclave and on this occasion, all samples of thread were sterile.

As far as the methods of sterilization in the theatre were concerned, all equipment such as sheets, towels, caps, gowns, masks, gloves and articles of this nature, were sterilized in the autoclave, whereas all instruments and suture material were sterilized by boiling.

As a result of these findings, it was decided to autoclave all suture material.

...

(4) THE AIR OF THE THEATRE.

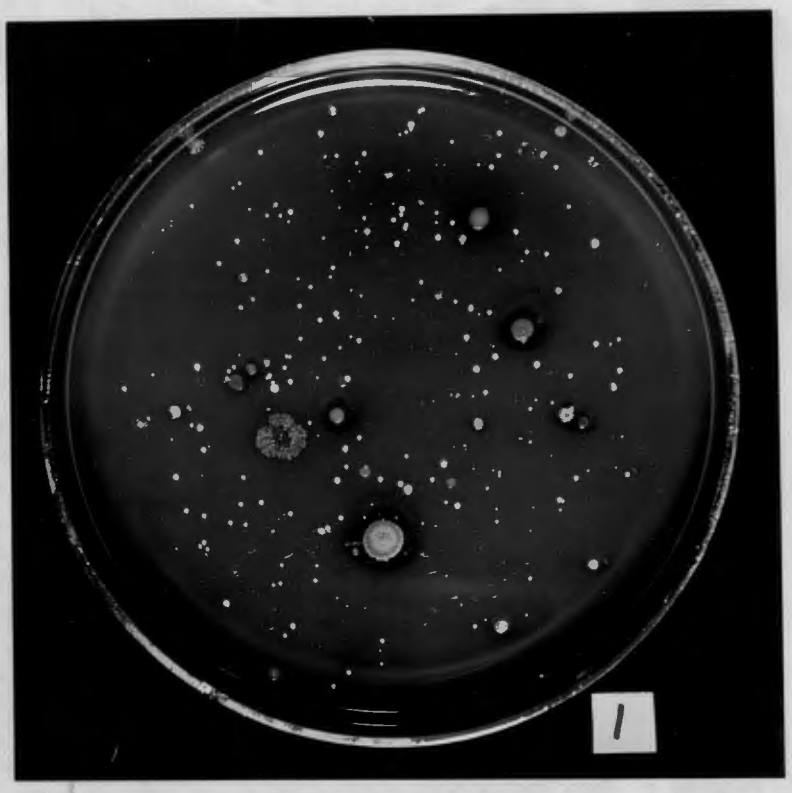
The air entering the operating theatres is first forced through a system of water filters, situated on the floor above the theatres.

At various times during the course of these investigations, samples were taken of the theatre air when all was quiet and before activity had begun in the theatre. In all of these it was found that there was a very minor degree of air contamination, namely about five to six colonies per cubic foot of air.

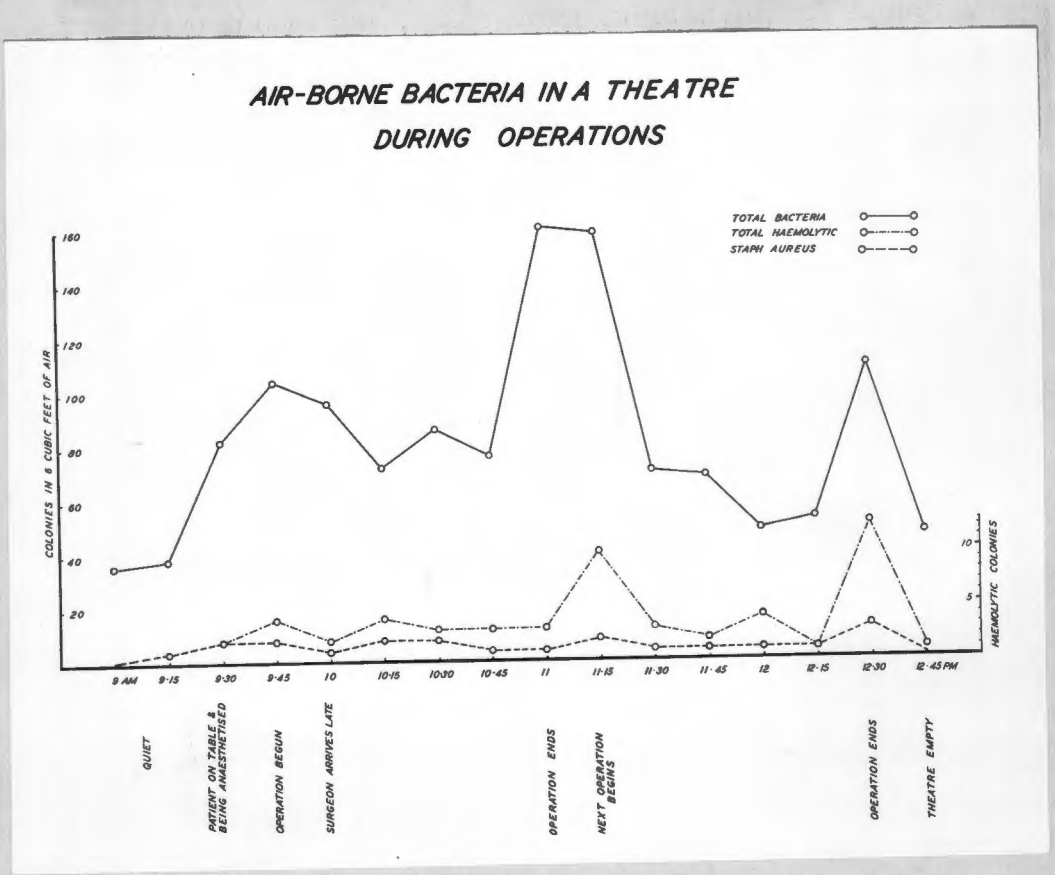
In association with the various experiments which were performed, a large number of air samples

were taken, and in all these experiments it was possible to demonstrate an increase in the bacterial content of the air as soon as activity began, and that this contamination was proportional to the number of people in the theatre at the time.

The picture below shows the air contamination in a theatre before activity had commenced in the theatre. The photographs on the next page are of air samples taken at the beginning and during an operation.



The chart on this page is interesting from several points of view. It records air samples taken every 15 minutes in one theatre during the course of two operations.



During the first operation, there were 12 people in the theatre, while during the second, there were only 8. This difference is reflected in the bacterial content of the air during the two operations.

