the sepsis that occurred from time to time. It was not, in fact, possible to study it on a scientific basis until 1933 when Wells[2] developed the air-centrifuge for counting the number of contaminated particles in the air. In 1941 the bacterial slit-sampler was introduced by Bourdillon, Lidwell, and Thomas.[3] This machine is particularly useful because it can relate the time of appearance of contaminated particles in the air to events taking place in the room. Its use in operating rooms during the last fifteen years has given much valuable information. But we should not forget an older and simpler method for studying the bacteriology of air—the exposure of plates of culture medium. On these plates, contaminated particles are deposited by gravity and are also thrown on to it by currents of turbulent air. They give information that cannot be obtained from the air-centrifuge and slit-sampler. The number of particles that contaminate an exposed surface depends on their concentration in the air, their density and size, and the amount of air impinging on the surface. The volumetric type of sampler measures only the first of these. The simple sedimentation plate takes account of and integrates them all.

In 1946 Bourdillon and Colebrook,[4] of the Birmingham Accident Hospital, found that the air in burns dressing rooms was loaded with bacteria. Many of these organisms came from sources inside the room—from wound-dressings, blankets, and the clothes of the dressing-room staff as they moved about their duties. The simple ventilation plant then in use was not able to prevent accumulation of these organisms. But more than this, the ventilation plant, consisting only of exhaust fans, was sucking contaminated air into the dressing room from other parts of the hospital. It seemed reasonable to reduce this contamination as Hart's earlier investigations had already suggested.[5] Lowbury[6] showed by a controlled trial in a burns unit that doing this by improved methods of ventilation really does cut down the amount of sepsis.

We now know that these things are true not only for burns dressing rooms but also for general surgical operating rooms. For example, my colleagues and I[7] investigated a chest surgery unit where Staphylococcus aureus infections were causing serious trouble. By improved ventilation and by other methods we reduced the bacterial contamination of the operating-room air. The frequency of wound sepsis fell from about 11 per cent of all operations to about 5 per cent and has now settled down at about 2 per cent. But this experience of ours was not conclusive proof of the importance of air-borne infection because at the same time as changing conditions in the operating room we also introduced improved technics in other parts of the hospital. A more conclusive experience was that of Shooter and and his associates[8] who reduced the frequency of sepsis by reducing the number of bacteria in the air of the operating room and by making no other changes at all.

From all this we must conclude that air-borne infection of wounds during a surgical operation is, sometimes at any rate, a considerable hazard. But this is only one aspect of a complex problem. It would be wrong to concentrate our attention on air-borne infection and to ignore important defects in other matters of surgical and nursing procedure. Nevertheless, my purpose is to discuss this particular problem and I want to further the subject by asking two questions, and by trying to answer them.

The first question is this: Can we define a bacteriological standard of safety for the air of an operating room? In an attempt to do this, let us examine the results of air-sampling during operations and put them alongside the sepsis records that are associated with them.

as to whether or not currently advocated control measures for staphylococcal disease in newborn nurseries are effective and practical.

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III. VENTILATION OF OPERATING ROOMS—BACTERIOLOGICAL INVESTIGATIONS

Robert Blowers, M.D., and K. R. Wallace, M.B., Ch.B.

JUST ABOUT A YEAR AGO one of my colleagues, Dr. Robert Williams, spoke at a national conference on hospital acquired staphylococcal disease, organized by the U. S. Public Health Service and National Academy of Sciences.[1] He reviewed the problem of staphylococcal infection in hospitals and he gave an account of the ways we are exploring in Britain in our search for its solution. It would be tedious if I were to cover the same ground again. Moreover, my knowledge of this subject is not as broad as Dr. Williams' so I shall discuss here, perhaps in a little more detail, only one of the subjects that he mentioned in his survey. This is the control of air-borne infection in operating rooms. I shall pay special attention to the ventilation of these rooms but I will first discuss the background to our investigations before telling something about the results.

Before we go to a lot of trouble devising new methods of ventilation for operating rooms we should satisfy ourselves that there really is a need for them. We should satisfy ourselves that the risk of air-borne infection during an operation really does exist. Lister, in the 19th century, believed that it did exist. But for many years after that, air-borne infection was not seriously considered as an explanation for

Table 1—Slit-Sampler and Sedimentation-Plate Counts During Surgical Operations. These Are Not Actual Results from a Particular Operating Room but Are General Indications of the Usual Findings.

