Bacterial Air Contamination and its Relation to Postoperative Sepsis *

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Since the time of Lister, surgeons have been interested in the relationship between bacterial contamination of the air and postoperative wound sepsis. Despite this long interest, there is even today a paucity of quantitative data regarding the relationship of bacterial air contamination in the operating theatre to the frequency of postoperative infection of clean wounds. Without such data there is no means of judging the level of bacterial air contamination that is safe in an operating room. This is necessary if we are ever to ascertain the merits of various means of controlling the numbers of bacteria in the air.

This paper correlates air-borne bacterial contamination and the frequencies of postoperative wound infections in the Barnes Hospital during 24 months.

Methods

During October 1958, we began a study of bacterial contamination in the operating room area. Between October 1958, and March 1959, methods were standardized for bacteriophage typing of staphylococci, and for sampling of the floors, personnel, and the atmospheric air. Five methods of air sampling were tested. These included fallout plates, sieve samplers, the all glass impinger, the Andersen sampler and the Fort Detrick slit sampler.

Since March 1959, two test operating rooms have been studied intensively. These operating rooms are somewhat dissimilar both in design and use. Room A is located in a recently modernized portion of the operating room suite and is used by the general surgical and gynecological residents. The air to this room is furnished from a large central air-conditioning unit which also supplies four other rooms; this air is not recirculated. The outside air is obtained from the fourth floor level and is filtered through an electrostatic precipitator before it is passed over coils cooled by chilled water. During this study no changes have been made in this air-conditioning system.

Room B is of older design than room A. It is used by senior general surgeons and also by the resident staff for most of the emergency operations performed at night. The air-conditioning system in this room was altered during the study to provide increasingly more efficient air filtration with and without recirculation of the air.

Samples of the air have been taken twice daily in each of these rooms, five days a week, for the past 24 months. The samples have been taken simultaneously on soy trypticase and tellurite glycine agar using the Andersen multistage sampler. Ten cubic feet of air have been collected per sample at the rate of one cubic foot per minute. A uniform rate of air sampling was insured by the inclusion of a Porter and Fisher Flowrater in the vacuum line which

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Fig. 1. This graph shows the number of viable bacterial particles collected per cubic foot of air in two operating rooms. Each point on the graph represents a weekly average. Room A, in which no recirculation of air was permitted, is represented by a solid line. Room B, in which the air was recirculated, is represented by a dotted line.

measured the rate of flow of the air through the sampler. The size of the particles collected was estimated from the level of impingement upon the six stages of the Andersen sampler. An estimation of particle size and a count of the total number of particles containing viable bacteria and the total number of coagulase positive staphylococci were made for each sampling. The bacteriophage type was determined for each coagulase positive staphylococcus. For nine months, fallout plates measuring 8.0 cm. in diameter and containing mannitol salt agar were placed in or very near the sterile operating field for a period of one hour each.**

The frequency of postoperative infection during hospitalization has been determined by a team of surgeons and record librarians who have conducted a monthly review of all surgical records for the past nine years. The frequency of postoperative infection relative to specific operations has been obtained by restudy of these data and review of the hospital charts. Throughout the study, efforts were made to improve housekeeping, dressing, and isolation technics.

Results

Figure 1 demonstrates a remarkable reduction in the total number of viable bacterial particles recovered per unit volume of atmospheric operating room air which has occurred during the early part of this study. This reduction in air contamination was observed in both operating rooms. The counts which were observed in the morning paralleled exactly those which were obtained in the afternoon in both test operating rooms. A similar reduction in the concentration of coagulase positive staphylococci was demonstrated as is shown on Figure 2. While the lowest concentrations of viable bacterial particles were being obtained in operating room B during the use of a highly efficient dry filtration of the recirculated air, the same low concentrations of bacterial particles were being found in operating room A, in which no changes in the air filtration or distribution had been made.
Figures 3 and 4 compare the total number of large particles to the total number of smaller particles collected in the Andersen sampler. While the total number of smaller particles (those less than 1 micron in diameter) has varied little during the entire period of study, the total number of larger particles (those 15 micra and upwards) has steadily decreased.

Table 1 describes the results of nine months of testing using the open Petri dish technic (fallout plates).

Table 2 describes the frequency with which infection follows inguinal herniorrhaphy at the Barnes Hospital. Table 3 describes the frequency with which infection follows gastrectomy (all types).