At the beginning and at the end of each operation, there is a marked increase in the air contamination, due to the extra movement of the personnel occurring at these times, thereby stirring up the dust

in the theatre.

The percentage of haemolytic colonies coincides with the total bacterial counts.

It will be noted that colonies of staphylococcus aureus were present in all the plates excepting those taken at the beginning and at the end of the experiment. The theatre was empty on both these occasions.

At the first operation there were present the surgeon and two assistants (one of whom performed the second operation). The second assistant at the first operation assisted at the second operation as well. His nose swab was positive for staphylococcus aureus. The anaesthetist present at both operations was similarly a carrier of staphylococcus aureus. The first surgeon was not a carrier.

It will be interesting to note that the only people in the theatre during both operations who had their noses uncovered by the masks were the surgeons, their assistants and the anaesthetist. All the other people in the theatre had mouth and nose covered.

These facts would suggest that the presence of staphylococci in the air was associated with the uncovered noses of nasal carriers present.

In the large number of air samples taken in the theatre at various times, it is interesting to note

that it was possible in a large percentage of the plates to identify colonies of staphylococcus aureus, and furthermore, that in a proportion of these, it was found that the organism was resistant to penicillin.

In view of the fact that it had been established that a certain percentage of the operating personnel was known to harbour penicillin resistant staphylococci in the nose, it would appear that these people were responsible for a certain amount of contamination of the theatre air with this organism.

On the other hand, there seemed to be another source for these organisms. It was shown on a previous occasion that the ward blankets accompanied patients on their way to the anaesthetic room. Here the ward blanket was removed, and a sterile theatre blanket was placed over the patient while he waited to be taken into the operating room. Very often the wait was considerable and in addition, the theatre blanket, being very thin, did not afford sufficient cover, so that the original ward blanket was placed on top of the theatre blanket. When the patient was finally taken to the operating room, the ward blanket was removed.

In view of the previous findings that a considerable proportion of the ward blankets was infected with staphylococci, and also resistant strains of this organism, it would seem probable that some of these may

be deposited on the theatre blanket in the anaesthetic room, and that these would later be distributed into the air of the theatre when the blanket was being disturbed.

A series of theatre blankets was swabbed in the same way as the ward blankets, but although organisms were always obtained from the cultures, on no occasion was it possible to demonstrate the presence of these penicillin resistant strains on them. It is felt, however, that in spite of these findings, the possibility of the theatre air becoming contaminated in this way must be borne in mind.

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CHAPTER SIX

DEDUCTIONS AND SUGGESTIONS.

DEDUCTIONS AND SUGGESTIONS.

INCIDENCE OF POST-OPERATIVE WOUND INFECTION.

In a study of two general surgical wards, extending over a period of a little more than seven months, 922 patients admitted to these two wards were examined. 577 of these patients underwent major surgical operations, which may be classified as clean operations. These were performed by 15 surgeons. Of the 577 patients, 20.42% presented obvious wound infection. Of these, a considerable proportion was invalided on account of the infection, from periods extending from a few weeks to a few months over and above the period normally required to remain in hospital. One patient died as a result of his infection, which was traced to the nose of the assistant at the operation. Other deaths were also associated with infection, although other factors were also concerned, and it would probably not be fair to state that infection was the cause of death. The infection, however, was a contributory factor.

In the vast majority of the cases of post-operative infection, staphylococcus aureus was the causal organism, and this organism was found to be the commonest wound infector in the wards.

During this period, 215 wounds of all types in the two wards were found to be infected with staphylococcus aureus. 110 of these strains were coagulase positive and of these, 28 were resistant to penicillin.

Of the penicillin strains, there seemed no doubt that in at least four cases, the organism was resistant from the beginning of the infection, and it is possible that others were equally resistant before therapy with penicillin began. It is probable that a certain number of these penicillin strains became resistant as a result of the penicillin therapy.

Certain changes in ward routine were instituted in one of the wards at the end of the first half period of investigations. These were as indicated under the heading "Suggestions" described later.

As a result of these changes, there was a slight improvement in the wound infection in that particular ward, but as it was felt that the greater part of the wound infection occurred in the theatre, it was not expected that there would be much improvement until the deficiencies in the aseptic technique practised in the theatre had been attended to.

THE CAUSES OF THIS INFECTION.

In an investigation of the aseptic surgical technique practised in the wards and in the operating

theatres, one came to the conclusion that it was impossible to trace post-operative infection to any one single defect in the system. Nor could it be traced to two or three faulty "links", for it seemed that there were very few links in the chain of aseptic technique which were really sound. There were loopholes for possible infection all along the chain, and it is perhaps a little surprising that the incidence of infection was not higher than it was found to be and that the sequelae of this infection were not more serious than was the case.

IN THE WARDS:

The defects were as follows:-

(1) The nursing of clean and infected wounds in the same ward.

(2) The ward routine. Dressings were conducted in the presence of general activity in the ward, and in the presence of sweeping and dusting operations.

(3) The dressing technique. One nurse was responsible for the dressings, and performed all the duties in connection with these procedures unassisted. In performing these duties, she wore neither mask nor gown. For the actual dressing of the wound, she used her bare hands (which were inadequately cleansed). No-touch technique was not employed, and gloves were not in use.

Contamination from infection in wounds was demonstrated to be transferred to the dresser's hands, and from there to the screen and the instrument trolley.

Contamination of the nurse's hands by handling infected blankets was shown conclusively.

(4) Inadequate practical training of nurses in the dressing of wounds, and in the principles of asepsis.

(5) Non-recognition of the importance played by blankets in the spread of infection. Blankets were not treated to lay the dust in them, and they were not sterilised. Tremendous contamination of the ward air was shown to occur as a result of bed-making and sweeping. The ward air was shown to contain penicillin resistant strains of staphylococci on numerous occasions. Most air samples from the wards contained pathogenic staphylococci.

The blankets of the wards were shown to harbour the same pathogenic strains.

(6) Insufficient care of the post-operative wound by the surgeon himself.

Suggestions:

(1) Clean operation wounds should not be nursed in the same ward along with infected wounds. Where this is

impossible on account of space, segregation of some kind, such as screening, should be practised. All infected cases could be nursed in the side wards, or else at the end of a large ward, and screened off from the rest of the ward by means of a partition. The wounds of these patients should be dressed after all the clean wounds have been attended to.