Slit-Sampler Contaminated Particles per Cubic Foot of Air		Exposed Sedimentation Plates Contaminated Particles Settling per Square Foot per Minute		
General Count	Staph. aureus: General Ratio	General Rate	Staph. aureus Rate (Approximate)	
20–50	1:20	10	0.5	Much sepsis
1–2	1:100	0.5	0.005	Less sepsis

Examples of these are shown in Table 1. In the first column are the general bacterial particle counts from the slit-sampler. These are the counts of all visible colonies—whether pathogens or not—developing after 18 hours' incubation on a simple nutrient-agar medium. When the general counts lie between 20 and 50 per cubic foot there is usually a great deal of sepsis arising from operations in that room. Associated with these counts of 20-50 per cubic foot we find several other interesting things. On the slit-sampler plates, the ratio of coagulase-positive Staphylococcus aureus colonies to the general colony count may be as high as 1:20. And we may find that exposed culture plates collect contaminated particles at about 10 per square foot per minute. These sedimentation samples are usually too small to allow direct measurement of Staph. aureus sedimentation rates. But if the Staph. aureus: general count ratio from the slit-sampler plates is assumed to apply to the sedimentation plates—though this may be an unjustifiable assumption—the Staph. aureus sedimentation rate would be about 0.5 particles per square foot per minute. During an operation the area at risk of contamination includes the wound, the hands of the surgeon and his assistants, the instruments, swabs and dressings, and the tables on which these things are placed. If these cover an area of, say, 20 square feet, particles contaminated with Staph. aureus may fall on it at the rate of about 600 an hour. Most of these particles contain only a few cocci[9] but each of them is a potential danger to the patient. Some workers[10] have recorded sedimentation counts much higher than ours because of differences in the conditions of exposure. These must be standardized if comparable results are to be obtained. If they include the periods of heavy contamination at the entry and departure of the patient, the mean sedimentation rates are much higher and the effect of the two peaks on the mean rate for the whole period is unduly influenced by the duration of the operation. To eliminate this variable factor we suggest that plates should be exposed from the moment of the first incision until the tying of the last stitch. Our sedimentation results have been calculated on this basis.

If we now turn to operating rooms where very great efforts have been made to reduce aerial contamination, the counts may be as low as those of the second example in the table. General counts may be only 1-2 per cubic foot; the Staph. aureus: general ratio may be 1:100 or even less; general sedimenta-

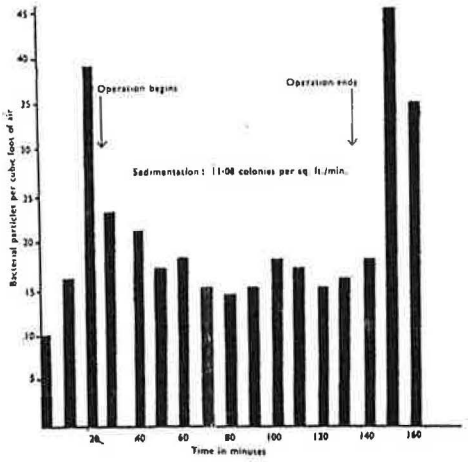

Figure 1—Air Sampling During Operation with Exhaust Ventilation and Much Activity; Theater Doors Opened 55 Times

tion rates may be as low as 0.5 contaminated particles per square foot per minute and our crude calculation gives a Staph. aureus sedimentation rate of about 0.005/sq ft/minute. With counts like this there is usually very much less sepsis. But we are not able to say how much of the sepsis that does occur under these conditions is still due to air-borne infection in the operating room or to other causes. And so, we cannot say whether an acceptable limit of safety for the air in operating rooms lies somewhere between these two sets of observations or whether even lower counts would give still better results. Before we can settle this matter and define our standards of safety for the air in an operating room we need to examine many carefully kept records of sepsis alongside the air-sampling results. There we must leave this matter for the time being.

This brings us to the second question: If we want to reduce the number of air-borne bacteria in an operating room, how do we do it? The first thing to do is to make sure, from smoke tests, that the ventilation plant is not sucking hospital air into the operating room. Modifications of the ventilation plant to prevent this were made in one hospital that we investigated, and Figures 1 and 2 show that the slit-sampler counts were reduced to about a third. But still more can be done. In this particular operating room we next made sure that no unsterilized blankets were brought in to cover the patient; that nobody in the room wore ordinary street clothes or ordinary hospital uniforms under their gowns; and that nobody went in or out of the room during the operation. During most operations, nurses trot back and forth to the clean-up, sterilizing, and workrooms about fifty times during an operation. Sometimes they go to fetch equipment that could have been in at the beginning; sometimes to take out equipment that could remain in until the end; and sometimes they go in and out for reasons that I have never been able to discover. If all this is stopped, bacterial counts are reduced even more. Indeed, in this particular operating room, we introduced these precautions and then,

