

BACTERIAL CONTAMINATION OF AIR AND DUST:

with Special Reference to  
Staphylococcus aureus.

A Thesis submitted for the Degree of  
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So whenever the air has been infected with  
such pollutions as are hostile to the human race,  
then men fall sick .....

Hippocratic Collection. 'On Breaths'.

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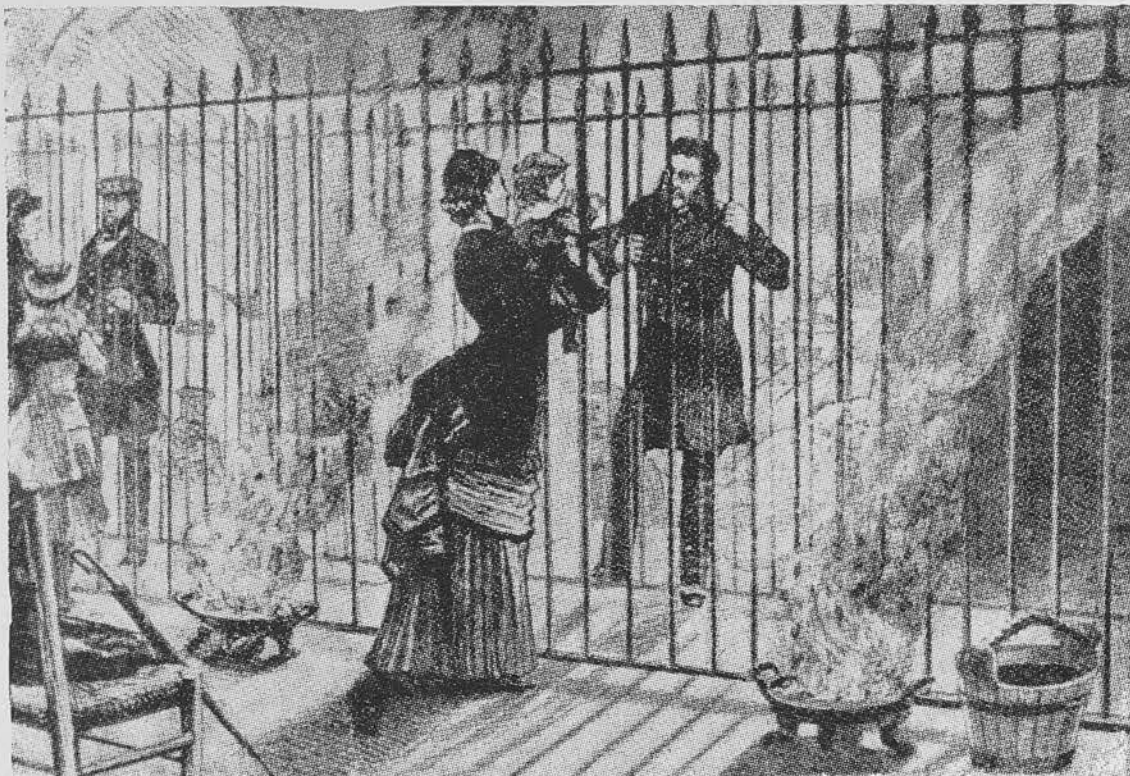
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## I. INTRODUCTION.

The observation that some diseases are spread by proximity is an ancient one, and precautions of one sort and another have been taken from early times to prevent the dissemination of infection through communities. There are many illustrations of this awareness which become more interesting as they approach our own times and are more fully documented. Among early records of efforts to control the spread of infection are those in the Pentateuch written in the fourteenth century B.C. or, probably, later. Isolation of individuals thought to be suffering from diseases spread by contact or proximity, is ordered, together with the scraping of the walls of the affected houses and the discarding of the mortar. St. Paul also uses the idea of communicable corruption when he writes, "Know you not that a little leaven corrupteth the whole lump?"

The Greeks also believed that the air might carry defilement. After the slaughter of Penelope's suitors, Odysseus ordered Eurycleia to fetch him brimstone, sweetener of taints, that he might fumigate the hall. Thucydides noted that the epidemic of typhus which broke out in Athens in the second year of the Peloponnesian War, 430 B.C., affected particularly those people who ventured to nurse the sick. The air was thought to carry the infection, and fires were lighted /



Quarantine in Marseilles, 1873. The families of officers in quarantine come to visit them. The visitors are protected by fumigation as well as by the double row of bars.

From "Storia della Medicina" by courtesy of Professor Arturo Castiglioni and Sig. Arnold Mondadori.



lighted in the streets to purify it, a practice which has continued to our own day. There is some hint that the air may carry infection in the essay "On Breaths" in the Hippocratic corpus which belongs to this period.

The vapour from bogs was also regarded as a source of infection. An ingenious suggestion has been made that Grendel, the monster in "Beowulf", was really a personification of the miasm of the marsh, which caused ague. He lived in the fen and ravaged the kingdom of Denmark. Caliban cursed the Duke of Milan in these terms: "All the infections that the sun sucks up from bogs, fens, flats, on Prosper fall." And Lady Blessington describing in "The Idler in Italy" her journey across the Pontine Marshes in the late summer of 1822, mentioned that ".... the persons at all the post-houses looked fearfully haggard; and their warning to us not to sleep while passing the Marshes, was invested with solemnity by the pallor of their cadaverous faces, and the hollow tones of their voices .... The aspect of the country between Velletri and Terracina is savage and desolate, and overgrown with masses of thick, tangled, rank grass, broken by pools of stagnant water whose deleterious vapours impregnate the air."

Leprosy was known to be contagious. The lepers in the leper house in the Gorbals in Glasgow, founded about 1350, were obliged to wear a cloth over the/

the mouth and face because of an idea that the infection rested chiefly in the breath. (Comrie 1932). Syphilis when it appeared, was soon placed in the same category. The Town Council of Edinburgh issued a regulation in 1497 banishing to Inchkeith those who were infected with the "contagius seiknes callit the grandgor". (J. Y. Simpson, "Syphilis in Scotland"). And it was occasionally believed to be airborne.

The contagion of plague was thought to be a venomous quality in the air, which penetrated and adhered to materials to an extent depending on their porosity and liability to putrefaction (Ritchie 1948). The destruction of this atmospheric poison or its replacement by clean air was the object of disinfection or, as it was sometimes called, expurgation. Dry and moist heat were used and clothing was boiled or heated in a kiln. Flaming the walls with burning heather was an approved method of disinfecting rooms - the whole town of Kelso was accidentally destroyed in this way in 1645. Immersion in sea water for several tides was a method readily available to ships. In addition to this "cleinging by fyre and wattir", fumigation with odoriferous substances was practised, and those who became sick of the plague or who were ailing were separated from the healthy - the sequestration of the sick. When plague broke out in Edinburgh in 1499, the Provost and Bailies directed that /





A physician's visit to a patient ill of the plague. From Fasciculus Medicinae, Venezia, 1500. The doctor holds to his nose a sponge impregnated with odoriferous substances while two of his servants burn aromatics.

From "Storia della Medicina" by courtesy of Professor Arturo Castiglioni and Sig. Arnaldo Mondadori.

that the furniture and clothing of the infected citizens were to be washed in the running Water of Leith - Drumsheugh was a favourite place for these ablutions - and forbade washing in the lochs round the town. The houses, in the meantime, were to be fumigated with burning heather. Suspected cases and contacts were isolated on the Burgh Muir (Comrie 1932).

Defoe in his "Journal of the Plague Year" recorded an opinion that "the best preparation for the plague is to run away from it"; a view which was held by the ladies and gentlemen in the "Decameron" who fled from Florence to a country villa to escape the plague which visited that city in 1348. Likewise King Charles and his court left London for Salisbury and Oxford to escape the plague of 1665. Defoe also mentioned a theory with which he disagreed, that "the calamity was spread by infection; that is to say, by some certain steams or fumes, which the physicians call effluvia, by the breath, or by the sweat, or by the stench of the sores of the sick persons .... which effluvia affected the sound who came within certain distances of the sick ...." He saw quacks who were hawking, among other remedies, "sovereign cordials against the corruption of the air". Orders were given that "bedding and apparel and hangings of chambers must be well aired with fire and such perfumes as are requisite within the infected house before they be taken again to use". The value of /



The post mortem examination of a patient dead of the plague. An attempt is being made to purify the air by fumigation. From "Loimotomia or the Pest Anatomized" by George Thomson, M.D., 1666.



The King and Queen with the High Almoner carrying posies of herbs when they left Westminster Abbey on Maundy Thursday, 1950, after His Majesty had distributed the Royal Maundy. The carrying of these bouquets is the survival of an old practice among persons of rank who sometimes carried herbs to protect themselves from the pestilence when their duties took them among crowds.

By courtesy of Messrs. P-A Reuter.



of ventilation was sometimes noticed. Dr. Nathaniel Hodges who stayed in London during the plague, not only fumigated the sick rooms and sucked lozenges of myrrh and cinnamon, but also noted the benefit of "brisk winds which help to dissipate the poisonous miasmata" (Guthrie, 1945). Almost eighty years later, in 1743, Stephen Hales described artificial ventilation and applied it to the Savoy and the Newgate Prisons in an effort to check the jail fever (Dict. of Nat. Biog.). As a result, there was a diminution in the annual mortality.

The value of isolating persons suspected of carrying the plague was recognized, and it was practised intermittently in the seaport of Leith. Ships' companies and passengers arriving in Leith Roads and suspected of carrying plague, were isolated on the Isle of May, or Inchkeith, or Inchcolm, or Cramond Inch, or at Newhaven for varying periods of time.

The authorities of the principal seaports of Italy were surprisingly enlightened on the subject of infection, possibly because these seaports were important centres of trade and were in contact with the Middle East. One example of this is found in a directive drawn up by order of the Magistrates of Health at Venice in 1784 in which they stress the value of isolation, cleanliness and ventilation by opening windows and lighting fires. (Howard, 1789). Lighting fires was still practised a hundred years later /

later in Marseilles.

In some Mediterranean countries there was a law which, in Italy at all events, dated from the mid-eighteenth century, that ordered the destruction of the personal possessions of patients dying of phthisis. After Keats had died in Rome in 1821, his friend, Severn, who had tended him during his illness, was embarrassed by this regulation because he had no money with which to replace the destroyed property. (Colvin, 1917). George Sand later found herself in the same position. In the winter of 1838, Chopin and she were in Majorca. "The rumour soon flew round that Chopin was consumptive and in an instant he found himself an object of horror and fear to the local inhabitants. When the news came to the ears of ... the owner of the house, he insisted that the polluter of his dwelling should quit it forthwith and pay for replastering and whitewashing. The bed and bedding would be burnt and paid for, that was the law". (Hedley, 1947).

On the other hand, Cornet (1889) in his paper on the spread of tubercle bacilli outside the body, described conditions in the Berlin of the eighties. The following is from one of his numerous social histories. One landlady insisted that her phthisical lodger should spit only on the newspapers which she distributed on the floor around the bed. One must suppose that the other landladies allowed their consumptive lodgers to spit indiscriminately on the floor. /



floor. Quite a number of the young men whom he described were sharing a room with several other lodgers. It is clear, therefore, that the Berliners of 1889 were not so much aware of the risks of infection as were the Italians and Spaniards of an earlier period. Cornet also mentioned an ingenious but inconclusive investigation which he carried out. He examined the street cleaners of Berlin for tuberculosis on the assumption that they, breathing in street dust containing an abundance of desiccated sputum, were more exposed to the risk of infection than other people.

In the limited but important field of obstetrics, there had been, from time to time, publications which showed some appreciation of the possible causes of puerperal fever which, according to Hippocrates, was a disease that few survived. Charles White of Manchester was one of the first in this field. The first outbreak of puerperal fever in Britain occurred in 1760, about a decade after the foundation of the first lying-in hospital in England (Sheehan, 1942). In his "Treatise on the Management of Pregnant and Lying-in Women", London 1773, he advanced his opinion that puerperal fever was contagious, and he recommended removal of the patient to another room not only for the sake of the patient but also for the sake of the other puerperas. Following a case of puerperal fever, the bed linen was completely changed, and the room fumigated and well ventilated. He considered /

considered that the infection was airborne, attributing it to the putrid miasmata lodging in the curtains, bed cloaths (sic) and furniture. In any case, the lying-in chamber was to be absolutely clean, the linen fresh and the room well ventilated - "no boards or other contrivance to block up the chimney, the curtains not to be closely drawn" and "no visitors or other persons, except such as are absolutely necessary, should be allowed to enter the patient's chamber."

John Leake in his rambling "Observations on the Childbed Fever", London, 1772, attributed the condition to a "noxious constitution or distemperature of the air".

A picture of the more generally prevailing state of affairs about this period is to be found in "Tristram Shandy". Laurence Sterne wrote that the midwife's reputation was established in the Yorkshire countryside with "the help of a little plain good sense" and as regards the instruments, Dr. Slop kept "the tire-tête, the forceps, the crotchet and the squirt hanging up in a green baize bag, betwixt the two pistols at the bed's head". And in that lengthy and detailed description of the birth of the writer, there is no reference to cleaning the instruments or anything else. No doubt the green baize bag was the repository of many organisms besides the instruments.

Gordon of Aberdeen was the most illuminating writer on puerperal fever in the eighteenth century. He noticed (1795) the association of puerperal fever and /

and erysipelas in the hospital at Aberdeen, and, by an analysis of the distribution of cases in the city and the surrounding countryside, he showed clearly that it was infectious and that the infection was being carried by doctors and midwives who had previously been in contact with other cases of the disease. He recommended purification of the bedclothes and apparel of the patient with the fever, and that nurses and physicians in attendance on such fever cases should wash themselves carefully and fumigate their apparel.

Collins in 1835 instituted a rigorous regime at the Dublin Lying-in Hospital of washing out the wards with chloride of lime, scouring and stoving blankets, changing the straw in the mattresses, and isolation of the sick mothers. After this he had a death rate of 1 in 186 and no cases of puerperal fever, an impressive record under any circumstances and especially when placed alongside the results obtained at that time in Edinburgh, London, Vienna and elsewhere.

In 1843, Oliver Wendell Holmes published his essay on the contagiousness of puerperal fever in which he repeated the observations made by Gordon, and stated that puerperal fever was, presumably, carried to the patient by the attending physician or nurse. He warned the physician against taking part in autopsies and midwifery simultaneously, and suggested that if two cases of puerperal fever occurred close in time to each other in the practice of a physician, /

physician, he should relinquish obstetrics for at least one month and endeavour to free himself by every available means of the noxious influence that he might carry about with him.

About this time Semmelweis who was assistant at the obstetric clinic of the Allgemeines Krankenhaus in Vienna, noticed that a colleague of his who had been wounded by a careless student with a knife soiled at a post mortem examination, died of a disease indistinguishable from puerperal fever. This observation gave him a clue to the high death rate among the mothers in the maternity ward supervised by the students or Praktikanten, while in the ward looked after by the midwives, the death rate was always relatively low. These post-graduate students of obstetrics engaged in autopsies and, although they washed their hands with soap, the "cadaveric particles" could still be perceived by the sense of smell.

Murphy (1947) reviewing information about this lying-in division of the Vienna General Hospital, calculated that each woman was examined some five times daily per vaginam. Once the infection had started in the unit there was little chance of getting rid of it. From 1792 onwards, as the teaching of anatomy in the Vienna school increased so also did the death rate from puerperal fever. Semmelweis introduced "Chlorwaschung" in the middle of May 1847, and the death rate dropped from 57 in April to 6 in June. Incidentally, Semmelweis mentioned in his book on childbed fever that /



that it was the custom of the English to change the clothes before attending a woman in labour so as not to carry childbed fever to her on the clothes, a practice which he called "a harmless but unnecessary precaution".

There was no clear differentiation between miasmata and particulate infection but a tendency appeared in the century preceding Lister to think in terms of the latter. Kirkland (1767) referred to "air which in rooms is filled with excrementitious steams", while Semmelweis in 1858 thought that the cadaveric particles adhering to the hands were the cause of infection and that childbed fever was due to a "Resorption eines zersetzten theirisch-organischen Stoffes". Occasionally minute, invisible, living agents were postulated but since these views could neither be affirmed nor denied, there was no progress. The older medical men had, apparently, no conception of infection of the air as we understand it. They generally regarded it as a gas, exhalations, steams, vitiated or corrupted air, malaria. The microscope, the most essential piece of apparatus in such a study, was still the toy of dilettanti and it was only to become an instrument of research in the nineteenth century when its performance was improved by J. J. Lister, Abbe and others.

The question of viable floating matter in the air was inevitably closely associated with the subject of spontaneous generation. It was in the course /

course of experiments to support or disprove this theory that the floating matter of the air was examined.

The most famous protagonists in this controversy were J. T. Needham (1713-1781) and Lazzaro Spallanzani (1729-1799). The former, along with the Comte de Buffon, had expressed the conviction that micro-organisms might arise from inert, organic material. Needham was the first to use vessels heated and then sealed, in his experiments on spontaneous generation. They were not, however, always sterile. On the other hand, Spallanzani (1765) in many observations showed that growth did not occur in sterile fluids. He demonstrated that animalcules were carried into the flask in the air and that if the fluid in the flask was to remain permanently barren, the air in the flask had to be free from animalcules.

At this time, John Pringle (1751) who had been the chief medical officer with the army sent to quell the rebellion of 1745, experimented with "bodies which resist or promote putrefaction in animal substances". He used spirits of hartshorn, vinegar, Jesuits' bark, myrrh, chamomile and other substances comparing their antiseptic properties with sea salt, on such things as ox gall, lean beef, pleuritic blood, exposing them, while under examination, in a lamp furnace to a heat of between 94 and 104 degrees Fahrenheit, or placing them on a window sill in the sun in /



in warm weather. He was one of the first to use the terms "septic" and "antiseptic".

Pringle's investigations were continued by Madame d'Arconville (1766). Her experiments had for their object "de rendre les substances animales inaltérables, et même d'enlever à la chair déjà corrompue, non-seulement son principe de corruption, mais encore de lui ôter la putridité qui en dépend". She did some hundreds of experiments with meat, eggs, fish and human bile, exposing them to the air either by themselves or after treating them with various substances. She recorded temperature, wind, weather and season of the year, and noted the period at which decomposition set in.

Appert (1812), a Parisian confectioner, applied Spallanzani's technique to the preserving of food. He bottled meat, poultry, fruit, vegetables, soups, gravies, in fact "all nutritive substances" with such success that the Napoleonic army marched, in part at least, on Appert's preserved food. The French Government directed him to publish his method, and in his book on the subject, he recommended "dispatch and the utmost cleanliness" to ensure success.

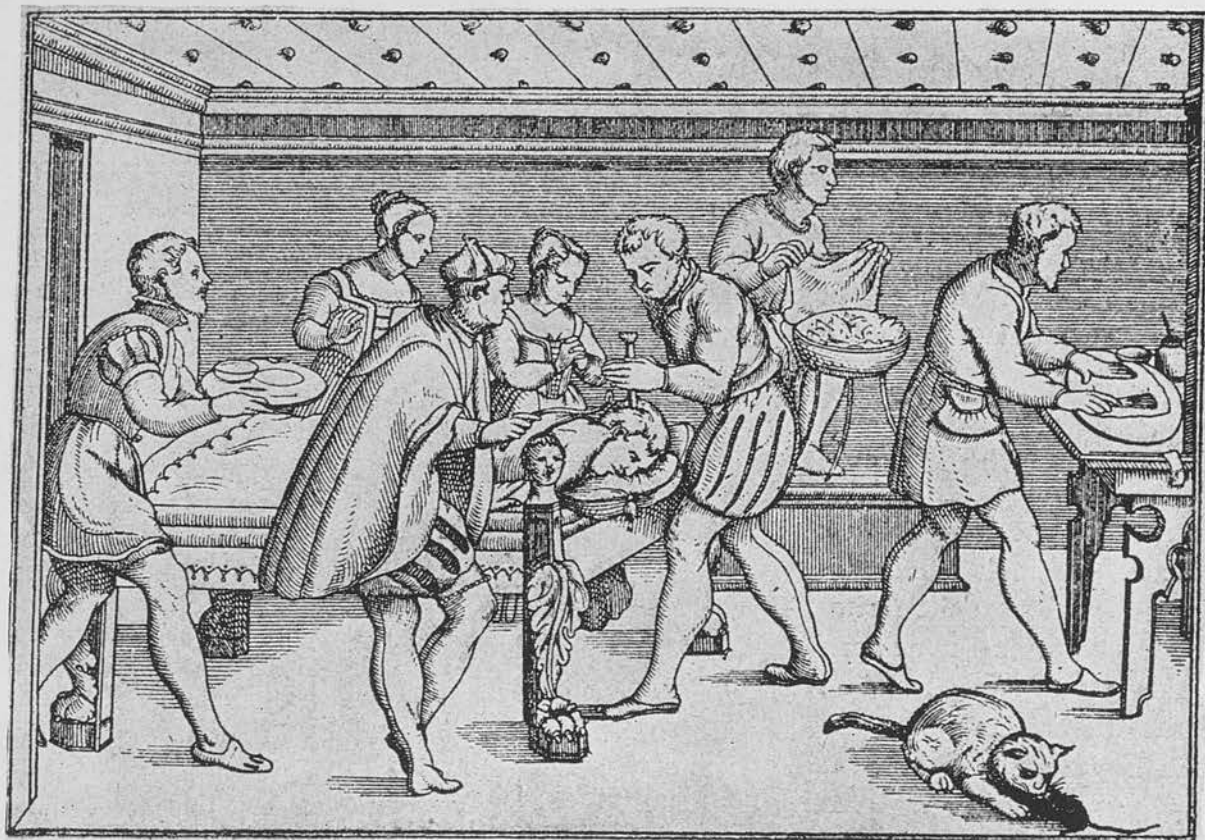
Schwann (1837) subjected fermentable fluids to heat and then admitted air to the flasks. The air was sometimes heated and cooled before admission, sometimes it was untreated. Fermentation occurred in those flasks to which unheated air had been admitted. He concluded that "for alcoholic fermentation as for putrefaction /

putrefaction it is not oxygen, at least the oxygen only of the air which causes them but a principle in ordinary air which heat can destroy".

Schulze also studied the subject (1836). He half filled a flask with a vegetable infusion and closed it with a cork carrying two bent glass tubes. The infusion was boiled and while steam was still issuing from the tubes, he attached an absorption bulb to each, one bulb containing concentrated sulphuric acid and the other a solution of potassium hydrate. For two months he aspirated air through the flask several times daily, the air entering through the sulphuric acid bulb. The infusion remained sterile, but when it was exposed to the air at the end of the two months, it soon teemed with life. Tyndall repeated these experiments in 1878 and found that the acid and alkali might be replaced by water and the infusion still remain sterile.

There was, therefore, before Pasteur, a considerable body of knowledge about micro-organisms and their activities, but much of it was not entirely conclusive. It was also scattered in journals of chemistry and obscure publications, and, possibly the interchange of information was not so easy at that time. Pasteur, however, established this knowledge on a secure foundation.

The knowledge about putrefaction and fermentation in the eighteenth and early nineteenth centuries /

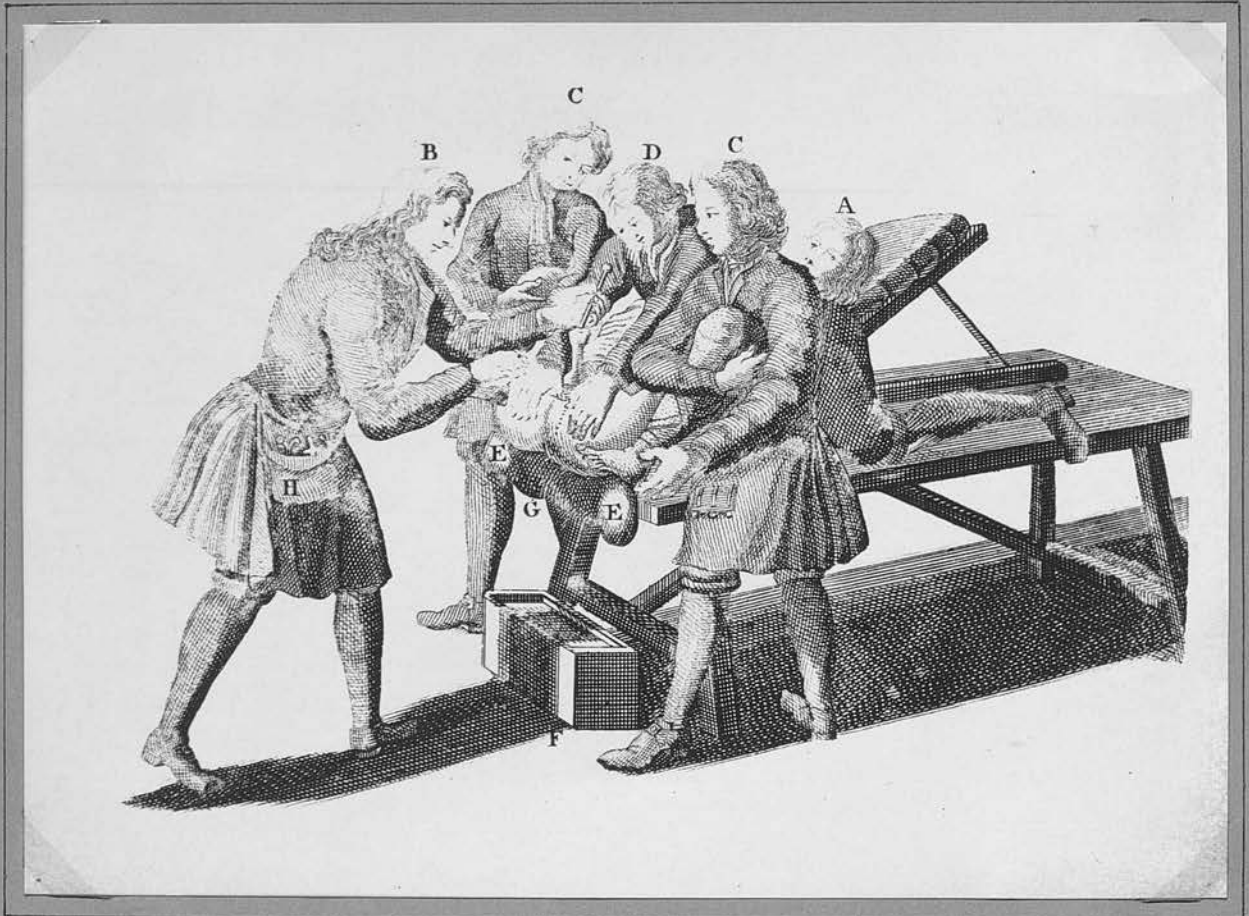


Trepanning the skull. From the "Chirurgia" of  
Andrea Della Croce, 1573. From "Storia della Medicina"  
by courtesy of Professor Arturo Castiglioni and Sig.  
Arnoldo Mondadori.



Amputation of the leg. From Laurenz Heister's  
"Institutiones Chirurgicae". Amsterdam, 1739.





Lithotomy. - From Laurenz Heister's "Institutiones Chirurgicæ". Amsterdam, 1739.

centuries had little effect on surgery. Of this period Trent (1947) wrote that drainage of empyema was the only operation done on the thorax. Amputation, lithotomy, drainage of abscesses and a limited amount of vascular surgery made up the bulk of the surgeon's practice. The abdomen, cranial cavity and spinal cord were practically untouched. Surgical results were judged by the mortality rate after amputation; 25% was considered a low rate while 50% was a more general figure. There is no evidence that regular antiseptic precautions were taken. Illustrations from various sources show no signs of preparation for the purification of the hands and instruments before the operation. With regard to the management of surgical cases, Alanson (1782) mentioned that he had noticed that surgical cases did better in the country. He stressed the necessity for cleaning and whitewashing the wards frequently, for an abundant supply of fresh air, and for a regular supply of clean bedding. There was, however, no technique for preventing the spread of infection during operations since the nature of the common sequelae to surgery were not understood. Illustrations and descriptions of operations at various periods showed no preparations to promote cleanliness. Manual dexterity was everything.

A.-F. Ollivier (1822) recorded the observations of a number of surgeons, that hospital gangrene had /



had affected the wound of a patient sharing the same bed with a patient suffering from hospital gangrene; and that it was apparently transmitted on linen rags used for dressing wounds and on instruments used during the dressings. Ollivier himself washed his instruments for a time but this did not lead to a reduction of the number of cases of hospital gangrene under his care, and so he left off. Likewise, when he and others inoculated healthy wounds with matter from wounds affected with hospital gangrene, the results were ambiguous. Sometimes the healthy wound became inflamed, sometimes not. Ollivier inoculated his own right arm with matter from an infected wound and produced a severe but localized infection which he called "pourriture d'hôpital" but from which he recovered by using the cautery and camphorated spirits. He wrote that ventilation was not enough to prevent putrefaction and went on to say that the English surgeons after a case of fever, washed the ward with vinegar or muriatic acid, fumigated with sulphur and aired well for eight days before admitting more patients. He suggested that, when putrefaction occurred in a ward, an increased surgical staff should be supplied to the ward because there would be more work, that they should be relieved every eight days, and that they should not attend in other wards. He recommended frequent washing of the hands with dilute hydrochloric acid and that the dressing instruments should be cleaned /

cleaned in it, and that, if the case were very putrid, the bed should be sprayed with the acid. He recommended common salt among other antiseptics.

Lemaire (1857) recorded in his study of carbolic acid that plasters containing coal tar had been successfully used for the disinfection of gangrenous wounds.

Such then was the position in the century preceding the advent of the antiseptic principle in 1865. Not only did surgeons take no precautions in the theatre against infection; they actually donned dirty clothes to operate. Some of the obstetricians, on the other hand, practised what was really scrupulous cleanliness and they achieved astonishing results. Their teaching was, however, empirical and so had little weight. Indeed, the views of Holmes and Semmelweis were bitterly opposed. Ingenious and sound study and much theorizing had been devoted to the subject of infection. A number of men had made brilliant deductions from their observations. Some facts were known to some people, but these facts were entangled in a mass of myth, and, no doubt, to contemporaries, the relevant facts did not appear so clear as to us looking back. They lacked the irrefragable proofs which Pasteur and his successors were to supply. The reader of these old treatises must guard against the tendency to catch "at words or phrases which seem to suggest that the author had an inkling /

inkling of what we now suppose to be the truth."

"Even in science homonyms are not synonyms thirty years apart."

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The immediate cause of the change of outlook on the subject of sepsis was the work of Pasteur which he did when studying so-called spontaneous generation and which was published in a series of papers from 1860 to 1866 (1922). He showed that organisms could be recovered from the air by drawing it through a tube containing gun cotton and then dissolving the gun cotton in alcohol and ether. He examined the sediment and found, in addition to the dust, oval bodies resembling the spores of minute plants or the ova of animalcules. He further demonstrated that the admission of dust-laden air into flasks containing sterile infusions caused them to teem with life whereas air which had been heated or had passed along a tortuous narrow neck into the flask had no such effect.

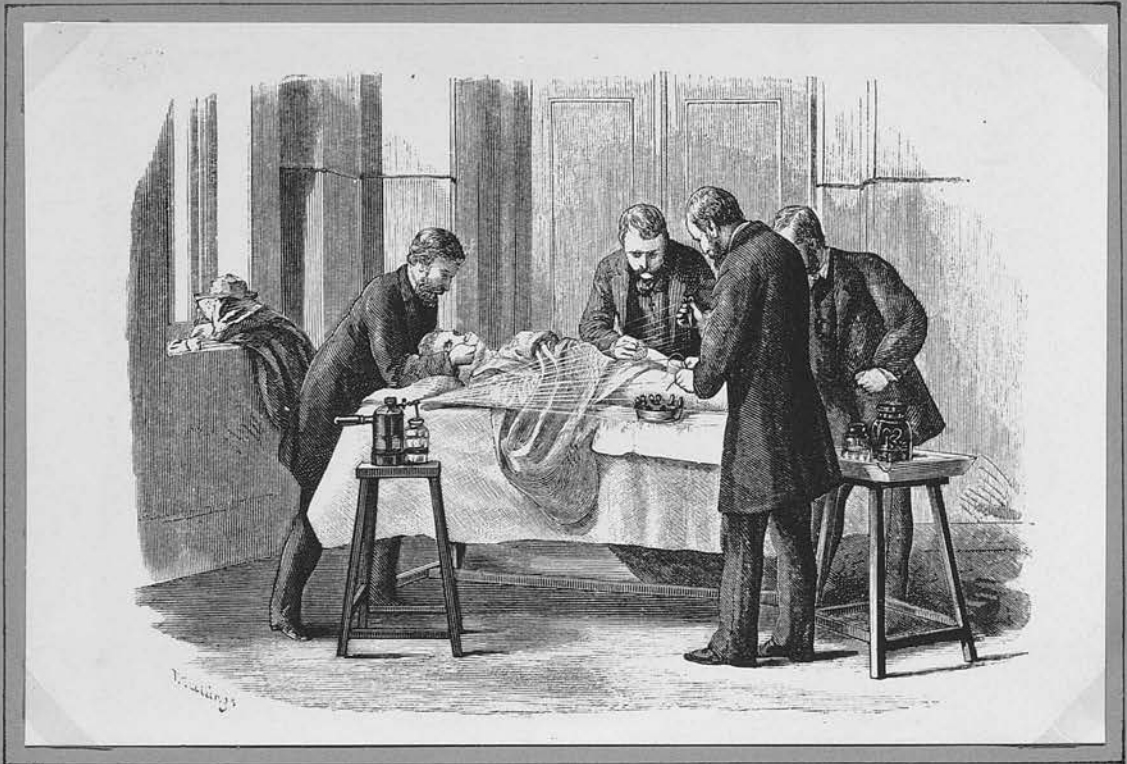
Pasteur showed also that germs are not evenly distributed through the atmosphere. Only a few of the sterile sealed flasks opened in the cellars of the Paris Observatory or on mountains were infected, but rather more of those which were opened on the road to Dôle.