(2) Ward routine. Doors and windows to be closed during dressings. Activity of all kinds to cease in the ward. Dressings not to commence until one hour after the completion of sweeping and dusting.

(3) Dressing technique. (These suggestions are based on the recommendations of the Medical Research Council - War Memorandum No.6.)

(a) Two nurses at least to perform dressings, working together, the one being the dresser, the other the assistant.

(b) Gowns, caps and masks (covering mouth and nose) to be worn for all dressings, by both nurses, and for sterilizing of instruments.

(c) Hands to be washed by both nurses between dressings, but these not to be regarded as sterile. The dresser uses a "no-touch" technique for all the dressings wherever possible, but where dressings are complicated, sterile gloves are worn, the hands being thoroughly cleansed, as for a surgical operation.

Where several complicated dressings have to be done, the gloves may be left on, but between dressings, the gloved hands are scrubbed with brush, soap and water for one minute, and then immersed in a strong solution of Biniodide in spirit, or Carbolic 1/20 for three minutes, after which they are rinsed in sterile water.

(d) The assistant arranges the screens and blankets of the patient and places the dressing trolley in position. She removes the bandages, and then when the dresser has arrived, she removes the dressings WITH A PAIR OF FORCEPS kept in a jar of disinfectant on the lower shelf of the trolley.

(e) The dresser removes from the trolley all instruments, dressings, and bowls she will require for the particular dressing, and places these on a sterile towel on the bad-side locker. THE STERILE COVER OF THE TROLLEY IS NOW REPLACED. The assistant pours the necessary lotions into the bowls from the stocks on the bottom shelf of the trolley.

(f) At the conclusion of the dressing, all instruments, dressings, etc., which have not been used, are discarded for resterilization. They are NOT returned to the dressing trolley.

(g) Dresser and assistant apply the bandages, and

adjust the blankets, BUT BEFORE THE ASSISTANT MOVES THE SCREEN AND THE TROLLEY TO THE NEXT PATIENT, SHE WASHES HER HANDS.

(4) Practical training of nurses: It is suggested that a specially trained Sister be appointed to inspect the dressings of wounds in all the wards of the hospital, devoting a whole morning to each ward in turn, and to instruct the nurses in the methods of wound dressing and aseptic technique on these rounds.

(5) Blankets: It is suggested that all blankets and linen used in the wards be subjected to a process of oiling as described in a previous chapter. This operation has been greatly simplified today, and merely consists of the addition of the required chemical to the last rinse of the normal laundry procedures.

Floors: Being covered from end to end with a rubberoid compound, it would not be practicable to oil these. It is suggested, however, that all sweeping and dusting be wet, thus eliminating the stirring up of dust considerably.

(6) It is felt that routine examination of post-operative wounds by the surgeon would assist in the maintenance of a strict and meticulous technique in the wards.

IN THE THEATRE:

The defects were as follows:-

(1) Insufficient recognition of the importance of the organisms normally living on the skin. In many cases, wound lining towels were not used, and in most cases, the wound was closed without special attention being paid to resterilization of the wound. All the swabs taken of the wounds at the end of the operations showed these to be infected.

(2) The high incidence of punctured gloves at the end of operations. In a series of gloves examined, it was found that no less than from 36% to 91% of the gloves were punctured or damaged, so that infection could escape from the hands to the outside of the gloves.

(3) The inefficiency of the mask in use; the method of wearing the mask over the mouth only; and the high incidence of staphylococcal carriers amongst the personnel.

A specially designed experiment proved conclusively the inefficiency of the old mask. A new mask was designed which gave favourable results in the same experiment.

Infection of wounds was traced definitely to the noses of surgeons and assistants.

There was a high incidence of staphylococcal carriers amongst surgeons, house-surgeons, and anaesthetists.

There was a considerable percentage of penicillin resistant strains amongst these carriers.

(4) The increased contamination of the theatre air as a result of not wearing overboots. Specially designed experiments proved that there was almost three times as much contamination in the air of the theatre when no overboots were worn as compared with the findings when these were worn.

(5) Repeated proof of the contamination of the theatre air by pathogenic organisms, identical with those which were responsible for the majority of post-operative infections.

A large percentage of the staphylococci obtained from the theatre air were resistant to penicillin.

It is probable that a certain percentage of these organisms was distributed into the theatre air by the unmasked noses of the personnel, and that a certain percentage was brought to the theatre via the ward blankets placed on the theatre blankets in the anaesthetic room.

(6) All types of operations, clean and badly infected, being operated upon in the same theatre.

Suggestions:

(1) (a) The use of a clean knife after the skin incision.

(b) Routine application of wound lining swabs.

(c) Washing of wound at the end of the operation, using either large amounts of saline solution or else swabbing with carbolic lotion 1/20.

(d) Resterilization of the skin prior to suturing of the wound.

(2) Records to be kept of the incidence of punctured gloves.

The surgeon or his assistants to change into a fresh pair of gloves immediately a tear or puncture is noticed.

(3) The use of a cellophane mask measuring at least 7 by 9 inches, covering the mouth and the nose completely. The mask to be worn as tightly as is comfortable against the mouth, thus allowing minute droplets to become attached to the fabric of the mask before they have evaporated, and thereby reducing the number of droplet nuclei escaping at the sides of the mask.

It is suggested in addition that routine swabbings be carried out of the noses and throats of the theatre personnel, and positive cases to take special precautions with regard to details of masking. Such cases should be treated where possible.

The wearing of masks should be made compulsory for every person entering the theatre at any time, whether an operation is in progress or not.

At the conclusion of the operation, the mask must not be removed until the theatre has been vacated.

(4) It should be made compulsory for every person entering the theatre to wear overboots, and these overboots to be oil-treated in the same way as the blankets in the ward. This treatment will allow the surgeon to move about more freely outside the actual operating room, without fear of disseminating the dust he has accumulated on the overboots.

(5) (a) Sterilization of the air of the operating rooms by means of Ultra-violet Radiation.

(b) Doors of the operating rooms to remain closed while operations are in progress, and no-one to enter or leave the theatre during this time.

(c) Restriction of movement in the theatre while operations are in progress to an absolute minimum.

(d) Oil-treatment of theatre blankets.

(e) Air samples to be taken in the operating theatres at regular intervals, and in addition, culture plates to be left exposed in the theatre from time to time, to ascertain the contamination of the air.

(6) A special theatre should be set aside for operations on infected cases.

