Clean air symposium—Part II

Local air blanket protection of surgical wounds to prevent airborne contamination

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It is well established that surgical wounds can be contaminated by airborne bacteria. That these airborne bacteria are a significant cause of postoperative wound infection, however, has not been proven. If one reviews the available literature on wound infection, he must reasonably consider that the air is only one of many possible modes of surgical contamination.

Charnley's infection rate in total hip replacement surgery has decreased dramatically in recent years.[1] He attributes this to his clean room facility. One cannot help but feel that the same effect may have come as a result of his increased experience with the procedure and, in part, to his elaborate preoperative preparation of the patient. Series of cases presently being gathered in the United States already show that a super clean ordinary operating room in which the surgeons follow a rigid aseptic technique and in which modifications to present air filtration systems are made can result in an infection rate for total hip replacement as satisfactory as Charnley's.[2] These are relatively early studies, and with the well-known delayed onset of infection in total hip replacement surgery, the figures may not stand

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the test of time. If one approaches the problems of surgical wound contamination with these thoughts in mind and realizes that the air is only one mode of bacterial transport, then a rational program to eliminate these factors can be considered.

Bacteria range in size from 0.3μ to over 10μ. Bacteria in air will usually not appear singly but rather in droplets in dried droplet nuclei, attached to dust, or on epithelial cells. The particles which carry these microorganisms are usually 8μ to 14μ in diameter.[3-5] It has been appreciated for some time that the highest concentrations of bacteria in an operating room are found within the circle of the surgical team, directly over the wound.[6, 7] It is ironic that such is the case, but its cause can be readily understood when one considers that the wound is "where the action is." This is where the surgeon's breath forms a droplet aerosol and his face and neck shed bacteria-laden particles of skin and sweat.

To become infected, a wound must not only have a low resistance, but the virulence and dose of bacteria must be substantial. In the presence of foreign material the infective dose of bacteria is substantially less than in its absence.[6, 8] It is in these wounds that small quantities of airborne bacteria previously considered insignificant may play a major role in the onset of a subsequent infection.

It is generally agreed that the operating room personnel and patient are the largest sources of bacteria.[3, 9] It is therefore only reasonable that attempts be made to isolate these reservoirs from the surgical environment despite the type of air filtration system used.

Presently available systems for removing bacteria from the air in operating rooms are generally quite expensive, hot, and frequently noisy. To eliminate the heat generated by the electric motors and compression of air behind filter banks, major modifications to existing air conditioning systems may be required. Major changes in electrical wiring and in the construction of the operating suite itself may also be required. Use of a vertical flow of clean air from above the surgical wound downward creates the possibility of washing bacteria from the surgeon's head and neck into the wound as he leans over. Horizontal laminar flow wall systems have the disadvantage that they create laminar flow for only a distance of approximately 3 feet from the filter bank.[7] From this point the air becomes turbulent and this effect is accentuated by the presence of any obstruction in the air flow, i.e., instrument tables, the operating table, and the surgical team. Because of this turbulence, it is conceivable that eddy currents set up about the operative site could actually bring air from the surgeon's head and neck into contact with the wound.

Because of the aforementioned problems concerning turbulence, cost, heat, and noise generation in existing clean air systems, a new method was developed. It was felt that placing a source of laminar flow bacteria-free air quite close to the wound could eliminate undesirable turbulence at the operative site. By making the air filtration units small, it was hoped that heat, noise generation, and cost could be kept to a minimum. In early 1971, after much trial and error, such a system was devised. A prospective controlled study was designed to evaluate its effect on the number of bacteria and particles at the wound during surgery and on the particulate content of the operating room outside the direct flow of air. All studies were conducted in a small community hospital on clean orthopaedic and general surgical cases.

A filter system was devised which projects essentially sterile air at a desired tangential flow angle across the surgical wound. The air is first passed through a prefilter which removes large particles of lint and dust, then it is forced through a HEPA filter which removes 99.9% of all particles 0.3μ and larger. The exhausted air obtains its identity and flows in smooth, streamline or laminar flow profiles having a Reynolds number less than 2,000. This air is then passed through an exit nozzle which was made removable for sterilization so that it could be moved into close proximity to the surgical wound. The entire unit was mounted on an adjustable base, so that the height and the potential flow core angle could be changed at will (*Fig. 1*).