Spencer Wells (1864) pointed out in a paper read before the British Medical Association at Cambridge, that Pasteur's experiments had "a very important /

important bearing upon the development of purulent infection, and the whole class of diseases most fatal in hospitals and other overcrowded places". This was an echo of Robert Boyle's prophecy that "he that thoroughly understands the nature of ferments and fermentation shall probably be much better able than he that ignores them, to give a fair account of divers phenomena of several diseases (as well Feavers as others) which will perhaps be never thoroughly understood, without an insight into the doctrine of fermentation".

At this time Lister was much perturbed by the degree of hospital infection that was occurring in his wards in the Glasgow Royal Infirmary. In 1865, Dr. Thomas Anderson, his colleague who held the chair of chemistry, drew his attention to the writings of Pasteur on fermentation and putrefaction. These writings made a profound impression on a mind already prepared, for Lister had suspected that something in or on the fomites was the cause of hospital wound infection. Two years later he published a paper (1909) in which he stressed the need for excluding air from wounds and noted that when almost all the beds contained cases with open sores, hospital gangrene or pyaemia were pretty sure to show themselves, but that since the antiseptic system had been brought into full operation and wounds and abscesses no longer poisoned the atmosphere with putrid exhalations, his wards, though in other respects under precisely the same /





An Illustration to show the use of the spray. From Sir William Watson Cheyne's "Manual of Antiseptic Treatment". London, 1885.

same circumstances as before, had completely changed their character; so that not a single instance of pyaemia, hospital gangrene or erysipelas had occurred in them.

Lister at first paid most attention to the air as the source of infection; and of the three available methods of purifying it - by heat, by filtration, and by chemical means - he chose the last. Dr. Anderson supplied him with German creosote or crude carbolic acid for the treatment of wounds and now he used it as a spray in order "to provide an antiseptic atmosphere". The fine mist of carbolic acid enveloped the operator, his assistants and the patient as is shown in the illustration from Watson Cheyne's book. It was, however, unpleasant to all, and harmful to some surgeons and patients and these surgeons were obliged to discontinue its use. Their results, using the Listerian technique, continued to be as good as before. Doubts were, from time to time, expressed about the need for the spray but it continued to be widely used until Bruns (1880) wrote a decisive paper bluntly entitled "Fort mit dem Spray". In Bruns' series of 1175 cases, 36 died - a 3% mortality - and there was no case of pyaemia, septicaemia or erysipelas during a period of two years when he did not use the spray. Lister himself about this time began to regard it as unnecessary and Godlee (1917) ascribed this change in view to the following reasons.

Lister /

Lister believed that the peritoneum had a great capacity for resisting infection, a belief which was supported by Thomas Keith's brilliant results in ovariotomy. He had reduced the mortality in this operation to 16% in 1870, or less than half the mortality of that time; and he achieved this result by gentle and dexterous manipulation and scrupulous cleanliness. Later he adopted the full Listerian technique and had a series of eighty successful cases. He was, however, obliged to relinquish the use of the spray, but nevertheless he maintained his good results. It was clear, therefore, that the spray was of minor importance in the prevention of infection, and Lister remarked at the International Medical Conference of 1881 that if further investigation should confirm the conclusion to which recent facts seemed to point and it should be proved that all idea of atmospheric contamination of wounds during operations might be thrown to the winds, then no one would say with more joy than himself, "Fort mit dem Spray". (Coll. Papers ii, 280).

Finally at the International Medical Conference at Berlin in 1890 (Coll. Papers ii, 336) he pointed out that the cone of spray, as it spread out, drew more and more air into its vortex, and that the microbes of the atmosphere, having only a fleeting contact, if any, with the disinfectant, could not possibly have been deprived of their vitality.

From that time onwards, interest in the atmosphere /

atmosphere of the operating theatre as a mediator of infection declined and remained in a state of abeyance for many years.

Instruments were recognized as carriers of infection. Keith practised scrupulous cleanliness. Lister allowed the fibrin in his sponges to "decompose" and then washed them thoroughly. He cleaned and sterilized instruments in 1:20 carbolic acid followed by 1:40, and he prepared ligatures in chromic acid. The older surgeons, contemporaries of Lister, preferred to use these methods until the end, but they were gradually replaced by other methods. Physical rather than chemical means were used to achieve sterility, and both dry and moist heat were applied. Bergmann and Neuber were the protagonists of the new methods which were generally referred to as the aseptic technique to distinguish them from Lister's methods which were called antiseptic. The differences between the two techniques were, apparently, profound, but this was not really so. The difference lay in the means taken to compass the same end, namely, sterility. The aseptic technique was generally regarded as the more satisfactory method, but it might be argued that apparatus sterilized by heat might become grossly contaminated if mishandled, whereas instruments treated with antiseptic were, initially at all events, covered with a protective coat of antiseptic. Some materials which did not withstand high temperatures, had to be sterilized by other means, for /



for example, catgut and gum elastic catheters. These last, composed of perishable material and with a long, narrow lumen, presented a problem in sterilization which has not yet been satisfactorily solved.

With regard to the operating theatre and the conditions prevailing at operations in the early Listerian period, they have been described, I think accurately, in Francis Brett Young's "Dr. Bradley Remembers": -- " ... a small room with a wooden floor sprinkled with sawdust, and white-washed, unwashable walls. There was a fire grate on which a black kettle perpetually sang, in one corner. On one side a couple of windows glazed with soot-grimed, opaline glass ..... admitted a mournful light. No running water was "laid on". The surgeons and dressers could wash their hands or instruments, if they were so minded, in tin basins of lukewarm water faintly purpled with Condy's fluid which stood on a long side table that also carried an assortment of dressings, spools of silk and catgut sutures, and a wide-mouthed jar full of sponges to be used as swabs.

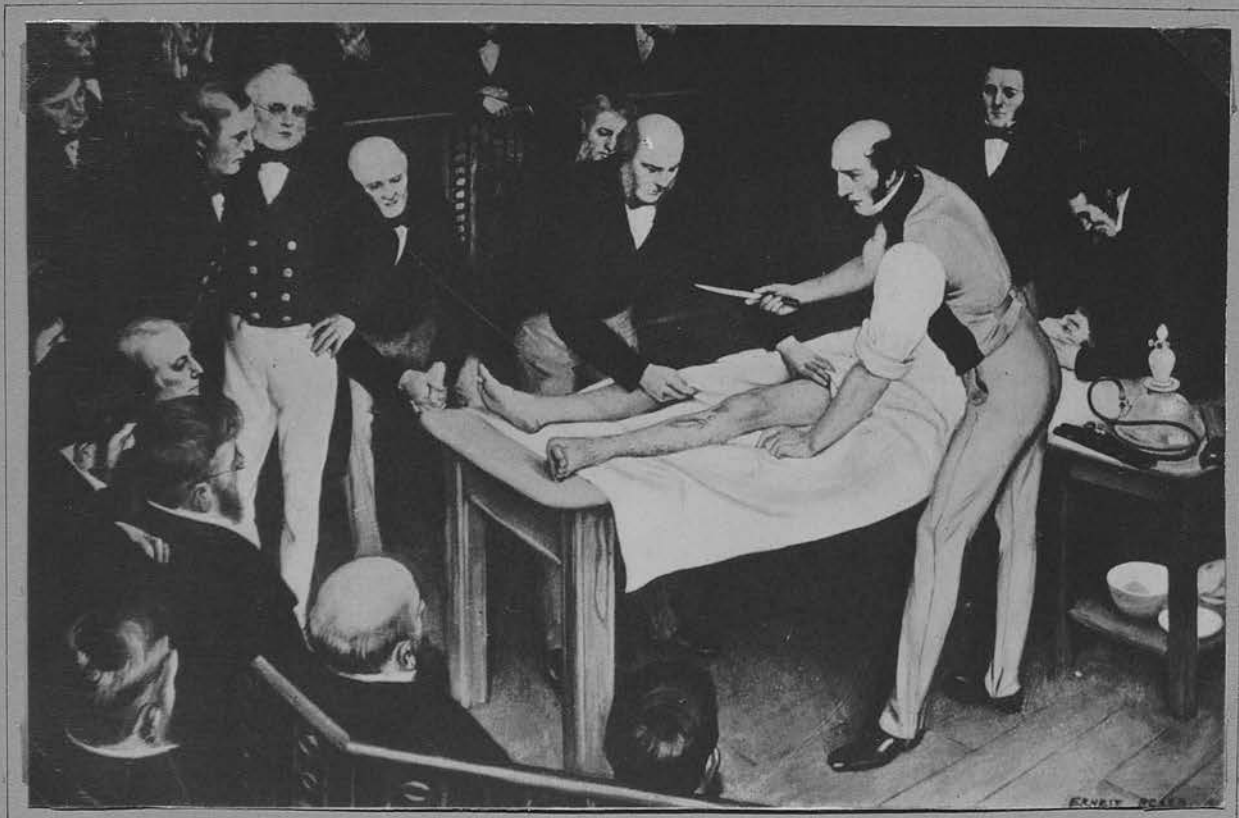
"In the midst of the room stood the operating table, a zinc-topped slab on trestles ..... and attached to the wall next the fire, ran a line of hooks from one of which was suspended the surgeon's operating coat, an old garment ..... threadbare with ten years of use and stiffened by ten years' accumulation of pus and coagulated blood, in the breast pocket of which were kept the favourite scalpels and bistouries which the theatre sister (sic) had wiped moderately /

moderately clean after the last operation ..... When the patient was ready, the surgeon turned up his sleeves and his collar and washed his hands with soap and water ..... Then he took his instruments out of his pocket .... blew his nose heartily with a bandana handkerchief and started to work. While he operated he snorted and muttered through his moustache over the wound. When he wanted to tie a cut artery the house surgeon would hand him a length of silk or whipcord, a wisp of which he always carried in his button-hole. If he dropped his scalpel on the floor, the dresser picked it up for him. He might wipe it perfunctorily before using it. He might not."

A reconstruction of an operating theatre in the 1890's was shown at the recent exhibition at the Kelvingrove Art Gallery in Glasgow to commemorate the 350th anniversary of the Royal Faculty of Physicians and Surgeons of Glasgow. It was based on a photograph showing Sir William Macewen and members of the Royal Infirmary staff in the operating theatre off ward 21, in 1892. It showed a simple operating table, a dressings sterilizer, a resin heater, douche and stand, a surgeon's stool and a squat 'Lister' stool. With regard to the surgeon's clothing, there was an operating garb of a sort in pre-Listerian days. In the "Life of Sir Robert Christison" (1885) Baron Dupuytren's appearance about 1820 was described. He "wore a dirty white apron superfluously protecting a dirtier pair of trousers, a greasy, threadbare coat, and /

and well-worn carpet shoes." Baron Larrey, the popular surgeon in Napoleon's army, wore a white apron. The illustration of an operation by Liston at University College Hospital in 1846, showed that the surgeon had been content to discard his coat and roll up his sleeves. Miles (1918) quotes a description of the first major operation performed under ether anaesthesia in this country. It was done by Liston in 1846.

Liston "takes from a long, narrow case one of the straight amputating knives of his own invention. It is evidently a favourite instrument, for on the handle are little notches showing the number of times he had used it before. His house-surgeon, Ransome, puts the saw, two or three tenacula, and the artery forceps named after the operator, on to the chair close by, and covers them with a towel, then threads a wisp of well-waxed hemp ligatures through his own button-hole. 'Ready, Mr. Ransome?' 'Yes, sir.' 'Then have him brought in.' . . . . Liston stands by, trying the edge of his knife against his thumb-nail . . . . 'Take the artery, Mr. Cadge,' cries Liston. Ransome, the house-surgeon, holds the limb! 'Now, gentlemen, time me,' says Liston to the students. The huge left hand grasps the thigh, a thrust of the long, straight knife, two or three rapid sawing movements, and the upper flap is made; under go his fingers and the flap is held back; another thrust, and the knife comes out in the angle of the upper flap; two or three more lightning-like movements, /



Robert Liston performing the first operation under ether anaesthesia in Britain at University College Hospital, London, in December, 1846.

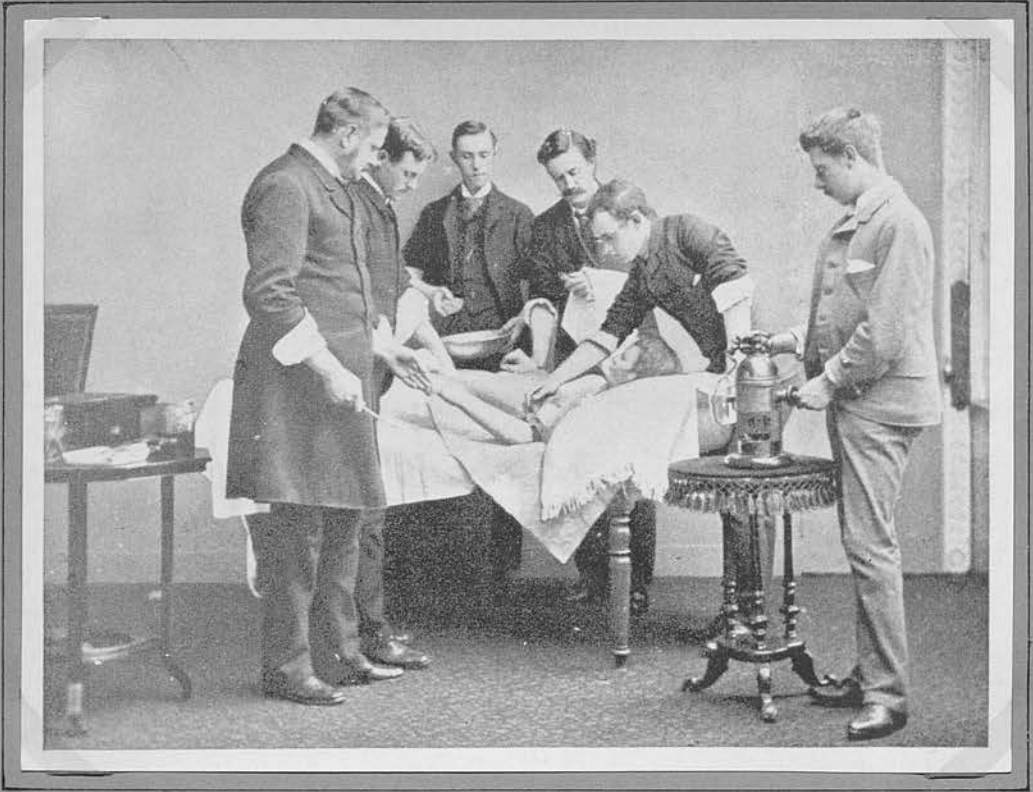
Reproduced from "Lord Lister: His Life and Doctrine" by Dr. Douglas Guthrie, published by E. & S. Livingstone, Limited, Edinburgh, 1949. By courtesy of the author and publishers.



movements, and the lower flap is cut; under goes the great thumb and holds it back also; a touch or two of the point, and the dresser, holding the saw by its end, yields it to the surgeon and takes the knife in return; half a dozen strokes, and Ransome places the limb in the sawdust ..... The femoral artery is taken up on a tenaculum and tied with two stout ligatures, and five or six more vessels with the bow forceps and single thread, a strip of wet lint put between the flaps, and the stump raised .....

After Liston's death in 1847, Professor William Ferguson became the leading operating surgeon in London. He was described as "carefully dressed in a black frock coat, wearing a black bow tie and with his feet encased in 'Bluchers' ..... With a white apron tied over his coat and with his voluminous wrist-bands turned well upwards, he was then ready to commence operations." (Turner, 1937).

Godlee in his biography of Lister (1917) gave the following description of the pre-Listerian surgeon. "When a dresser or house-surgeon entered upon his term of office, he hunted up an old coat, in the lapel of which he probably carried a wisp of ordinary whipcord for tying arteries. This garment did duty for six months or a year, and was then very properly discarded. There was no such limit, however, for the surgeons themselves. Their operating coats lasted from year to year, and eventually acquired an incrustation of filth of which the owners appeared unconscious. /



An operation at Aberdeen. The carbolic spray is on the plush-covered table. Sir Alexander Ogston is fourth from the left. From "A History of Medicine", by courtesy of Dr. Douglas Guthrie and Messrs. Nelson & Sons Ltd.

unconscious. . . . . "Even fifteen years after the introduction of the antiseptic principle, some surgeons seem to have been unaware of it. Professor J. Spence in his "Lectures on Surgery" published in 1882, gave no instructions about antiseptics in his directions for preparing for an operation. And J. E. Erichsen in "The Science and Art of Surgery" (1884) limited himself to stressing the need for pure air and clean bedding.

The early Listerian surgeons did not modify their dress, but worked with well-washed hands in a cloud of carbolic acid spray as is shown in the photograph of Sir Alexander Ogston operating in Aberdeen in the eighties. Lister himself discarded his coat, rolled up his sleeves and pinned a huckaback towel across his waistcoat to protect his clothes, not to protect the patient. He dressed in this way until he finally ceased operating.

The absolute is expressed in the term "asepsis" but this ideal is still a long way off and is probably unattainable in operating theatres. The technique which has been developed in the University of Notre Dame for raising and perpetuating sterile animals is too complicated to adapt to surgical requirements. However, with the introduction of the aseptic technique by v. Bergmann, clothing was necessarily modified. The surgical gown appears, first of all, to have been a garment designed to protect the surgeon's clothes. Later it was supposed to protect the /



An operation in the year 1900. Caps, masks and gloves are not worn. Only the surgeon and his assistants wear gowns.



the patient from the surgeon's clothes and skin organisms. It does not seem to have been modified much except that it is now not quite so long.

Sterilized caps were introduced by Mikulicz in Breslau some years before 1898, and by 1900, caps and gowns were in general use.

The rubber gloves now universally used had an interesting history (Halsted, 1913). In America and Britain, Halsted is regarded as the originator of them. In the winter of 1889 or 1890, the nurse in charge of his operating room at Johns Hopkins Hospital complained that the solutions of mercuric chloride were producing a dermatitis of her arms and hands. Halsted asked the Goodyear Rubber Company of New York to make two pairs of thin rubber gloves with gauntlets. At first the nurse and the assistant who passed the instruments wore them and found them so satisfactory, that their use gradually spread to other members of the operating team. Halsted commented on the slowness with which he and others - his clinic was much frequented by surgeons from America and abroad - came to regard the gloves as a means of protecting the patient against the organisms on the hands of the operator rather than a means of protection of the skin against the antiseptic. At first the operator wore them only when making exploratory incisions into joints. The photograph<sup>1</sup> of an operation for the removal of a breast for carcinoma, taken in Halsted's clinic in 1893, showed that the gloves were not being regularly worn by Halsted and his assistants at that time. The surgeon was wearing finger stalls on /

<sup>1</sup> This photograph was not made available.



Fig. 436.—The Use of Rubber Gloves. A photograph of Halsted's first operation in the new surgical amphitheatre at Johns Hopkins in 1904; Drs. Finney, Cushing, Young, Mitchell and Bloodgood appear in the picture. This is one of the earliest photographs showing an entire operating team wearing rubber gloves. Notice the absence of masks. (Reproduced through the courtesy of the Johns Hopkins Press, from W. G. MacCallum, *William Stewart Halsted, Surgeon*, Baltimore and London, 1930.)

on two fingers. Bloodgood, one of Halsted's house surgeons, was the first to wear gloves constantly. In his reminiscences of Halsted's clinic, Bloodgood (1931) mentioned that, before the routine use of rubber gloves, if streptococcal infection or erysipelas were introduced into the hospital, they were usually followed by streptococcal infection of clean wounds provided that one of the surgeons or nurses whose hands came in contact with the streptococcal lesion assisted at the operations within a few days. His investigation of this matter led to the routine wearing of rubber gloves not only in the operating theatre but also in the dressing of all infected cases in the wards. As a result of this innovation, suppuration in closed wounds fell from over 9% to less than 0.5%. Halsted had given up the use of silk on account of the risk of infection, and had adopted silver wire. After the introduction of the gloves, he returned to the use of silk and had no further trouble with sepsis.

On the other hand, Jayle (1928) claimed that the first surgeon to use rubber gloves was probably his teacher, Jalaguier. The skin of his hands was very sensitive to antiseptics and so he had taken to wearing rubber gloves with gauntlets about 1888. He went on to quote from a treatise of Jalaguier written in 1890: "Les mains et les bras seront désinfectés. On doit prendre garde à ne toucher aucun objet non désinfecté, à ne serrer la main de personne aussitôt après les ablutions. Au besoin, on mettrait des gants stérilisés à l'étuve pour protéger les mains purifiées jusqu'au moment d'opérer." /



Contemporary operating dress. From "A Manual of Operative Surgery" by H. J. Waring. Edinburgh, 1904. By courtesy of the Oxford University Press.



d'opérer." In 1895, Jayle made a study of peritoneal infection following laparotomy and concluded that "la main du chirurgien ou celle de ses aides, telle est la cause la plus ordinaire de toute infection chirurgicale." He went on to say that even in 1928 a few surgeons were operating without gloves and since no complications followed as a result of this, he concluded that the hospital environment was much less dangerous than formerly. At the moment one doctor in the Western Isles operates with bare hands, apparently without detriment to his patients.

Mikulicz (1897) was using cotton gloves in 1896 rather to improve his hold on sutures than with a view to preventing sepsis. They had to be changed as soon as they were wet through.

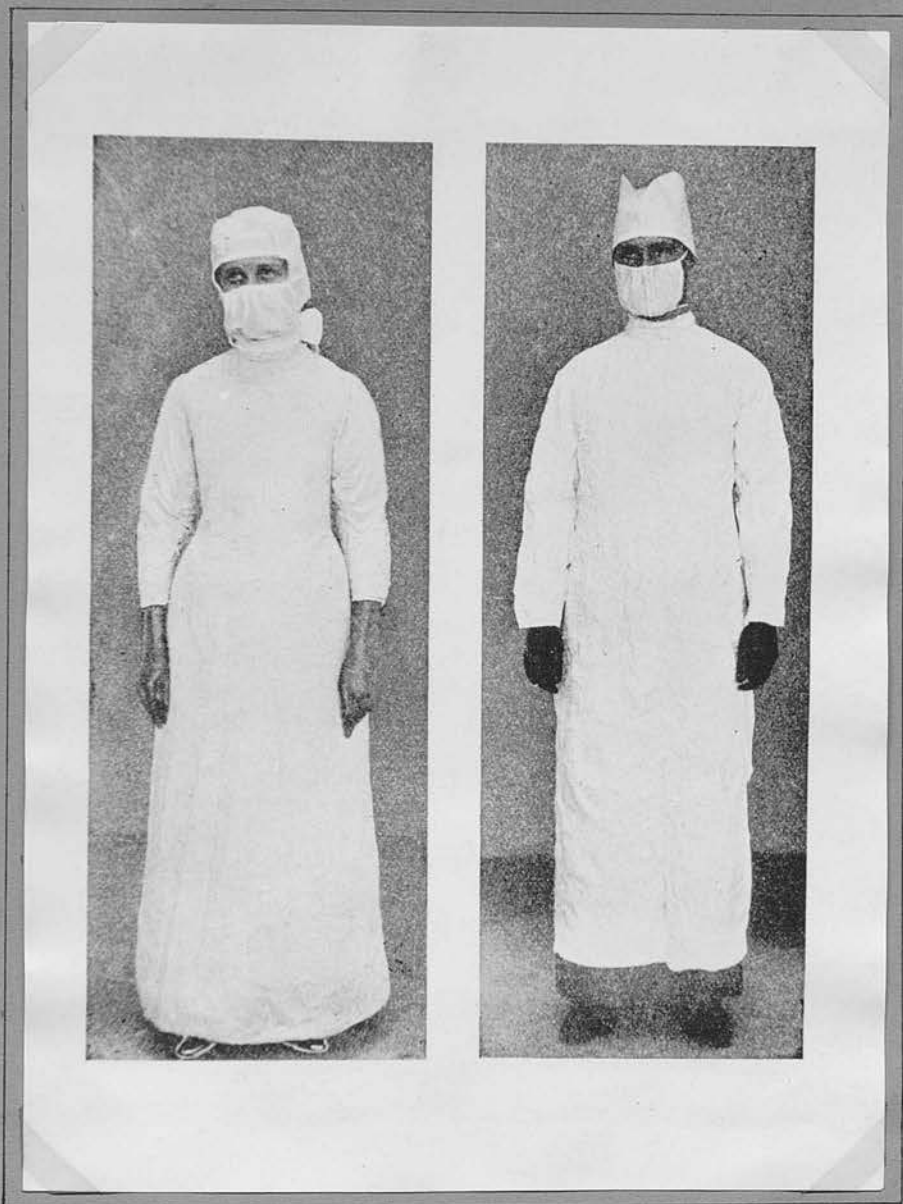
Waring (1904) recommended that the surgeon and his assistant divest themselves of shirt and collar and to replace them by a sterilized soft shirt which would be more comfortable than the stiff collar and shirt, and would absorb perspiration. At operation, they were to wear a gown sterilized by moist heat, made to fit not too tightly, to extend to the heels, to fit closely to the neck, and to fasten behind. The sleeves should extend to a little below the elbow and have an arrangement for being fastened. He went on to say that some surgeons wore rubber gloves, but that he found that they impaired the sense of touch. He recommended them only when the surgeon's hands were eczematous or when the case was suppurating.

Thomson and Miles (1904) said that many surgeons /

surgeons recommended the use of cotton gloves. The gloves were to be changed frequently because they became moist and, therefore, permeable. Kocher, they wrote, used them only when ligaturing blood vessels or inserting sutures in order to avoid contaminating the catgut or silk by the surgeon's hands. They repeated this information in the 1906 edition of their book, and in the 1909 edition, they said that "some surgeons wear rubber gloves while operating on all cases". Cotton gloves were still mentioned. They also recommended Furbringer's method of washing the hands, that is, cutting the nails right down to eliminate the sulcus, and washing in soap and water, alcohol and sublimate.

In the 1906 edition, Thomson and Miles recommended that the surgeon, his assistant, and the anaesthetist wear overalls sterilized by steam. Sterilized cotton caps were also worn by the surgeon and assistant to retain dust, scurf and drops of perspiration. Simple masks were worn to hold back drops of saliva.

These authors stated in their 1904 edition, that "the risk of infection from the air is now known to be very small so long as there is no excess of dust floating in it." All sweeping, dusting and disturbing of curtains, blinds and furniture were to be avoided before and during an operation. However, "it has been shown experimentally that the presence of spectators increases the number of organisms in the atmosphere. In teaching clinics therefore, the risk /



Operating garb in 1913. From "The Operating Room and the Patient" by R. S. Fowler. Philadelphia and London, 1913. By courtesy of Messrs. W. B. Saunders Company.

risk from air infection is greater than in private practice."

Moynihan (1905; 1906; 1914) in successive editions of his book, gave a similar picture of the evolution of operating garb and Fowler (1913) showed that, just before the first world war, the operating theatre staff were dressed as they are to-day.

Concurrently with these developments in surgical technique, hospital authorities recognized the risk of cross-infection. They improved accommodation and provided more space for each patient. Where the risk of cross-infection was obvious as in the exanthemata, they built hospitals of the pavilion type, and patients suffering from the same disease were grouped in the same ward. Even here, however, cross-infection might occur, particularly in the case of streptococcal infections, and it was only with the development of streptococcal typing by Griffith and Lancefield, that the reason for this could be known. A further advance was the isolation of patients who are likely to infect or be infected, and wards are now divided into cubicles where space and money allow. The most prevalent type of cross-infection is respiratory, and this suggests that the pathogen, whatever its source, is present in dust and air.

More recently, the risks of intimate and prolonged communal life in shelters, canteens, barracks and ships has aroused widespread interest in the organisms that may be present in the atmosphere and /



and dust.

These organisms have also become the concern of those beyond the frontiers of medicine. In the manufacture of photographic films, a dust-free atmosphere is necessary. Many drugs and surgical supplies must now be prepared and packed under sterile conditions. Sutures, for instance, in an Edinburgh factory are packed in a large, almost sterile room from which all are excluded except the two workers who, except for the face, are completely enveloped in sterile coverings. Supplies are admitted to this room only through hatches which are irradiated with ultra violet light.

Methods to secure sterility are also applied to the rearing of animals under sterile conditions. Generations of animals have been reared, it is claimed, in a sterile environment at Notre Dame University. The elaborate technique includes the wearing of a suit something like a diving suit, which completely encloses the worker, and in which he passes through an antiseptic bath to reach the sterile room in which the animals are reared.

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In this thesis, four outbreaks of Staphylococcus aureus infection are described. The first occurred in a maternity unit among the newborn; the second in a thoracic unit, and the third and fourth in a neurosurgical unit. The probable source of the outbreaks /

outbreaks is shown and methods of control are suggested.

Women, nowadays, commonly go to maternity hospitals instead of remaining at home, and, possibly, because of this new social practice, staphylococcal infection among the babies has become more prevalent. It is little more than a nuisance to the busy attendants, but the presence of *Staphylococcus aureus* in the dust and air of a ward or nursery is a constant menace to the life of the child. It will sometimes cause a fatal pneumonia or meningitis.

With the recent development of thoracic surgery and neurosurgery, the highest standard of aseptic technique is essential. In operations on the limbs and abdomen, sterile instruments, swabs, solutions, towels and hands are all that is generally necessary. Masking, capping and gowning are, no doubt, of some use; nevertheless, they do not seem to be of the first importance since those not immediately in contact with the patient, such as the anaesthetist, the nurses, the orderlies and the students are certainly inadequately covered. The loose gown, possibly taken from a hook outside the theatre and flung over the tweed suit or ward dress, does not reduce the amount of infective particles given off from the surface of the clothing by a great deal. Indeed, it appears to rub off particles from the clothing which it only partly covers, and disseminates these particles as it flaps about when the wearer moves. /

moves. In spite of this, there is no conclusive evidence to show that harm has resulted. When a wound 'goes wrong', and it seldom does, there are other possibilities than infection by dust and from the air. It is a matter which, in a general surgical theatre, seems hardly worth pursuing.

With the advance of surgery in the last ten or twenty years into the thorax and cranial cavity, however, infections do occur in these sterile regions with their susceptible tissues, which cannot be traced to a breach in the aseptic technique which has been used in general surgery for some fifty years with success. These post-operative infections are often serious and occasionally result in loss of life. But whether serious or slight, their unexpectedness makes them obvious and distresses the surgeon and all concerned. It is necessary, therefore, to review the traditional methods, and to modify them in such a way as to secure almost complete sterility in the surgical theatre. One very obvious source of infective particles in a theatre, is the clothing of all those who are not immediately engaged at the site of operation - the anaesthetist, the assistant nurses, the onlookers and all those who enter the theatre in search of something. Bacteria-carrying particles from the surface of the garments float away in the air or subside on to the floor to collect as dust and to be stirred up again as people move about. The mask, also, is often worn loosely, and it may not be worn in the periods between operations. Organisms from the nose and lips can thus be cast adrift in the air currents, /

currents, and, if they are resistant, they accumulate in the dust in spite of the most scrupulous cleansing of the floor and fixtures. *Staphylococcus aureus* is one of these resistant organisms. It is carried in the nose and a rather high proportion of nurses in hospital are carriers. It survives for a long time in dust and is the most important cause of infection in maternity, thoracic and neurosurgical units.

The work described below was done while the writer held the appointment of Lecturer in Clinical Bacteriology in the University of Edinburgh. It covers a period of three years.

In conclusion, the writer wishes to record his indebtedness to Professor J. T. Mackie, to the surgeons in charge of the Department of Neurological Surgery and the Thoracic Unit, and to the physician in charge of the Maternity Unit for generously providing the opportunities to collect the material for this thesis.



II. METHODS.

II. METHODS.1. AIR SAMPLERS.

The requirements for a satisfactory air sampling device have been given by various authorities as follows. Firstly, it should be reasonably efficient in collecting different sizes of bacteria-carrying particles. This efficiency may, however, be permitted to vary depending on the nature of the work to be done, and some falling off in this respect can be allowed if it is compensated by certain advantages. The device should be relatively simple in structure and easily manipulated. Portability is a point of considerable importance in field work, and, if the sampler can conveniently be carried by one person, it becomes a much more useful instrument than an unwieldy apparatus even if more efficient. It must sample the air fairly rapidly; one cubic foot a minute is a minimum below which it is seldom useful to go. Finally, it should be free from the risk of extraneous contamination.