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PART TWO

EXPERIMENTAL WOUND INFECTION

CHAPTER ONE

INTRODUCTION

INTRODUCTION.

Experiments in animals in regard to the production of infection and in regard to the in vivo effect of the simultaneous introduction of various antiseptics and antibiotics, have hitherto all been limited, more or less, to simple inoculation procedures in the healthy animal, either subcutaneously, intraperitoneally, or by some other route. The study of wound infection, as far as can be ascertained from the literature, has been confined to simple superficial wounds, and no record can be found of major surgical operations simulating what we find in the human being, and at the same time of such a nature that they can be applied in the laboratory as a suitable experimental procedure.

The intention was to perform an operation in a suitable laboratory animal such as the mouse, which would simulate fairly closely a major surgical procedure in the human being, and in doing so, to evolve a technique which would not preclude its being used on a large scale in the laboratory by a person with average surgical ability. In view of the previous work in this thesis in connection with the infection of operation wounds, and in view of the recognition in recent times of the paramount importance of the air-borne route with regard

to these infections, it was decided to embark on a lobectomy in the mouse.

If it were possible, in a large series of animals, to use a technique producing a uniform degree of trauma in each animal, and one which was accompanied by a reasonable and predictable percentage of survival, it seemed that the operation might be of value in the experimental production of infection, both by direct contact, and in this particular case, by the air-borne route.

If it were then possible to produce in such animals a uniform and predictable degree of infection by means of an organism which was pathogenic to man, it seemed that there could be no limit to the number and variety of experimental procedures that could be evolved for the purpose of studying the problems of post-operative infections in wounds.

In the following chapters, a technique for lobectomy is described which is not only very simple in its application, but which at the same time is attended (with reasonable care) by an almost 100% survival rate.

It was also possible to produce an infection of the pleural cavity after lobectomy, of uniform intensity, by the inoculation of a known number of organisms of a strain of staphylococcus aureus, which was coagulase positive to human plasma.

Some experiments were then performed to

determine the effect of the simultaneous application of various antiseptics and antibiotics to the pleural cavity.

It was intended to attempt to infect lobectomized animals by exposing them to an aerosol of the particular strain of staphylococcus in a specially prepared chamber, followed later by other experiments to evaluate the effects of various preventative measures. Unfortunately, delay in the preparation of the special chamber, and the limited time at one's disposal to conduct these experiments, made it impossible to include the latter, although it is hoped at some future date to be able to publish material devoted to this study.

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A colour cinematographic film record of the operation of lobectomy in the mouse accompanies this thesis.

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CHAPTER TWO

LOBECTOMY

IN THE

MOUSE.

LOBECTOMY IN THE MOUSE

White mice, weighing from 20 to 30 grams, were used for all these experiments.

At the outset, it must be recorded that a great many difficulties were experienced in attempts to perform the operation successfully at the beginning, and that only after many variations in technique and methods was it possible to arrive at a procedure which carried a negligible mortality rate. Some 300 mice were eventually subjected to the final technique; the survival rate following the operation was almost 100%; and a certain batch of animals survived the operation for a period of more than three months, after which time they were subjected to further procedures.

With the aid of one assistant, it was always possible to perform from six to eight lobectomies in the hour.

ANAESTHETIC.

The only anaesthetic used was Veterinary Nembutal, injected intra-peritoneally.

Following the recommended dose of 1 cc per 5 lb. body weight, a dilution was made of 1 in 10 in normal saline, and of this solution gradually increasing doses were given to animals weighing approximately 20 grams, and beginning with an initial dose of 0.05 cc.

It was found that an intra-peritoneal injection of 0.3 cc of this solution produced complete surgical anaesthesia in a mouse weighing 20 grams, within a period of from four to five minutes, and that the animal did not regain consciousness for a period of from two to two-and-a-half hours. For the purpose of the operation, the anaesthetic was found most suitable, being very convenient to apply, and, provided the animal was not over-dosed, there were no apparent ill-effects from its use.

THE OPERATION.

At the commencement it became immediately obvious that opening of the pleural cavity on one side produced an instantaneous collapse of both lungs, with the result that the animal died within the space of minutes. This, then, was the chief difficulty to be overcome, and it was quite clear that even if the operation could be performed in the minimum possible time, i.e. by leaving the pleural cavity open to the air for as short a time as possible, the chances of survival were very remote.

Aspiration of the air in the pleural cavity immediately after closure, by means of a syringe, was also unsuccessful.

Obviously it was imperative to keep the lungs inflated while the pleura was open and until the

wound in the chest wall had been closed, if the animal was to survive, and with this object in view, three different procedures were attempted.

The first consisted of applying to the snout of the animal a rubber teat, the one end of which was attached to a tube from an oxygen cylinder, and the end fitting over the snout being cut on the slant so as to produce a reasonably air-tight fit. This was unsuccessful.

The next attempt was to insert a blunted needle which was attached to the oxygen supply, through the mouth and into the trachea, in the hope that by applying sufficient pressure of oxygen, the lungs could be kept inflated. Several animals were dissected and a technique evolved for the introduction of the intra-tracheal needle, but although it was possible to perform this procedure in the live animal on a number of occasions, it was a matter of some difficulty, requiring a great deal of patience, and usually taking a considerable time. The needle invariably entered the oesophagus and when it did eventually pass into the trachea, it was felt that a considerable amount of trauma had been produced which might later affect the animal's chances of recovery. The first post-operative survivals were obtained in this group of operations, but they were very few; and taking into consideration the difficulties of introducing the

needle, together with the possibility of trauma to the upper respiratory passages resulting in subsequent obstruction to the respiration, it was decided to abandon the method.

The final procedure meant the performance of an additional operation, i.e., a tracheotomy with visual insertion of a needle into the trachea. The original objection to this procedure was the fear that a double operation on an animal of this size would possibly increase the operative mortality. On the contrary, it was found that this procedure solved the problem of pulmonary collapse, and, in addition, was very simple to perform.

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The anaesthetised animal is placed on its back on a cork board, and is kept in position by means of loops of thread attaching the legs of the animal to pins fixed into the board. Another short strip of thread passes in its centre over the upper incisor teeth (the animal is on its back) and is fixed at each end by means of a pin to the board. This keeps the head rigid.

The fur over the tracheal region, the front of the chest and the side of the chest, is now removed by means of a pair of scissors.

Spirit on a swab is now applied to the area of operation.