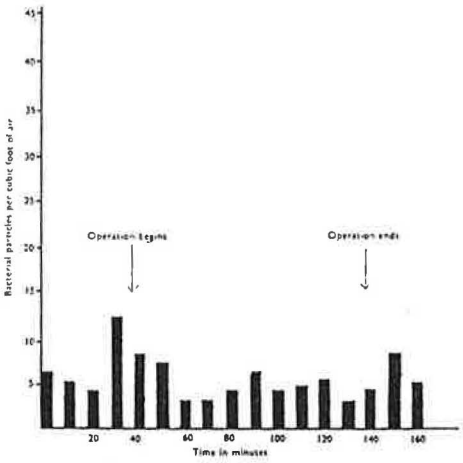

Figure 2—Pressure Ventilation and Much Activity; Doors Opened 47 Times

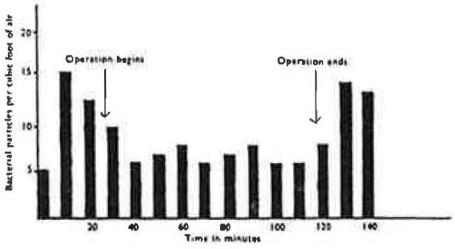

Figure 3—Exhaust Ventilation and Reduced Activity; Doors Not Opened

because of a mechanical breakdown, temporarily reverted to the old ventilation system. The new operating room discipline alone gave an improvement almost as great as that from the new ventilation system (Figure 3). It was only when good ventilation was combined with the new operating room discipline that we saw the best results (Figure 4). In a few good units we have been able to maintain this very low level of contamination. But in many others, where the discipline or the standard of organization is not as high, we have been unable to prevent the many journeys in and out of the room that keep the counts up. So we are looking for ventilation methods that will yield these lower counts more easily.

The Newcastle Regional Board and the Public Health Laboratory Service have built, in the Public Health Laboratory at Middlesbrough, a full-sized dummy operating room. In it we first re-examined the conventional methods used for pressurizing a room to prevent in-flow of contaminated air. This is usually done by arranging for the air input fans to have a slightly greater capacity than the exhaust fans. This works well when all the doors are closed and only a small volume of air leaks from the room; but it is unreliable when the doors are open because the small surplus of air is insufficient to cause strong outward flow through all parts of the large opening. We have, therefore, discarded forced extraction of air and rely on free escape through ports low down on each wall, fitted with simple, weighted flap valves. When a door is opened, pressure in the room drops, the valves close and the entire air supply is available to give a strong outward draft through the door opening.

Removal of organisms that have been liberated inside the room is a more difficult problem. Ventilation plants for doing this are of three main types: First, a stream of air may be aimed, obliquely or horizontally, at the center of the room to create turbulence and prevent stagnation of contaminated air in the area enclosed by the lamp and the ring of people and equipment around the patient. Second, air may be introduced at the top of the room so that, with mild turbulence, it mixes rapidly with air already in the room. By this method, contamination is reduced by a constant process of dilution. Third, air may be brought in at the top of the room in such a way that there is the least possible turbulence and little mixing with the contaminated air, which is thus removed by downward displacement.

The merits and disadvantages of these three systems are being examined in

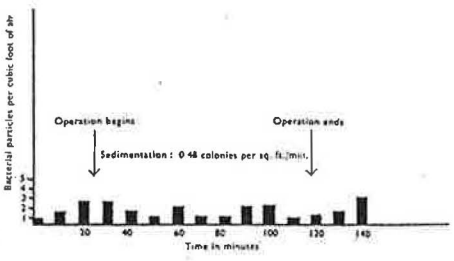

Figure 4—Pressure Ventilation and Reduced Activity; Doors Not Opened

(Figures 1-4 published through courtesy of John Wright & Son, Ltd., London, England, from "Medical Annual," 1958.)

several ways. In the dummy operating room we liberate a cloud of nonpathogenic bacteria to give uniform contamination of the air. We then assess the performance of each ventilation system by observing two things. We measure, with the slit-sampler, the speed at which the organisms are removed; and at the same time, we record the numbers of them that are deposited, during the process of removal, on an exposed culture plate representing the wound.

We find that the downward displacement or "piston" method of ventilation removes organisms more quickly than the other methods; and that fewer organisms are deposited on the exposed plate during removal. Some of the turbulent systems are fairly effective for removing the bacteria, but they all do so at the expense of heavy deposition on the exposed plate. This is not surprising because the number of organisms that come in contact with a surface depends not only on the concentration of bacteria in the air but also on the amount of air impinging on that surface. With turbulent systems of ventilation the amount of air impinging on the wound is greater than from a system with a uniform downward movement.