Bourdillon and Lidwell (1948) have divided the numerous types of sampler that have appeared in the past eighty years into two groups, namely, broth samplers and agar samplers. Both terms must be stretched a little to include all types of air sampler. The former collect the bacterial contents of the air immediately /

immediately or ultimately into broth or other fluid. They break up or "atomize" bacterial clusters and give a total count of the individual organisms. The agar samplers, on the other hand, collect the bacterial clusters from a moving air stream by impact or impingement. The clusters do not break up and only one or two of the organisms in a cluster develop into colonies. The counts from agar samplers are, therefore, counts of bacterial clusters.

Broth samplers may collect the bacterial flora directly into a fluid medium. Pasteur (1922)\* *A little modified in* used sterile flasks containing a little broth which had been boiled before sealing the flasks so as to displace most of the air. A set of these flasks was opened in the atmosphere to be examined, and the number of flasks which became infected after opening indicated the degree of impurity of the air. Tyndall (1876) put broth in a set of test tubes and estimated the amount of floating matter in the air from the number of test tubes in which the broth had become contaminated. Miquel (1888) in his studies of the air of Paris used first the Pasteur flasks and then a flacon barboteur or bubbler. Straus and Wurtz (1888) bubbled the air sample through gelatin, a method proposed before, and used by von Sehlen in researches on the air of marshy regions in Italy. This apparatus sampled 50 litres in 15 minutes and was said to be efficient. But the gelatin sometimes solidified in cold weather. Rettger's aeroscope was a bubbler containing /

containing saline, while Oker-Blom (1912) used water. McConnell and Thomas (1925) passed the air samples through Japanese silk submerged in water, but it was difficult to cultivate the organisms thus collected. Wheeler and others (1941) introduced a bead bubbler which was an Erlenmeyer suction flask containing broth and beads into which the end of a bubbling tube was sunk. Three to nine litres of air could be sampled in one minute. Schneiter and others (1945) used it later and found it efficient. Moulton, Puck and Lemon's (1943) somewhat elaborate atomizing device is very efficient and will sample  $\frac{3}{4}$  cubic foot a minute.

A second subgroup of the broth samplers are those which collect the organisms on to a dry filter or viscous substance which, afterwards, has to be washed off, or dissolved in broth or in the final solid medium. Pasteur (1922) aspirated air through plugs of gun cotton which he then dissolved in a mixture of alcohol and ether. He examined the sediment microscopically and found spores of moulds. He also put the plugs into broth and noted the development of bacteria and moulds. William (Oesterle, 1935) used a narrow spiral tube or a succession of U-tubes lined with laevulose which was washed out after sampling. Freudenreich and Miquel (Frankland, 1887) aspirated a measured quantity of air through sterilized glass wool which was then shaken with water of which aliquot parts were pipetted into broth. Frankland (1887) used powdered sugar or powdered glass or glass wool coated with sugar which, after sampling, was shaken up with gelatin and poured into a flask. He was able to sample /



sample a litre of air a minute by this method. Es-march (1886) used sugar or glass powder which was shaken up with gelatin. Petri (1888) filtered the air samples through cotton wool, or asbestos, or gypsum, or fine sand. Ficker (1896) employed, in addition to these, powdered gelatin in a glass tube with an "Ausbauchung" or dilatation which increased its efficiency. Hahn (1909) used sodium sulphate or grains of rock crystal, and Browne (1917) combined a filter tube containing sand, with a diluting tube in order to avoid extraneous contamination. Oesterle (1935 and 1938) used a mixture of salts, and Hettche and Schwab (1940) made their filters with glass beads and glycerine, or Raschig's rings and glycerine, or sintered glass and glycerine.

Agar samplers were also introduced in considerable numbers. Koch (1912) was the first to use a solid medium for collecting the organisms of the air. He exposed plates of gelatin to the air for a certain period and counted the colonies which appeared after incubation. This method is so simple that it is still used in conjunction with other methods. It can detect particles that are too heavy to remain airborne for any length of time and that settle quickly. Hesse (1884) used a glass tube 70 cm. long and 3.5 cm. in diameter lined with a layer of gelatin, through which he drew a measured quantity of air. The tube was so narrow and so long, and the air was drawn through so slowly that the organisms had a chance to sediment; even /

even moulds came down in the distal part of the tube. Carnelley and others (1887) obtained interesting results with it in the schools and houses of Dundee and Perth, and called Hesse's method "a most convenient and elegant process". The tube was, however, difficult to prepare, and the colonies were not accessible to examination and picking. Above all, it would only take one litre of air in three minutes.

The impinging principle was first used by Winslow (1908) who drew air into two flasks with a layer of nutrient agar at the bottom. The bottle device of Schneider and others (1944) was somewhat similar. It was an eight ounce bottle with the medium on one of the broad sides. The air was aspirated from the bottom of the bottle and entered through a tube with a fan-shaped opening, in the neck. The air passed over the surface of the agar and the organisms were deposited on it.

The first of the more recent and more precise agar samplers was Wells' ingenious air centrifuge which he described as follows. "The rapid revolution of a glass cylinder about its vertical axis causes a current of air to enter through a central axial tube and to escape along a thin layer of nutrient medium supported on the walls of the cylinder. Particles suspended in the air are deposited on the medium. Colonies develop where the individual bacteria have been precipitated and can be counted with the naked eye." It has certain advantages but requires care in preparation and in counting.

Hollaender /

Hollaender and Della Valle (1939) introduced a sampler which was essentially a funnel inverted over a Petri dish. This simple apparatus gave the best results when the air flow was about one cubic foot a minute. When tested in series, the authors claimed that it collected 80% of the bacteria in the air. Berry (1941) applied an electrostatic device to the funnel sampler. It was more efficient and when it followed the funnel sampler in series, then the latter was found to collect not more than 50% of the bacterial clusters. The electrostatic principle was also applied to air sampling by Luckiesh and others (1946).

The slit sampler of Bourdillon, Lidwell and Thomas (1941) was inspired by the jet dust counter or konimeter of Owens who introduced an instrument in which dust particles were deposited on a glass plate from a jet of air moving at high velocity through a narrow slit. Bourdillon's sampler is a small box containing a turntable to carry a Petri dish over which is arranged a radial slit of certain dimensions through which air is aspirated so that the particulate contents impinge on the medium in the revolving plate. Such an instrument can be at least 95% efficient. A small model will sample one cubic foot of air a minute, and a large model 23 cubic feet.

Elliott (1941) adapted the cloud chamber method of Wilson to bacteriological air analysis. He drew the air to be sampled through water vapour. By cooling the saturated air, all particles were precipitated by the deposition of water upon them. This method was too cumbersome, and has not been developed. DuBuy /

DuBuy and Crisp (1944) introduced a sieve device. It was a brass plate with 300 holes each less than a millimetre in diameter, through which air was aspirated on to a plate of medium behind. It became less efficient when sampling more than forty litres, that is just less than a cubic foot and a half, a minute.

Lastly, there is the cascade method of Miles (1948) which is a combination of impingement and atomization. After the plate is exposed in a slit sampler, a cascade of molten medium is poured over it and some of the clusters are, in this way, broken up.

Broth samplers give a count somewhat higher than that yielded by agar samplers. From their experiments DuBuy and Hollaender conclude "that the difference in bacterial counts between the atomizing and impinging devices is due mainly to the fact that bacterial clusters are broken up in the atomizing devices, giving rise to higher bacterial counts, and that, on the basis of the dye experiments, these counts are only to a small degree due to a somewhat more efficient manner of air sampling by the liquid devices."

On the other hand there are certain disadvantages associated with the broth samplers. Those that sample directly into broth are inconvenient to carry about as the contents may be spilled. They are not suited to a series of examinations, say sixty, following one another at intervals of a minute, as they /



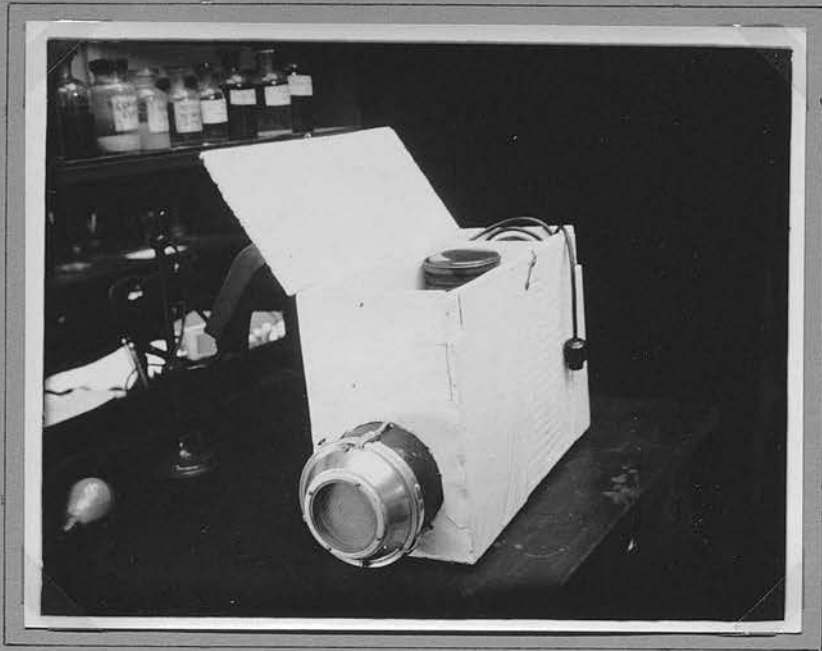
they must be sterilized and recharged after each examination. Frothing occurs with the passage of the larger volumes of air, and neither the dry filter nor the bubbler are capable of sampling large quantities of air in a short time. Their usual capacity is several litres a minute. If the filtering material is in powder form, some of it is carried away in the stream of air, or else it is caked by the moisture of the atmosphere. Soluble filters cloud the final solid medium, and the grains of the insoluble filters can easily be confused with the colonies developing in the solid medium.

Of the impinging devices, the Bourdillon slit sampler is one of the most reliable. The conditions for exact sampling have been studied, the capabilities of the machine have been exploited and there is now a model which will sample for twelve hours without attention (Bourdillon and others, 1948). It is portable but somewhat unwieldy, and for field work Duguid's (1949) modification of the DuBuy and Crisp air sampler has proved satisfactory and convenient.

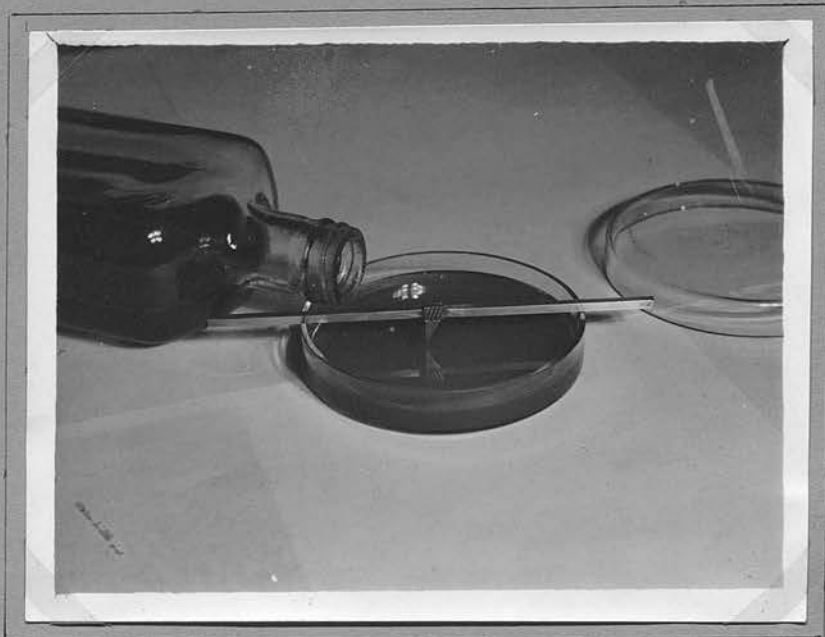
Reviews of the capacities and merits of the more useful samplers are to be found in the following authors. Pasteur (1922)\*, Miquel (1888) and Petri (1888) gave full accounts of the early work. Ficker (1896), Oesterle (1935) and Hettche and Schwab (1940) described and compared the broth filters in use. Of recent /

recent reviews, those of Bourdillon, Lidwell and Thomas (1941) and DuBuy and Hollaender (1945) are comprehensive.

The field work in this investigation was done with a modified DuBuy and Crisp sampler. The apparatus was simply an electrolux vacuum cleaner. The end to which the cleaning attachments are affixed can be removed, and it is fastened to the body of the cleaner by three clips. A circular opening 10 cm. in diameter was cut in this dome-shaped end and was replaced by a perspex sieve plate pierced by 258 perforations 0.796 mm. in diameter. The sieve plate itself was 8.5 cm. across, that is, just under the diameter of the bottom half of a "4 inch" Petri dish. It was surrounded by a ditch 10 mm. deep, on the inside aspect. There were three stops 3 mm. high in the ditch to support the rim of the Petri dish which was held in position by a stout elastic band fixed at both ends to hooks and with a rubber bung in the middle to give added support to the dish. The medium in the Petri dish was poured to such a height that the surface of the medium was 2 mm. away from the back of the sieve plate, that is, 9 mm. below the rim of the dish. When the vacuum motor was turned on, air was drawn through the perforations in the sieve plate, some of its contents impinged on the surface of the medium, the air current passed over the edge of the Petri dish between the stops supporting it, and so backwards and out of the machine. The air currents /



The sieve sampler.



"Pouring the plate" for the sieve sampler.

currents behind the sieve plate have not been studied as it would be difficult if not impossible to do so; but they must be confused, and this is, possibly, one of the causes of reduced efficiency.

The body of this apparatus was loosely packed with wool and corrugated paper in a box in order to reduce the noise of the motor. Some of this packing had to be removed as the motor was getting overheated and it was designed to run in free air. The noise, however, was not great, and neither staff nor patients complained about it.

Numerous tests were carried out to determine its efficiency (Duguid, 1949) in comparison with the Bourdillon slit sampler. Results varied widely from over 100% to as low as 33%. It was eventually decided to regard it as 50% efficient in terms of the Bourdillon slit sampler. This rather low efficiency was, no doubt, due in part to the large quantity of air sampled in a minute, namely 19 cubic feet. DuBuy and Crisp (1944) found that air velocities at a rate of 40 litres or higher caused a decrease of the total bacterial count due to a relative decrease in the number of marginal colonies. They also found that there was a greater recovery of organisms with an increase in the number of holes in the sieve plate from 150 to 300. In practice, however, this sampler has always given consistent results. When there was movement or other disturbance in the room, the sampler always reflected this and the results were comparable to the degree of disturbance.

It was found that the plate - medium distance should /



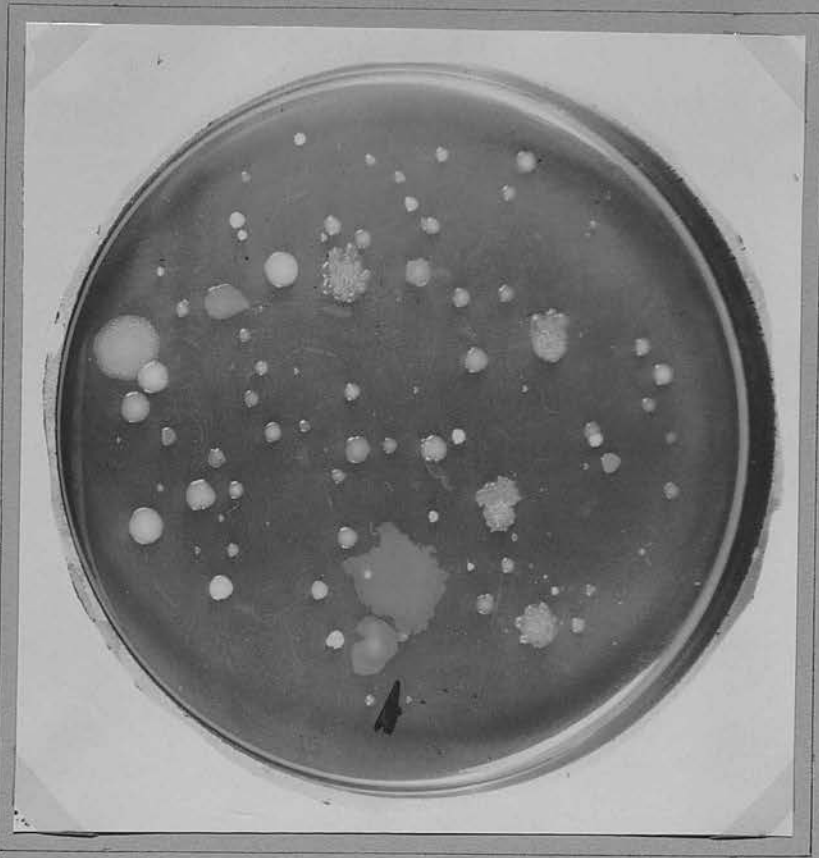
should be 2 mm. or just over. If the surface of the medium were nearer, then there was a reduction in the rate of flow of the air. If the medium were 3 to 4 mm. away from the back of the plate, then the number of the organisms recovered from the air dropped.

The medium was, therefore, poured so that its surface was just under 2 mm. from the back of the sieve plate, that is, between 8 and 9 mm. from the rim of the Petri dish. The necessary drying in the incubator reduced the volume of the medium so that when the plate came to be used, the surface of the medium was 2 mm. or a little more from the back of the sieve plate. Petri dishes of flint glass were used. The lower parts have an internal diameter of  $3\frac{1}{2}$  inches, and the bottom is flat. If the bottom is concave inside, the medium may slip, if convex, then the medium in the middle of the plate dries or tears. A level part of the bench was chosen with the aid of a spirit level. A rod with a square cross-section so that it would rest securely on the rim of the Petri dish, was furnished with a downward-pointing indicator 9 mm. long. This rod was placed across the Petri dish and the hot medium was poured into the dish, until it reached the point of the indicator. The surface of the medium would be now, with the plate in position in the sampler, just within 2 mm. of the back of the sieve plate. It had to be used within a few days, otherwise the medium shrank too much and moulds began to appear. /

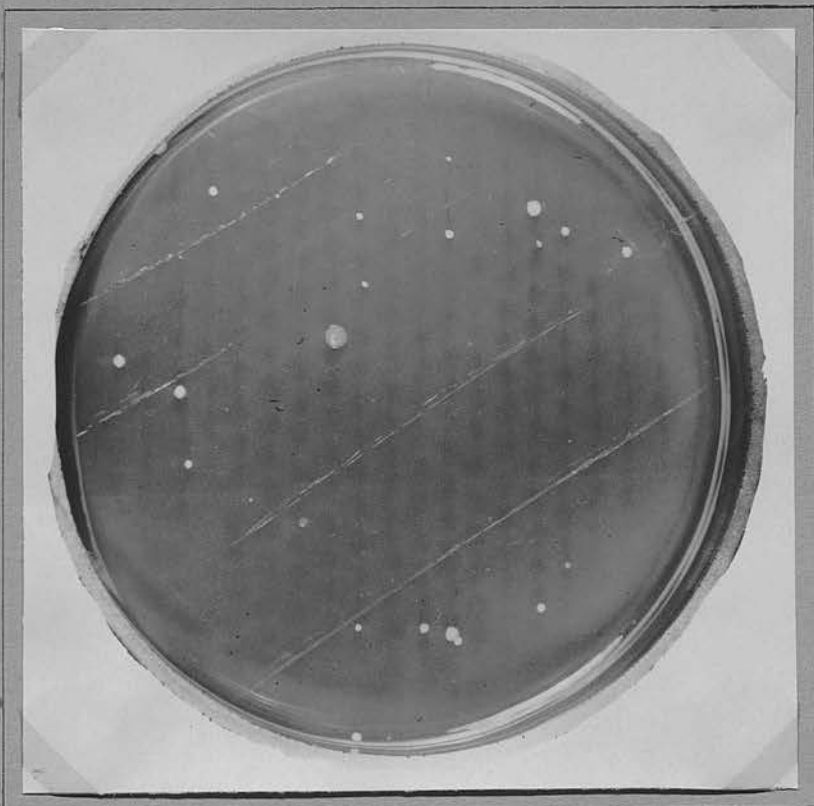
appear.

The sieve sampler will draw through 19 cubic feet of air a minute, after it has been running for a few minutes. The sampler was recently tested again after two years' use and was still sampling the same quantity of air in a minute. (1). Generally speaking, this is a suitable volume in a large, well-aired room. More will cause too great a deposition of organisms. In very clean air such as is found in a room that has been standing empty and closed overnight, the plates can be exposed for five to ten minutes. Such a lengthy exposure to a brisk current of air has the effect of drying the medium, and there is an increase of the sieve plate - medium distance to  $2\frac{1}{2}$  mm. This does not, however, affect the efficiency to a degree that can be detected. The sieve plate has been swabbed repeatedly after sampling. There is no evidence to show that it is contaminated during sampling.

After exposure, plates were incubated at 37°C for 18 to 24 hours. When the experiment was a long one covering a period of, for example, six hours, the plates were placed in the incubator at the end of the experiment so that the period of incubation was the same for all. The medium in the plates was then scored by parallel cuts with a razor blade into convenient segments so that colonies might be more easily counted. On a plate from a sieve sampler, the colonies are mostly aggregated in the depressions in /



A Petri dish which has been exposed in the sieve sampler, showing a satisfactory number of colonies for counting.



A Petri dish scored for counting. The honeycombed appearance is caused by the currents of air which are drawn through the sieve plate of the sampler.

in the medium opposite the holes in the sieve plate. In heavily inoculated plates, colonies are often clustered together and it may be impossible to identify all of them with certainty. Probably more exact counts are obtained where some of the depressions in the medium have no colonies while others have only one to three. The operator attempts to arrange the sampling period to achieve this. If two or more colonies overlap, they are counted separately. To begin with, the plate microscope magnifying twenty times was used, since it was believed to be necessary for the identification of tiny colonies. Later, however, the plate was held at an angle to a strong light which was screened from the eyes - a pluslite lamp does very well - and it was found that all the colonies could be counted without difficulty and much more rapidly than with the plate microscope. Even very small colonies could readily be detected provided that the surface of the medium was quite smooth. Tiny depressions such as might be left after the bursting of bubbles, caught the light and resembled minute colonies. If the medium were opaque, if, for instance, it contained 5% of blood, the counting was rendered still more simple since the reddish brown background contrasted with the white and yellow colonies, and cut off the transmitted light. In cases of doubt or where, as occasionally happened, numerous minute colonies of diphtheroids appeared, a watchmaker's lens was used to confirm the presence of colonies and to distinguish /



distinguish between them and particles of dust. In this way, counting was much easier and more expeditious than with the plate microscope. With the latter a count would take five minutes even when comparatively few colonies were present. The time was expended largely in pushing the plate from side to side on the stage and in scrutinizing the whole surface with a high power lens. With high magnifications one tended to lose one's bearings as the whole plate was not visible at one time. In order to find out if the enumeration was as complete with the naked eye as with the plate microscope, twelve plates were counted with the latter and then recounted with the naked eye occasionally aided by the watchmaker's lens (2). There were slight differences in the counts, but they were not significant. The naked eye count of the colonies took only as long as would be required to count aloud to the total number, whereas the count with the plate microscope required four or five minutes for even a moderate number of colonies.

Some of the experiments were done in the laboratory and for these a Bourdillon slit sampler was used. This was a small box to which access was gained by an airtight door in the side. A shaft carrying a turntable to hold a Petri dish, passed through the bottom of the box, and was actuated by a small electric motor. A rod passed through the top of the box over the centre of the turntable. It was furnished with a disk at the lower end and an indicator at the upper end, which lay against a scale and showed /



A side of the sampling cabinet and the Bourdillon  
slit sampler.

showed the position of the surface of the medium in relation to the slit. Laterally, but still over the turntable, was a short tube in a sleeve in the top of the box. The lower end of this tube inside the box, was occluded except for a slit 27 mm. long and 0.5 mm. broad, lying radially in relation to the turntable. The top of the tube was connected with the interior of the sampling cabinet by a gently curving glass tube all the joints being sealed by adhesive tape and plasticine. A water manometer was mounted at the side of the box to measure the negative pressure inside when the apparatus was in use. Air was sucked from the cabinet through the tube and slit into the box of the sampler and so out, by means of an electric vacuum cleaner. The tube from the sampler to the vacuum cleaner was branched and on the branch was a pinchcock to regulate the amount of air passing through the sampler.

The cabinet (see illustn.) in which the subjects of the observations were placed, had a capacity of 100 cubic feet, that is, it was 7 feet high by 3 feet 9 inches deep and 3 feet 9 inches broad. The frame of the structure was on the outside so that the interior might be as smooth as possible. The junctions of the walls with each other and with the ceiling and floor were accurate, and a strip of wood was fixed around the doorway so that the door might fit as tightly as possible.

The tube from the sampler passed a little

way /



way into the cabinet and the opening was protected by a small canopy from the dust that might drop directly into it. The cabinet was ventilated by a chimney which passed through the ceiling and out of a neighbouring window. It was carried well above roof level in order to avoid the dust from the ground and roof. The lower end of the pipe was lightly stuffed with cotton wool so that there would be no draught in the cabinet. There was a small window in the ceiling to give light, and another in the door, used principally to observe the subject of the experiment within.

The interior was soaked in spindle oil as was also the floor which was of concrete. This soaking was repeated from time to time, and the walls of board were finally impregnated with oil. The glass tube and slit were cleaned occasionally. It was not necessary to clean them after each experiment.

The cabinet was erected in a little-frequented room. The room was well aired and the floor for some distance around the cabinet was oiled to lay such dust as there might be. The door of the cabinet was kept locked so that adventitious dust could not be added during the absence of the operator.

A box for sampling respiratory acts under various conditions, was made. It was 1 foot by 2 feet by 4 feet. It stood on end and had a rectangular aperture above, 10 inches by 12 inches, and a circular aperture 4 inches in diameter on the opposite side at the bottom, for the sieve plate of the /



the modified DuBuy and Crisp sampler. The opening had a flange so that the sieve plate might fit snugly. This box was oiled inside and could be readily ventilated by taking it into the fresh air.

THE BACTERIOLOGICAL EXAMINATION OF  
DUST.

A common method employed for the collection of dust is to use a throat swab moistened in saline or broth. I have seldom isolated pathogens in this way. The swab rapidly loses its moisture to the surface which is being sampled and is soon covered with a dry layer of dust and fails to pick up more. The area of floor or wall which can be examined with a swab is limited.

A sterilized test tube brush may also be used for the collection of dust. These methods are best suited to the examination of small objects such as taps, switches, tide marks in wash hand basins and the like.

A satisfactory way of examining dust is to clap an open Petri dish containing medium over the area to be examined. The clapping stirs up the dust some of which adheres to the tacky surface of the medium. This method can be used for floors and blankets.

Or one may use a holder to carry an open Petri dish upside down and clear of the floor. A brass tube 3 feet long opens beneath the holder and beside the Petri dish. A rubber bulb is fixed to the other end of the tube and held in the hand. The holder is placed on the floor, for instance, under a bed. The bulb is squeezed and puffs of air blow dust /

dust from the floor on to the surface of the medium in the Petri dish. This method is being used at the Knightswood Fever Hospital in Glasgow.

A third method is to sterilize a long piece of heavy cloth and to beat the objects to be sampled with it. If the cloth is heavy enough, it can be slapped against walls and floors, and will "lick" around pieces of furniture and under sinks and pipes. In the meantime, the air is sampled with the sieve or slit sampler. This is a crude method and does not indicate the locality of pathogens in a room. It is, however, a searching procedure and is suitable when the objects to be sampled are heavy or fixed to the floor.

Blankets, pillows, the cloth of screens and similar things, are conveniently sampled by beating or shaking them in the cabinet described above, and sampling the air.

PRECAUTIONS TO BE TAKEN BY THE  
OBSERVER.

The observer should take every precaution not to add organisms to the air which he is examining. Clothes are a prolific source of microorganisms, and the operator will contaminate the air in the neighbourhood of the sampler to which he is attending. The sieve sampler used in most of these experiments, requires /

requires the constant presence of the operator. A surgical cap, mask and dustproof garment are worn. This last is a boiler suit of twilled cotton fastened with a zip fastener in front, tied firmly to the wrists with tapes, and having a padded neck to occlude as far as possible the opening in that part of the garment. Cloth boots are sewn on to the trouser legs. Such a suit will reduce the contamination from the wearer by 90% (Duguid and Wallace, 1948).

The operator should always move quietly and slowly. He should not be a carrier of the organism for which he is looking.

The present writer did not carry Staphylo-  
:coccus aureus.



## 2. THE IDENTIFICATION OF PATHOGENIC STAPHYLOCOCCI.

Staphylococci are commensal on the skin and mucous membranes of man. They are, consequently, abundant in his environment, in the air, and the dust and on anything accessible to these, such as food, milk, drugs for injection, wounds and sinuses, and pathological specimens for examination. How are pathogenic or potentially pathogenic strains to be distinguished from non-pathogenic varieties? Many criteria have been used. One of these, namely the source of the organism, cannot be applied to the staphylococci derived from air or dust or from the healthy carrier.

### Chromogenesis.

On a solid medium the first criterion is the appearance of the colony and its colour. Rosenbach in 1884 made a thorough study of the organism and named the pathogenic variety Staphylococcus pyogenes aureus. The colony was golden in colour, of medium size, moist, smooth, and butyrous in consistency. Winslow and others (1920) studied chromogenesis on nutrient agar incubating for fourteen days at 20° C. Portions of the growth were spread on white paper (Whatman No. 2) and the hue and tint were compared with a colour standard. Duran-Reynals (1933) found that the invasive strains of staphylococci were golden, /

golden, while 82% of the non-invasive staphylococci were white. Pinner and Voldrich (1932) and Cruickshank (1937) confirmed that the golden pigment was closely associated with pathogenicity.

However, colour should be noted as soon as possible (Dudgeon, 1908) as some strains lose their colour on prolonged cultivation (Neumann, 1897; Noguchi, 1911; Baerthlein, 1918; Breinl and Fischer, 1923; Bigger, Boland and O'Meara, 1927). Pinner and Voldrich (1932) and Hoffstadt and Youmans (1932) described the dissociation of Staphylococcus aureus into strains of varying degrees of pigmentation including the white "porcelain" variety. The variants were non-pathogenic, but Pinner and Voldrich were able to restore albus strains to the virulent aureus strains by growing on media containing homologous serum. So also was Geisse (1914) who enclosed pathogenic Staphylococcus albus in collodion sacs and inserted them into the peritoneal cavities of guinea pigs. He recovered highly virulent Staphylococcus aureus.

Mellon and Caldwell (1926) concluded from serological studies that aureus and albus staphylococci have a common ancestor. Indeed, Burnet (1930) demonstrated the identity of white variants with the aureus parent strain.

In view of reports of this sort and evidence accumulated by themselves, some authors thought that albus strains must be regarded as, at least, potentially pathogenic (Burnet, 1930; Bigger, 1933; Nélis, 1934), and some said that the pigment was not related to the pathogenicity of the organism (Panton et al., 1931; /

1931; Wright, 1936).

There are often to be found in the air and dust organisms that produce lemon yellow colonies; these are saprophytes. Sometimes it is rather difficult to decide whether a colony is golden yellow or not. There is a gradation from bright gold appearing at 18 hours to pale gold at 48 hours. The colour develops well on serum media, for instance, Loeffler's medium, or on potato, or on a medium containing 33% of milk (Christie and Keogh, 1940). The optimum temperature for pigment production is 22° C. Alternatively, the culture can be left at room temperature for 24 to 48 hours after incubation at 37° C. when the pigment will develop further. Crystal violet agar (Chapman and Berens, 1935) may be used. It should be incubated for 36 to 48 hours. The Staphylococcus aureus colonies are orange or deep violet, or sometimes orange surrounded by a fringe of violet. Non-pathogenic strains are either white or pale violet. The colour is, however, not characteristic after prolonged incubation or storage. In any case a heavy inoculum is required. Brom-thymol agar (Chapman et al., 1937) yields a luxuriant growth of Staphylococcus aureus in 48 hours. Other staphylococci fail to grow. Phenol red mannitol agar is useful (Chapman et al., 1938). The colonies of Staphylococcus aureus are surrounded by a yellow zone. Ludlam's (1949) medium contains lithium chloride and tellurite. It is selective and the colonies of Staphylococcus aureus are slate /

slate blue in colour.