Using a fine pair of scissors and a pair of fine iris forceps, the trachea is exposed by an incision of about $\frac{3}{8}$ inch in length, beginning at the supra-sternal notch and extending upwards. The pad of fat lying under the skin is lifted and a small nick made in the deep cervical fascia. The scissors are placed in this small opening which is now widened by spreading the scissors, and the pretracheal muscles are now brought into view, and are easily defined. It is essential to adopt this method of exposing the pretracheal region, as cutting will sever the external jugular vessels. These lie very close to each other and are easily damaged, whereas stretching of the fascia as indicated always results in excellent exposure and a completely dry field.

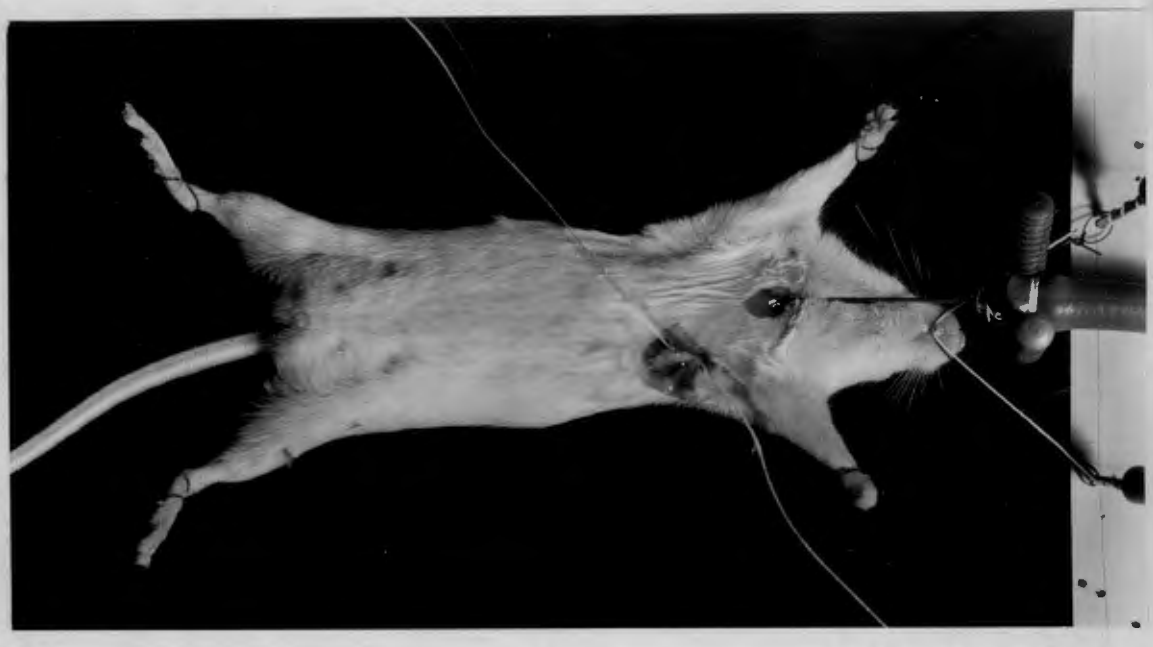
Using two pairs of iris forceps, cleavage is obtained in the pre-tracheal muscles, the trachea exposed, and a number 14 intra-muscular needle inserted between the rings and into the lumen of the trachea. The needle is attached to a piece of rubber tubing, the end of which is held in the mouth of the operator for the purpose of ascertaining whether the needle has been correctly inserted. This having been done, the end of the tube is attached to the glass outlet tube from a glass jar containing a small quantity of water and through which is bubbling the oxygen from a cylinder. By employing this jar, it is possible to ascertain roughly the flow of oxygen. The needle in the trachea is kept firmly in

place by means of two pins fixed into the cork board. An incision of about ¾ inch in length is now made in the mid-axillary line on the left side, and in the direction of the ribs. Running distally in the mid-axillary line, are usually two small vessels which are easily damaged and produce quite brisk haemorrhage. This can be avoided by making a small incision between them and then separating them together with the underlying tissues, by spreading the scissors placed in the small incision. This now brings the ribs into view and in the complete absence of bleeding. A short length of linen thread, looped in the centre and gripped at each end by means of artery forceps is now placed in position with the noose over the operation site. This noose is tied at the lung pedicle when the lung has been delivered on the surface.

Using the scissors, a small opening is made through the chest wall into the pleural cavity and this is extended by the usual technique of spreading the scissors, to an extent of about ½ inch. The inflated lung can now be easily seen. With the scissors in the lower end of the wound opened slightly to act as rib spreaders, the lower lobe of the lung is now grasped very gently with a pair of iris forceps. A part of the lobe having been brought out on the surface, the scissors can now be disposed of, and a second pair of iris forceps used to

assist in the complete delivery of the lobe. This is the most difficult part of the operation as the lung is exceedingly friable, being damaged by the slightest rough handling. Tearing of the lung will increase the difficulties of delivery and immediately increases the chances of non-survival of the animal.

The lobe having now been brought carefully out on to the surface of the chest wall, the assistant tightens the noose which was previously placed in position. It is found that there is a distinct pedicle to the lobe of the lung, and in all the operations it was found that one tie of linen thread was sufficient. The lobe is now severed from its pedicle, the linen threads cut short at the pedicle, and this now retracts into the pleural cavity.



The wound in the chest wall is closed with one suture of fine catgut on an eyeless needle. For this purpose, either a circumcision suture No. 00, or else the same size of catgut on an intestinal needle, serves very well indeed. The skin wound is closed with the same suture, after which the tracheotomy wound is closed with a mattress suture, and the oxygen needle is removed.

The animal is now placed on cotton wool in its box, and lying on the side of the operation. Oxygen is supplied to the mouse at intervals by placing the tube from the cylinder near its snout, and until the tail becomes a bright pink colour. In most cases it was not necessary to supply oxygen for more than about ¼ to ½ hour at intervals after the operation, this being one of the duties of the assistant.

Two hours after the operation, the animals usually woke from the anaesthetic, and within another ½ hour, they were quite active again, while on the following and succeeding days, their activity suggested that nothing had been done to them.

In all these experiments, the left lower lobe was removed, the left side having been chosen on account of the arrangement of the light and the equipment in the laboratory, it being found that this position was most convenient.

In post mortems on animals killed four days

after the operation, it was found that the wounds had healed completely, and that the lobectomy stump had granulated over completely.