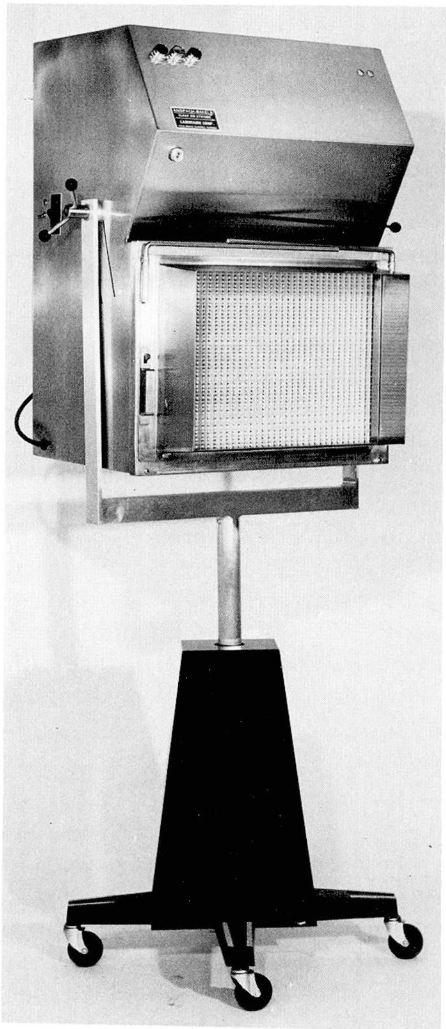


Fig. 1. Unit mounted on adjustable base.

The maximum design capacity of the unit was 2,000 cubic feet per minute; however, the blower speed was variable so that flow rates could be adjusted. In an average operating theater, the air theoretically could be filtered in 1 minute. Actually, part of the air would be in a recirculating sequence and the probability would be that in a 2,000-cubic foot operating room, 50% would have passed through the system in 1 minute and 90% would have been exchanged in approximately 10 minutes.

Air flow studies

Several studies of incompressible axial symmetric air jets exhausting into quiescent air were made to achieve a sterile laminar air profile having a constant velocity region as wide as possible from a small source.

If a jet of air is directed into a still environment, its path is straight and the streamlines become parallel, if they are not already parallel. This must be true, because any turning, divergence or velocity change would require a corresponding static pressure change which cannot exist in the surrounding still air.

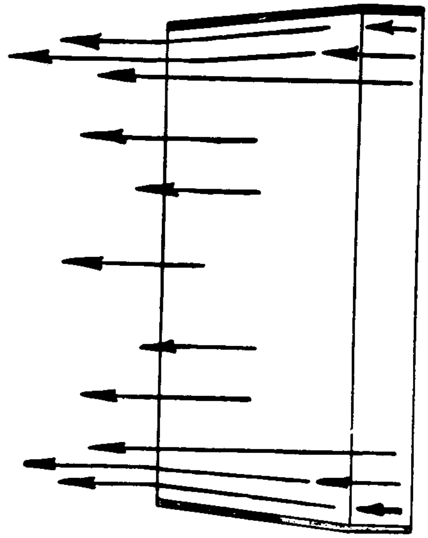
However, if air is exhausted through a filter at uneven pressures, the high pressure zones will tend to mix with low pressure areas. Thus, the streamline having the higher pressure will shear the weaker stream, become unstable, and eventually break up to form vortices. These vortices will transport mass inertia, temperature, and any other characteristics slowly across the stream.

Due to the importance of equalizing the pressure over the HEPA filter face, a series of vanes were developed and mounted at the blower exit orifice. The extreme turbulence created by these vanes resulted in a remarkably equal diffusion of pressure behind the HEPA filter.

Air flow measurements were made with a hot wire anemometer for low velocity flows and for determining the turbulent regions. A Kiel probe in conjunction with a 6-degree inclined micromanometer was used to plot the core flow region. To further extend the laminar flow region, a low angle nozzle was designed so that the filter exit flow would be compressed and thus maintain its identity for a longer time when exhausted into the ambient environment (*Fig. 2*).

Entrainment of room air into the clean zone was further discouraged by placing sterile drape sheets at a tangential angle along the sides of the exit nozzle. The operating team along the table are usually in quite close contact with these drapes so that a partial side wall along the sterile flow is created (*Fig. 3*).

Warren,[10] Kranz,[11] and others have shown that air streams will remain



NOZZLE

Fig. 2. Low angle nozzle designed for compression of filter exit flow.

linear in a constant velocity cone-shaped pattern when released from an orifice for a distance equal to approximately three times the orifice diameter.