### Haemolysis.

Kraus and Clairmont (1900) when examining the haemolytic power of *Cl. tetani* and other organisms, noticed that staphylococci haemolysed rabbit red blood cells. Eijkman (1901) used blood agar to detect haemolysis, and Neisser and Wechsberg (1901) found that haemolysis was a constant feature of Staphylococcus pyogenes aureus and they showed that the filtrates of broth cultures contained haemolytic substances. Kutscher and Konrich (1904) attempted to differentiate pathogenic from saprophytic staphylococci by haemolysis and agglutination, and they recommended the former. Daranyi (1926) on this subject, said that the test for haemolysis was the oldest and recorded that Jochmann had used a medium containing one third of blood and two thirds of agar, as it was believed that only pus-producing staphylococci were haemolytic (Noguchi, 1911). With less blood it was found that non-pathogenic staphylococci were also haemolytic (Axenfeld, 1908). Gross (1927) looked for a method or methods to differentiate quickly pathogenic from non-pathogenic staphylococci. Haemolysis was most conveniently and quickly detected on a blood plate. Rabbit blood was lysed most easily, while that of man and horse were more resistant. Moreover, staphylococci which could not lyse human or equine red blood cells, might, nevertheless, be pathogenic. /



pathogenic. Dolman (1932) found that rabbit blood gave the most consistent results. Forssman (1933) confirmed that horse red blood cells were not very sensitive to the alpha haemotoxin of staphylococci. Daranyi agreed that rabbit blood was more sensitive than human or horse blood and suggested that the optimum percentage was 1% since with this he recovered the highest number of haemolytic staphylococci from the air of a steam bath. He also obtained haemolysis with all of 30 pathogenic strains. On the other hand, 20% to 60% of staphylococci in the environment and 30% to 70% of the staphylococci from the skin of fifteen healthy men were haemolytic. Koch (1908) found 10% and Geisse (1914) 5% of haemolytic staphylococci in the environment, using other types of blood and larger quantities of it. Duran-Reynals (1933) recorded that the haemolytic titre for rabbit red blood cells was proportional to the toxicity for the rabbit.

Burnet (1929, 1930) thought that the haemolysis, skin necrosis and death were produced by the same toxin. He recommended an atmosphere of 10% to 20% of carbon dioxide to obtain marked haemolysis. Dudgeon and Goadby (1930) believed that the loss of haemolytic power was related to the loss of pigment. However, these two are independent and the pigment is the more stable (Chapman et al., 1938). Chapman and others (1934) reviewing a series of 4081 strains, found that 67.5% of aureus and 10.8% of albus strains were haemolytic. They did not include narrow zone haemolysis, /

haemolysis, whereas Thompson and Khorazo (1937) did do so (v. infra). Chapman concluded that haemolysis was a useful supplementary test in the case of possible aureus strains.

Cruickshank (1937) found alpha staphylolysin in 38 out of 40 virulent strains of staphylococci and in none of the saprophytic strains. Plastridge and others (1936) showed that there was a relationship between haemolysis of cow's blood and the invasiveness of the staphylococci in bovine mastitis. Hallman (1937) reported that 91.4% of 480 strains of staphylococci from the nasal mucous membrane haemolysed human blood agar. 67% of these strains were potential pathogens. Thompson and Khorazo (1937) and McFarlan (1938) obtained similar results. Julianelle (1922), on the other hand, studied haemolysis but did not associate it with pathogenicity. Some pathogenic strains did not produce haemotoxin. However, the majority of observers have correlated these two properties. In order to detect the haemolysis, the tests should be done in a tube; the haemolysis does not always appear on a blood plate. Caution must be used in making deductions from this test.

With regard to the correlation of haemolysis with properties other than pathogenicity, Duran-Reynals (1933) showed that albus variants differed from parent strains in haemolysis production and the liquefaction of gelatin. Christie and Keogh (1940) found that the great majority of coagulase positive strains produced /

produced alpha or beta haemolysis on sheep blood agar, whereas no coagulase negative strains of human origin did so. Cowan (1938) and Gillespie and others (1939) found complete correlation between the production of alpha haemolysis and coagulase production.

#### The Fermentation of Carbohydrates.

The capacity to ferment carbohydrates persists longer than the haemolytic power (Dudgeon and Goadby, 1930) and the coagulating property (Pinner and Voldrich, 1932). Hallman (1937) stated that many of the strains had to be incubated for from 2 to 7 days before fermentation occurred. Thomson and Khorazo (1937) incubated for three days and Julianelle (1937) apparently incubated for 7 days before reading. Dudgeon (1908) found that mannitol fermentation was useful. Mannitol was fermented by

89% of orange strains (Winslow et al., 1920)

88% of 50 pyogenic strains (Thompson, 1932)

78% of 60 orange strains (Thompson and Khor-  
:azo, 1937)

100% of 40 coagulase positive strains  
(Cruickshank, 1937)

91% of 487 coagulase positive strains  
(Hallman, 1937)

95% of 102 pathogenic strains (Hallman, 1937)

100% of 39 necrotoxic strains (Chapman et al.,  
1938)

In the non-pathogenic group mannitol was fermented by

51% of white cocci (Winslow et al., 1920)

28% /

28% of skin cocci (Thompson, 1932)

18% of 39 white staphylococci (Thompson and Khorazo, 1935)

55% of 20 non-coagulating variants (Cruickshank, 1937)

42% of 33 non necrototoxic strains (Chapman et al., 1938)

11% of 375 non-coagulating strains (Chapman et al., 1938)

Salm (1945) found that sorbite was useful as only a quarter of 125 white strains fermented this sugar. Christie and Keogh (1940) picked out from a variety of carbohydrates mannitol, trehalose and mannose, and stated that these had a limited value in distinguishing coagulase positive and coagulase negative strains of Staphylococcus aureus. The use of three sugars reduced the possibility of error. Mannitol was the most useful single sugar and a strain fermenting this in 48 hours was almost always coagulase positive. Mannose was of little value and might be omitted. Cruickshank (1937) however, pointed out that fermentation of lactose and mannitol was not confined to the pathogenic strains; while Gordon (1903) believed that the sugars had no value in classification of staphylococci.

I examined the fermentative reactions of 175 strains of staphylococci isolated from the air and dust of a maternity unit (3). The carbohydrates used were glucose, lactose, saccharose, mannite and maltose as suggested by Knott and Blaikley (1944). The strains were selected by their golden colour and oil /



oil paint appearance. The inoculated sugars were incubated at 37° C. for 96 hours. If golden-coloured colonies of staphylococci giving a positive coagulase reaction are regarded as pathogenic, and if only those fermentation reactions which appear in 24 hours are read as positive, then the following results are obtained. Staphylococcus aureus is biologically active and nearly all the strains ferment glucose, lactose, saccharose, mannite and maltose in 24 hours. Of the other staphylococci, 96% attack glucose, 61% attack saccharose, and 64% attack maltose. These sugars are, therefore, of little or no value in differentiating pathogenic from non-pathogenic strains of staphylococci. On the other hand, only 33% of the coagulase-negative staphylococci ferment lactose, and only 29% ferment mannite. These carbohydrates are, therefore, of some value in identifying pathogenic staphylococci.

In another series of 189 strains of Staphylococcus aureus so called because of their colour and coagulase-positive reaction, and which were isolated from the air and dust of a maternity unit, I found that 172 fermented glucose, lactose, saccharose, mannite and maltose in 24 hours (4). Sixteen fermented all the sugars in 24 hours except mannite which was fermented in 48 hours; and one fermented all in 24 hours except mannite which broke down in 96 hours.

Miscellaneous /

Miscellaneous Biochemical Tests.

Pinner and Voldrich (1932) mentioned an alkali production test; but a conclusive answer is only obtained at the end of ten days.

The liquefaction of gelatin has been used as a test of pathogenicity. Dudgeon (1908) found that gelatin was almost always liquefied by aureus and often by albus. Kligler (1913) believed that the difference in the rate of gelatin liquefaction by the white and the orange staphylococci was a valid point of distinction. Winslow and others (1920) left their cultures for 30 days at 20°C.; the difference in the rate of gelatin liquefaction between white and orange staphylococci was relatively slight. Daranyi found that this test did not run parallel with pathogenicity. Gross (1927), on the other hand, found a parallelism between the degree of gelatin liquefaction and pathogenicity. He examined his cultures for upwards of six days. Pinner and Voldrich (1932) kept their cultures for fifteen days, and aureus strains liquefied gelatin in three to four days. Sasaki and Fejgin (1937) examined the proteolytic power of staphylococci using as substrates gelatin, horse serum, casein, and cooked white of egg cut into thin slices. The last two gave the most reliable results.

The clotting of milk has been used to differentiate staphylococci. Daranyi (1926) thought that it was useful, and better than gelatin liquefaction as a test for pathogenicity. Nevertheless he found that some pathogenic staphylococci failed to /

to clot milk and that some saprophytic staphylococci clotted it although they took longer than the pathogenic strains. He read the results in three days. Gross (1927) found that milk clotting was variable but that pathogenic staphylococci produced acid in 24 hours with litmus whey (Lackmusmolke). Cruickshank (1937) also found that clotting of milk was not confined to pathogenic staphylococci.

#### The Coagulase Test.

Loeb (1903) was the first to study the coagulation of plasma when inoculated with Staphylococcus aureus; a few drops of broth culture coagulated 3 cc. of blood plasma of a goose. Much (1908) dealt with the reaction in detail. He found that certain strains of Staphylococcus aureus coagulated plasma from man, horse (this was the best) and wether, and exudates containing fibrinogen but not fibrinogen by itself, and he named the active substance staphylokinase by analogy with thrombokinase. Gratia (1920) made an inconclusive study of the mechanism of the phenomenon and regarded the active principle as analogous to thrombin. Kleinschmidt (1909) confirmed Much's work and noticed that some strains of Staphylococcus albus likewise produced a clot but rather slowly. Gonzenbach and Uemura (1916) repeated the work of Much and Kleinschmidt using plasma from man, goat, sheep and rabbit; the last, when pure, clotted most readily. Fibrinogen, they said, was not coagulated by staphylococci. After that time, the test began /

began to be advocated as a good measure of the pathogenicity of staphylococci. Daranyi (1926) suggested that it might be used for this purpose and Gross (1927) made the same suggestion noting that the coagulation of plasma is a property of Staphylococcus aureus only, and a few strains of Staphylococcus albus. Streptococci, meningococci, gonococci, organisms of the enteric and dysentery groups and *Br. melitensis* did not have this effect. Much (1908) had also looked for coagulase activity without success in *Bact. coli*, streptococci, pneumococci, meningococci, gonococci, the enteric group, *H. influenzae*, *H. pertussis*, *B. pyocyaneus*, *Proteus*, *B. anthracis* and the bacillus of Friedländer. Kemkes (1928) extended this list of inactive organisms. He found that *B. pyocyaneus*, *B. fluorescens*, *B. prodigiosus*, *B. anthracis*, the hay bacillus, *B. cholerae*, *sarcinae* and root bacteria did not coagulate plasma, and concluded that the coagulase test was specific for Staphylococcus aureus. He found no saprophytic staphylococci that were coagulase positive and, therefore, regarded the test as of value both when positive and when negative, as an indication of the pathogenicity or otherwise of the staphylococcus. He further confirmed his work by injecting his strains into the knee joints of rabbits. Those that were pathogenic by this test coagulated rabbit plasma and produced haemolysin.

Gross (1927) thought that the tests most valuable in determining the pathogenicity of staphylococci were the coagulase test, haemolysin production, gelatin /



gelatin liquefaction, and the lesions produced by intracutaneous injection in rabbits. Chapman and his fellow workers (1934) regarded the coagulase test as an index of the pathogenicity of the staphylococcus. They recommended the coagulase test, haemolysin production and pigment production after 48 hours on solid media. Pinner and Voldrich (1932) showed that the golden-yellow strains that they studied, lysed red blood cells, liquefied gelatin, produced alkali and coagulated plasma. The haemolysis and coagulase activity were roughly parallel to the pathogenic effect on rabbits (see also Daranyi, 1926). Burnet (1929, 1930) writing on staphylokinase, said that only aureus strains caused coagulation in three hours. The albus strains caused clotting when left overnight. Salm (1945) in a study of 325 strains found that the coagulase test tallied with Staphylococcus aureus identified by colonial appearance, in over 99%. Daranyi (1926) found that eighty strains from the environment of man and from healthy skin were coagulase negative, while thirty strains from pus were positive. His assistant, Buzna, noted that Staphylococcus albus from the lower animals was sometimes coagulase-positive. Daranyi concluded that the coagulase test and animal inoculation were the most important tests; there was complete correlation between the presence of coagulase and pathogenicity, and the former was characteristic of Staphylococcus aureus. Christie and Keogh (1940) noted the close association of coagulase and pathogenicity in 156 strains of staphylococci, and absence of coagulase activity /

activity among 64 non-pathogenic strains. Chapman and others (1938) found that, with few exceptions, a coagulase positive strain was pathogenic whereas a coagulase negative strain was non-pathogenic. Hallman (1937) and Cruickshank (1937) agreed with this. On the other hand, pigmentation on 33% milk agar, haemolysis and fermentation reactions failed to show this close correlation (Christie and Keogh, 1940). Chapman and others (1938) found that coagulase production was more stable than pigment which in turn was more stable than haemolysis. Indeed, Cruickshank (1937) thought that coagulase production was permanent. Chapman and his co-workers (1934, 1935, 1936, 1937, 1938) comparing pigmentation, haemolysis and coagulase production in the detection of pathogenic strains favoured the last. Duncan and Walker (1942) regarded a positive coagulase test as evidence of pathogenicity whether the colony produced a golden or a white colony.

Daranyi (1926), Gross (1927), Kemkes (1928), Chapman and others (1934), Cruickshank (1937) and Sasaki and Fejgin (1937) all found it of value in differentiating pathogenic from non-pathogenic staphylococci.

Errors may occur due to the use of unsuitable plasma, the time of observing the results, or missing a small coagulum. Fisher (1936) found that human plasma yielded a firm clot after comparatively short incubation and that organisms other than staphylococci did not clot it. Cruickshank (1937) used human plasma diluted 1 in 10 and regarded rabbit plasma as second. /

second. He found that the presence of coagulase was most closely associated with the pathogenicity of the strain for the rabbit, a view shared by Christie and Keogh (1940) who regarded it as the most useful single test.

Burky (1933) and Fisher (1936) noted quantitative differences, but found complete correlation between coagulase production and pathogenicity for rabbits, while non-coagulating strains were not lethal. Chapman and others (1938) obtained quantitatively similar results in 98.7% of 393 strains. Most of the strains clotted the rabbit plasma in less than three hours but many of the clots disappeared overnight almost completely. Human plasma on the other hand was clotted more firmly after overnight incubation.

Daranyi (1926) used whole blood; but it may fail to coagulate with pathogenic staphylococci (Salm, 1945) and it has nothing to recommend it.

Dried rabbit plasma (Colbeck and Proom, 1944) is useful. Salm (1945) used dried unfiltered plasma with good results. It will keep for over a year.

The plasma can be diluted to make it go further. Fisk (1940) diluted rabbit plasma 1 in 10, but Chapman and others (1938) suggested a maximum dilution of 1 in 4. Small coagula are produced in the higher dilutions and these may be overlooked. (MRC War Mem. No. 2, 1943). Neat or slightly dilute plasma /

plasma gave a firmer clot in a shorter time (Salm, 1945). Smith and Hale (1944) showed that 10% of an extract of human or rabbit testicle hastened the clotting time of a typical human plasma or slowly clotting plasma from various animal species. Salm (1945) found that plasma diluted with broth was no better than plasma diluted with saline. Cultures on solid and fluid media were equally good. Solution of the clot should be distinguished from retraction of the clot associated with higher dilutions of the plasma.

Gillespie (1943) advocated the use of sterile tubes. False negatives could be obtained when cultures were mixed with *Proteus* or fibrinolytic streptococci of groups A and C. These organisms destroyed any clot that was present, when added afterwards, or prevented the formation of a clot, if they were already present.

Fibrinogen solution has been recommended (Fisher, 1936; Cadness-Graves et al., 1943; Berger, 1943; Hodgson, 1943) mainly for slide agglutination but also for the coagulase test. It is, however, of no advantage. It does not keep longer than plasma which lasts for several weeks at 4° C. or even at room temperature (Fairbrother, 1940; Fisk, 1940; War Mem. No. 2, 1943; p. 26; Di Rocco and Fulton, 1939; Birch-Hirschfeld, 1934).

Much (1908) noticed that the clot produced by staphylococci finally dissolved, and he attributed this to the presence of fibrinolysin. Attempts were made /



made to turn this observation to account. Fisher (1936) and Sasaki and Fejgin (1937) left their tests for coagulase in the incubator for another four or five hours to determine the presence of fibrinolysin. Under such circumstances the conditions may not be optimum. Meter (1937) gave details of the test and described also an anti-coagulant factor which, however, could be rendered ineffective by dilution. Several days are often required to liquefy a plasma clot (Fisher, 1936). Certain contaminating bacteria can also cause this - *B. subtilis*, *Proteus vulgaris*, *Pseudomonas aeruginosa*, *Alkaligenes faecalis* and diphtheroids. Among the staphylococci, fibrinolysin is produced almost exclusively by strains from human sources. On the other hand, relatively few strains dissolve the plasma clot.

Much (1908) noticed that plasma caused clumping of staphylococci and Birch-Hirschfeld (1934) found that coagulase positive strains of Staphylococcus albus clumped as well as aureus strains. Berger (1943) noticed that a few coagulase-negative staphylococci also clumped but the clumps took longer to form. He thought that the clumping was due to the activity of coagulase on the surface of the cocci. Cadness-Graves and others (1943) obtained with fresh human plasma a correlation of nearly 100% with the coagulase test using 442 strains of staphylococci. They stressed the importance of reading the result quickly, that is, in five to fifteen seconds, and accepting only coarse clumping. They recommended it as a routine /

routine test. Salm (1945) obtained false negative as well as false positive results. He also found that occasionally a strain would fail to clump at the first attempt, but, under the same conditions, would clump on the second. Some pathogenic strains, however, give off coagulase negative variants (Pinner and Voldrich, 1932; Chapman et al., 1938) and that might account for the discrepancy if one colony only were used.

#### Serological Reactions.

Dudgeon and Simpson (1928) found that the ability of staphylococci to form precipitins might be correlated with pathogenicity, and Burky (1933) in a small series, found that the precipitin test showed a better correlation with source and rabbit pathology than pigment and haemolysis. Julianelle and Wieghard (1935) by precipitation of soluble specific substances demonstrated the existence of at least two immunologically distinct types, one, designated A, composed of virulent strains, and the other, B, containing avirulent strains. These carbohydrates were type specific. Julianelle (1937) found that, in 102 cultures of staphylococci, it was possible to differentiate types A and B identified by the precipitation test, by the fermentation of mannite with an error of less than 5%. Julianelle's groupings were confirmed and extended by Thompson and Khorazo (1937) in a study of 286 strains, and by Cowan (1938) with 157 strains. The last suggested that the divisions should be called groups rather than types.

Kolle and Otto (1902) were the first successfully to differentiate staphylococci by agglutination with rabbit antisera. The authors suggested that this method might be used in wide reviews of staphylococci, since they claimed to be able to distinguish pathogenic from saprophytic staphylococci. Proscher (1903) examined many pathogenic and saprophytic staphylococci and found that those from lesions agglutinated with a specific antiserum, but that staphylococci from air, skin and vaccine did not. Veiel (1904) produced an agglutinating antiserum for strains of Staphylococcus aureus isolated from cases of chronic eczema. He failed to produce agglutinins for non-pathogenic staphylococci, and the antiserum which agglutinated Staphylococcus aureus, did not affect saprophytic staphylococci. He used agglutination and haemolysis for identification and found that the staphylococci of the eczema which he was studying, gave the same reactions as those derived from pus.

Kutscher and Konrich (1904) examined 57 strains of staphylococci from various sources. They found that those derived from lesions agglutinated readily with the specific antiserum. The saprophytes agglutinated with their own antiserum but much less markedly. Julianelle (1922) defined three groups in 25 strains, while Hine (1922) divided the staphylococci into two main groups. The first formed acid with mannite and contained at least three serological types. /

types. Absorption of agglutinin tests were necessary. Cowan (1938) classified staphylococci by slide agglutination. Hopkins and Barrie (1928) found no sharp demarcation of types. Christie and Keogh (1940) were able to separate 88 coagulase producing strains from 42 coagulase negative strains by using unabsorbed agglutinating antisera.

Hobbs (1948) has enlarged the scope of serological typing, and has increased the number of types to 13. She refers to work of Andersen which suggests that staphylococcal antigens are both protein and polysaccharide in nature. It may be possible to turn this to account in the same way as the group-specific and type-specific antigens of the streptococci.

Julianelle (1922) found that staphylococci with antiserum fix complement, but he could not classify them by this means.

#### Bacteriophage Typing.

Fisk (1942) and Fisk and Mordvin (1944) introduced a method of typing staphylococci by means of bacteriophage. Wilson and Atkinson (1945) obtained 18 'phage filtrates and with these, recognized 21 staphylococcal types or subtypes. Their methods have been of value in the study of outbreaks of staphylococcal infection. Smith (1948) however, showed that apparent differences between certain strains may be due to acquired 'phage resistance; the reaction of the staphylococcus to the 'phage depends /



depends to some extent on the previous history of the organism with regard to 'phage infection. 'Phage types are quite stable, but an organism may undergo a change in type if it is associated with another strain carrying a 'phage to which it is susceptible. This change may occur naturally and so may limit the usefulness of 'phage typing when it is used over a long period.

#### Animal Inoculation.

The value of animal inoculation has been investigated. Daranyi (1926) thought that the coagulase test and animal inoculation were the most useful methods for the identification of pathogenic staphylococci. Gross (1927) used intracutaneous inoculation of rabbits. Koch, however, had pointed out that, although staphylococci from the environment are less virulent, a fatal result can be produced by increasing the dose. Chapman and others (1937) found that animal inoculation was not so reliable as might be supposed. On intravenous injection of 131 rabbits 21 or 16.3% gave erroneous results or died before others which had received a larger dose.

#### Tests Employed in the Following Investigation.

Of the above tests for the identification of Staphylococcus aureus, I used, first of all, colour and consistency of the colony. All golden and cream-coloured colonies were examined. Some could be rejected immediately as the colonies were not butyrous, but, rather, tenacious, and came away from the medium complete /

complete on the inoculating wire. In examining colonies recovered from the air, I did not take into consideration white variants as these could not be distinguished without examining all the porcelain-white colonies. Possible Staphylococcus aureus colonies were picked on to an eighth or a twelfth of a Petri dish of 5% horse blood agar. The colour was again noted after incubation. With experience, the number of colonies picked could be decreased. As horse blood was used, the haemolysis was variable. In any case, the fairly heavily inoculated plates were not suitable for demonstrating haemolysis.

Of all the other criteria, the weight of evidence is in favour of the coagulase test as an indication of pathogenicity. I used rabbit plasma usually fresh and seldom more than a fortnight old. It was diluted 1:5 with saline and inoculated with a sweep from the culture. The tube was incubated at 37° C., and examined several times in the course of the day and again in 24 hours. The majority of coagulase positive strains produced a clot in three to four hours. All positives were recorded when noticed.

III. AN OUTBREAK OF STAPHYLOCOCCUS AUREUS  
INFECTION IN A MATERNITY UNIT.

### III. AN OUTBREAK OF STAPHYLOCOCCUS AUREUS INFECTION IN A MATERNITY UNIT.

In recent years it has become increasingly common for expectant mothers to enter maternity units, partly because of the greater care that is now taken of this type of patient and, no doubt, also because of the difficulty of getting assistance and accommodation at home. Coincidentally, there has been an increase in the number of cases of pemphigus neonatorum in the nurseries of these units, and this may be due to the new social habit just as the appearance of puerperal fever was related to the institution of maternity hospitals in the middle of the eighteenth century. These outbreaks of pemphigus neonatorum are usually mild, but they require increased attention from a depleted nursing staff, and they are associated with the occasional fatal case of staphylococcal pneumonia. Obstetricians have, therefore, interested themselves in the presence of Staphylococcus aureus in their wards.

In the winter of 1946-47, an increase in the number of cases of pemphigus neonatorum and 'sticky eyes' was noticed in a maternity unit, and the obstetrician sought bacteriological help in finding the cause. The following work was done in collaboration with Dr. J. P. Duguid.

The unit consisted of a maternity ward, 26' x 16' x 13', of nine beds; a large nursery, 30' by 14' x 13', containing 26 cots; and a small nursery, 18' x



18' x 16' x 13', with fourteen cots. In addition, there were a sluice room with lavatory, a changing room for the infants, a duty room and an isolation ward. The unit was staffed by two sisters, and, depending on the number available, six or seven day nurses some of whom were pupil midwives, and four night nurses.

Nurses were masked and gowned when attending to the infants. They used communal soap and towels at the wash hand basins of which there was one in each nursery. The babies were changed seven times a day or oftener. They had individual towels and soap. The sterilized cord powder was shared. When taken to the changing room, they were put into compartments in a trolley or barrow, and, in the changing room, they were laid on a table covered with towelling. They went to the ward for nursing. Visitors were admitted to the ward but not to the nurseries. Mother and child were in hospital for about ten days.

The air was sampled by using settling plates during the day and night and while the ward was being swept; and by Bourdillon's slit sampler. The media were 10% blood agar, MacConkey's medium, and milk salt agar. This last medium contained 20% of milk and 7% of sodium chloride in nutrient agar. Dust was sampled by clapping the open Petri dish containing the medium, several times quickly over the selected area.

In 16 examinations of the maternity ward with settling plates of MacConkey and milk salt agar left out usually for 24 hours, Staphylococcus aureus was /

was found 11 times (5). In 42 examinations of the large nursery with settling plates, Staphylococcus aureus was recovered on 27 occasions; in 42 examinations of the small nursery, Staphylococcus aureus was found on 27 occasions; and in 26 examinations in the sluice room, Staphylococcus aureus was found 16 times. The highest number of colonies of Staphylococcus aureus recovered in the large nursery was 9, distributed on a milk salt plate and a MacConkey plate. If the two Petri dishes have an area of 20 sq. in., then 27,000 particles bearing Staphylococcus aureus will fall on the 420 sq. ft. of nursery floor in 24 hours; or some 500 particles on to a cot of 8 sq. ft. where they menace the infant more immediately.

Staphylococcus aureus was recovered when the coverlet of a cot was clapped with an open Petri dish, and a blanket treated in this way likewise yielded Staphylococcus aureus. In the small nursery, the highest number of Staphylococcus aureus-carrying particles recovered in 24 hours was also 9. This means that some 18,000 of such particles dropped on the floor of 288 sq. ft. in 24 hours. In this nursery on one occasion, 20 colonies of Staphylococcus aureus were recovered from the dust.

The air in the maternity ward was sampled on 3 occasions with the Bourdillon slit sampler (6, 7 and 8). Sampling began at 7.30 a.m. and went on until 2 p.m. There was a considerable amount of activity - sweeping the floor, feeding, toilet, nursing, doctors' /

doctors' round, nursing again, dinner, with little pause between the events. In spite of the natural ventilation which was adequate as judged by the senses, the curves of total organisms per cu. ft. (Graph 9 ) are rather high at times, although usually they are between 5 and 15. The spikes in the curves suggest physical disturbance. There is a drop in two of the curves which coincides with the doctors' round, the only time when there was no bustle. Staphylococcus aureus occurs, it appears, in clouds; sometimes there is a considerable number even when the total number of organisms is low. In one experiment, 1 Staphylococcus aureus-carrying particle occurred in 10 cu. ft. of air - a very high figure; in the second 1 in 23 cu. ft., and in the third 1 in 50.

In the large nursery which was sampled twice (10 and 11) with the slit sampler, the curves of the total number of organisms are lower (14). The highest point is 9 per cu. ft. Here ventilation was satisfactory and there was much less movement. The cots were tidied at 7.30, then the sister went round. The infants were lifted for nursing and changing. This continued from 8.30 until 10, but as the nursing and changing were done outside the nursery, there was little disturbance. A doctors' round followed and the babies were lifted again. In spite of the low curves which do not show spikes, Staphylococcus aureus was plentiful - 1 in 25 cu. ft. on one occasion and 1 in 27 cu. ft. on another.

In /

In the small nursery (12 and 13) the same routine prevailed, and the curves of the total number of organisms are low (14). 4 per cu. ft. was the highest number of organisms. 1 Staphylococcus aureus-carrying particle was recovered from 108 cu. ft. on one occasion; 1 in 25 cu. ft. - the only sample - on another; and 1 in 38 cu. ft. on a third.

At the end of the series of observations in July 1947, nasal swabs from 7 of the nursing staff on day duty were taken. Two gave a growth of Staphylococcus aureus. Eleven nasal swabs from 26 babies yielded a growth of Staphylococcus aureus.

During the period of observation, from the beginning of February until the beginning of July, 51 babies showed signs of infection (15). They had 'sticky eye', pemphigus neonatorum, umbilical sepsis, aural discharge and there was one case of pneumonia. This last and seven other infections were bacteriologically confirmed as due to Staphylococcus aureus. Out of approximately 90 mothers in the five month period, 16 had staphylococcal sepsis (16); Staphylococcus aureus was isolated from the high vaginal swabs of 13 mothers; one had a boil, one a septic wound, and from the sputum of the last, Staphylococcus aureus was isolated.

#### Discussion.

Pemphigus neonatorum, an outbreak of which was the cause of this investigation, has been recognised since Ochene described it in 1773. It is known /



known also as pemphigus contagiosus, impetigo contagiosa neonatorum, bullous impetigo of infants and impetigo contagiosa bullosa. The severe form in which the horny layer is rapidly separated over large areas of the body, is known as Ritter's disease.

Cole and Ruh (1914), Benians and Jones (1929) and Poole and Whittle (1935) are among those who give references for the early and less accessible papers.

Almquist (1891) was one of the first to study the bacteriology of the condition. He isolated from the serum of the vesicles an organism which was identical with Staphylococcus aureus, but he hesitated to call it so since it produced vesicular rather than pustular lesions. This depended not on the coccus, however, but on the texture of the affected skin. Falls (1917) in an exhaustive study of the coccus isolated from 6 cases, confirmed that it was Staphylococcus aureus. Dermatologists now recognize that pemphigus neonatorum "has precisely the same cause as impetigo contagiosa but produces its characteristic features on account of the ease with which the horny layer separates from the underlying mucous layer in small infants." (Price, 1947).

Epidemics are said to have become more frequent in recent years. Reed (1929) noticed a marked increase in its incidence in the United States in 1917. Certainly, reports of such outbreaks are more plentiful in the medical journals of the last two decades.

The /

The condition is usually mild and does not affect the health of the child. However, the mortality may reach 50%. Maguire (1903) described an epidemic of 18 cases of which 8 were fatal. All but one of the cases had come into contact with a nurse who had pustular acne. The older writers were often successful in tracing the outbreak to a midwife with some septic lesion and they were able to stop the epidemic by removing the cause.

The nurse, the mother, other infants, the physician, fomites and the environment are possible sources of an outbreak.

The nurse is most frequently suspected of being the source of the infection, probably because she is most intimately concerned with the child during the first fortnight when the disease is most prevalent and when the baby is most susceptible to infection. Medical journals contain a considerable number of reports on the rôle of the nurse as carrier and transmitter of the infection. Belding (1926) described an outbreak of 17 cases among 202 babies. The two wards in which the cases occurred, were on different floors. They were self-contained and had separate staffs. Cases of pemphigus neonatorum appeared in the ward downstairs and cases began to occur upstairs only after a nurse had been transferred to the upstairs ward. Benians and Jones (1929) described a series of 18 cases. The outbreak stopped when a nurse suffering from 'a series of boils' was posted away. Collins and Campbell (1929) had 50 cases. Some /

Some of these were attended by a midwife who had no obvious sepsis. In spite of complete disinfection, cases of pemphigus neonatorum continued to occur among the babies under her care. She went on holiday for five weeks during which time there were no cases in her district. On her return, she had 6 more cases in a fortnight. A thorough medical examination of the midwife failed to reveal a source. Poole and Whittle (1935) had 9 cases with 2 deaths. A nurse who had had a whitlow a few days before, had been supervising 8 of them. The 9th case was under the care of another nurse who came from the same home as the first. This second nurse may possibly have been a temporary carrier. Hobbs (1944) described an outbreak in a nursing home which subsided when the suspected nurse went away.

The infant may infect the nurse. Brewer (1937) mentioned the case of a nurse who, in the middle of an outbreak, developed a small boil on her hand. She was not in contact with the earlier or later cases. He believed her to have been a victim.

The mother may be the source of an outbreak. Mellon and others (1925) in a study of six hospital outbreaks, attributed four to infected mothers' milk. In one of these, the woman fed her own baby and a premature infant whose mother had no milk. Both developed pemphigus and the premature child did not tolerate the heavily infected human milk. It progressed satisfactorily on artificial feeds. The authors /

authors showed that the milk from the deeper mammary tissue was infected with Staphylococcus aureus, and they believed that this indicated an infection from the blood.

The breast milk is generally regarded as acquiring infection from the infant. This view was advanced in an Editorial (1936) in the 'Lancet'. Mastitis due to Staphylococcus aureus had occurred in a maternity home and in the district, and there was dermatitis among the infants. No source was found. Staphylococcus aureus was, however, isolated from the noses and throats of all the mothers with mastitis, and 40% of the babies examined had Staphylococcus aureus in the throat. The editorial suggested that the mothers had infected the infants by kissing and that the babies in their turn, had infected the breasts. Duncan and Walker (1942) likewise, found that Staphylococcus aureus was commonly present in the milk of nursing mothers and in the throats and intestines of their babies. They thought that the infection was picked up by the infants in the nursery or, possibly, from the mothers' respiratory tract, and then transmitted to the milk. Benians and Jones (1929) found Staphylococcus aureus in the throats and milk of healthy mothers.