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CHAPTER THREE

PRODUCTION OF INFECTION

PRODUCTION OF INFECTION.

It was originally suggested that various strains of streptococci from Groups A, B and C, from the stock in possession by the Department of Bacteriology, should be used in an attempt to produce infection in mice.

Five different strains were selected, and dilutions of from 10^{-1} up to 10^{-6} were made of the in-vacuo dried cultures. 0.5 cc of each of these dilutions was then injected into different batches of normal mice, subcutaneously and intra-peritoneally, six mice being used for each series.

After five days, the surviving mice were killed and autopsied, and cultures made on blood agar, from the blood and from the local lesions.
The results were as follows:-

Strep. "WARD" - Group A.

Intra-peritoneal: All dead by the third day.

Sub-cutaneous: Only survivals by the fifth day were those that had received 10^{-6}.

Macroscopically and culturally, there was no evidence of infection, and no organisms were grown.

Strep. "MATTHEWS" - Group A.

Intra-peritoneal: All alive. No infection.

Sub-cutaneous: All alive. No infection.

Strep. "BROWNETTE" - Group B.

Intra-peritoneal: All alive. No infection.

Subcutaneous: All alive. No infection.

Strep. "SHIPLEY" - Group B.

Intra-peritoneal: All 10^{-1} up to 10^{-3} dead by 3rd day. All 10^{-4} up to 10^{-6} alive, but no evidence of infection.

Subcutaneous: Few deaths up to 10^{-3}. Macroscopically, and culturally, obvious infection of all remaining mice inoculated with dilutions up to 10^{-3}. All higher dilutions showed no evidence of infection.

Strep. "1484" - Group C.

Intra-peritoneal: All up to 10^{-4} dead by third day. Remainder showed no sign of infection.

Subcutaneous: All up to 10^{-5} dead by third day. Remainder showed no evidence of infection, macroscopically or culturally.

The results were therefore unsatisfactory, but it was decided to use a dilution of 10^{-3} of the Shipley strain for intra-pleural injection immediately after lobectomy. 0.5 cc quantities of this culture were

then measured out accurately into small tubes, and these were then dried and sealed in vacuo.

For the experiments on lobectomised mice, six animals were usually inoculated in a batch.

In the first experiment, 0.5 ccs were injected into the pleural cavity immediately after closure of the chest wound, but it was found that this quantity was too great so that the animal died soon after. It was then decided to use 0.1 cc of the same culture. By the third day, all the mice had died and showed positive blood cultures. In the next experiment, a 10^{-4} dilution was used, and again 0.1 cc of the dilution injected into the pleural cavity. One animal died the same afternoon.

Two died the following day.

The remainder were all alive on the fourth day. Of these, none showed a macroscopic infection in the pleural cavity. In one case, streptococci were obtained from the culture of the pleural cavity, and in one case the blood culture was positive. All the other cultures were sterile.

Thus we find that a 10^{-3} dilution was too heavy a dose while 10^{-4} dilution was not heavy enough. It was felt that the organism was not a satisfactory one for experimental purposes and it was decided therefore to repeat the experiments, but this time using a staphylococcus.

INFECTION WITH STAPHYLOCOCCI.

A strain of staphylococci, identified as G 91 which was known to be coagulase positive to human plasma, and resistant to penicillin, was titrated from an 18 hour broth culture.

Dilutions of this culture were made from 10^{-1} up to 10^{-3}.

0.1 cc of the pure culture, and of each of the dilutions was injected into normal healthy mice, using three mice in a batch. The injections were subcutaneous.

The mice were killed on the fourth day after inoculation, and autopsied.

A localised abscess had developed in every case, injected with pure culture, and dilutions of 10^{-1} and 10^{-2}. Those injected with 0.1 cc of the 10^{-3} dilution presented no abscesses, and no staphylococci were obtained from the cultures.

It was then decided to use this strain for the lobectomized animals, and another 18 hour culture was prepared.

This was diluted ten times, and 0.5 cc amounts of this dilution were accurately measured out into small tubes, and these were then subjected to drying in vacuo.

For the first experiment on lobectomized animals, dilutions of the dried culture, in 10^{-1}, 10^{-2}

and 10^{-3} concentrations were made, and 0.1 cc of each of these were injected intra-pleurally into different batches of mice, each batch consisting of six mice.

In all these experiments, the surviving mice were killed on the fourth day after operation or inoculation and then autopsied immediately. In all cases, the macroscopic nature of the lesion was noted, and a culture made from the pleural cavity which had been inoculated.

In all experiments, identical quantities of the injected dose, and smaller dilutions of the same dose, were plated in blood agar for counting.

RESULTS:

DOSE	Number alive:	Macroscopic Lesion + ve	Culture + ve
10^{-1}	6	6	6
10^{-2}	6	6	6
10^{-3}	6	6	6

It was decided to use the 10^{-3} dilution for future experiments, and using of this 0.1 cc.

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CHAPTER FOUR

SUSCEPTIBILITY TO INFECTION

SUSCEPTIBILITY TO INFECTION.

Having established an infection in the mouse after operation, it was now necessary to establish to what extent the mouse was susceptible on various days after the operation.

EXPERIMENT to determine the susceptibility to infection at various times after the operation:

A series of operations was performed on successive days for five days, ten mice being operated upon on each day. On the last day all the mice were inoculated with 0.1 cc of the dilution of staphylococcus culture, intra-pleurally, and in addition an equal batch of mice which had been operated upon two months previously, were subjected to the same infecting dose.

RESULTS: (All mice killed on fourth day and autopsied).

Day of operation :	All infected.	All positive cultures.
Day after operation :	Three infected.	Three positive.
Second day :	Three infected.	Three positive.
All others:	No evidence of infection. One-third day positive culture.	

This was a most interesting finding, showing the marked susceptibility of the animal to the particular infecting dose on the day of the operation; much less marked on the next two days; and immune to the infection

by the third day. By this time, it may be assumed, all raw surfaces had healed over.

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CHAPTER FIVE

PREVENTION OF INFECTION

PREVENTION OF INFECTION.

In this series of experiments, lobectomy was performed on batches of animals, and immediately after closure of the chest wound, the infecting organism was injected into the pleural cavity, followed by an injection into the same pleural cavity of the antiseptic solution. The substances used were:-

1. Penicillin: 10 units in 0.1 cc.
2. Acriflavine: 0.1 cc of a 1/1000 solution.
3. Sulfanilamide powder: (Steraps). Enough to go on a threepenny piece.
4. B.I.P.P. : A quantity equal approximately to the size of a match head.