Before we could investigate these methods we had first to find out how to produce a good downward displacement or piston movement of air. We had to give careful attention to the number, position, and design of the high-level air-inlet ports and the low-level outlet ports. If any heating was needed it had to be provided by the ventilation plant itself and not by heating panels. The efficiency of a ventilation plant in removing bacteria is considerably influenced by the difference in temperature of the air coming in at the top and the air already in the room. It is lowest when we put cold air into a hot room and highest when warm air comes into a cool room. We realize that there are many parts of the world where ventilation with cold air is often essential. But when heating is necessary let us, if we want piston ventilation, take advantage of this effect by letting the ventilation plant do all the heating during operations. If heating panels are needed to maintain wall and room temperature when the ventilation plant is out of action, they should be turned off when the ventilation plant is switched on. Finally, we could maintain a good piston movement of air only if the scrub, sterilizing, and other annexes adjoining the operating room were separated from it by doors, which were kept closed during operations.

The methods of assessment that we have used depend on clearance of bacteria from a uniformly contaminated room. But during surgical operations, bacteria are probably liberated irregularly by people in different parts of the room. The ventilation methods that take these organisms away without carrying them across the wound area may not be those we have found most suitable for uniform clearance of uniform contamination. To investigate this point Drs. R. E. O. Williams and O. M. Lidwell of the Air Hygiene Laboratory in Colindale have used an infra-red gas analyzer to trace the flow of nitrous oxide liberated as a tracer in different parts of the room. I am grateful to them for giving me permission to mention their incomplete and unpublished results. They find that for contamination arising close to and above the level of the operating table, mildly turbulent ventilation gives the lowest concentration of gas in the region of the wound. For contamination arising below the level of the table or well away from it, the downward displacement system is more effective. We must now know if these results are valid for particulate as well as for gaseous contamination. If they are, we must discover exactly where staphylococci are discharged into the air during an opera-

tion. Is the main risk from particles that are disturbed from the floor, or do they come directly from the carriers? Does most contamination come from the relatively still people close to the patient or from the more active ones further away? There is already evidence that Staph. aureus is rarely shed from the respiratory tract of nose and throat carriers; and that many come from the body and clothes of skin and perineal carriers. Do these people liberate most of their staphylococci from sites above or below the belt?

It has not been my purpose, in this short paper, to say how an operating room should be ventilated but, rather, to give some facts on which the method must ultimately be based. All the facts that we need are not yet available, but even when they are we must remember that a new, chromium-plated operating room will not prevent infection. This can only be done by the people who work in it.

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IV. PROCEDURES APPLICABLE TO SAMPLING OF THE ENVIRONMENT FOR HOSPITAL USE

Lawrence B. Hall, M.S., and Herbert M. Decker, M.S.S.E.

IN THE LAST FEW YEARS, hospital cross-infections have received unprecedented attention, particularly those involving Staphylococcus aureus. Many investigators in research institutions and in individual hospitals are studying the problem. Intensive work is going on in the bacteriology and the epidemiology of these infections, but the tools with which to work are still somewhat lacking. A conference on the relation of the environment to hospital acquired staphylococcal disease, sponsored by the Communicable Disease Center and the National Research Council last December, emphasized the fact that the entire area is short on quantitative studies.

Strictly quantitative technics have not been developed which are adaptable to all types of bacteriological sampling. In some situations we are of necessity limited at present to methods which are at best only semiquantitative.

However, many improvements have been made recently in sampling technics, particularly in air sampling, and wherever possible these improved quantitative technics should be used. It is not enough to merely know whether or not Staphylococcus is present; we also require knowledge of the extent of the contamination. Thousands of organisms are obviously more dangerous than just a few.

The requirements for studies of human sources, be they carriers or frank infections, are necessarily largely qualitative in nature, but if the comparative importance of the routes of transmission through the environment are to be evaluated quantitative methods are essential.

Before considering actual equipment and technics it would be well to review the theories of transmission as we see them today. There is, first, the direct contact, illustrated by the transfer of organisms directly from a carrier to a susceptible by contact of the two human beings through, say, a break in a rubber glove. This route of transmission hardly lends itself to quantitative evaluation, nor is there much of a need for quantitation in this situation. We are sure the route exists. The majority of the aseptic technics of surgery are used with this in mind.

All other theoretical routes of transmission pass, of necessity, through the environment in one way or another. In the environment they may be studied quantitatively with varying facility and accuracy.

The first of these routes through the environment is by means of droplets which, propelled by coughs and sneezes, move at high speed from the human source to the susceptible. The period of time involved varies, probably, from microseconds to seconds. This route has been classified by many as "direct" because the organisms remain in their original body fluids during the period of transfer. Nevertheless, the droplets do move through the air, a part of the environment, where they may be captured.

Less direct may be the droplet nuclei, the organisms themselves, which remain in the air after the rapid evaporation of the body fluids in which they leave the human source. These may, under some circumstances, move directly from the source to the susceptible human in