Falls (1927) had a patient with acne and herpes simplex of the lower lip. The baby of this patient developed pemphigus on the face which Falls attributed to kissing.

The /



The doctor is a possible source of infection, but on the rôle of the physician in starting an epidemic the records are, for the most part, silent. He has not been suspect, doubtless because he does not come into intimate contact with the baby. McCandlish (1925) in a study of 175 cases among 608 deliveries, found that one intern had delivered 35% of the infected cases while the others had only 25% among their deliveries. But this difference is probably not significant.

The baby may start an epidemic. Cole and Ruh (1914) described a series of 8 or possibly 9 cases which started from one case of typical pemphigoid which became exfoliative. Some outbreaks begin with one or two cases of Ritter's disease which are then followed by a less severe form of infection and, at last, the epidemic dies out with the babies having only a few slight lesions. McCandlish (1925) described such an outbreak. An infant with Ritter's disease is, no doubt, a prolific source of Staphylococcus aureus which can be broadcast to nurses, and to other babies and to the environment whence it continues to menace the occupants of the nursery.

Falls (1927) described a case of self-infection in a baby. A doctor was demonstrating the presence of Hexenmilch and expressed some of it from the breast of an infant. A few days later, a mastitis developed, and the discharge gave a growth of Staphylococcus aureus. Within 24 hours a lesion of /

of pemphigus developed an inch from the breast, from which Staphylococcus aureus was isolated.

Fomites may be the cause of an epidemic. Schultheiss (1923) described an interesting outbreak involving 21 infants. The first cases were not from the same ward, and new cases continued to occur in spite of isolation. The writer reviewed all the members of his staff and the patients, but failed to find a possible source. Then the breasts of a woman who could not nurse her baby, were bound up. When the binder was removed several days later, some pustules were seen on the skin of one breast, which had been healthy before the application of the binder. The doctor now directed his attention to the linen and found that a woman with a septic, undressed finger was putting away the washing on its return from the laundry. When she was sent elsewhere, the epidemic ceased.

Carter and Osborn (1936) had a number of cases under their care over a period of seven years. Finally, there was an epidemic in 1933-34. The lesions in these cases were mostly under the clothes. This suggested that the laundry might be the source. Several of the laundry workers had septic lesions of the hands, arms and face. They were sent away, the laundry methods were revised and the outbreak came to an end.

Kinsman (1943) described a series of cases which continued to appear for years in spite of the fact /

fact that the hospital followed the same regime as the two others in the town, which were comparatively free from pemphigus. In 1939, the incidence rose to 15 out of 50 deliveries a month. In spite of a thorough cleansing of the department and a rigorous technique, the cases continued to occur. The rinsing water in the laundry was found to be heavily contaminated - the author does not specify the organism.- Bleach was introduced, the number of organisms in the rinsing water dropped, and the epidemic came to an end. Two further outbreaks in this department were associated with grossly contaminated rinsing water. When this was corrected, the outbreaks ceased.

There is, as far as I know, only one paper in which the authors suggest "that widespread distribution of an infecting strain in the nursery environment may bear a causal relationship to the onset of an outbreak." Allison and Hobbs (1947) recovered the epidemic strain from the ward air of a nursery on the two occasions when they examined it with settling plates. They also recovered the epidemic strain from the dust in the nursery and from blankets one of which had been laundered.

Duguid (1949) has advanced a case for the environmental origin of the outbreak described above. He pointed out that an infant in this maternity unit will breathe in a Staphylococcus aureus-carrying particle every twenty four hours, and suggested that colonization of the nose may start from this. Indeed the child may inhale more than one particle as its nose /

nose is nearer to a source of dust, namely the bed-clothes, than either the Petri dishes on the table or the sampler more than 3 feet above the floor. Allison and Hobbs (1947) found that, out of 32 healthy infants in the nursery which they were studying, 28 were harbouring Staphylococcus aureus in the nose, 11 strains of which were of the epidemic type. Only 10 out of 15 members of the staff were carriers at that time. Again, of 13 infants from four days to two months old, 11 were heavy carriers of Staphylococcus aureus. At this time, 33 out of 48 members of the staff were carrying Staphylococcus aureus in the nose. The infants were, therefore, heavily infected. It seems, therefore, that, given the opportunity, the newborn will rapidly pick up Staphylococcus aureus and become nasal carriers, without necessarily developing lesions. Torrey and Reese (1945) found that Staphylococcus aureus tends, in the newborn, to overgrow other organisms, and to persist. In any case, these infant carriers have now got a concentrated source of infection on their persons from which skin, lungs and even meninges may be infected, and as babies are prone to infection with Staphylococcus aureus (Menton et al., 1932) and as staphylococcal infections are more likely to develop in carriers, these babies are likely victims.

Staphylococcus aureus is distributed widely. It occurs in the nose and throat of at least 20% of people. It is a frequent cause of minor skin sepsis whence it can contaminate the clothing and dust. It is /



is a hardy coccus and can survive for some months under favourable conditions. The primary source of an infection can, therefore, only be suspected and no more than probability can, generally, be attained. The first overt sign of the presence of Staphylococcus aureus in a unit is not necessarily its first appearance there. The use of 'phage typing will limit the range of possibilities but before an epidemic begins, the strain is usually widespread. The only way, it seems to me, to find out how the organism spreads in a department, is to keep the coccus under observation for a long time, swabbing noses, throats and skin, examining air and dust and septic lesions, 'phage typing all strains and watching their progress or regression among the personnel and matériel of the unit.

With regard to the arrival and development of bacteriological flora in and on the infant, Gundel and Schwartz (1932) found that the upper respiratory passages were sterile at birth, and they thought that the organisms in the mouth of the baby did not necessarily come from the vagina or breast of the mother, or hands of the attendants, but from among the oral organisms in the environment. Kneeland (1930) found that 85% of nasal cultures in the first day of life were sterile. Out of 25 cases at the time of their first positive swab for Staphylococcus aureus, two gave a predominant growth of the organism.

Torrey and Reese (1945) found that, of nose, nasopharyngeal /

nasopharyngeal and throat swabs taken from 29 infants within 6 hours of birth, those from 26 infants were sterile; and that all of 17 infants examined in the same way 19 to 24 hours post partum, that is after first contact with the mother, had organisms in the nose and throat. Staphylococcus aureus was implanted later in the first day than Staphylococcus albus, and in a much smaller percentage of infants. Staphylococcus aureus, when acquired, tended to overgrow other forms and to persist indefinitely. This Table is based on figures from their paper.

Day	Number of Infants Swabbed (nose and nasopharynx)	Number and Percentage from which <u>Staph. aur.</u> isolated.
1st	105	7 6.6%
2nd	61	31 50.0%
3rd	79	41 62.0%
4th-8th	63	56 88.8%

There were 55.5% of throat carriers on the 4th to 8th days. They also said that the primary implantation of Staphylococcus aureus was, with few exceptions, in the throat. It spread to the nose and tended to disappear from the throat.

Witkowski (1934-35) found that the presence of vaginal flora in the mouth of the child depended on the kind of birth, its duration, and the time of rupture of the membranes. The pathological flora was related to that in the surroundings and in the mother's /

mother's mouth. From the second day onwards, haemolytic staphylococci and other pathogens were to be found in the mouth.

Neufeld (1943) examined the skin of babies the day after birth, with swabs moistened in broth, but found no difference between the skin flora of these infants and that of older ones. Swabs of the palms of the hands and of the back of the trunk were mostly sterile 15 minutes after a Caesarean section. Swabs taken one hour after the operation gave a growth of 10 to 20 white staphylococci on an agar plate, while, on the following day, the flora was indistinguishable from that of an older child. He pointed out that a variety of organisms must fall on the skin but some obviously cannot multiply there, and he distinguished between the Dauerbewohner or permanent settlers, and the fremde Bakterien which fail to colonize the skin.

Potter and Abel (1936) found that the skin of some infants was sterile at birth, but that, in the majority, it was not sterile. The skin of infants born of mothers with a vaginal discharge, was never sterile. The usual organisms were Staphylococcus albus and Bact. coli. Neufeld suggested that bacteria may be pressed into the skin during birth. In any case, they are very soon picked up from the hands of the attendants and mother.

In this series of mothers whose high vaginal swabs gave a growth of Staphylococcus aureus, only one had a child who was infected. This infant had "sticky /

"sticky eyes" and may well have been infected in the nursery. Another woman had a boil and her child had a blepharitis and pustules on the head and neck. A third had a staphylococcal discharge from a wound - possibly the wound of the Caesarean section, the record does not say - and her child had pustules on the abdomen. If the skin of a child born by Caesarean section is almost always sterile, then only two of the children of the 16 mothers with Staphylococcus aureus infections could have been infected by the lesion on the mother. Possibly the only mother whose staphylococcal infection was a menace to her child, was the patient with the boil. She may well have been a nasal carrier; and, while the woman with the obvious lesion is treated, the nasal carrier is unrecognized and can contaminate her surroundings. Or she might have been one of Barber's (1930) "pyococcus carriers" whose skin is heavily contaminated with Staphylococcus aureus.

Cases of congenital pemphigus neonatorum have been recorded. Labhardt and Wallart (1908) collected previous records of possible cases and added three which they had observed. Their own case notes seem to me to be unimpeachable. One child born of a healthy mother, had a generalized eruption. Staphylococci - the authors did not name the species - were isolated. The mother of the second had a septic finger and cubital and axillary adenitis. The child was born 10 minutes after the rupture of the membranes, and had a widespread eruption. Cultures from the vesicles were sterile. The third was one of twins. There /



There were only a few vesicles on the eyelids. The mother and the other child were healthy.

Reed (1929) reported a series of 9 cases that were born with a vesicular eruption. The first two were merely noted at birth. Of the remaining seven, five had sterile vesicles, one was infected with staphylococci - species not stated - and, from the last, haemolytic streptococci were isolated. In this case the lesions at birth were on the scrotum. There is no record of the births of these children. However, if there really are cases of antenatal pemphigus, they are certainly uncommon. Ordinarily, Staphylococcus aureus must reach the skin of the child after birth.

A condition called "sticky eye", that is, blepharitis or conjunctivitis, is associated with epidemics of pemphigus neonatorum. Schultheiss (1923) noticed this association, and Benians and Jones (1929) found that it sometimes occurred without the skin lesions. In the present series, 19 had "sticky eyes" only; 18 had pemphigus neonatorum only; and 4 had both conditions together.

Cohen (1938) noted that Staphylococcus aureus has a predilection for the lungs of very young children. In his paper on staphylococcal pneumonia, he showed that the pulmonary infection might be secondary to a focus of infection elsewhere, generally the skin. Menten and others (1932) in a series of 131 autopsies on cases of pneumonia in children, found that /

that 58% were due to Staphylococcus aureus. Eighty nine of these 131 cases were under a year of age, and of them 56.2% had staphylococcal pneumonia.

Smith (1935) described an outbreak of 4 cases of staphylococcal pneumonia in a maternity hospital. In the preceding three weeks, there had been a number of infants with upper respiratory catarrh and septic eruptions, and there were many staphylococcal carriers among the healthy babies. Several of the mothers had breast abscess.

In the present series there was one case of pneumonia. Staphylococcus aureus was isolated.

Staphylococcal meningitis may also occur. Among 21 cases of neo-natal meningitis Craig (1936) found 5 that were due to Staphylococcus aureus. One was associated with a Staphylococcus aureus infection of the eye, a second with a Staphylococcus aureus infection of the ear and skin, a third with Staphylococcus aureus in the blood, a fourth with Staphylococcus aureus lung abscess, and in the fifth no other lesion was found.

Bloch and Pacella (1938) reported the case of a child operated upon for occipital meningocele at six days. Ten days later, the baby developed a staphylococcal meningitis and an abscess at the site of operation.

Meningitis in the newborn due to Staphylococcus aureus is not commonly diagnosed, and there were no cases in the present series.

Dunham (1933) reported 11 cases of staphylococcal septicaemia in the newborn, confirmed bacteriologically and with adequate precautions in the taking of the specimens. Three survived.

In this particular unit, there was no obvious source of infection such as a septic finger. On the one occasion when nasal swabs were examined, two out of seven of the nursing staff were infected, and 11 out of 26 infants. Thirteen high vaginal swabs from the mothers over the five months' period of observation, gave a growth of Staphylococcus aureus. Sampling of the dust showed that it contaminated both nurseries and the sluice room. Settling plates revealed its presence in the air in the nurseries, ward and sluice room, and sampling showed that it was present in 25 cu. ft. of air in the large and small nurseries, and, on one occasion, in 10 cu. ft. in the ward. The whole unit, must, therefore, have been heavily contaminated with the organism. The dry dusting and sweeping which were practised, and the continual movement in such a department, must have stirred up the infected dust. To wear masks under such circumstances is to close the stable door after the horse has bolted. Masks were conscientiously worn in the nurseries. They were the pocket type with inset of grease proof paper or cellophane, and they were firmly applied to the nose and chin. Under these conditions, I found that only a few organisms escaped during a simulated sneeze (17). Masks, therefore /

therefore, should be worn properly, and sneezing must be suppressed. No usable surgical mask will hold back all the droplets of a sneeze.

The more numerous the organisms in the dust, the more likely they are to establish themselves in the noses of susceptible individuals, where they multiply and continue to stock the reservoir in the dust. Since Staphylococcus aureus is resistant and will survive for some months in dust, this process, once started, should continue with increasing speed and range involving more and more people, and the bombardment of susceptible and damaged tissues will become heavier. According to the sister in charge, the lesions of pemphigus were common on the face and neck. This could be explained by contamination of the pillow with infected dust or with mucus from an infected nose of the infant; the Staphylococcus aureus-carrying particles on the pillow would in turn infect the moist, tender skin of the cheeks and neck. Staphylococcus aureus was recovered from the bed linen. That infected linen can produce lesions in the adult skin was shown by Schultheiss (1923) whose patient developed an eruption on the breast from a contaminated binder; and by the common observation that men develop boils on the back of the neck which is exposed to the friction of the collar, and that horsemen and oarsmen are susceptible to boils on the buttocks. I attempted unsuccessfully to produce a carrier condition by lightly rubbing a culture of Staphylococcus aureus /



aureus on the dorsal aspect of the forearm but succeeded merely in producing a crop of pustules.

With regard to the spacing of cots in this unit, in the large nursery each cot had 16 sq. ft. of floor space, and in the small nursery 20 sq. ft. Cross (1949) recommended 50 sq. ft. per cot for premature infants, and in a memorandum of the Department of Health for Scotland, 25 to 30 sq. ft. per cot were suggested for nurseries for children under 1 year. There are apparently no standards of this sort for the newborn, who, if healthy, are immobile and asleep for most of this time.

Certain measures for the control of pemphigus neonatorum and accompanying conditions have been suggested by various writers. Rulison (1929) recommended the supply of a complete outfit sterilized when suitable, for each baby; that the nursing staff should be adequate in numbers and training; and that each nurse should confine her attention to several, say three, mothers and babies. The infant should not come in contact with anything that had been touched by another infant, without intervening sterilization, for example, the table for changing, or the pan of the scales. The use of bland, antiseptic ointments instead of energetic bathing with an irritant soap has also been widely advocated.

The wearing of sterilized gowns, a fresh one for each child or for each session, will protect the infant from the organisms which the nurse may have /

have picked up on her dress during the course of the day. Masks are now generally worn. Elliott and others (1941) found that the use of masks, gowns and rubber gloves did not appear to restrain the spread of infection. Adequate masks when properly worn, will reduce the amount of organisms escaping from the nose and mouth. The pocket type of mask with cellophane inset will effectively reduce the number of organisms produced by the most violent of expiratory efforts.

Dry sweeping and dusting are to be condemned, and should be replaced by dusting with a damp cloth and the use of a vacuum cleaner. Oiling of the floor is a satisfactory way of keeping down the dust (van den Ende et al., 1940). Bedmaking should be finished some time before the infants are brought into the ward.

Liquid soap in a container over the basin would be better than the cake of soap. Benians (1943) isolated Staphylococcus aureus from soap in a maternity unit. Taps should be elbow- or, better, foot-operated. Paper towels that could be discarded after use, or small squares of cloth which could be flung into a basket for rinsing and sterilization, or a current of hot air would be better than the communal towel. Wash places should be reserved strictly for the staff and patients of the unit. Hands should be washed after using a handkerchief.

However, the source of the organism is the carrier or the individual who has a lesion. All the nursing /

nursing staff should be examined regularly for carriage, and carriers - not the person who is temporarily contaminated - should be excluded or treated. The nasal swabs of mothers might also be taken as soon as is convenient after admission, and treatment begun where necessary. Certainly, nurses who have staphylococcal lesions should not come on duty in the maternity unit, and mothers so infected should be isolated. Review of the staff should include the laundry workers unless returned washing is sterilized. Visiting physicians who are carriers are not of so great danger; nevertheless, it would be desirable to free them also from the organism since, in course of time, their clothes will become contaminated and these in turn will infect the surroundings. Knott and Blaikley (1944) found that control of the carrier reduced the incidence of infection in their unit.

As for the control of the outbreak, isolation is advisable, with different nurses for each group of patients. In extensive outbreaks Swendson and Lee (1931) recommended a three nursery system, one nursery for the original cases, another for the other infants, and a third for those born after the outbreak had begun; all these nurseries to have separate personnel.

Cleaning and closing the ward for a few days will not rid the room of the organism. If the rooms are contaminated with Staphylococcus aureus, it can easily be recovered by suitable methods even when the room is scrupulously clean and there is little or no dust to be seen. It can also survive in dust for some months and so an outbreak may recur when infants are /

are returned to a ward which has been cleaned and allowed to stand empty for a few days (Benians, 1943).

#### Summary.

An outbreak of Staphylococcus aureus infection in a maternity unit is described, causing pemphigus neonatorum, blepharitis and pneumonia. Eleven out of 26 babies and 2 out of 7 of the staff were nasal carriers. The air and dust throughout the unit were heavily infected.

A possible sequence of events is suggested, namely contamination of dust by carriers, colonization of the noses of numerous babies, lesions due to Staphylococcus aureus in some babies.

Suggested measures for the prevention of such an outbreak are the treatment or exclusion of carriers among the nursing staff; treatment of carriers among the mothers; and the adoption of measures to minimize dust and droplet nuclei in the atmosphere of the unit.



IV. STAPHYLOCOCCUS AUREUS INFECTION IN A  
THORACIC UNIT.

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In the early summer of 1948 an outbreak of Staphylococcus aureus infection occurred among the operated cases in a thoracic unit. Specimens of pus from wounds were examined in the Bacteriology Department of the University of Edinburgh, and Staphylococcus aureus was isolated. Several of the staff including two surgeons and a theatre sister were carrying Staphylococcus aureus in the nose, and the organisms from the nasal swabs and wounds belonged to the same 'phage type - 47. The outbreak subsided but, with a view to finding the reason for such a spread of the organism and devising measures which would lessen the risk of recurrence, the possible channels of infection were reviewed. The recognized theatre technique was unimpeachable. It was decided, therefore, to examine the air of the operating theatre in the first place. Later ward air, blankets, dust and the noses of staff and of patients would come under review.

The theatre block is a one storey, brick building branching off a main hospital corridor. It is entered through double swing doors beyond which is a broad corridor with changing rooms for surgeons and sisters, office, store, waiting room, examination room and x-ray suite, on one side or the other. At the far end is the sterilizing room separated from the corridor by a high fixed screen, together with two /

two theatres, one on either side. One of these is used for thoracic surgery (18). It is 24'3" by 23'10" by 10'1". The roof makes a 30 degree angle with the walls, and the capacity of the theatre is, therefore, about 7,860 cu. ft. There are two windows, a doorway without a door opening into the sterilizing room, a double door opening into the corridor, and another opening into a short, broad passage leading from the corridor to an outside door. The floor is cement and the walls of board, the paintwork of which is in good condition.

There are two systems of artificial ventilation. One is designed to supply filtered air in large quantities to the whole theatre block, the quantity delivered to a particular room being controlled by an occluding disk over the vent. The air is taken in on the roof and the intake is remote from obvious sources of contamination. It passes through a glass fibre filter and between thermostatically controlled steam pipes, and is delivered to various rooms in the theatre block through gently curving, wide-bored ducts. The vent in the thoracic theatre is 7'6" from the floor. Messrs. Davidson and Co. Ltd., 53 Bothwell Street, Glasgow, the makers, say that the fan will deliver 6,200 cu. ft. a minute when running at 450 r.p.m. The inflow of air is sufficient to blow the double doors at the end of the corridor of the theatre block slightly ajar. 1,719 cu. ft. of air are passed into the theatre in a minute (19). Since the theatre has a capacity of 7,860 cu. ft., the /

the air can be changed twelve times an hour.

The other ventilating system is smaller in capacity and its filter is designed to free the air from toxic gases before passing it into the theatre. There are three openings from this system near floor level in the theatre.

Generally speaking, the place of an investigation in the following series, is fortuitous. The experiments are not detailed enough, there are too many variables, and the apparatus is too crude to relate findings to the season of the year or the state of the weather, if, indeed, that could be done under any circumstances. It will be convenient, therefore, to group like experiments and observations together instead of describing them in the order in which they were done.

First of all the theatre air was sampled when the theatre had been standing empty for ten hours. The operative work is usually done in the morning. Dressings are done in the same theatre in the morning when there are no operations; otherwise, in the afternoon. These are usually finished at 4 p.m. and, after that, only one or two people enter the theatre; there are no more major events in it. The staff go off duty at 8 p.m. and the whole theatre block is deserted unless there happens to be an emergency, until 7.30 the following morning. The best time, therefore, to examine the theatre air is from 6.30 until 7.30 a.m. when the theatre has been empty for the maximum period. I entered the theatre quietly, clad in surgical cap, mask and dust proof suit, and /



and set up the sampler on a stool, 3'6" from the floor, with a minimum of disturbance.

In a series of six examinations (20, 21, 22, 23, 24, 25, 28) inside the theatre on different days, exposing three or four plates on each occasion, the number of organisms per cu. ft. was below one except on four occasions. Each plate was exposed for five minutes since the air was so slightly contaminated. The range was from 0.4 to 1.7. The ventilator was then turned on. As the switch was some distance from the theatre, this took some thirty seconds, then a pause until the second hand of the watch was at a suitable point, and altogether a minute or so would elapse between turning on the fan and beginning to take the sample. The position of the sampler was about ten feet from the inlet. There was no draught, but a perceptible freshness in this region when the fan was running. Sometimes the bacterial content of the first sample after the fan had been turned on, would be higher than that of the preceding sample in the unventilated room. This may have been due to organisms which had sedimented in the ventilating duct, being blown out of it. In any case, the range of organisms recovered over the six experiments was slightly lower, from 0.1 per cu. ft. to 0.8. Finally, the air on the roof near the point of intake was sampled (20, 21, 22, 23, 24, 25, 26, 27, 28). The intake is on the roof of the single storey theatre block in the angle made by two diverging, two storey pavilions. /

Tea that  
numbers

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pavilions. It is on a level with the upper flats but well away from them. Otherwise, there are lawn and trees and, beyond the high boundary wall, allotments. Here the figures were slightly higher with a wider range - from 0.2 to 2.8. The organisms recovered included moulds. These did not commonly appear in the theatre.

The next set of figures (29, 30, 31, 32, 33, 34, 35) applies to the ends of the ventilator both inside the theatre and outside on the roof when the fan was running, to see if the filter, which is designed to remove dust, was acting as a bacterial filter. The intake of the sampler was held up to the ventilator in the theatre and three two-minute samples were taken on six occasions. The number of organisms per cu. ft. was fairly constant and rather low, the range being from 0.1 to 0.6 organisms per cu. ft. in eighteen readings. Then the sampler was taken on to the roof and the air in the immediate vicinity of the intake of the ventilating system was sampled while the fan was running. Three samples of two minutes each were taken on six occasions. The figures are higher than those for inside and they also cover a wider range, from 0.3 to 3.4 in eighteen readings. The latter is much higher than most of the readings and was interposed between two low counts. Looking back, I could not recollect any incident which would account for it. Clearly, some bacteria-carrying particles are removed from the air in its passage through the ventilating system. It may be that the glass wool filter or the whirling blades /

blades of the fan are responsible. They cannot be removed by impingement further in as the curves of the ducts are gradual.

The figures for the air at the exit from the ventilator, and in the theatre while the fan is running, are nearly identical, being 0.1 to 0.8 for the theatre air and 0.1 to 0.6 for the air at the ventilator opening. There was no dust in the theatre to be stirred up by draught. During these experiments, Staphylococcus aureus was not recovered.

The theatre air was then examined when the room was in use (36 - 44). The theatre staff begin to come on duty at 7.30 a.m. The floor is swabbed, dusting is done and the theatre is laid out. This means that one to three people are in and out of the theatre for an hour and a half. Then there is a pause until the surgeon and assistants appear. They scrub up, and, in the meantime, the patient is brought in accompanied by the anaesthetist, assistant anaesthetist, transfusion officer and a nurse or two. There may now be ten to fifteen people in the theatre. Up to this point, apart from the pause after the theatre is laid out, there is a gradual and steady increase in the degree of physical activity. The operation begins and movements in the theatre decrease. The operation may continue for one to two hours.

The activities during an operating session can be divided roughly into two: namely those occurring from the time of the entry of the first nurse at 7.30 /

7.30 until the theatre is laid out nearly two hours later, and, secondly, from the entrance of the patient until the end of the operation. I had thought that the pause between the laying out of the theatre and the entrance of the patient might be split off from the other two divisions, but this period is not reflected clearly in the number of organisms per cu. ft., possibly because it is seldom long enough and, in any case, there is some movement in the theatre during the pause.

When the theatre is empty and no activity has occurred in it for the preceding eight hours, the number of organisms in the air is low, generally less than one per cu. ft. Then there is a gradual increase in the number with the increase in the number of people in the theatre and the greater amount of movement. The graphs (46) show that it may rise to over 30 during the first period. When the patient and the attendants who come with him, enter, the number of organisms per cu. ft. can be as high as 31 and, after that, there is a gradual decline with one or two upward thrusts, as the operation progresses. There is little movement except between the operation table and the sterilizing room, and so the dust in the atmosphere has a chance to settle. Moreover, the theatre is large and so clouds of bacteria released at the table which is the only source for them, will be diluted and dissipated before reaching the sampler. At the end of one operating session, before the patient was moved, the /



the number of organisms per cu. ft. of air had dropped to 3.6 although there were six people and the patient in the theatre.

The composite graph (47) has been made by charting averages of the figures obtained at approximately the same time during the operations (45). Some of the points are derived from one figure only; some from ten. It is, therefore, only of use to give the general trend of the numbers of organisms in the air. The green lines show the averages of bacteria-carrying particles when the ventilator is turned on. They show that the ventilator lowers the number of organisms in the air.

Staphylococcus aureus was isolated from time to time. For instance, there were 2 particles carrying Staphylococcus aureus in 494 cu. ft. (37 and 40), 1 in 570 (39), 2 in 703 (43) and 6 in 684 (44). On one occasion, it was recovered from the air in the morning before anyone had entered the theatre. (The operator of the sampler was not a carrier). Dust in which it was lying, may have been disturbed when the operator entered the theatre. The presence of Staphylococcus aureus in the air is not related to the degree of contamination of the air with other organisms. It is present as often as not when the number of bacteria-carrying particles is low. If it is derived from the dust, then the distribution in the atmosphere is, probably, fairly even, and is no more concentrated in the neighbourhood of the operation table /

table than near the sampler which is 7 ft. away. If, on the other hand it is derived directly from an individual or individuals around the patient, then the concentration of Staphylococcus aureus in the neighbourhood of the wound will be much greater. Whether the concentration is great or small, the wound is often extensive, and is exposed for a long period, say an hour, and so the risk of contamination from the atmosphere is greater than it would otherwise be. No arrangements to blow air currents across the operation site towards the sampler were made so that the organisms sampled reached the sampler by diffusion or draughts.

The next group of samplings (48 to 59) were done during the dressings sessions. These take place in the morning when there are no operations, otherwise, in the afternoons. A dressing trolley is all that is required in the way of equipment. Walking patients discard their upper garments, the dressings are removed, fresh ones are applied and the patient dons his clothes. Patients who cannot walk, are brought in to the theatre on their beds. Blankets are turned down in the theatre, pillows are removed, the dressing is changed, pillows are put back and the blankets are replaced. The bed is then wheeled out of the theatre. The sister who does the dressings, is changing gloves and gown while the patient is being prepared. Another sister helps with the dressing, while a nurse is preparing a trolley for the next case. There /

There is, therefore, continuous, brisk activity by three people in addition to the disturbance of clothes, bed-clothes and dressings, and this considerable activity continues without pause for an hour or more. There is no time for the dust to settle. Hence the graphs (61) for the dressings are considerably higher than those for operations. There are also a number of spikes due to some disturbance in the neighbourhood of the sampler, for instance, a bed being pushed past might send the count up to about 40 bacteria-carrying particles per cu. ft. The general level of the curves is high, the average being between 15 and 20. The effect of turning on the fan is more marked under these circumstances than it is during operations. The curve of the averages (60 and 62) is, on the whole, below 5. The effect of forced ventilation is to flatten the curves and to lower the general level, and since the air in the unventilated theatre is more heavily contaminated during dressings than at operations, the effect of ventilation on the former is more marked. Staphylococcus aureus is more plentiful during the dressings sessions. Its presence is not necessarily associated with high counts. One in fifteen cu. ft. was obtained during a session when the ventilator was in action throughout (59). The whole curve was low.

On six occasions (63), throat swabs moistened in broth were rubbed over floor, wall, window sill, ventilator, radiators, electric switches, taps, sinks and elsewhere. Staphylococci, anthracoids and /

and diphtheroids predominated. Staphylococcus aureus was not isolated. The number of colonies obtained by this method was almost always small; occasionally dust visible on the swab did not yield aerobic growth.

The nasal swabs of the staff were not taken during this investigation, but swabs submitted to the Public Health Laboratory in the University by the staff, yielded, in some cases, a growth of Staphylococcus aureus. Two of the surgeons and one of the nursing staff were carriers.

Air in the lower male ward was sampled on six occasions (64). I have not attempted to relate numbers of organisms to activity as the ward is large, and there were, at the times of sampling, a number of up-patients, and some passing backwards and forwards near the sampler. An average of from six to twelve samples was thought to give a rough approximation to the general degree of air contamination in the ward. The number of organisms ranged from 2 to 18 per cu.ft. Staphylococcus aureus was recovered from the air on each occasion, the highest being 29 in 114 cu. ft. or 1 in 3.9 cu. ft., and the lowest 1 in 247 cu. ft.

As regards nasal carriers, out of 39 patients among those who inhabited the ward over the sampling period, 20 were infected with Staphylococcus aureus, 4 of whom were positive on more than one occasion (65). One was a temporary carrier and the others were not re-examined as the period between examinations was too long and the patients had gone before the next swabbing took place.



Sheets and blankets were shaken in the oiled box and the air was sampled with the Bourdillon sampler (66). The blanket or sheet to be examined was taken from the bed of a Staphylococcus aureus carrier. It was wrapped in sterile paper for transport. It was tied firmly to an oiled window pole and shaken in the box through the almost closed door. The air was sampled afterwards at intervals up to an hour. In this way 4 to 6 cu. ft. of box air were examined. In one case four particles carrying Staphylococcus aureus were recovered from 4 cu. ft., and in others, one, two and three from 5 cu. ft. (67).

Twenty-three used sheets from the beds of patients, often children, with enteritis or dysentery, were examined in the same way, but the air of the box was sampled over a longer period (68). Samples taken immediately after shaking, yielded counts which were sometimes high, for instance, 2,000. Samples taken eight hours after the shaking occasionally gave raised counts; even then not all the bacteria-carrying particles had settled. The number recovered at each experiment varied widely, possibly depending on the texture of the sheet and the length of time for which it was in use. Staphylococcus aureus was not recovered in any of these experiments. The total quantity of air sampled for the twenty-three sheets was 99 cu. ft.

In order to see what effect, if any, a wet floor had on the rate of sedimentation of organisms, the /

the following experiments were done. A windowless room 18' by 18' by 10' artificially ventilated and with an impermeable floor was chosen. An agar plate was exposed for one minute as a control. Then a saline suspension of a 24 hours' culture of Staphylococcus citreus was sprayed into the air with a Deedon nebulizer. I chose Staphylococcus citreus because it grows rapidly and has a distinctive colour. The bulb of the nebulizer was squeezed 200 times and the operator moved about the room as he was doing this. Half a minute after the cessation of spraying, a series of agar plates was exposed for one minute in every five for the following forty five minutes. As soon as this was finished, the air was again sprayed in the same way as before, a control plate was exposed and then the occluding disk over the vent of the air duct was unscrewed. This took a minute. Immediately afterwards, a series of agar plates was exposed each for thirty seconds in every minute. This took eighteen minutes altogether. Finally, the air was sprayed as before, the floor was flooded with water, and a control plate was exposed. Then the ventilator was opened, and a series of plates was exposed, each plate for thirty seconds in every minute. This section of the experiment lasted for eighteen minutes.