In the case of the first two, these solutions were injected after closing the wound in the chest. In the case of the latter two, these substances were inserted into the pleural cavity before it was closed, and then the infecting organism was injected afterwards.

In a sense, the experiment does not mimic the conditions applying in actual practice, but it was found convenient to inject the bacterial culture after closing the chest wall as this prevented spilling, and thus affecting the dose of organisms.

At the end of the experiments, the dose of organisms used on the animals, and higher dilutions of this dose, were plated out and incubated, to determine

the actual numbers of organisms injected in each case. Six animals were used for each experiment, and in all cases the survivors were killed on the fourth day after the operation, each one autopsied, and cultures made from the pleural cavities.

The results were as follows:-

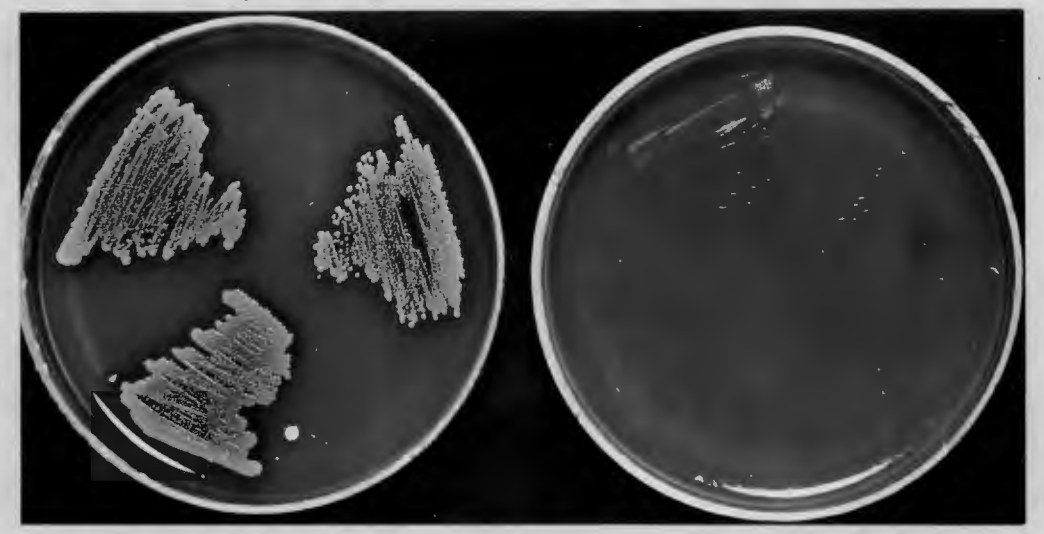
	Number alive:	Number infected:
Penicillin	6	5
Acriflavine	3	3
B.I.P.P.	3	None
Steraps	5	5
B.I.P.P. (repeated)	6	4 + +, 1 +, 1 nil.
Control	6	6

In view of the extraordinary results obtained with the B.I.P.P. the experiment was repeated, but in this instance, the smallest amount of the substance was placed on the lobectomy stump only. As will be seen from the above chart, one was sterile, one was slightly infected, and four were grossly infected.

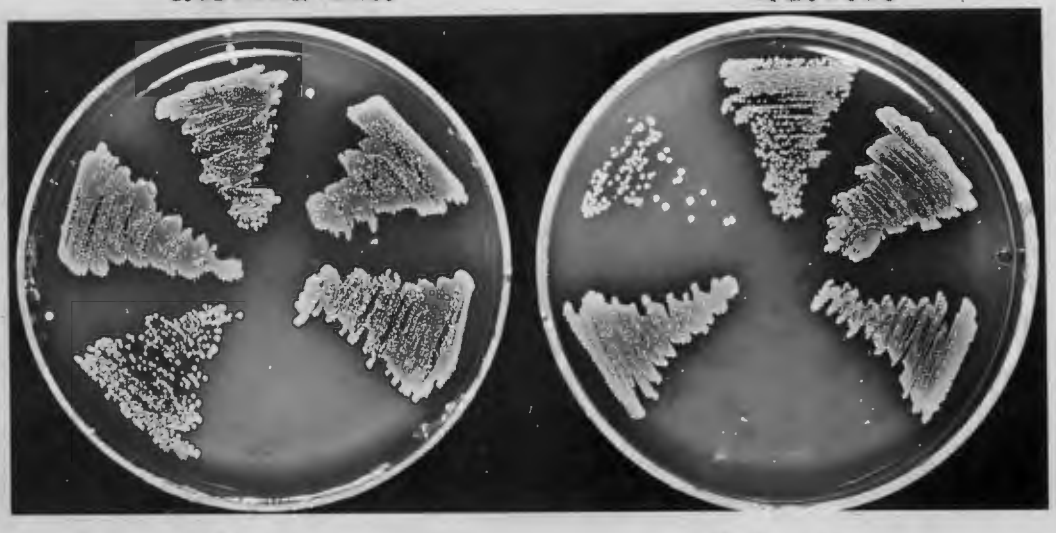
To illustrate these results, photographs were taken of the culture plates, the cultures from each batch of animals being inoculated on the same plate. Where cultures were positive, it will be noted that in each case pure cultures were obtained.

The dose of infecting organisms was 650,000.

Control. Penicillin.



Acriflavine. B.P.P.P.



Steraps. B.I.P.P.

CHAPTER SIX

DISCUSSION

DISCUSSION.

It would seem that the lack of experimental work in the past, on animals in connection with the problems of wound infection, and the prevention of wound infection, has in large measure been due to two important facts:-

(a) The inability to produce in a suitable laboratory animal, a major surgical wound, capable of reproduction on a scale large enough for experimental purposes.

(b) The resistance of such animals to infection by the common human wound infecting organisms.

In the experiments which have been described, it is clear that it was possible to overcome both these difficulties. The operation of lobectomy in the mouse, although presenting certain difficulties at first, proved to be a comparatively simple procedure. Apart from requiring the services of an assistant, the operation presented no special difficulties, nor did it require any special skill for its successful execution. It was found that at least six to eight operations could be performed in an hour, which meant that it could be suitably employed for experimental purposes.