Discussion

Although much effort has been directed to the elimination of infections which occur in wounds postoperatively, the problem has not been satisfactorily defined. Despite an almost total lack of definition of the quantitative relationship between the numbers of particular bacteria in the air of operating rooms and the frequency of postoperative wound infections, complicated devices have been designed and installed in an effort to rid hospitals and operating rooms of bacteria.

Increasing reliance is being placed upon such devices and although quantitative determination of their effectiveness is generally lacking, some have stated that surgeons in their hospitals would hesitate to operate without such equipment. Because of the belief that the air is a very important vehicle for the transmission of bacteria to
wounds in operating rooms, reliance upon this bacteria eliminating equipment is so great that in some institutions operating room regulations have become less strict and antiseptic and aseptic technics have been relaxed.

Surgeons at the Barnes Hospital have all but ignored suggestions that air contamination might be a factor in the cause of infection in the postoperative wound. With the exception of the air-conditioners involved in this study, air conditioning has been used solely for the comfort of the patient and the personnel. During the colder months of the year, the air-conditioners are usually turned off and no artificial circulation of the air is provided. Despite this lack of regard for air contamination by bacteria, no epidemics of infection have occurred. The frequency of in-hospital wound infection following uncomplicated inguinal herniorraphy has averaged 0.94 per cent and has not varied significantly year by year for the past nine years.

Because few quantitative determinations of air contamination in surgical operating rooms have been made, it is impossible at present to obtain any notion of the degree of bacterial contamination which exists or has existed in surgical centers throughout the world. For this reason, all measurements of bacterial air contamination in this study have been made with equipment which has been extensively tested and described, and which is available and easily used for comparisons at other surgical centers.

Bacterial air contamination, as detected by the Andersen sampler, has dropped from an initial value of 10 to 20 viable bacterial particles per cubic foot to an average of 4.2. This latter concentration has been maintained for over one year. The relationship of coagulase positive staphylococci to the other bacteria in all types is one in three to four hundred. This means that during the past year, an average of only 40 staphylococcal bearing particles were to be found in an operating room containing 4,000 cubic feet of air (20' x 20' x 10'). Particles containing coagulase positive staphylococci fall out on settling plates in the test operating rooms at the rate of one particle in every 28 hours. One might expect, therefore, the fall out of only one staphylococcal bearing particle in every 28 herniorrhaphies, since the area covered by one of these plates approximates the area of the wound exposed for one hour, about the time required for herniorrhaphy. While the actual infective dose of staphylococci in clean

* This number has been maintained at 3.8 viable bacterial particles per cubic foot for the past six months (January, 1961–July, 1961).

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Table 1*

<table>
<thead>
<tr>
<th>No. Samples</th>
<th>Total Hrs. Sampling</th>
<th>No. Coagulase Positive Staphylococci Collected</th>
<th>Ratio of Staphylococci to Hours of Exposure</th>
</tr>
</thead>
<tbody>
<tr>
<td>780</td>
<td>780</td>
<td>28</td>
<td>1:28</td>
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</tbody>
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*The frequency with which coagulase positive staphylococci fall out upon Petri dishes, 8.0 cm. in diameter, which were each exposed for one hour in proximity to the field of operation.

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Fig. 4. This graph shows the number of viable bacterial particles per cubic foot of air which were collected on two of the six stages of the Andersen sampler in Room B. The upper stage is represented by a solid line, the lower stage by X's connected by a solid line.
The frequency of wound infection and death related to infection following inguinal herniorrhaphy at the Barnes Hospital, 1951-1959.

*The frequency of wound infection and death related to infection following inguinal herniorrhaphy at the Barnes Hospital, 1951-1959.

wounds of this type is not known, it is unlikely that such a small inoculation could be significant.

The improvement in the degree of air contamination which was observed in this study seems most closely related to improvements in housekeeping technics and practices, to reduction in operating room traffic, as well as to improvement in dressing and isolation technics throughout the hospital. The continuous use of air-conditioning in the test areas may have had some general effect, and the rapid circulation of filtered air may serve to remove bacteria from operating rooms more quickly following contamination; however, over-all measurements of air contamination did not differ significantly between the two test operating rooms despite the attempts that were made in one of them to increase the efficiency of air filtration. The reduction in air contamination was most closely related to the decrease in the number of large bacteria-containing particles.