The plates were incubated and separate counts were made of Staphylococcus citreus and all other organisms (69 and 70). In the first part of the experiment, when there was neither ventilation nor water /

water on the floor, the droplets or droplet nuclei containing Staphylococcus citreus settled slowly. To begin with, there were thirteen in a cubic foot. Then there was a gradual decline in numbers over the 45 minute period during which observations were made and, at the end, there was one in one to two cubic feet. The other organisms remained fairly constant at the same level throughout, that is, at five more or less. There was some slight disturbance in the room due to the activities of the observer who, however, kept as quiet as possible.

At the beginning of the second part of the experiment, there were two to four nuclei carrying Staphylococcus citreus per cubic foot even though the operator had been careful to spray the air in exactly the same way as before and with the same suspension. When the ventilator was opened, the count dropped to less than one per cubic foot in four minutes. They were still present in small numbers at the end of thirteen minutes. The number of other organisms was rather high to begin with. This may have been due to the inevitable disturbance when the disk which closed the ventilator, was unscrewed. The count descended rapidly to below the level for the unventilated room, that is, to about two per cubic foot. In the last section of the experiment, ventilation and a wet floor were combined. The number of Staphylococcus citreus nuclei at the beginning was between four and eight. The number sank to one in six minutes and the organisms were gone in ten minutes. As regards other organisms, they were rather high at first, again /

again possibly because of the mechanical difficulty in opening the ventilator. The descent was rapid and to a lower level than that for the unventilated room, but there was no noticeable difference between this curve for ventilation and a wet floor and that for ventilation alone.

This experiment shows that a powerful ventilating fan will clear or almost clear the air of contaminating organisms fairly quickly. If the floor is wet, then ventilation will clear the air more rapidly of the contaminating organism. In the first case, not only does ventilation cause more frequent impingement of organisms on objects in the room, where they will stick; there is also a very rapid dilution of air and many of the organisms must be driven out of the room on the air currents. When the floor is wet, the droplets will not evaporate so readily. The floating masses will be heavier and, consequently, will sediment more quickly or be hurried to a resting place more rapidly.

Another experiment was done in the same room (71 and 72). A control plate was exposed and showed that the same number of bacteria-carrying particles were present as before. Then the ventilator was opened but the fan was not turned on. A culture of Staphylococcus citreus was sprayed into the air, the bulb being squeezed 200 times. The fan was turned on and the sampling began immediately. Plates were exposed for thirty seconds in every minute for 21 minutes. Then the fan was turned off, the suspension of /



of organisms was sprayed once again into the atmosphere, the floor was flooded with water and the fan was set going. Sampling began immediately with the same timing as before. After incubation, it was found that the Staphylococcus citreus had lost its colour and could not be distinguished from Staphylococcus albus. The counts in this second set of experiments are, therefore, a combination of Staphylococcus citreus sprayed into the air and all the other organisms present there. When the results are expressed as a graph, there is no noticeable difference in the fall in the count when the floor is wet and when it is dry. If the graphs are placed side by side, they are seen to be nearly identical.

The air of an unventilated room, 15' by 15' by 10' with two doors and a closed roof light, was sprayed with a suspension of Staphylococcus citreus (73 and 74). The initial count for Staphylococcus citreus was low - 1 in 4 cu. ft. This was ten minutes after spraying. The organisms disappeared from the atmosphere of the room between forty and fifty minutes after spraying. The number of other organisms was low also; to begin with, less than five per cu. ft. and, finally, eighty minutes later, one in 1 cu. ft.

It seems, therefore, that adequate ventilation will rapidly disperse organisms introduced into the air, in fifteen minutes; they will settle out of the air entirely or almost entirely in forty to /

to fifty minutes; and wetting the floor with water may, as in the first experiment, hasten the disappearance of the organisms by a minute or two. The initial drop caused by ventilation is so sharp, however, that it seems unnecessary to flood the floor.

#### Discussion.

Someone has said that the Victorian doctor who operated on the kitchen table had at least one advantage over the surgeon in the teaching hospital, in that he operated in quite clean air. The modern concentration of work in the operating theatre, and the great number of people who frequent it, contaminate the air and dust with organisms some of which are pathogenic. Among them is Staphylococcus aureus which may survive in the dust for many weeks to breach the most careful aseptic technique. Dust in the theatre is not gross, visible dust; that is removed by the frequent cleansing. It is the invisible matter that is given off from skin and clothing as a person moves, and it is visible only with the aid of a lens on the surface of a culture medium exposed in an air sampler.

Hart (1938a) in his study of 37 operating rooms in 33 hospitals in 17 American States, found widespread distribution of pathogens in the air of these rooms, and suggested that such a condition is universal. He wrote further that "pathogenic bacteria floating in the air and universally present in the occupied room, are the greatest cause of infection /

in the modern, well-run operating room."

The first and most significant feature of the present investigation was the high rate of carriage of Staphylococcus aureus among the surgeons, nurses and patients, and its widespread distribution in theatre and ward. Two surgeons and five of the theatre staff were carriers; two surgeons and two nurses were carrying the epidemic type which was 47. (The staphylococci isolated from operation wounds and from members of the operating team, were kindly 'phage typed by the staff of the Staphylococcal Reference Laboratory, Colindale Avenue, London.) It was penicillin-resistant. Staphylococcus aureus was also recovered from the air of the theatre and the male ward. It was found in the theatre air when other organisms were scanty. It was recovered on one occasion before anyone but the observer had entered the theatre. It may have been derived from the dust. The observer was clad in a dust-proof garment after removing his suit outside the theatre. He was not a carrier and so he did not introduce the coccus. It must have been in the theatre or in the immediate neighbourhood.

The method employed for examining the dust-throat swabs moistened in broth - was unsatisfactory, as it sampled too small an area. Hence the negative results are, I think, of no value. The swabs might pick up visible black matter from the inside of the ventilating duct; or a tangle of fibres from between the /

the pipes of the radiators. When plated directly on the blood agar, there was frequently no growth or, perhaps, only one or two colonies of staphylococci. Such visible dust as I could find in this theatre, was sterile or nearly so. Hart and Schiebel (1939) cultured material from the shoes, hair and clothing, and also from the walls and dust of a room, but isolated relatively few organisms. Even when they agitated the air and dust with electric fans, they recovered little. They concluded, therefore, that the organisms must be brought in by the occupants of a room, and that they die out rapidly rather than multiply. I doubt if the air currents from the electric fans would stir up the contaminated dust which is very finely divided and, therefore, presents a small surface to such air currents. They would, no doubt, have picked up larger particles and threads, but there are very few of these in a well kept theatre. In later investigations elsewhere, I found that moistened throat swabs rubbed on the floor, in the cracks between the pieces of waxcloth and over various fixtures in the theatre, did not yield a growth of Staphylococcus aureus but that beating the interior of the theatre with a long and heavy piece of sterilized cloth quickly contaminated the air, sometimes quite heavily, with Staphylococcus aureus. These minute bacteria-carrying particles may be dislodged by vibration rather than by draughts. From this later experience, I think that Staphylococcus aureus was present in the dust of this theatre but the method used /



used to find it was inadequate.

At the time of the investigation, no useful treatment could be prescribed for dealing directly with the carrier condition which was the cause of the widespread contamination. The problem, therefore, had to be dealt with on general lines and along with the second feature which was brought out by the investigation, and that was the high degree of aerial contamination associated with physical activity. This was only just less important than the widespread presence of Staphylococcus aureus since it did not produce such obvious sequelae.

Hart and Schiebel (1939) in a twelve months' study of the flora of the nose and throat of ten men, and the degree of air contamination of the room in which they worked, showed that the two conditions were roughly parallel not only for gross numbers but also for the species of organisms particularly the haemolytic yellow staphylococci. When I was examining the air of another theatre, I noticed that the plates were heavily contaminated with a "spreader" during several sessions. At that time, I recovered a similar organism from the noses of an anaesthetist and a nurse in the theatre. It is such an unusual inhabitant of the nose, that I think that the nasal carriage and air contamination were associated. Both the carriers were masked, but their clothes may have been infected.

Hart (1937a; 1938a) found that, other things being equal, the degree of air contamination varied directly /

directly with the duration of occupancy, the number of occupants, and the degree of nose and throat contamination of the occupants; and it was further influenced by the amount of activity and talking, and by the efficiency of the ventilating system. These views require some qualification. As to the duration of occupancy, I found that, in major operations which might last for an hour and more, there was a considerable rise in the count when the patient accompanied by some six people, was brought in to the theatre which was already occupied by five or six people. As the operation progressed, however, the count declined although there might be twelve people around the operating table. This was, I believe, due to the fact that there was hardly any movement; a spectator might try to find a better vantage point, and a nurse fetch something; but apart from that, everyone was still. And so, when the theatre was occupied for an hour by a dozen people, the count tended to drop provided that there was little movement.

On the other hand, the degree of contamination of the air was directly related to movement. The greater the movement, the higher was the number of bacteria recovered from the air. During the dressings, there were two or three nurses and the patient in the theatre. However, there was a great deal of movement, each working without intermission for an hour or more. There was a high degree of air contamination as is shown by the charts for the dressings. The theatre was a large one, however, and the /

the movements in this large room were fairly circumscribed. There was, therefore, plenty of free air to act as a diluent, and, after a certain point, there was no further rise in the bacterial count.

There was hardly any talking in the theatre and as everyone was masked with the pocket type of mask with cellophane inset, there was little risk of air contamination directly from the upper respiratory tract.

Those in the operative field were clad in operating garb covered with a sterile gown. In this unit the dressing room accommodation was ample and there was no likelihood of the freshly laundered surgical suit rubbing against the outdoor clothes. Those, however, who were outside the operative field, wore ordinary garb covered with a surgical gown. Duguid and Wallace (1948) found that infection may be disseminated from the respiratory tract by way of clothing dust to the air from whence it may reach the wound, and the instruments and dressings. The surgical gown restrained this dissemination only slightly - to the extent of 50% or less. Hart (1942) likewise found that the degree of contamination of the front of the operating uniform of nurses, doctors and orderlies varied directly with the nose and throat flora of the wearer and the length of time for which the uniform was worn. He recommended that personnel should put on freshly laundered uniform every day.

Hand carriage of Staphylococcus aureus was not investigated, nor the percentage of punctured and torn /

torn gloves. This ought to have been done in view of the fact that two of the surgeons were nasal carriers. The theatre was always comfortably warm and hands would be perspiring behind the rubber gloves. There is the possibility that, in some cases, infected perspiration leaked through a puncture in a glove into the wound.

It was suggested that ultra violet light might deal with the air contamination. Wells and Wells (1936) advocated this method and produced evidence to support their contention. Robinson (1942) pointed out that the most lethal rays lie between 2500 A and 2600 A, and that these are most abundantly produced by a low pressure quartz discharge lamp. Direct irradiation may be used in rooms which are occupied for only a short time and where the occupants can take appropriate precautions, for example, in operating theatres. Indirect irradiation is more suitable for wards, nurseries and classrooms; while irradiation of air circulating through the ducts of the ventilating system is applicable only when the air can be treated apart from the room in which it is used, as in food processing rooms. Robinson lays down as a guiding principle the destruction of the contaminating organisms at or near their source of origin.

Hart (1937a, b; 1938a, b) has been the great exponent of this method of control. His experience was similar to that recorded above. At one time, he found that 90% of the infections of clean wounds were due /



due to Staphylococcus aureus. He thought at first that the infections were coming from the patients' skin, but thorough preparation of the site of operation had no effect on the incidence of infection. Then the entire operating room technique was checked bacteriologically. Staphylococcus aureus was recovered from the floor, walls and ceiling, but from nowhere else. The theatre was, therefore, repainted frequently and washed daily; but again without effect. While the theatre was in use, he would recover as many as 78 Staphylococcus aureus-carrying particles on settling plates; although incoming air in the operating room was practically sterile. Further studies throughout the hospital showed that the degree of air contamination in any room was directly proportional to the duration of occupancy, the number of occupants, the percentage of carriers and the intensity of growth in their noses and throats. Moreover, the peaks of contamination were associated with epidemics of respiratory infection.

In view of these findings, heavy carriers and chronic carriers were excluded from the theatre, and treated with vaccine and bacteriophage, with what result he does not say. Masks were to be worn at all times, and the number present in the theatre was to be kept at a minimum. Visitors and students were not allowed to attend. He used also forced ventilation, and installed ultra violet light tubes around the spot light. These last killed a sprayed culture of /

of Staphylococcus aureus at 5 ft. within 60 seconds. The use of these methods led to a reduction of the air organisms by 60 to 90%, and less than one colony per hour was recovered on Petri dishes in the operative field. Hart (1942) reported later that, by using ultra violet light, he had secured an immediate reduction of wound infection from 1/20 to 1/100 of the previous level. His experience with ventilation was not satisfactory, and he found that ultra violet light was necessary to obtain good results. It is, however, most effective against droplet nuclei (Bourdillon and Lidwell, 1948) whereas organisms in the theatre are associated with dust. The larger particles of dust protect the organisms to some extent from the effects of the ultra violet light (Andrewes, 1940) and, therefore, one would expect it to be not so satisfactory as Hart suggests. His preliminary experiments were done with sprays which are, of course, analogous to droplet nuclei, and not to dust. On the other hand, the infection rate in the theatre was so low after the installation of ultra violet light - less than 0.25% - that it must be of considerable use. He noticed also that convalescence was smooth and that wounds healed rapidly, and he concluded that the ultra violet light exercised some direct influence on the healing process. Gudin (1936) had this experience also, but he operated in an atmosphere purified by chemical means. This rapid healing is due, therefore, to avoidance of contamination of the wound rather/

rather than to any stimulating power which the ultra violet light might exert.

Electrostatic precipitation of dust from the air is a method which has found favour in France. Éts. André Walter built the theatre in ward 20 in the Royal Infirmary and make considerable claims for the electrostatic precipitation equipment which they have installed there.

The use of germicidal aerosols was also considered. These were introduced by Trillat (1938) about 1935, and are a kind of non-wetting "spray". The particles are minute, have an exceedingly small mass, and their velocity is normally not great enough to cause them to burst on impact. Andrewes (1940) found that they were effective against bacteria in droplet nuclei, but not against organisms in dust. Lidwell and others (1948) reviewed previous work and added more on propylene glycol and lactic acid. They confirmed the finding that these agents were relatively inefficacious against dust-borne organisms, and found that the conditions of their being effective were complex. On the whole, they have no application in the purification of the air of the operating theatre.

During the course of the investigation, it was thought that the ventilation system might be worth using as a temporary measure to reduce air contamination. There were two systems, but the smaller one made a considerable amount of noise and the openings were near the floor where it might stir up dust particles which had collected during the day. It was, therefore, /

therefore, not used. The other ventilator had a greater capacity and the opening was in the middle of the theatre, 7 ft. 6 ins. from the floor. Although it was only meant to supply fresh air, it did in fact supply very clean air containing seldom more than 2 bacteria-carrying particles per cu. ft. If warmed, the incoming current of air was hardly perceptible. This air diluted and drove out the contaminated air from the theatre and, other things being equal, the plate counts dropped. Bourdillon and Colebrook (1946) did not suggest a standard for the bacterial content of the air of a thoracic theatre. In view of the length of the operations and the frequent occurrence of contamination of the wounds, I suggest that it should be rather more rigorous than that put forward for the general theatre, and that something less than 10 bacteria-carrying particles per cu. ft. should be aimed at. In fact, the standard should approximate as nearly as is convenient to that for the neurosurgical theatre, which is 2 to 0.1 bacteria-carrying particles per cu. ft. This can be almost but not quite attained by ventilation during operations. With a more rigorous limitation of admissions to the theatre, the discarding of ordinary clothes for freshly laundered shirt and trousers, and a reduction of movement to a minimum, combined with the use of the present ventilating system, the surgeon would be secure of very clean air.

Colebrook's (1950) experience at the Burns Unit in the Birmingham Accident Hospital has shown that /



that it is possible, by means of a carefully devised ventilating system, to prevent infection to a very large extent and to maintain that freedom from infection for a period of  $3\frac{1}{2}$  years (734 patients). A full bacteriological investigation throughout this period has shown that only 5% of the patients whose burns were free from haemolytic streptococci on admission, acquired that organism at any time during their stay in hospital. In the burns unit in the Glasgow Royal Infirmary, before special precautions were instituted, the streptococcal infection rate in a group of 26 cases was 83%.

Hart (1938b) says that "sterilization of the polluted air has closed the greatest remaining source of contamination of clean operation wounds."

Dressings should, obviously, not be done in the theatre of a thoracic unit because they contaminate the air so grossly. Blankets, especially old ones that have been washed many times, give off immense quantities of broken wool fibre as is seen if such a blanket is held over the polished surface of a bench, and lightly rubbed. Staphylococcus aureus persists on bedclothes for a long time. Snippets from a piece of used blanket and a piece of used sheet contaminated with a culture of Staphylococcus aureus in October, 1949, and kept since then in Petri dishes in a cupboard, are still yielding in August, 1950 a growth of the organism. The danger of infected dust is now well known. Cruickshank (1935) showed that most third degree burns became infected with haemolytic /

haemolytic streptococci after admission to hospital, and that both the dust and the air contained haemolytic streptococci of the same type. White (1936) found that air could be contaminated not only by organisms from the respiratory tract, but by organisms from discharges. She isolated from the dust haemolytic streptococci of the same type as that infecting puerperal patients. She also described the case of a person who contracted streptococcal pharyngitis after sweeping out a room which had been vacated by a patient with puerperal fever, five days previously, with whom she had had no direct contact. The haemolytic streptococci from the patient and the maid were of the same type. In a neurosurgical unit, I have recovered Staphylococcus aureus of the same 'phage type from the noses of nurses and patients, and from the air and dust of the theatres.

I suggest that dressings should be done in a suite of two rooms both artificially ventilated to the outside with the discharge well away from wards and theatres. Both rooms should be small with low ceilings and impervious walls so that they could be easily washed out or hosed down. There should be absolutely nothing in these rooms; even the lights would be embedded in the ceiling, and the heating would be of the panel type. In the first room the patient could be prepared for the changing of his dressing. If he is on a bed, blankets would be turned down, pillows removed to the bottom of the bed so as not to contaminate the floor. The upper dressings /

dressings would also be removed, and the bed and patient as far as possible, covered with sterile sheets and cloths. In the next room similarly ventilated and bare, the patient would meet the nurse with her dressing trolley which would also have been prepared outside. At the end of each dressings session, the rooms would be thoroughly cleaned.

Where artificial ventilation is not available, and as a temporary measure, two rooms might be used alternately for dressings so as to allow of some sedimentation of dust between the dressings.

#### Summary.

An outbreak of Staphylococcus aureus infection in a thoracic unit is described, affecting clean operation wounds. Two surgeons and two of the theatre staff were carrying the epidemic type - 47. Staphylococcus aureus was recovered in quantity from the air of the theatre while it was in use, and from the air of the male ward. While dressings were being done in the theatre, the total bacterial content of the air was considerable.

The ventilation system already installed, was shown to reduce the total air contamination. It is suggested that stringent control of entry to the theatre, combined with modification of dress, will do much to prevent further outbreaks.

V. STAPHYLOCOCCUS AUREUS INFECTION IN A  
NEUROSURGICAL UNIT.



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The Department of Surgical Neurology at Bangour Hospital was started in June 1940 (under the care of Professor then Mr. Norman Dott). There are a male and a female section each of which contains a large ward and several small wards of one or two beds each. A long passage connects this part of the unit with the two theatres and annexes, the X-ray room, the side room and the duty room. This latter part of the building is of wood on a brick foundation.

Bacteriological help was sought when, in October and November 1949, an alarmingly high incidence of infection occurred in cases after operation. Staphylococcus aureus was isolated from some of these cases. In others no organisms were recorded in cultures but the high cell count in the cerebrospinal fluid suggested the presence of infection.

The members of the staff gave the following account of the infections in the unit.

After the department was opened, occasional infections of clean cases occurred, possibly 1%. They were, for the most part, minor infections such as stitch abscesses, and the causative organism varied. The number of infections, however, gradually increased and from 1943 small outbreaks occurred, about four or five cases in the course of a fortnight, while the intervening periods of several months were free.

These /

These outbreaks became more frequent and more severe but, even so, only two deaths occurred. During this period one surgeon had about two cases of infection a year while several assistants had a much higher incidence although there was no obvious breach in technique. In the past two years, however, the bouts of infection began to occur several times a year with sporadic infections every few weeks. Six deaths from infection occurred in the latter half of 1949, and in October and the first half of November, every case was infected. The surgeon in charge was so much alarmed that he intended to stop operating and to close the wards. Technique was the same as before. The personnel had not been altered with the exception of two subordinate members who were not in immediate contact with the operative field. A new sterilizer had been introduced some months previously, but it was satisfactory. In any case it had been there for some time before the outbreak.

The evidence of infection occurred at varying times after operation. Sometimes it was there on the following day; when the dressing was taken down for the first time, the flap might be inflamed. Sometimes it was delayed for a week. It might take the form of local redness or a rather greater disturbance of temperature than normal after the operation; or a greatly increased cell count in the cerebrospinal fluid, for example, 600 cells per cm.<sup>mm</sup> which is considerably more than that which follows operative interference. /

interference.

To begin with, the outbreak appeared to be recent and limited to the previous six weeks. At the end of September all the members of the theatre staff namely four surgeons, two house surgeons, two anaesthetists, three sisters, one nurse, three orderlies and one radiographer, with the exception of one of the sisters who was on holiday, had a 'streaming' cold. It was in the subsequent six weeks that all the operations were followed by untoward signs. On inquiring further into the bacteriological history of the unit, I found that there had been previous outbreaks of infection as recorded above. It appeared that the present one was not a sudden visitation, but rather the culmination of a long 'grumbling' period of infection. This had not been bad enough to excite the suspicion that there were some sources that could be dealt with. It had been accepted as due to chance, and inexplicable. In fact the outbreak had drawn attention to itself by the steep increase to 100% of infected cases.

From a number of these cases Dr. Purdie, Bacteriologist at Bangour Hospital, isolated coagulase-positive staphylococci from the cerebrospinal fluid or operation wound. She also reviewed her records of bacteriological examinations done for the unit in the preceding two years, and writes: "Between 1st January, 1948 and 24th November, 1949

78 infections were examined bacteriologically; from 45 of them coagulase-positive staphylococci were isolated. Most of the staphylococci were penicillin-resistant." The organism mainly or entirely responsible for the infections was, therefore, a coagulase-positive staphylococcus. This coccus is carried in the apparently healthy nose of about 20% of people. The carriage rate among nurses in hospital is somewhat higher and may reach 60%. It is occasionally carried on the skin especially of the hands, but this is almost always associated with nasal carriage. The investigation was, therefore, directed to identifying the carriers and finding out to what extent the environment was contaminated with the coccus. Dr. Purdie found that, out of 45 members of the staff, 15 were carrying coagulase-positive staphylococci in the anterior nares with the exception of one in whom they were recovered from the throat. A fortnight later she found that out of 48 members of the staff 18 were carrying coagulase-positive staphylococci in the anterior nares with the exception of one who was carrying them in the throat. The surgeons, house surgeons, anaesthetists and the psychologist, nine in all, were free from infection.

The activities in a neurosurgical theatre are, in some respects, different from those in a general theatre. In the case of an intracranial lesion the timetable for the day is as follows. The nursing staff begin to prepare the theatre about



8 o'clock. From one to three nurses, one of them a man, are in and out of the theatre for an hour. One of them is engaged in fairly quiet work such as threading needles, laying out instruments, charging catheters and adjusting apparatus while the others move actively about. There is then a pause in the bustle for upwards of half an hour until the surgeons arrive. The surgeon and his assistant wash up while the patient is brought on his trolley to the anaesthetic room where the anaesthetist is working with, possibly, the help of an orderly. The patient is then brought into the sterilizing room and so to the theatre. Now there may be four people around the patient and, in addition, a sister and an orderly who move in and out of the theatre. The surgeons are dressed in white shirt and trousers and rubber boots. One surgeon wears cloth boots which cover the leg to below the knee, and are laced to it. The sisters are dressed in ordinary uniform and the anaesthetist and orderly in lounge suits with or without jackets. All wear surgical gowns, caps and masks of the cotton pocket type with cellophane inset. The gowns, in the case of the anaesthetist and orderly, cover the back only in part.

The first part of the operation is the preparation for the ventriculogram. With the patient lying face downwards, two small incisions are made in the occipital region. Two holes are trephined in the skull and two catheters are passed into the lateral ventricles. The patient is then sat up, a lumbar puncture /

puncture is done and filtered air is pumped into the ventricles. The wounds are then dressed by placing partly divided swabs around the catheters which are folded towards the midline and covered with more swabs. The whole head is then enveloped in a surgeon's cap which is pleated at the front so that it fits the head snugly. It is bound down with adhesive tape which is crossed on the forehead, the ends being brought down to the temples and attached to the skin. This dressing fits well and is secure, and cannot be disturbed by any ordinary manipulation. All this takes three quarters of an hour. The patient is then transferred to a trolley and wheeled out of the theatre to the X-ray room by two orderlies. During the examination, the radiographer has to adjust the patient's head for the four different positions that are required and in doing so, her own face frequently comes near to the patient's head. In any case, she is hanging over the patient all the time during the X-raying, she is not masked and she wears ordinary clothes covered by a white coat which is usually changed once weekly. Two exposures are taken in each position and these are developed before the next two exposures are made. The procedure therefore occupies about thirty minutes. Then the patient is returned to one of the rooms adjoining the theatre and lies there lightly anaesthetized for an hour or more while the X-rays are being examined. The major operation, if there is to be one, begins at one o'clock. The gas and /

and oxygen mixture is normally passed through a tube in the mouth. Occasionally, however, it is necessary to pass a tube through a nostril either to administer the anaesthetic or to remove mucus from the throat. Sometimes the pillow is contaminated with the nasal secretions of the unconscious patient. Then the major operation begins. The flap of skin is cut and folded back, and completely covered with a dressing. Then the bone flap with the periosteum is cut, covered with a dressing and folded back. The whole is secured and is not exposed again until the end of the operation. The dura matter is opened and the operation on the brain substance begins. Because it is absolutely necessary to secure complete haemostasis, this part of the operation is lengthy. Parts of the field of operation on the brain may be exposed for three or four hours. The whole of the major part of the operation may last for six to seven hours, and, although much of the tissue is covered for part of the time, there are long periods of exposure. The operating surgeon's face is directly over the wound, sometimes fairly close. Thereafter the patient is returned to bed, and ventricular drainage, lumbar puncture and dressings follow as required.

There was no detectable flaw in the theatre technique to account for the infection; and the staff, at least those close to the operative field, and connected intimately with it, were experienced in this type of work with the exception of one orderly /

orderly who acted as intermediary between the theatre and the preparation room, and who was later found to be a nasal carrier of Staphylococcus aureus.

In view of the nature of the infecting organism, namely Staphylococcus aureus, I decided to search for carriers and to find out how heavily the air and dust of the unit were infected with this organism. As mentioned before, I used a sieve sampler, and I was clad in sterilized dust-proof garment, cap and mask. I was not carrying Staphylococcus aureus.

The south theatre (75) is 24 ft. square by 12 ft. high and has, therefore, a cubic capacity of 6912 cu. ft. It communicates through a doorway without a door with the sterilizing room, and by a door with one of the preparation rooms. This door is kept shut but it has a rectangle of metal gauze in it so that the theatre is in constant aerial contact with this preparation room and so with the corridor beyond. There is always someone in the preparation room and there is often a considerable amount of traffic through it to the sterilizing room. These rooms cannot, therefore, act as bacteriological precipitating chambers. There is no window in the theatre, the air being introduced through three ventilators the intake points of which are just above a grass bank outside. A sheet of gauze is stretched across the inner aspect of the ventilator to catch flies and leaves. One of the ventilators has a fan which /



which produces a current of air just strong enough to billow out the gauze in front of it, but not strong enough to affect an anemometer (76). The other two between them introduce 653 cu. ft. of air a minute. Hence there should be six turnovers an hour. One of the anaesthetists states that when the wind is in certain quarters, the gauze in front of the ventilators does not billow out since the fans are too weak to suck in the air. An extract fan in the roof is ducted to both theatres.

Since it was first built as an emergency theatre during the war, the structure of the theatre has undergone progressive deterioration, and the flooring is weak and defective. The room is kept scrupulously clean so far as that is possible under the existing conditions of structure.

The first sampling was done in the afternoon when the theatre had been empty for three hours. 304 cu. ft. of air were sampled and the average number of bacteria-carrying particles was 1 per cu. ft. (77). Staphylococcus aureus was not isolated.

On a subsequent occasion the air of the theatre was again sampled (78). The theatre had been in use four hours before. The charwoman had washed it out immediately afterwards and thereafter it had stood empty. On this occasion a long piece of heavy cloth which had been sterilized, was slapped against the walls and all fixed and heavy objects in the theatre. The cloth was sufficiently heavy to "lick" around /

around pipes, and under radiators and sinks, and to flake off the crumbling paint from the walls. It was also whisked across the floor. The control plate exposed before this beating gave a count of 2 bacteria-carrying particles per cu. ft. During the beating, 209 cu. ft. of air were sampled and contained on an average 4 bacteria-carrying particles per cu. ft. Staphylococcus aureus was not isolated. Four sterile swabs moistened in broth were rubbed along the edge of the waxcloth, and picked up some dust. Only one anthracoid colony was isolated from the swabs in a 24 hours' aerobic culture<sup>4</sup> (78).

Throat swabs moistened in peptone water were rubbed on the viewing box switches, the four tap handles, the insides of the two sinks, the soap and the soap tray, both radiators and the horse shoe head rest of the operating table in the south theatre<sup>5</sup> (79). Staphylococcus aureus was not isolated.

A draught screen is used to occlude the doorway leading to the sterilizing room, during an operation. The cloth from this screen was shaken in the sampling box<sup>6</sup> (80). Staphylococcus aureus was not isolated.

The south theatre was then examined while in use, from the time that it was partly laid out until well on in the operation, a period of two hours and a quarter<sup>7</sup> (81). The sampler was eight feet away from the operating table, and away from the door in the least frequented part of the room. The air ought to have been fairly still in this area. 836 cu. ft. /

ft. of air were sampled with an average of 4 bacteria-carrying particles per cu. ft. Before the entrance of the surgical team and the patient, the theatre had been empty or else the scene of very quiet activity such as threading needles. 437 cu. ft. of air were sampled during this period with an average number of bacteria-carrying particles of 3. After the entrance of the surgeons, 399 cu. ft. were sampled and contained 5 bacteria-carrying particles per cu. ft. From the total quantity of air sampled, namely 836 cu. ft., three colonies of Staphylococcus aureus were recovered, that is, one in 280 cu. ft. One of these was obtained when the theatre had been empty for half an hour; the other two were recovered from the same sample after the entrance of surgeons and patient, and while the number of bacteria-carrying particles was still raised as a result.

Nasal and hand swabs were taken immediately after the operation (82). Of the eight members of staff, two were nasal carriers and the hands of one of them were infected. A third was carrying Staphylococcus aureus on the hands only. The organism was not isolated from him at any other time. These carriers were not assisting at the operation; they were merely present in the room. The patient was also a carrier. She had a cervical sympathectomy.

The north theatre is a mirror image of the south theatre and is in the same state. It is ventilated by means of three ventilators, only two of which /

which are in working order<sup>9</sup> (83). Between them they introduce 292 cu. ft. of air a minute. There are, therefore, three changes of air in the theatre in an hour.

The air in the theatre was sampled in the afternoon after it had been standing empty for four hours<sup>10</sup> (84). 190 cu. ft. of air were sampled and contained an average of 2 bacteria-carrying particles per cu. ft. Staphylococcus aureus was not isolated.

On another occasion, dust was stirred up with a sterile cloth as before<sup>11</sup> (85). The control plate showed 1 bacteria-carrying particle per cu. ft. After the beating, there were 7. Three colonies of Staphylococcus aureus were isolated from the total 209 cu. ft. of air sampled, that is, one in 70 cu. ft. There were, possibly, two more but these could not be identified with certainty as the plates were covered with spreading organisms. Four swabs of dust were taken from the edges and between the pieces of wax-cloth. There was a growth of fungi and staphylococci two of which were coagulase-positive.<sup>12</sup> (85).

A cloth from the screen in this theatre was shaken in the sampling box<sup>12</sup> (86). Staphylococcus aureus was not recovered.

The air coming through one of the ventilators was sampled. 95 cu. ft. were examined and contained an average of 0.5 bacteria-carrying particles per cu. ft.<sup>13</sup> (87). Staphylococcus aureus was not isolated. /



isolated. There were also particles of dust on each of the five plates exposed. They were usually only detectable with a hand lens and were not associated with colonies.

The air was again examined when the theatre was in use<sup>14</sup> (88). While the theatre was empty or almost so, 114 cu. ft. of air were sampled and contained an average of 3 bacteria-carrying particles per cu. ft. After the entrance of the surgeon and his assistants, 228 cu. ft. of air were sampled with an average bacterial content of 2. The anaesthetized patient had been pushed in on the operating table by the anaesthetist 25 minutes before. During that period the average was 3 per cu. ft.; in fact no significant rise since the heavy operating table necessarily retarded the speed of movement of the anaesthetist. While the theatre was being prepared, there had been a considerable amount of movement in the early stages. During this period, 418 cu. ft. of air were sampled with an average content of 5 bacteria-carrying particles per cu. ft. Staphylococcus aureus was not recovered. In all, 874 cu. ft. of air were sampled with an average content of 4 bacteria-carrying particles per cu. ft. In this examination the sampler had been placed in a corner in front of a ventilator. The draught was slight but possibly enough to cause the clouds of organisms to drift away from the sampler.