The difficulty of producing an infection in

the mouse was amply borne out by the fact that very rigid aseptic precautions were not employed, and that with reasonable care in this direction, all wounds had healed completely by the fourth day with absolutely no trace of infection.

The deliberate production of infection by means of various strains of streptococci chosen at random from Groups A, B and C was found to be unsuccessful. Those strains that were pathogenic to the mouse, invariably caused death in the higher concentrations, while doses of the same strain which did not kill the animals, failed to produce a localised infection. The organisms therefore produced either a fatal septicaemia, or else they were completely overcome by the natural body defences.

The successful choice of a staphylococcus strain capable of producing a predictable degree of infection of the operative field and without killing the animal, would appear to be a most fortunate one, because it is known that mice present a remarkable degree of resistance to infection by this group of organisms.

Most work on staphylococcal infectivity in animals has been done in rabbits, which are readily infected with most aureus strains. This is not the case with guinea pigs and much less so with mice.

The capacity for staphylococci to survive and

multiply in the tissues of the host depends on a number of factors. As regards the destructive effects which are produced in the tissues, these result from the production of certain alpha toxins, leucocidins, and probably other toxic substances, but before the organisms can become established in the tissues to produce these effects, a protective barrier of fibrin has to be set up around them. This is one of the important mechanisms involved in local staphylococcal infections, and it is dependent on the ability of these organisms to produce a coagulase which will clot plasma.

Pathogenic strains of staphylococcus aureus are recognised by their ability to coagulate human plasma, and it is usually found that these pathogenic strains are equally capable of coagulating the plasma of rabbits and horses. This ability to coagulate plasma is, however, not extended to the same degree to guinea pigs and mice, with the result that these animals are not readily infected by these strains.

The work of Smith, Hale and Smith (168) has shown that those strains of staphylococci which will coagulate guinea pig plasma, are pathogenic to the guinea pig, and that the degree of infectivity to a particular strain is dependent more on this ability to coagulate the plasma than on the alpha toxin production. They were not able to demonstrate the same correlation

between pathogenicity and coagulase production in the case of mice, which they found presented a marked degree of resistance to infection by staphylococci. They were, however, able to increase the virulence of staphylococci for mice by suspending the organisms in a coagulable plasma before inoculation.

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In the case of strain G.91 used for the lobectomy experiments, it was found that NO coagulation of mouse plasma was produced by the organism.

In all the infected cases, the macroscopic picture presented the same extensive fibrinous type of inflammatory process involving the whole of the pleural cavity, mediastinum, and pericardium, and causing a matting together of all the structures mentioned. In many cases the inflammation spread over to the other side, but it was never as severe there as on the side of the lobectomy.

The organisms were resistant to penicillin, and it was found that this resistance persisted in those organisms which were later subcultured from the chest infections.

The infecting dose (650,000 organisms) used in the experiments, always produced the same degree of pleural infection when injected into the pleural cavity immediately after the operation.

When injected on the second or on the third day after the operation, only a third of the animals became infected. By the fourth and subsequent days after the operation no infection occurred.

In addition, this dose injected subcutaneously into a healthy animal produced no evidence of infection.

It was shown previously that in autopsies performed on the fourth day after the operation in animals which had not been infected, there was complete healing of the chest wound and also of the wound at the hilum.

In view of these findings, it must be inferred that the ability for this particular infecting dose to produce an infection in the mouse is markedly increased by the presence of a fresh wound. Once the local tissue reactions have commenced, with the production of granulation tissue, there is marked increase of resistance to infection, and it would seem that this resistance is set up very rapidly in the case of the mouse. This is probably on account of the speed with which the wound normally heals in the mouse, and it was found that by the time normal healing should have occurred, it was not possible to produce an infection of the pleural cavity with the same dose of organisms. It was also not possible to infect those animals that had been operated on some time previously.

In addition, it was not possible to infect the pleural cavities of those mice that had not had an operation (with this particular dose of organisms).

Having established these facts in connection with one strain of staphylococci, it is not improbable that they can be repeated with other strains. The question must also arise whether strains which have been found to be non-pathogenic to mice when injected sub-cutaneously or intra-peritoneally, would not produce infection of the pleural cavity after lobectomy.

With regard to the experiments which were performed in an attempt to prevent the infection after introduction of the infecting dose, the interesting fact emerged that the substances which are now most commonly used such as penicillin and sulphonamide powder, had literally no effect at all in controlling the infection. In two separate experiments it was found that the degree of infection in the pleural cavity after introduction of these substances was identical with that in which no antiseptic solution had been used. In the case of acriflavine 1/1000, the identical degree of inflammation was found in all the survivals. In the first series of experiments, it was found that the introduction of B.I.P.P. had resulted in completely sterile pleural cavities in all the survivals. The three deaths which had occurred before the fourth day were probably due to

the toxic effects of the antiseptic, and it is assumed that this was also the case when acriflavine was used. In the second experiment when a minute quantity of B.I.P.P. was applied to the stump of the lung pedicle only, there was a 100% survival rate, one pleural cavity was completely sterile, one was slightly infected and the remaining four were grossly infected.

In connection with the doses of antibacterial substances used, it must be noted that the quantities were always far in excess of what would have been used in the human subject, relatively speaking.

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As indicated before, it was not possible to embark on further experiments, but it is obvious that a large field of experimental possibilities has been opened up as a result of these established facts. To mention only a few of these, it would be interesting to determine:-

(1) The ability to coagulate mouse plasma, of a large number of different strains of human coagulase positive and coagulase negative staphylococci.

(2) The comparison of the introduction of these mouse coagulase positive and mouse coagulase negative strains:-

(a) Subcutaneously and intra-peritoneally into

healthy mice.

(b) Intra-pleurally into recently lobectomized animals.

(3) The introduction intra-pleurally of other human pathogenic organisms such as Ps. pyocyanea, B.proteus, etc., after lobectomy.

(4) The effect of the simultaneous introduction of various other antiseptics, and antibacterial measures.

(5) The effect of the introduction of antiseptics, and antibiotics, both locally and generally, at various stages after the production of an infection in the operated animal.

(6) The possibilities of producing an infection on the operated side by exposing the animal immediately, and at various stages after the operation, to an aerosol of known concentration, for a given time.

(7) The possible prevention of such infection becoming established by subjecting the animals later to an aerosol of penicillin solution or other antiseptic solution; or possibly by the local application of various antiseptic measures.

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A C K N O W L E D G E M E N T S

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