It is impossible to tell whether this reduction in air contamination has been associated with a similar reduction in clean wound infections. If wound infections were completely eliminated following herniorrhaphy at the Barnes Hospital, a statistically significant effect would not be apparent for three years. If only a 50 per cent reduction in the infections following herniorrhaphy were achieved, this would not be statistically significant until the effect had lasted for more than ten years.

Much that has been said recently about postoperative infections would indicate that the major problem has been unexpected infections following clean surgical operations. It has become increasingly apparent that unexplainable infections in clean wounds play a rather minor role in the over-all problem of postoperative sepsis at the Barnes Hospital. Less than one-fourth of the infections which follow operations occur in clean wounds. Only one per cent of the patients developed wound infections after operations for hernia, and none died of infection in nine years. However, following gastrectomy 10.2 per cent of wounds were infected and death was associated with the infection in 3.3 per cent of the cases. Review of the infections which occurred during this study show that over 75 per cent occurred in wounds which were potentially contaminated or contaminated. These groups may serve as a reservoir of virulent organisms which may be spread throughout the hospital and add to the total number of bacteria in the air, even of the operating suite.
Our experiences have led us to the conclusion that, at least in the Barnes Hospital for the past 24 months, wound infection attributable to air contamination has been an unimportant factor in the over-all problem of postoperative sepsis. While further reduction in bacterial contamination of the air might improve some further improvement in the incidence of wound infection following clean operations, it is unrealistic to expect any significant effects on the incidence of wound infections following contaminated or potentially contaminated operations.

Unless exceedingly dirty conditions prevail, the solution to the problems of wound sepsis rests upon perfection of aseptic operative technic, and not upon sterilizing the air with filters or other devices any more than it rested upon sterilization of the air with phenol mist. Until this has been achieved, the surgeon has no right to blame hospital administrators or to curse unseen forces in the air for the wound infections of his patients. However, hospital administrators should see that the maximum effect has been achieved from perfection of housekeeping and isolation technics before resorting to complicated and expensive devices to reduce bacterial air contamination. By the simple expedients of vacuum washing of operating theatre floors, the reduction of floating lint, and simple filtration of the air, the number of air-borne bacterial particles has been so reduced that on the average only one staphylococcus falls upon a settling plate each 28 hours. Absolute reliance upon physical devices to rid the environment of bacteria becomes extremely dangerous because these devices do fail for mechanical or other reasons.

No matter what technics are used in an institution in the attempted elimination of postoperative sepsis, the results should be checked by quantitative estimates of air contamination and by up-to-date analyses of the postoperative wound infection rate. From these data the safe limits of bacterial contamination in the air of operating rooms may ultimately be determined.

Eventually better ways must be found of preventing wound infections in patients whose wounds are grossly contaminated and to prevent contamination of the wound during operations performed on potentially contaminated organs.

References

Books Received for Review

Larson, Carroll B., M.D., F.A.C.S.
Gould, Majorie, R.N., B.S., M.S.
Maingot, Rodney, F.R.C.S., (London)
Muir, Edward G., M.S., F.R.C.S., (London)
Sigerist, Henry E., M.D., D.Litt., LL.D., Dr.h.c.
Sodeman, William A., (Edited by), M.D., Sc.D., F.A.C.P.
Candiani, G. B.
Remotti, G.
Higgins, Charles, M.D., M.Sc., D.Sc.
Committee on Dietetics of the Mayo Clinic
Gross, Ludwik, M.D.
Joyce, John J., III, M.D., B.A.
Harty, Michael, M.A., M.B., M.Ch., F.R.C.S., (England)
Rubin, Eli H., M.D., F.A.C.P., F.C.C.P.
Potter, John M., M.A., M.B., B.Chir., F.R.C.S.
Harkins, Henry N., M.D. (Edited by)
Moyer, Carl A., M.D.
Rhoads, Jonathan E., M.D.
Allen, J. Garrett, M.D.

Carcinoma of the Colon, Williams & Wilkins Co., 181 pages, 1961, $8.50.
A History of Medicine, Early Greek, Hindu and Persian Medicine, Volume II, Oxford University Press, 352 pages, 1961, $11.00.
Istopatologia Ginecologica e Gravidicocoriale, Edizione Farmitalia, 269 pages.
Frontiers of Mammary Cancer, Glasgow University Publishers, Jackson, Son & Co., 29 pages, 1961, $1.05.
Orthopaedic Approaches: A Stereographic Manuel, Williams & Wilkins Co., 80 pages, $28.00.

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