The opportunity to examine the north theatre during an operation occurred on another occasion<sup>15</sup> (89).

760 cu. ft. of air were sampled with an average of 9. bacteria-carrying particles. This time the theatre was occupied throughout the sampling and there was continual movement. The two peak counts were associated with the entrance of the patient accompanied by the anaesthetist and two orderlies after which there was a gradual decline in the number; and again, when the patient was sat up, still unconscious, for lumbar puncture. This involved a certain amount of disturbance of clothes, and friction, the anaesthetist and orderlies pushing and pulling the patient in to the sitting posture and maintaining him there. The figure then rose to 17. Three colonies of Staphylococcus aureus were recovered, two from one plate and another from a second plate, that is, there was one particle carrying Staphylococcus aureus in 253 cu. ft. of air.

There was a considerable increase in the number of bacteria-carrying particles as compared with the previous sampling. It persisted throughout and did not depend on some observed event. In the first examination, the sampler had been on the far side of the theatre and away from the traffic; a ventilator behind the sampler may have caused a drift of organisms away from it. On the second occasion, the sampler was near the door and near the line of traffic. This may account for the higher figures. In the first, also, there had been a long quiet period, while, in the second, there was continuous activity.

Swabs from the nose and hands were taken after the operation (90). One orderly (S.) was a nasal carrier and he had been in and out of the theatre but not in direct contact with the operative field. A sister (R.) was also a carrier but she was working in the annexe during the operation, which, however, was in close aerial association with the theatre. The patient also had a nasal infection. He died in the afternoon and so the matter could not be pursued.

As mentioned above, the patient is X-rayed between the operative part of the ventriculography and the major operation. The X-ray room is 18 by 24 ft. and 12 ft. high and without a window. Defective waxcloth covers the floor. There are an X-ray table and tube, two cupboards, plaster shells, a trolley, a coat rack, a large box and some smaller things. It is, in fact, a store. This room is reached across a long narrow room containing apparatus and packing cases, and this opens on to the corridor.

The radiographer takes two exposures for each position of which there are four. Normally she develops the two films for each position before doing the next. The exposure takes one minute, the developing eight. The patient is, therefore, in the X-ray room for half an hour. He comes into fairly intimate contact with the radiographer. The radiographer attached to the Neurosurgical Unit was carrying Staphylococcus aureus in the nose.

A mock radiological examination was done (91). A nurse not carrying Staphylococcus aureus acted as patient /

patient and the radiographer went through the motions of X-raying the head of the nurse. On this occasion there was no pause for developing the plates. She went straight on and had finished her work in the first six minutes of sampling. The sampler was six feet away from the radiographer and the patient's head. 190 cu. ft. of air were examined and contained an average of 6 bacteria-carrying particles per cu. ft. 71 colonies of Staphylococcus aureus were obtained from the 190 cu. ft. of air, that is, one particle in 2.7 cu. ft. was carrying with Staphylococcus aureus. This extremely high content was not satisfactorily explained. The active movement was at the head of the table where the radiographer was working. Elsewhere in the room, everything was as still as could be.

Cultures were taken on moistened swabs from the ventilator, the radiator, the edges of the wax-cloth, the exposed floor boards and the plaster casts (92). Staphylococcus aureus was not isolated. The cloth from the draught screen was shaken in the sampling box. No Staphylococcus aureus was recovered (93).

On the following day, the X-ray room was beaten with a sterile cloth as in the theatre (94). A control before beating showed that there were 2 bacteria-carrying particles per cu. ft. During the beating, 209 cu. ft. of air were sampled. There was an average content of 12 bacteria-carrying particles per cu. ft. Eleven colonies of Staphylococcus aureus were /



were recovered from the 209 cu. ft., that is, one in 19 cu. ft. It is clear, therefore, that the dust in the room was heavily contaminated with Staphylococcus aureus in spite of the negative cultures from the swabs of dust.

The room was again examined on another afternoon (95). The radiographer had done two encephalograms at 11 a.m. Two control plates exposed at 3 p.m. showed an average of 2 bacteria-carrying particles per cu. ft. Then someone in a dust-proof garment, mask and cap imitated the movements of the radiographer whom he had previously observed. 190 cu. ft. of air were sampled and an average of 2 bacteria-carrying particles was obtained. Staphylococcus aureus was not recovered. This suggests that the radiographer's movements do not stir up dust containing Staphylococcus aureus, but, rather, that she gives off the organism from her clothes or person. Immediately following this the dust was whirled into the air by means of a sterile cloth, particular attention being paid to the area in which the radiographer stands. 152 cu. ft. of air were sampled with an average content of 4 bacteria-carrying particles per cu. ft. Two colonies of Staphylococcus aureus were recovered, that is, one in 76 cu. ft. A fortnight had elapsed between this beating and the previous one, during which time the radiographer had been on a ten days' holiday. She had, therefore, been working in the X-ray room at the most for four days. The charwoman had been accustomed to sweep it daily. Even though /

though Staphylococcus aureus survives a long time in dust, the brushing would remove some of it. This and the absence of the radiographer might account for the reduced number of Staphylococcus aureus recovered from the air on this last occasion.

Finally, the radiographer was examined on the fifth day after her return from holiday<sup>25</sup> (96). On this occasion she was masked, talked very little and was dressed in a white coat. A house surgeon acted as patient. He did not carry Staphylococcus aureus. He wore a sterile surgical gown, cap and mask, and got into position on the table with a minimum of movement. 228 cu. ft. of air were sampled containing an average of 2.5 bacteria-carrying particles per cu. ft. Staphylococcus aureus was not isolated. The radiographer was still carrying the organism in her nose.

These results seem to me to show that, before going on holiday, the radiographer's clothing and surroundings were heavily contaminated with Staphylococcus aureus. They were not derived directly from the nose during the sampling as she spoke little - a few directions to the nurse on the couch - and there were no violent respiratory activities. Nevertheless, during her movements, the atmosphere was grossly contaminated with the organism. On her return, she was still a carrier, but the number of Staphylococcus aureus in the X-ray room had been diminished by sweeping, her white coat was fresh, and, possibly, there were other alterations in her clothing. The large male ward was examined on one occasion /

occasion to find out if Staphylococcus aureus occurred in the air (97). Dinner was just finished and a little sweeping was done as the sampling began. Following this, the nursing staff were in and out of the ward for 25 minutes during which period 247 cu. ft. of air were sampled, with an average content of 25 bacteria-carrying particles per cu. ft. For the next forty minutes there were only one or two brief visits from the staff, and the patients lay quietly reading or sleeping. During this period 399 cu. ft. were sampled with an average of 15 bacteria-carrying particles per cu. ft. Then nine visitors arrived but, once seated by the beds of the patients, there was little movement. 114 cu. ft. of air were sampled and it had an average content of 15 bacteria-carrying particles per cu. ft. The total amount of air examined was 760 cu. ft. with an average content of 18 bacteria-carrying particles per cu. ft. Five colonies of Staphylococcus aureus were recovered, that is, one in 152 cu. ft. The nares and hands of the seven patients in the ward were swabbed. Four of the seven were carrying Staphylococcus aureus in the nose and one of these four had Staphylococcus aureus on the hands (98).

The Staphylococcus aureus was recovered only during the quiet period before the visitors arrived, and two of the colonies were found on one plate. The visitors caused a slight rise in the count when they entered, but since they all sat down at /

at the bedsides of the patients, the counts dropped. The visitors did not bustle about and therefore, did not raise much dust.

The large female ward was next examined (99). Tea was just finished and bedmaking began. 399 cu. ft. were sampled and there was a steady rise in the count from 5 per cu. ft. after tea, to 33 when a bed near the sampler was made. Six colonies of Staphylococcus aureus were recovered, that is, 1 in 67 cu. ft. Nasal swabs of the six patients were taken and of these, only one was carrying Staphylococcus aureus (99).

The examination was repeated two and a half weeks later (100). 817 cu. ft. of air were sampled. The visitors had just left and tea was in progress when the examination began. Tidying up followed tea, and continued throughout the examination which lasted for an hour. The plate counts were lower than in the former experiment and the range was narrower - from 6 to 18 - the average for the period being 10.5 bacteria-carrying particles per cu. ft. The activities in the ward were much the same throughout and the counts did not fall into groups. Nine plates could not be counted because of the presence of "spreaders" which occasionally become prevalent in a room where they have not been noticed before. Seventeen colonies of Staphylococcus aureus were recovered, that is, 1 in 48 cu. ft. The six patients were nose swabbed. Three were carrying Staphylococcus aureus - one a patient admitted since the previous examination, and two /



two who had been free on the previous occasion (100).<sup>26</sup>

Staphylococcus aureus was not isolated from the towel in the preparation room, the vulcanite taps of the saline tanks in the sterilizing room, the "three in one" instrument oil, a horse shoe head rest, washings from a ventricular catheter, washings from the rubber tubing attached to another ventricular catheter, and the trolley pillows and the macintoshes that covered them. The pillows were examined by placing them on a clean rabbit cage in the sampling cabinet and beating them vigorously with a window pole through the almost closed door. The trolley blankets which had been in use during the period of infection, had been sent to the laundry and so were not available for examination.

Dr. Purdie, Bacteriologist at Bangour Hospital, found that on 16th November, fifteen members of the available staff of forty five were carrying Staphylococcus aureus; fourteen of them, in the nose, and one in the throat. A fortnight later eighteen of the available staff of forty eight were carrying Staphylococcus aureus; seventeen, in the nose and one, in the throat. A selection of strains from staff and from infected wounds or cerebrospinal fluid in patients were reported by the Central Public Health Laboratory to belong to the same 'phage type.

In conclusion, Staphylococcus aureus had been recovered in quantity from both theatres, the X-ray room and the two wards. At least a third of the nursing /

nursing staff were carriers of the organism, among whom were a key sister in the theatre and a theatre orderly. The surgical and medical staff were free from the infection.

Under the circumstances, the surgeon in charge thought it best to transfer cases for operation to the Department of Neurosurgery in the Royal Infirmary. He excluded carriers from the theatre and those who were working there were examined from time to time. No further cases of post-operative infection occurred.

In the meantime, an effort was made to clear the carriers of the infection. The Ear Nose and Throat Surgeon kindly examined as many of them as possible and excluded underlying pathological processes. He recommended the use of Ung. Hydrarg. Ammoniat. 1% twice daily for a fortnight, after which he undertook to review the cases. It was, however, impossible to follow up all the carriers as some were on night duty and some were sent to other wards. Of those who were available for examination, not one responded to the treatment. Propamidine (May and Baker) was then used, but there was, likewise, a complete lack of response.

Of the two carriers in the theatre, the orderly was replaced and the sister was sent on holiday to a farm where she had an abundance of good food and outdoor exercise, and continued the treatment with the Ung. Hydrarg. Ammoniat. She sent several nasal and hand swabs to me but the nose swabs always yielded /

yielded a growth of Staphylococcus aureus. Dr. G. A. G. Peterkin has since told me that "outdoor exercises rather tend to increase the number of staphylococci on the skin."

Practically all the strains of Staphylococcus aureus were penicillin resistant. It was, therefore, decided to use staphylococcal 'phage of the homologous type. While this was being prepared, Professor Ellis of the Department of Child Life and Health kindly made available a supply of chloromycetin. The capsules were broken and the antibiotic was incorporated in Unguentum Alcoholium Lanee (B.P.) to make a 30% concentration. Ung. Alcoh. Lan. was chosen as it is the base in penicillin ointment. A quantity of this chloromycetin ointment, small enough to be inconspicuous, was applied to the anterior nares, to find out if it was irritant. No untoward effects were observed but the quinine-like taste of the substance was clearly perceptible for at least twelve hours. It appeared that the chloromycetin was dissolving in the mucus, out of the little depot of ointment in the anterior nares, and drifting in the mucous current backwards to the throat.

The first carrier was treated with 30% chloromycetin ointment thrice daily for seven days (101). A week after the cessation of treatment, swabs from the anterior nares were sterile. Then patients 2, 3 and 4, who were carriers, were treated with the ointment twice daily for seven days. One was /

was clear from infection twenty days after the end of treatment, another was clear six days after the end of treatment, but Staphylococcus aureus recurred in the third. In the meantime, a 10% chloromycetin ointment had been supplied to Dr. Purdie for trial, but she found that it was ineffective. I therefore made a 20% chloromycetin ointment and treated eight infected patients with it twice daily for seven days. All of them were free from infection on the third day. One was discharged before finishing treatment; three were not examined after completing the course; one had a recurrence as soon as the course was finished; another was clear seven days later; while another had a relapse which cleared up spontaneously. It may have been that the relapse was really a transient contamination of the mucous membrane from air or dust. This seems to happen frequently. One isolates a few colonies of Staphylococcus aureus from the nose of a patient on one occasion, while, at the next examination, one fails to do so.

With regard to these last eight cases, several criticisms can be made. Cases 5, 6, 7 and 8 may or may not have been permanent carriers. Only one swab was taken before treatment. Transient carriers clear up spontaneously. A number of patients and members of the nursing staff in ward 20, Royal Infirmary, showed this transitory infection. Indeed it was quite common. It would be more accurate, it seems to me, to regard it as a contamination of the nose /



nose rather than as a colonization. The mucous-moistened vibrissae must be a fairly efficient filter. Cases 9, 10 11 and 12 were not permanent carriers because they had one or two negative nasal swabs in the four weeks preceding the isolation of Staphylococcus aureus from their nares. The organisms might well have disappeared at the time they did without treatment, and they would certainly have gone eventually. Patients 2, 3 and 4 were probably genuine carriers since they yielded two positive swabs at intervals of one to two weeks before treatment.

The residual chloromycetin may have interfered with the growth of Staphylococcus aureus from the swabs taken during treatment. This is suggested by cases 5 and 6, where there was a recurrence of the organism on the day following the cessation of treatment. On the other hand, six of the swabs taken during treatment were positive.

The theatre sister, the first part of whose history is recorded above, was more readily available for bacteriological examination and treatment than the other carriers. She was undoubtedly a permanent carrier; the nasal swabs always yielded a heavy growth of Staphylococcus aureus. After returning from holiday, she continued to apply the Ung. Hydrarg. Ammoniat. twice daily until the 10th January; that is, she had six weeks of treatment with the ointment. There was no improvement in her condition; all of the twelve cultures from the nose, which had been taken since she had come under observation on the 31st /

31st October, had yielded an abundant growth of Staphylococcus aureus. The Ear, Nose and Throat Surgeon saw her once again and reported "Hair follicles in vestibule perfectly healthy. Nasal airways clear." After that, she used Propamidine Ointment (May and Baker), 0.1% chloromycetin solution, and 10% chloromycetin ointment in succession. On the result of these treatments Dr. Purdie wrote, "There was very little variation in the bacterial flora during treatment with Ung. Hydrarg. and later propamidine cream. Following the use of chloromycetin solution the number of aureus colonies decreased and albus appeared. With chloromycetin ointment, there remained a mixed growth on culture, but the number of both types, aureus and albus, decreased."

The sister then began to use 20% chloromycetin ointment twice daily for three weeks, beginning in the middle of February. Nasal swabs taken two, six and ten weeks after the cessation of treatment, have failed <sup>to yield</sup> a growth of Staphylococcus aureus. They are still negative in October, 1950.

It can be claimed, therefore, that chloromycetin, if applied in adequate concentration and for a sufficient length of time, will temporarily clear the nose of Staphylococcus aureus. There may, possibly, be no relapse. If the organism returns, then the treatment may be repeated; there is, so far, no record of resistance to chloromycetin.

Professor Ellis has lately kindly supplied a quantity of aureomycin. The effects of this antibiotic /

antibiotic will probably be more certain and more permanent than those of chloromycetin. When the opportunity arises, it is proposed to use a 20% ointment of aureomycin in Ung. Alcoh. Lan. Such an ointment can be applied to the nose without producing irritation. It has the minor disadvantage of being bright yellow and so, obvious in use.

Twenty four strains of Staphylococcus aureus isolated from the air, and from the noses and hands of nurses and patients, were tested for their sensitivity to chloromycetin and aureomycin (102). The cocci were inoculated on to plates of nutrient agar containing 10, 50 and 100 micrograms per ml. of chloromycetin and aureomycin. All were sensitive to 10 micrograms of chloromycetin per ml. of nutrient agar. All except one were sensitive to 10 micrograms of aureomycin per ml. of nutrient agar. This one exception grew scantily on the 10 microgram plate but not on the 50 or 100 microgram plates. Twenty were tested for sensitivity to penicillin; three were sensitive to 10 units per ml. Sixteen were tested for streptomycin sensitivity; ten were sensitive.

In the meantime, the operative work of the neurosurgical unit had been taken to the Royal Infirmary. All the theatre staff were examined and found free from Staphylococcus aureus. One nurse in the sterilizing room had a paronychia from which Staphylococcus aureus was isolated. The neurosurgical theatre in the Royal Infirmary is small - 14 ft. /

14 ft. by 14 ft. When the operating table, two large service tables, one or two smaller tables, the anaesthetic apparatus, the movable basin and the two movable lights are in the theatre in addition to six or more people, there is little spare room, and it is difficult to move without coming in contact with sterile tables. Those who must move, have to sidle.

The air of the theatre was sampled just after the staff had taken over (103). They were not used to the theatre and did not know where things were, and there was, necessarily, much movement especially of one sister and one orderly. The volumes of air sampled under these circumstances were too great to allow of accurate counting, as the air was heavily contaminated. Counts of bacteria-carrying particles per cubic foot varied between 41 during the laying out of the instruments to 16 at the end of the series of observations and near the end of the operation. During the first part of the operation, one colony of Staphylococcus aureus was recovered from the air, but none subsequently; that is, one particle carrying Staphylococcus aureus in 817 cu. ft. of air. During the operation the fan was turned on, but a slight drop in the bacterial count was followed by a rise. Another drop in the count occurred towards the end of the operation when there was less activity and the organisms had a chance to settle. The small theatre was so crowded with personnel and apparatus, that the air had little chance to circulate; hence the slight drop when the fan was turned on.

With /



With regard to the presence of Staphylococcus aureus, the patient was a carrier. For lack of anything else, powdered penicillin was insufflated into his nose on the night before the operation, on waking the following morning, and before going to the theatre. A nasal swab taken after the operation was stained with penicillin and yielded a good growth of Staphylococcus aureus. Between the ventriculography and the operation for the removal of a right occipital tumour, the patient was taken to the busy X-ray department. The radiographer who took the X-rays of the patient's head, was a carrier. Moreover, as mentioned before, the nurse in the sterilizing room, had a paronychia infected with Staphylococcus aureus, and was a nasal carrier.

The theatre was again examined (104) and, on that occasion, 1387 cu. ft. of air were sampled. Five colonies of Staphylococcus aureus were obtained, or one in 277 cu. ft. None of the staff in the theatre were carriers. The patient (B.G.) when swabbed four days before the operation, was not carrying the organism. Staphylococcus aureus may have drifted in from the neighbouring rooms or from the corridor; or it may have been present in the dust. The plate counts were high throughout and the counting was, therefore, inexact. Twenty-nine of the plates could not be counted because of the 'spreaders'. These were not present on the previous occasion a fortnight before although the counts were then, if anything, /

anything, higher; the range then was from 16 to 41, while, on the second occasion, the range was from 12 to 34. In this theatre, there is no excess of air to act as a diluent. It is so small that the bacterial clouds cannot disperse.

Out of 21 physicians and surgeons working at various times in the clinic, only one was found to be carrying Staphylococcus aureus in the nose and that on only one occasion (105). His nasal swabs had been negative on two previous examinations, and were negative on two subsequent occasions. His nose was, in fact, contaminated, not colonized. The number of nasal swabs taken from each individual varied from one to eight, and the period was from October until May. There were, therefore, no carriers among the medical or surgical staff.

Of 43 of the nursing staff, 4 were carriers, that is, their nasal swabs yielded a growth of Staphylococcus aureus on two or more occasions (106). Four were positive once, but negative on previous or subsequent swabbing. Four had only one positive swab, and no other examination was done. Of the two domestics, both were intermittent carriers, that is, their nasal swabs sometimes gave a growth of Staphylococcus aureus and sometimes did not. One had a chronic blepharitis.

of 122 patients, 13 were positive on two or more occasions, 21 were positive on the only occasion on which they were examined, and 11 were positive once, /

once, and negative before or subsequently (107).<sup>33</sup>

Swabbing was done at fortnightly intervals and, consequently, a number of the nursing staff and of the patients were seen only once.

#### A Surgical Dust-Proof Suit.

One of the sources of infected particles in the air is the skin and the clothing. It is known that an increasing degree of activity is associated with an increasing degree of aerial contamination. This is of some consequence when handling an air sampler, and Duguid and Wallace (1948) made an attempt to design a dust-proof garment. This was effective and reduced air contamination during activity by 90%, while the surgical gown when carefully put on, would only reduce air contamination by 50%. (108).

The garment as used for air sampling, was much too heavy for the use of surgeons. Nevertheless, Professor Dott thought that it might be adapted to their use if it were made of cloth of lighter weight. He also suggested the introduction of zip fasteners into the arms and legs of the garment so that it might be put on without coming in contact with the floor, and so that the surgeon might wash his arms after he had donned the suit.

The final garment was as follows. The upper part or blouse was made of light weight down-proof cotton with a satin finish which is said to prevent the escape of down. The trousers sewn on to the blouse, were made of the same type of material but heavier in weight. A zip fastener secured the trunk of /



The first stage in putting on the surgical, dust-proof suit. For use in the theatre, it would be worn next the skin.





The left arm and right leg are now dressed. The left leg and right arm have still to be enclosed.

of this garment and finished at the neck. The up-  
:standing collar was padded to fit closely to the  
neck and was fastened in front by tape. A zip  
fastener extended along the inside of each sleeve  
from above the elbow to the wrist. The sleeves  
could be tied to the wrist by tape. A zip fastener  
extended down the inside of each trouser leg from  
knee to ankle, the legs of the trousers being fasten-  
:ed to the ankles by tapes. When the zip fasteners  
are opened the legs of the garment can be looped up  
to the waist, and the sleeves to the shoulders. It  
is folded in this way for sterilization. The surgeon  
can put on the garment without its touching the floor.  
He then undoes the trouser legs, fastens the zips and  
ties the ankles. Long cloth boots previously steril-  
:ized, are now drawn on. They are of heavy twill  
cotton, have soles reinforced with canvas, and lace up  
like buskins. The front of the blouse is closed, the  
neck adjusted, and the arms and hands are washed.  
Finally the sleeves are unlooped, closed by the zip  
fasteners, and tied at the wrists with the tapes.  
This is the basic garment; for use in the operating  
theatre, there would be little or nothing between it  
and the skin. Over it is worn the surgical gown.

This dust-proof suit was examined as foll-  
:ows (109). Each of twelve volunteers was the sub-  
:ject of three experiments. On each occasion he  
marked time for ten minutes in the sampling cabinet  
described above, the capacity of which is 100 cu. ft.

On /

On the first occasion, he wore ordinary clothes; on the second, ordinary clothes plus a surgical gown; and on the third, ordinary clothes plus the dust-proof suit. He always wore a surgical cap and mask to exclude dust from the hair and droplets from mouth and nose. The sampling was done as follows. First, a 10 cu. ft. control was taken. Then the subject entered the cabinet and marked time for ten minutes, during which period four samples of two cu. ft. each were taken, forty seconds being allowed between each to change the Petri dish in the sampler. In this series of experiments, the surgical gown reduced the number of bacteria-carrying particles to 74%, while the dust-proof garment reduced them to 18%. Some of the subjects were women and slightly built and so the garment did not fit well. In the zip fasteners also, there are gaps between the interlocking elements. These gaps might be partly stopped up by having a flap of cloth something like the tongue of a shoe, behind the zip.

The zip or slide fasteners are made by Messrs. Newey Brothers of Birmingham. The interlocking elements are made of nickel-plated brass and the body of the slider is made of nickel-plated die cast zinc. The body of the slider under repeated sterilization, will first lose its nickel covering, and then the exposed zinc will oxidize. At first, I tried to prevent this corrosion by smearing the slider with vaseline, before sterilizing the garment, but this was ineffective. The sliders begin to show signs /

signs of corrosion before the twentieth sterilization. After 72 exposures to steam, however, the sliders still work. If it is necessary to sterilize zips, then the bodies of the sliders can be specially chromium-plated, or treated with one of several anti-corrosion finishes. This might prolong the life of the zip.

However, the surgeons thought that even the modified dust-proof suit would restrict movement and would make them uncomfortably hot. There is a third disadvantage, namely, that, if the suit is to be effective, it requires careful maintenance.

#### Epithelial Debris from the Face.

There is a possibility that epithelial scales may fall from the face and eyebrows of the surgeon into the wound over which he is working. Duguid and Wallace, when designing a dust-proof garment, covered face and hands with vaseline in order to reduce aerial contamination from this source. However, such an application did not lessen the number of bacteria-carrying particles recovered from the air, and they concluded that air was not contaminated from this source. In prolonged neurosurgical operations, however, the surgeon's face is directly over the wound many times during six hours. Here is the possibility, not of airborne infection, but of heavy and visible debris falling from the face directly into the wound.

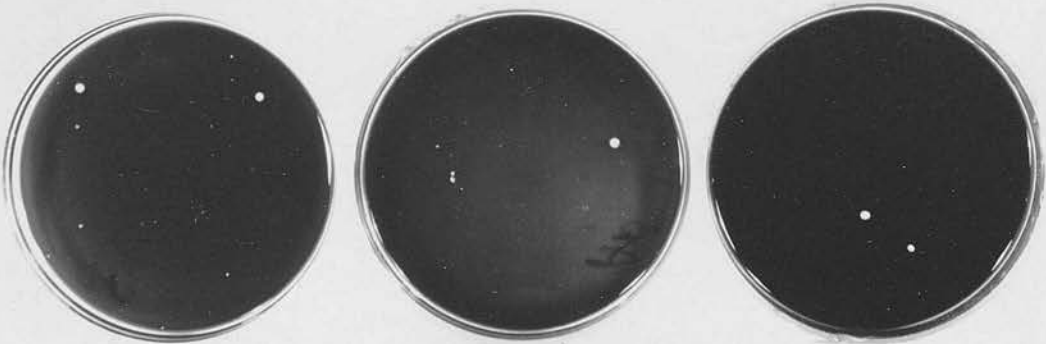
Three Petri dishes containing blood agar were arranged in a triangle close together at one corner of a table, and three at another corner (110).

Between /





Three Petri dishes showing the growth which occurred when the unvaselined side of the face was held over them and scraped.



Three Petri dishes showing the growth which occurred when the side of the face smeared with vaseline was held over them and scraped.

Between the two sets was a Petri dish to serve as control. The room was shut and not entered again for twelve hours. At the end of that time the subject of the experiment clad himself in a sterile dust-proof suit, surgical cap and rubber gloves. One half of the face including the eyebrow was smeared with vaseline, and then the subject entered the room and opened one set of Petri dishes and the control. Holding the face about a foot above the set of three Petri dishes, he scraped the unvaselined eyebrow from the lateral to the medial end six times with the edge of a sterile glass slide, holding his hand and arm out of the way as much as possible. The scraping was repeated on the cheek of the same side using another edge of the glass slide. During the scraping, epithelial scales fell into the Petri dishes especially from the eyebrow which also shed a few hairs. The three plates were closed and the subject repeated the operation over the other three dishes using this time the vaselined side of the face. No falling epithelial debris was seen. The Petri dishes including the control were closed and, after incubation, the colonies were counted.

Groups of colonies of Staphylococcus albus were clustered around a central epithelial scale or lay along the course of eyebrow hairs on those plates exposed to the debris from the unvaselined side of the face. These groups were counted first and then an attempt was made to enumerate the total number of colonies. Epithelial scales and eyebrow hairs were not found on plates exposed to the vaselined side of the /

the face. All the colonies on these plates were separate. Indeed, their numbers were little in excess of the control plate. The control plate was open for twice as long but its area was only a third of the three Petri dishes.

The degree of scraping of the treated and untreated sides of the face was, of course, equal. It was rather more vigorous than that to which the skin of the face would be subjected by the rubbing of a cap or mask. On the other hand, the lightest friction will sometimes send down a shower of epithelial scales from the cheeks and especially from the eyebrows, more particularly when the skin is dry.

Greasing the face has been advocated before and at least one neurosurgeon practises it. If the aim in neurosurgery is complete asepsis, then the surgeon, it seems to me, should take this small precaution.

#### Discussion.

The presence of Staphylococcus aureus in surgical theatres is not a new phenomenon. It has been recorded on a number of occasions some of which are summarized in the following table.

---

Author /

Author.	No. of Cases.	Total Infections.	Infections with <u>Staph. aur.</u>
Beckman (1914) Mayo Clinic	6,825	117 (1.7%)	21 (18%)
Meleney (1933) Presbyterian Hospital, N.Y. City	-	-	- (35%)
Eliason and McLaughlin (1934)	-	10 (serious)	5 (50%)
Hart (1937)		Clinically infected wounds. Clinically not infect- :ed extra- :pleural :thoraco- :plasties	- (90%) - (35%)
Ives & Hirsh- :feld (1938) New Haven Hospital	1,361	72 (5%)	18 (25%)
Devenish & Miles (1939)	54 (Surgeon A)	-	14
	41 (Surgeon B)	-	1
Miles et al. (1940)	154	- (91.2%)	- (53.3%)

A variable number of wounds becomes infected, the numbers discovered depending on the methods used to detect the presence of the organisms. The infection which produces a general reaction is, of course, not common, but the number of wounds which become contaminated, is high. Staphylococci and micrococci are, apparently, chiefly responsible and these are derived from the skin and whatever comes in /



in contact with it. Staphylococcus aureus is partly or wholly responsible for a considerable number of these infections and it is also a surface organism. Indeed, the site of its colonization and the immediate neighbourhood, is possibly, touched more frequently than any other part of the body, and the contaminated fingers and hands can spread it far and wide.

Infections due to organisms derived from the throat are not so common. Cushing (1931), Cairns (1935) and Paine (1935) described cases of post-operative streptococcal infections associated with throat infections among the theatre staff. Duguid and Wallace (1948), however, found only 0.018% of Str. viridans in the air artificially contaminated by individuals. If Str. viridans is accepted as an indicator of the presence of organisms originating in the throat (Gordon, 1903), then organisms coming either directly from this source, or mediated by clothing, are not a grave menace in the operating theatre.

On the other hand, Staphylococcus aureus lodging immediately inside the nares, is a threat, a kind of Damoclean sword suspended over the operation wound. Duguid (1945) found that normal nose breathing for a five-minute period, resulted in the expulsion of a few droplets from the nose. He pointed out that if two droplets are expelled every five minutes, the daily total of about 500 is not negligible. A third of this would be expelled in a working day of eight /

eight hours. If several people do this daily for some months, then the contamination of the environment will be considerable.

The area colonized by Staphylococcus aureus is also subject to drying, and is accessible to the fingers and handkerchief. A small daily scattering of organisms from such a source into the air and dust of the theatre, will add up in time to a sizeable quantity and, as the coccus survives under adverse conditions, it will form an ever-increasing reservoir in the dust. The danger is not so much from the nose directly, as from the nose to the dust and then to the wound. Duguid and Wallace (1948) recovered 0.06% to 0.12% of Staphylococcus aureus from air contaminated by carriers of the organism. This was derived from the clothes as the subjects were carefully masked and did not speak. The organism was also recovered from the chin, hands and clothing of the carriers. Hare (1941) showed that the nasal carrier contaminated his person more widely than the pharyngeal carrier. Moreover, sneezing experiments done by carriers gave a lower degree of contamination of the air with Staphylococcus aureus than that which occurred when the organism was derived from the clothes and skin.

None of the twenty two surgeons and doctors attached at one time or another to the neurosurgical unit, was infected with Staphylococcus aureus. One would have expected to find four or five carriers among them. Indeed, the carrier rate among them should /

should have been over 20% since they spent long hours in the theatres and wards where the dust was contaminated with the organism, and among nurses and patients among whom the carrier rate was high.

On the other hand, over a third of the nurses were carrying Staphylococcus aureus. Two carriers spent all their working day in the theatres or neighbouring rooms, and one of these two was well within the operative field for the six to eight hours of an operation. Moreover, in the most carefully cleaned theatre, there are large areas that are not washed down daily, for instance, the walls, ceiling and chandeliers. The beating technique which I used to sample dust, did not show where the infected dust came from, whether floor, walls or ceiling. Hart (1937) however, said that he had recovered Staphylococcus aureus from the walls and ceiling as well as from the floor.

The risk of infection is probably greater in operations on the central nervous system than in other regions, partly owing to their longer duration and partly to the greater vulnerability of some of the contents of the cranial cavity. Cairns (1939) thought that the brain has probably a considerable degree of resistance to infection and that it is, rather, the cerebro-spinal spaces that are vulnerable.