That this distance was significantly extended by the incorporated modifications to the air source is shown in *Figure 4*, which illustrates the actual measured air patterns. The central triangle of the diagram should be considered a three-dimensional cone, with a base having an equivalent diameter equal to

$$\frac{\sqrt[2]{\text{Filter Area}}}{\pi} \times \left(\frac{L}{W}\right) .025$$

The apex of this constant velocity region where the flow is laminar extends to 6 feet 8 inches from the filter face, after which the velocity drops and gradually becomes zero. As can be seen in *Figure 4*, the flow becomes less laminar outside the central core. The

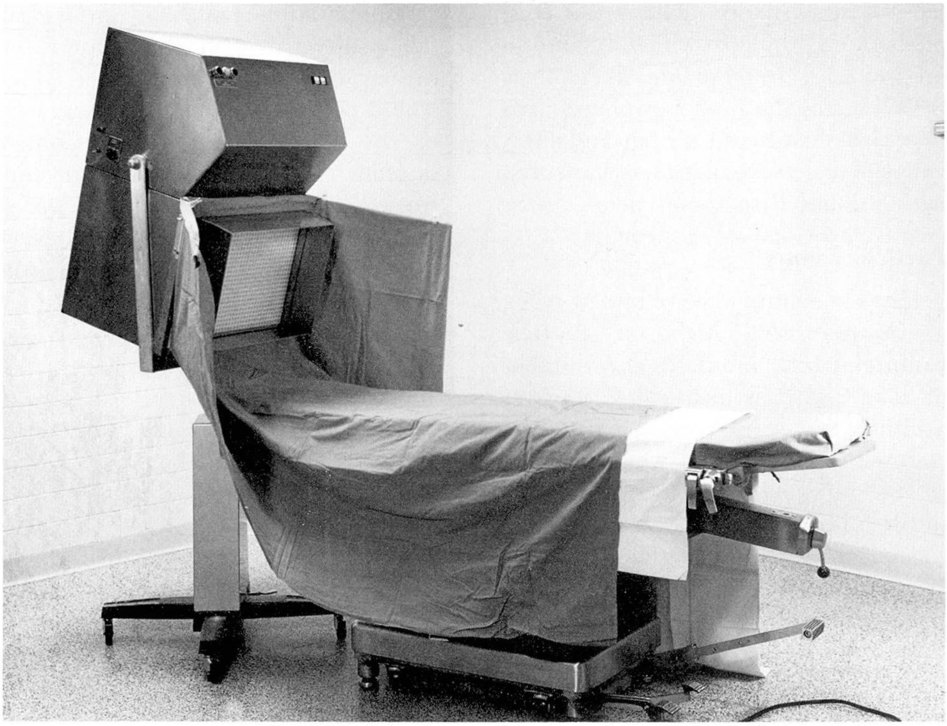


Fig. 3. Sterile drape sheets placed at tangential angle at sides of exit nozzle.

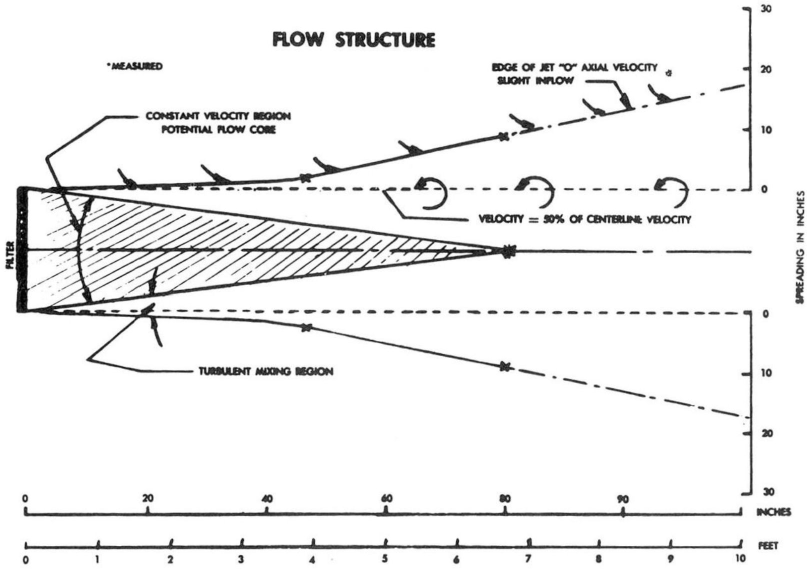


Fig. 4. Demonstration of measured air patterns.

outer funnel-shaped area is the edge of the flow profile in which maximum mixing with ambient air takes place. It delineates the most peripheral area in which the filtered air has any effect and where zero velocity was measured with the hot wire anemometer.

Particle counts

Particle counts were obtained using a Coulter 550 Airborne Particle Counter which tabulates the number of 0.5μ particles per cubic foot of aspirated air. A hose was run from the counter to the area in which air was to be sampled. During surgery, a sterile plastic tube was clamped into the surgical incision so that its orifice aspirated air directly from the wound. It has been our experience that when studies of airborne particles are made in an operating room, they are seldom taken directly from the wound but rather from an adjacent area which would not produce data representative of the actual wound area. Control samples were taken with the air unit turned off but with the tube left in its original position. Intermittently, during each surgical case, air samples were taken over the instrument tables. Particle counts were also taken with and without the surgical team's hands and arms in the air flow.