In the neurosurgical theatre, two bacteriological objectives have to be attained. Firstly, the total number of organisms must be reduced to the lowest /

lowest possible level; Bourdillon and Colebrook (1946) suggested that the total count of bacteria-carrying particles per cu. ft. should not exceed 2. Secondly, Staphylococcus aureus has to be banished from the theatre.

The former objective can be compassed by providing, first of all, clean outside air slightly under pressure to the theatre. If the air is taken into the ventilating system a few feet above the roof and well away from sources of bacterial contamination, it will certainly be better than that provided by natural ventilation through windows and doors. Filtration through glass fibre will remove dirt and the air can be further purified by passing it through an oil filter. Absolute sterility is rather expensive to maintain and is probably not necessary. The slightly raised air pressure in the theatre will prevent bacteria-carrying particles from the corridors and annexes from invading the theatre.

Every effort should be made to avoid contaminating the air and the environment. The bacterial count is proportional to activity since the bacteria-carrying particles are derived from the skin and clothes. The greater the activity, the higher the count. The peak figures in the neurosurgical unit occurred when the nurses were laying out the theatre and when the patient was brought in. This contamination of the air with saprophytes is not altogether to be ignored. Cairns (1939) in a theatre opening off /



off a main corridor and ventilated by a fan, recovered Staphylococcus albus at the rate of 23 an hour on settling plates. Two cases of sepsis due to Staphylococcus albus occurred among those operated upon in this theatre. In another theatre supplied with filtered air and not opening off a main corridor, Staphylococcus albus was recovered at the rate of 10 an hour and there were no cases of sepsis from without, in 80 major operations. Cowan (1938) described six cases of cerebral infection with organisms normally regarded as saprophytes or contaminants. Five of them followed operative procedures. Leriche (1939) thought that saprophytes which settled in wounds, although not producing inflammation, might cause weakness of the scar. He also suggested that the adhesions which may form in the peritoneal cavity after an operation even when no viscus has been opened, may be due to saprophytes.

Unauthorized persons should not enter the theatre. It should be kept locked and regarded as sacrosanct. The smallest possible number should enter it to work; and they should be suitably clad. The surgical gown when worn over ordinary clothes, will reduce the contamination from them by 50% or less (Duguid and Wallace, 1948). This is not sufficient. Those who enter the theatre should, therefore, change into freshly laundered shirt and trousers which will be sterile or nearly so if they have been protected from dust after their return from the laundry. /

laundry. The sterile surgical gown over the top of this will protect the surgeon's clothes from blood and fluids, and the patient from the clean but not completely sterile clothes of the surgeon.

The dust-proof garment will reduce the amount of dust given off from the surface of the body by 90%. The suit might retain this dust-proof quality even if made of lighter cloth provided that the weave is close enough. The closely woven cloth will, of course, interfere with the movement of air, and the wearer may find the garment too warm.

The cotton, dust-proof garment, especially after repeated sterilization, will give off cotton fibres which can be recovered on the agar sampling plate. Nylon does not disintegrate in this way. Surgical gowns and boiler suits of nylon are comfortable to wear and, unlike the early artificial silk garments, are not cold and clammy. They can be sterilized by steam under pressure, and the brown discoloration which appears after such treatment can be removed by laundering. At the moment, if the nylon is available, it will cost £5 for one garment.

The zip fasteners are convenient and easy to use. Moreover, they close the garment more completely than buttons do. They do not withstand hard wear and repeated sterilization. Messrs. Dewey Brothers of Birmingham would, if presented with a sufficiently large order, undertake to make zip fasteners with sliders of some suitable material which /

which would withstand water and heat.

A hood with eyeholes held open and in position by tapes, is a convenient headdress and combines the cap and the mask. If the lower part is tucked inside the neck of the dust-proof suit, it will act as a kind of valve to hinder the escape of bacteria-carrying particles from the neck opening. Or a cap with a flap at the back, and a yashmak might be used. I think that it is advisable to wear a close-fitting mask below the hood or yashmak as these cannot be arranged to fit firmly over nose and mouth. A mask of 24 layers of gauze will prevent the passage of droplets. I spread some congo red over the tip of the tongue, teeth and lips, and, while wearing the mask, counted deliberately from 1 to 200, shouting the numbers. The inside of the mask was deeply stained with the dye but none was evident on the outside. This mask was, however, rather heavy and hot to wear. The type of mask worn in the neurosurgical unit, is the pocket of gauze with cellophane inset. Blett and Dale (1933) who introduced it, found that the air escaping at the sides is practically sterile. I found that a few droplets would escape if the wearer sneezed; but that is a severe test. If properly worn, that is, firmly covering everything from the bridge of the nose to below the chin, it should restrain the few droplets produced by the occasional utterances in the theatre.

Gloves can be a source of trouble in the theatre. /

theatre. They are frequently punctured during an operation. There is no reason to suppose that defective gloves were the cause of this outbreak. None of the surgeons carried Staphylococcus aureus in the nose; their hands were, therefore, almost certainly not contaminated. Hand swabs taken at the end of operation from those engaged in it, did not yield a growth of Staphylococcus aureus.

The size of the theatre should be in proportion to the number of people who are likely to be working in it, and to the amount of apparatus required. The total number of organisms was seldom high in the Bangour theatres which were large. The theatre in ward 20 is small, and the total counts were usually high. When in use, the lower part of the theatre is crowded with personnel and matériel, and it is not possible to ventilate it adequately; the circulation of air is impeded.

The operating theatre for intracranial surgery should be reserved for non-septic cases, otherwise pathogens may contaminate the dust and remain there to menace patients who come later.

Gudin (1936) described what he called 'sterilisation totale'. The air of his theatre is sterilized by formaldehyde which is then neutralized by ammonia, and the resulting urotropine and the residual ammonia are absorbed by tartaric acid. The surgeon and his assistant are completely enveloped in sterilized hood and suit, and the patient is also hooded /



hooded and covered up with sterile drapes before being wheeled into the theatre. The anaesthetic must be principally spinal. The illustration accompanying the paper, shows only three people in the theatre, the surgeon, his assistant and the patient. Chemical sterilization, the author points out, allows of sterilization of such things as electric motors and anaesthetic apparatus. In fact complete sterilization is said to be achieved. Under the protection of this 'integral asepsis', wounds heal rapidly with a scarcely visible scar, no drainage is required, and no herniae develop. Hospitalization is reduced by 40%. Professor Leriche has operated in this theatre and says that it is comfortable to work under such conditions.

Contamination of the theatre with Staphylococcus aureus can only be prevented by identifying and excluding carriers. Knott and Blaikley (1946) describing their experience in a maternity unit, covering a period of four years, have found this rigorous control vexatious but possible. This difficulty will be overcome if the carrier can be freed of his staphylococci. Continuous bacteriological control will be necessary, and this will include monthly nasal swabbing of personnel with more frequent examinations when colds are prevalent. House surgeons and nurses should be swabbed before they are posted to the unit; and patients should be swabbed as soon as is convenient after admission. Patients admitted /

admitted for an emergency operation could have anticipatory treatment, so that a possible carrier will not enter the theatre.

The problem of the carrier of Staphylococcus aureus has loomed large in recent years. General surveys have been made of students, out-patients and R.A.M.C. personnel. Otherwise, they have generally been confined to hospital staffs in connection with outbreaks of staphylococcal infection. Some of these surveys are presented in the following table. I have excluded the results of swabs taken from other parts of the body, when nasal swabs have been done also, in order to simplify the table and because skin carriage is generally dependent on nasal carriage (Gillespie et al., 1939; Martin, 1942; Miles et al., 1944; Williams, 1946). Where only skin or throat swabbing has been done, I have included it as a higher percentage of nasal carriage may be inferred.

Author.	Number, and Type of Case.	Nasal Carriage.	Comments.
Shibley et al., 1926	13 individuals	II 11/13	
Benians & Jones, 1929	66 antenatal		12% (throat)
	83 puerpera		15% (throat)
	25 newborn	2 (8%)	

H art /

(Table continued).

Author.	Number, and Type of Case.	Nasal Carriage.	Comments.
Hart (1937)	57 theatre Staff	35 (61%)	January
	44 " "	44 (100%)	"
	53 " "	14 (26%)	February
	56 " "	9 (16%)	September
	54 " "	39 (70%)	January
Hallman (1937)	272(2mth.- 12yrs.)	159(58%)	
	38(13yrs.- 19yrs.)	23(61%)	
	49 Hosp.pat- :ients	22(45%)	
	109 students	40(37%)	
McFarlan (1938)	101 students	33(34%)	
	31 adult hosp.pat.	13(42%)	
	33 child hosp.pat.	19(58%)	
Devenish & Miles (1939)	40 surgeons, nurses & a few patients	18(45%)	
Gillespie et al. (1939)	159 med. stud- :ents & young graduates	49(31%)	
Bartley (1941) (quoted Miles et al., 1944)	82	(22%)	
Smith /			

(Table continued).

Author.	Number, and Type of Case.	Nasal Carriage.	Comments.
Smith (1941)	100 personnel Gen.Hosp.	32(32%)	
Martin (1942)	100 soldiers		38(38%) upper lip
Vierthaler (1942)	50 med. stud- :ents		14(28%) skin
	50 patients with non- staph. dis- :eases.		7(14%) skin
McFarlan (1942)	16 newborn with pem- :phigus	15(94%)	
	25 newborn contacts	18(72%)	
Oxford (town) (1942)	19 ward attend- :ants	9(47%)	
	5 newborn with pem- :phigus	5(100%)	
	14 newborn contacts	8(57%)	
Benians (1943)	Mat.Unit Nurses	(85%)	January
	" " "	(70%)	February
	" " "	(50%)	April
	" " "	(25%)	June
	Admissions to Mat. Unit	(30%)	
	Newborn up to 10 days	/	



(Table continued).

Author.	Number, and Type of Case.	Nasal Carriage.	Comments.
Benians (1943) (continued)	Newborn up to 10 days	(100%)	Nearly
	Patients in children's ward, same hosp.	(30%)	
	Nurses in children's ward	(50%)	
Miles et al. (1944)	479 O.P.s Birmingham	(47%)	
	536 patients on admission	(49%)	
	74 nurses	(64%)	
Torrey & Reese (1945)	74 physicians, nurses & ward attendants	32(43%)	
	70 mothers	15(21%)	
Findlay & Abrahams (1946)	150 W.African soldiers		35(23%) nasopharynx
	150 W.African villagers		33(22%) nasopharynx
	100 Europeans in R.A.M.C.		38(38%) nasopharynx
Allison & Hobbs (1947)	103 medical, nursing & domestic staff	72(70%)	
Williams /			

(Table continued).

Author.	Number, and Type of Case.	Nasal Carriage.	Comments.
Williams et al. (1947)	14 nurses	5(36%)	Mat.home with pem- :phigus
	17 mothers	7(41%)	
	17 newborn	7(41%)	
Moss et al. (1948)	Male surgical patients	(20%)	
Martyn (1949)	130 healthy newborn 0 - 7 days	81(62%)	
Forbes (1949)	50 hosp. nurses	23(46%)	Peni- :cillin resist- :ant " "
	50 clerks	1(2%)	
Barber et al. (1949)	62 nurses & 2 M.O.s	44(69%)	19(54%) conjun- :ctival swabs
	35 healthy infants		

The percentage of nasal carriers is usually given from 20% among the general population, to 60% among nurses. The table shows, however, that the figures for the general population are often more than 20%, and that they may range upwards to 100% for nurses. Admittedly, some of the groups are rather small, and certain groups do not maintain a high rate of carriage, that is, some of the members of the groups are temporary carriers. Another feature which appears in the table, is the high rate of /

of carriage among the newborn; some of these figures are drawn from groups in which Staphylococcus aureus infection was present, and these groups have been selected for study on that account. Probably, the rate is not so high among the infants born at home. However, the noses of the newborn appear to be more susceptible to colonization with Staphylococcus aureus than those of older people.

The permanent carriers are those who have either an abundant growth on one examination, or a moderate growth on repeated examinations. The temporary carriers are those from whom only a few colonies of Staphylococcus aureus are obtained on one occasion. They have possibly inspired a few organisms from contaminated air. What with the moisture, the vibrissae and the convolutions of the nasal cavity, the nose must be a fairly efficient bacterial filter.

A number of attempts have been made to treat carriers of Staphylococcus aureus. Smith (1935) used 2% argyrol in the noses of infant carriers; he does not say with what result. Delafield and Straker (1941) used snuffs of 10%, 33.3% and 50% sulphathiazole, the last mixed with 50% sulphapyridine. The snuffs were used six times daily and there were no toxic signs. Seventeen carriers were treated. In all except one the quantity of Staphylococcus aureus was greatly reduced but it did not entirely disappear. Small numbers of coagulase-positive white staphylococci and Staphylococcus aureus tended /

tended to persist in a few carriers. Three to six weeks after the cessation of treatment, a heavy growth of Staphylococcus aureus was again obtained. Delafield and others (1941) tried tobacco snuffs, and lycopodium snuff containing sodium sulphate with and without menthol; but the results were not promising. Later, they used proflavine 5%, penicillin 1%, and sulphathiazole 10%. There was no detectable effect on the throat or nasopharynx. In the nose, penicillin effected a marked reduction in the numbers of Staphylococcus aureus. Sulphathiazole was very effective. Proflavine gave varying results, discoloured the lip and the handkerchief, and was not worth pursuing. The authors preferred sulphathiazole with magnesium carbonate as an excipient. There was no demonstrable effect on the normal flora. An antiseptic snuff, they said, would only hold in check the surface organisms but would not affect those vegetating deep in the crypts.

Spink and others (1945) suggested the application of a sulphonamide and penicillin combined, since Staphylococcus aureus resistant to penicillin, might be sensitive to the sulphathiazole or sulphadiazine. Burrows and others (1945) reduced the number of relapses of sycosis barbae by applying penicillin cream to the anterior nares as well as to the infected skin of the beard area. Fleming (1946) confirmed this, and Hobbs and her colleagues (1947) used penicillin snuff with success to treat the nasal carrier condition associated with sycosis barbae.

Knott /



Knott and Blaikley (1946) who, from 1942 onwards had excluded Staphylococcus aureus carriers from the Maternity Unit at Guy's Hospital, introduced a penicillin spray so that erstwhile carriers might be admitted to work and study in the unit.

Foley and Lee (1948) described the "antibiotic coaction" of gramicidin and penicillin in a mixture and found that together they had a more efficient bacteriostatic and bactericidal effect against Staphylococcus aureus than either in comparable quantities working alone.

Moss and others (1948) in a study of 21 patients who were both nasal and skin carriers, found that intranasal penicillin for ten days significantly reduced nasal carriage during treatment and, associated with this reduction, there was a decline in skin carriage.

This must be one of the last occasions on which penicillin was used successfully for such a purpose. Fleming (1942) encountered a few strains of Staphylococcus aureus which "were almost insensitive" to penicillin although he found that the majority were about equally sensitive. Spink and others (1945) wrote that "the sensitivity test as used in this laboratory has failed to reveal a strain of staphylococcus not previously exposed to penicillin, that was not inhibited by 1 unit of penicillin per cc. of medium, and well over a 100 strains have been tested." Barber (1947) noticed that resistant strains were becoming more and more common in hospital, and that strains picked up by patients in hospital /

hospital were frequently resistant. Out of 200 such strains, she found that 25 were resistant to 10 units of penicillin per cc. Klimek and others (1948) produced strains which were 20,000 times more resistant than the parent strains.

A man was admitted to the neurosurgical unit for operation two days later. He was a heavy carrier and, since nothing else was available, penicillin was insufflated into his nose the day before operation and again the following morning, and just before going to the theatre. A nasal swab taken after the operation was stained with penicillin and yielded a profuse growth of Staphylococcus aureus. Out of 143 strains of Staphylococcus aureus isolated from the noses of staff and patients and from the air of the theatres and wards, I found that 100 were resistant to 10 units of penicillin. The sensitive strains tended to occur on the same days and in groups as though they had a common origin. As the number of resistant strains is increasing, it is clear that penicillin is no longer of value in treating Staphylococcus aureus carriers.

Nasal carriage is normal for one fifth or more of the population, but such carriage must be controlled in hospital or, at least, in surgical and maternity units. Further work should, therefore, be directed to two ends. First of all, an attempt should be made to find out why that fifth are prone to carry the organism. Local histological peculiarities, the chemistry of the mucous membrane and of the secretions might be investigated, and then, if it is practicable, the /

the conditions should be altered in the direction of those prevailing among non-carriers.

The second less fundamental but more promising line of work is to be prepared for the development of resistance of the Staphylococcus aureus to antibiotics and drugs in use. Resistant staphylococci might be rendered susceptible once again to penicillin. Spink and Ferris (1947) found that the resistance which develops in vivo, is permanent and depends on the production of penicillinase to which Perlstein and Liebmann (1945) have produced an anti-penicillinase immune serum. Voureka (1948) sensitized penicillin-resistant staphylococci to penicillin by growing or, simply, mixing them with other organisms; even *Bact. coli* and similar Gram-negative organisms had this effect, and five minutes association was sufficient to confer sensitivity on the resistant organisms. Likewise, bacterial autolysates produced by bacteriophage or sodium oleate, restored sensitivity to some staphylococci. Himmelweit (1945) found that penicillin and bacteriophage together were more effective than either alone in sterilizing a culture of Staphylococcus aureus. He thought that organisms resistant to one of these agents, might not be resistant to the other or, at least, to the combined action of both. MacNeal and his colleagues (1947) described a case of septic staphylococcaemia successfully treated with penicillin and bacteriophage which they believed to have a synergistic action. /

action. Winner (1948) found that resistant staphylo-  
cocci became sensitive when grown with sensitive staphylo-  
cocci.

It is, perhaps, better to try new antibiot-  
ics as they appear. An account of the use of chloro-  
mycetin in the treatment of carriers is given above.  
Since Staphylococcus aureus is still sensitive to  
chloromycetin, this antibiotic will control the  
carriage if it does not altogether clear the carrier  
of Staphylococcus aureus. I had thought that it  
would not be so effective and had hoped to use aureo-  
mycin, but an opportunity to do this has not, so far,  
presented itself. This antibiotic is effective  
against Staphylococcus aureus and its use is recommend-  
ed when the organism is penicillin-resistant. It is  
potent and only slightly toxic. Many of the studies  
on aureomycin have appeared in the less accessible  
American journals but Strax and Wright (1949), Collins  
and others (1949), Chandler and others (1949), Brain-  
erd and others (1949), and Harvey and others (1949)  
recorded excellent, even dramatic results in the  
treatment of Staphylococcus aureus pneumonia, lung  
abscesses, pyoderma and septicaemia with aureomycin.

Bacitracin in solution or in an ointment  
has been used successfully in the treatment of super-  
ficial pyogenic lesions and carbuncles (Strax and  
Wright, 1949).

Carriers who are freed from infection by  
the use of antibiotics or drugs will, sooner or later,  
be re-infected if there is a local nasal susceptibility  
as /



as there appears to be. However, the opportunity for re-infection will be much less if hospital staffs are controlled and treatment begun as soon as the infection is found.

#### Summary.

An outbreak of Staphylococcus aureus infection in a neurosurgical unit is described, affecting clean operation wounds and cerebro-spinal spaces. Staphylococcus aureus was recovered from the air of both theatres and the X-ray room while in use, and also from the male and female wards. It was isolated from the dust of both theatres and the X-ray room. A third of the nursing staff were carriers and the theatre nurse who assisted at operations, carried the epidemic type - 47.

A dust-proof garment modified to suit surgical requirements, is described. Identification of carriers and their exclusion from the theatre when possible, is recommended. Methods of treatment of Staphylococcus aureus carriers are reviewed, and the results obtained by the use of some drugs is described. A 20% chloromycetin ointment is found to control the condition temporarily.

STAPHYLOCOCCUS AUREUS INFECTION IN A NEURO-:SURGICAL UNIT.ADDENDUM TO SECTION V.

During the vacation the nasal swabbing in the neurosurgical unit had lapsed. In the second and third weeks of September, 1950, four cases showed evidence of post-operative infection. There was undue elevation of temperature or an increased cell count in the cerebrospinal fluid which could not wholly be attributed to operative interference. Gram-positive cocci were seen in the films of pus from one case; but organisms were not isolated from the other three. The surgeons suspected, however, that an outbreak of infection with Staphylococcus aureus had begun.

Visits were paid to the unit every day and, later, every second or third day, in order to take nasal swabs from the staff and patients. In this way nearly everyone in the unit was examined at one time or another (Ill a - e). This swabbing showed that one surgeon, one house surgeon, one anaesthetist, and one post-graduate student all of whom were frequently in the theatre, were carriers of Staphylococcus aureus. Treatment with 20% chloromycetin ointment was begun immediately. The house surgeon and post-graduate student left the unit, the anaesthetist was replaced by another who was not carrying the organism, and the surgeon became clear in the course of three days and has, since then, remained free.

With regard to the nurses, the four in the theatre /

theatre were not carrying the coccus. Among all the nurses including the theatre staff but excluding those on night duty, ten were not carriers and nine were. There were four ward maids one of whom was free from infection, while two were heavy nasal carriers - the husband of one of them had "boils on the neck" - and the fourth had a chronic blepharitis from which Staphylococcus aureus was isolated. Of the eighteen male patients, four were carriers; and of the eight female patients, three were carriers. Generally speaking, twenty five to thirty or more nasal swabs were examined at every session, and more than a third yielded a growth of Staphylococcus aureus (111 f).

The theatre air was examined (112) after the theatre had been occupied all day, and had just been cleaned. The windows were open. In spite of this, four colonies of Staphylococcus aureus were recovered from 247 cu. ft. of air, or one Staphylococcus aureus-carrying particle in 62 cu. ft. The coccus was not recovered from swabs rubbed over various objects in the theatre (112).

The following day, the air in the theatre was sampled (113) after work had finished and cleaning had been completed, while the walls, fixed objects and floor were beaten with a sterile cloth. Five colonies of Staphylococcus aureus were recovered from 228 cu. ft. of air, or one in 46 cu. ft.

Two days later the beating technique was again used (114). On this occasion, ten colonies were recovered from 228 cu. ft. of air, or one in 23 cu. ft. Swabs /

Swabs of dust were taken at the same time and two colonies of Staphylococcus aureus were obtained from the floor.

Although aerosols are said to be of little use in sterilizing infected dust, it was decided to vaporize triethylene glycol every night in the theatre after the day's work was finished. A visible mist was produced and it remained to settle in the theatre all night. This was done for ten days.

At the end of this period 114 cu. ft. of air were sampled (115). The dust was also sampled, using the air sampler for this purpose. Staphylococcus aureus was not isolated. Two days later, a sampling of 171 cu. ft. of air while walls, fixed objects and floor were beaten with a sterile cloth, failed to yield Staphylococcus aureus (116). Finally, three weeks later, 152 cu. ft. of air were sampled while the dust<sup>was</sup> whirled up with a sterile cloth, and one colony of Staphylococcus aureus was recovered (117). At the same examination, dust was sampled with the sampler, and again one colony of Staphylococcus aureus was obtained. Nightly vaporization of triethylene glycol was begun again.

With regard to the wards, I thought it unwise to whip up the dust with a sterile cloth, and so I used the sampler for sampling the dust, by tilting it forwards with the sieve plate towards the floor. Thus, dust was sucked in and collected on the medium behind /



behind the sieve plate. One cannot relate the findings to the volume of air passed through the sampler. I sampled dust twice in the men's ward and recovered two colonies of Staphylococcus aureus from six plates on the first occasion (118 and 120).

The women's ward was examined in the same way (119 and 121). The plates were too heavily contaminated the first time. On the second occasion, I exposed the plates for half a minute each and recovered three colonies of Staphylococcus aureus from six plates.

In the meantime, there was a fifth post-operative infection. A nasal carrier developed a stitch abscess after operation, from which Staphylococcus aureus was isolated.

An attempt was made to clear all the carriers of infection by using 20% chloromycetin ointment twice daily (123). The results varied. Several cleared up completely and there was no relapse while they remained under observation. The organism persisted in the others, possibly because of inadequate or irregular treatment. The two ward maids, Mrs. Ho. and Mrs. El., gave nasal swabs which were frequently positive. In their case a nurse applied the ointment, but, in spite of this, the organism persisted. They may have been unco-operative. There was no history of nasal or sinus infection. Mrs. El. was, however, in close contact with a probable carrier; her husband had furunculosis.

For /

For whatever reason, whether because of treatment, or because of change of staff, or on account of both, there was a decline in the carrier rate per 25, from ten to two, although it was followed later by a rise (111 f).

I have made a list (122) of those in the unit who showed occasional or intermittent nasal contamination with Staphylococcus aureus. Usually, only one or two colonies of the coccus were isolated from the positive nasal swab. Two of these cases, Dr. He. and Mrs. Co. became carriers while under observation, that is to say, they yielded an uninterrupted series of positive swabs in which Staphylococcus aureus made up more than a quarter of the total number of colonies in the culture.

The strains of Staphylococcus aureus isolated from noses, air and dust during this investigation, were tested for their sensitivity to penicillin, streptomycin, chloromycetin and aureomycin (124). Out of the sixty six strains, thirty were sensitive to penicillin, and forty three to streptomycin. They were all sensitive to chloromycetin and aureomycin.

#### Discussion.

It was not certain that an outbreak of Staphylococcus aureus infection was about to begin; the coccus had not been isolated from any of the four cases. However, the nasal swabbing which was prompted by these cases, revealed what must, in the light of /

of past experience, be regarded as an alarming state of affairs in the theatre; four people who were frequently there were carriers of Staphylococcus aureus, and the organism was present in considerable quantity in the air and the dust. Among the ward staff and patients also, the carrier rate was quite high.

Table III f shows that a third or more of the people in the unit were carrying the coccus. Admittedly, some of these were more likely to spread infection than others, but, even so, the carrier rate in the unit was higher than was safe. After the first week or so, there was a decline in the number of positives. This may have been due in part to treatment and possibly also to the changing of staff which goes on all the time particularly among the nurses.

An attempt was made to treat everyone but this was not entirely satisfactory. Another possible cause of lack of response or poor response to treatment is that there may be some underlying lesion such as a sinusitis. There was no history of headache, pain or nasal or faucial discharge among those who remained carriers during treatment, but I think that an ear, nose and throat surgeon should be consulted in cases of doubt or when response is poor. Certainly, if conclusions are to be drawn about the efficacy of chloromycetin ointment in eliminating the carrier state, supervision of treatment will have to be more stringent. In the meantime, one nurse who was a heavy and persistent carrier last year, was cleared of infection at the beginning of this year and /

and is still clear. Of the cases in this last group (123 b), case 1 and case 13 have been freed of infection and have remained so, the first for a month and the second for a fortnight.

In the meantime, it seems wiser to confine attention to the carriers in the theatre. I still think, however, that one ought not to neglect the staff outside the theatre, and the patients most of whom will pay a visit to the theatre sooner or later, and may contaminate it. Moreover, carriers may contaminate or infect their neighbours. The intermittency of carriage demonstrated in Table 122 suggests that this happens and also that the carrier state may quickly develop in a healthy nose which has previously been free. And so, there is not only the risk of Staphylococcus aureus reaching the theatre on shoes and on air currents; patients with infected noses may contaminate the theatre and infect their own wounds. For instance, the patient who developed a stitch abscess due to Staphylococcus aureus was carrying the same type in his nose. Since it was a stitch abscess, it may have been an infection from the patient's skin. A possible series of events is that this patient with nasal carriage infected his bedclothes including the pillow particularly during sleep when the nose may be turned towards the pillow. This in turn infected the scantily covered back before the operation and then the organism multiplied in the tissue traumatized by the passage of the suture. Some days elapsed before I heard of this infection so I was not able to gather evidence for this view.



A question must arise with regard to the intermittent carriers and that is, whether swabbing several times around the nares with a moistened swab is sufficient to pick up the coccus if it is present in only small numbers. Are they constantly present at the bottom of glands and do they only occasionally appear on the surface to be gathered on to the swab? I think that inadequacy of technique is, at least occasionally, a cause of a negative result particularly when a series of scanty positives is interrupted by a negative. That, it seems to me, is an unlikely intromission. The one positive in a series of negatives is more likely to be normal because contamination can so obviously occur. One knows that dust is commonly infected with Staphylococcus aureus. Dry sweeping of this dust fills the air with fine particles that are readily seen when a ray of sunlight strikes into the room during the sweeping. Indeed, it is, rather, surprising that not everyone becomes infected by such a practice.

In the previous discussion, I had suggested that chemical, histological and physiological study of the nose and its secretions might show why some people are carriers and some are not. In view of this more recent experience, I think it may be a matter of size of inoculum rather than of personal peculiarity. Staphylococci invading the nose in a succession of large waves, may succeed in colonizing the nares, while one or two cocci may be overcome by the natural defences.

Some /

Some of the strains of Staphylococcus aureus isolated in the course of this investigation were kindly typed by the Director of the Staphylococcal Reference Laboratory. The same type was isolated from the post-graduate student and the nose and stitch abscess of the patient. The anaesthetist had a type which was not related to the others. I sent only one strain from the theatre dust and that was different from the other strains. Cultures from two nurses were the same but not related to the others.

Some of the strains of Staphylococcus aureus were resistant to penicillin and streptomycin but all were sensitive to chloromycetin and aureomycin. It is clear, therefore, that in the treatment of carriers, the latter two will be more useful. Of course, all these strains were derived from sources inside the unit; and so the figures in Table 124 are not necessarily valid for other groups. Nevertheless, a considerable number of penicillin-resistant strains of Staphylococcus aureus would be found in other groups. I have recently isolated a strain of Staphylococcus aureus which was resistant to 10 micrograms of chloromycetin per ml. It came from the ear of an infant who had had a course of chloromycetin for gastroenteritis. If, therefore, chloromycetin is to be used in the treatment of Staphylococcus aureus carriers, a brisk and determined attack will be required in selected cases.

Summary. /

Summary.

Nasal swabbing in a neurosurgical unit from the 23rd September until the 8th November showed that, at the beginning, one third of the staff and patients were contaminated with or were carrying Staphylococcus aureus. Dust in the theatre and wards was also contaminated with the organism. Intermittent nasal contamination occurred and the carrier state developed quickly in two cases. The strains isolated were all sensitive to chloromycetin and aureumycin, but some were resistant to penicillin and streptomycin. Two carriers were cleared of the infection, at least temporarily, with 20% chloromycetin ointment.

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POSTSCRIPT.

In the light of the experiences described in this thesis, I think that there is one essential matter in dealing with an outbreak of infection with Staphylococcus aureus. Nasal carriers of the organism among the staff and the patients should be identified and the further dissemination of the coccus stopped by their treatment, or transfer, or exclusion from the theatre in a surgical unit, or from the ward in a maternity unit. Once the primary source of infection has been removed, the secondary sources such as hands, bedclothes and dust will fail.



SUMMARY OF THE THESIS.

The subject of bacterial contamination of the air and dust is introduced by a review of early notions on the nature and spread of infection. The work of Pasteur's forerunners is described, and the development of antisepsis and asepsis is followed.

In the second section, the merits of various air samplers are considered, and the construction, use and advantages of a modified DuBuy and Crisp air sampler are described.

Methods of identification of Staphylococcus aureus are reviewed and a selection of tests for this work is made.

Section III. An outbreak of Staphylococcus aureus infection in a maternity unit is described, causing pemphigus neonatorum, blepharitis and pneumonia. Nasal carriers were found among the staff and babies. The air and dust throughout the unit were heavily infected with the organism. The sequence of events appeared to be contamination of the dust by carriers, colonization of the noses of numerous babies and lesions due to Staphylococcus aureus in some babies. Suggested measures for the prevention of such an outbreak are the treatment or exclusion of carriers among the nurses, treatment of carriers among the mothers, and the adoption of measures to minimize dust and droplet nuclei in the atmosphere of the unit.

Section IV. An outbreak of Staphylococcus aureus post-operative infection in a thoracic unit is described. /

described. Carriers in the theatre were identified, and the organism was recovered from the air of the theatre and the ward. While dressings were being done in the theatre, the total bacterial content of the air was considerable. The ventilation system in the theatre was shown to reduce the contamination of the air. It was suggested that stringent control of entry to the theatre and modification of dress would do much to prevent further outbreaks.

Section V. An outbreak of Staphylococcus aureus infection in a neurosurgical unit is described, affecting clean operation wounds and cerebrospinal spaces. Staphylococcus aureus was recovered from the air and dust of the theatres and x-ray room, and from the air of the wards. A third of the nurses were carriers and a theatre nurse carried the epidemic type. A surgical dust-proof garment is described. Identification of Staphylococcus aureus carriers is recommended in the control of infection. Methods of treatment of carriers are reviewed and the results obtained by the use of some drugs are recorded. A 20% chloromycetin ointment was found to control the carrier state, at least temporarily.

An addendum is appended to Section V, in which a suspected outbreak of Staphylococcus aureus infection is described. Nasal swabbing showed that a third of the staff and patients were contaminated with, or were carrying Staphylococcus aureus. Intermittent nasal contamination was observed, and the carrier state developed quickly in two cases. All the strains /

strains of Staphylococcus aureus isolated in this outbreak were sensitive to chloromycetin, and treatment with 20% chloromycetin ointment was, at least temporarily, successful in clearing carriers of infection.

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