Figure 5 compares the number of 0.5μ particles counted per cubic foot of air at the wound during surgery within the air flow and particles counted with the unit turned off. The air unit was always kept within 42 inches of the wound and closer, if possible. The average of 61.3 particles

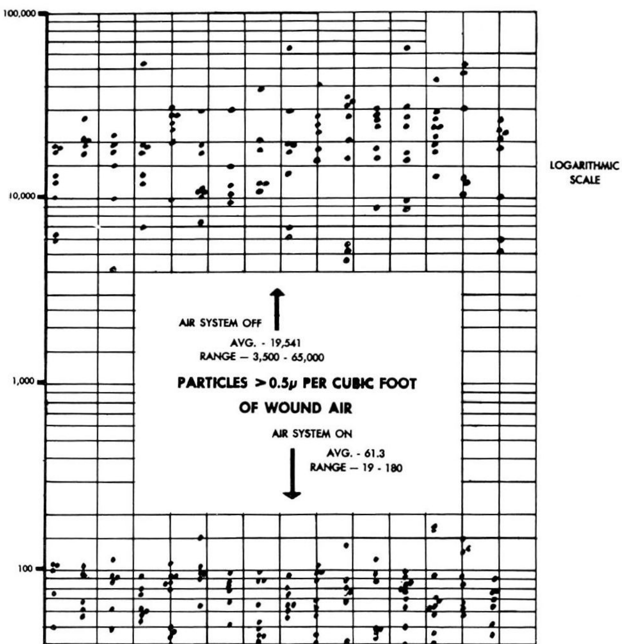


Fig. 5. Number of 0.5μ particles per cubic foot of air within air flow and with unit turned off.

per cubic foot with the air unit turned on is considerably less than the 19,541 particles per cubic foot found in the same area with the system off.

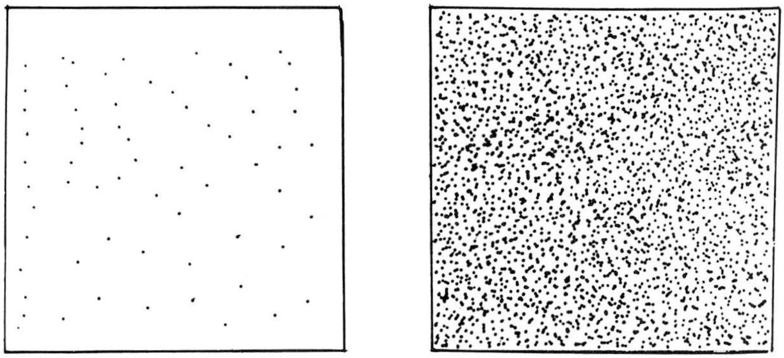
Figure 6 visually shows the relative density of 0.5μ particles at the surgical site, with the air system functioning as contrasted to the same area without the air filtration.

It was initially felt that the turbulence generated by the surgeon's hands and arms in the air flow would adversely affect particle counts. There is no question that turbulence is generated in this fashion, but we were surprised to find that the particulate content rose only if the surgeon's hands were placed directly upwind and in line with the sampling probe. If the hands were placed even an inch or so above the sampling orifice, no increase in the particle count was recorded. It is hypothesized that the central core of laminar flow air is quite uniform and that transfer of particulate matter from one lamina to another occurs only with some difficulty in this region. Particle counts made over the back instrument tables are shown graphically in *Figure 7*. Once the filter was turned on it was evident that the counts decreased rapidly.

Bacteriologic sampling

Viable airborne particles were counted by clamping two sterile plastic hoses with their orifices directly at the wound edge. The hoses were kept as short as possible to minimize entrapment of bacteria along their inner walls and were connected to either a standard millipore air sampler or a sampler of our own design.

The millipore sampler is essentially a sterile chamber containing 30 cc brain-heart infusion broth. Air is projected into the broth, thus trapping most particulate matter. This culture media is then passed through a millipore filter where bacteria are deposited on its surface. A pad beneath the filter is kept saturated with a nutrient media to promote bacterial growth. This system, although theoretically quite efficient, has many disadvantages. It is fragile, difficult to set up, it samples only 1 cubic foot of air, and if the slightest error is made when the broth is drawn through the filter, the filter is



61 Particles 19,000 Particles

Fig. 6. (*left*) Relative density of 0.5μ particles in area with air system functioning; (*right*) same area without air filtration.

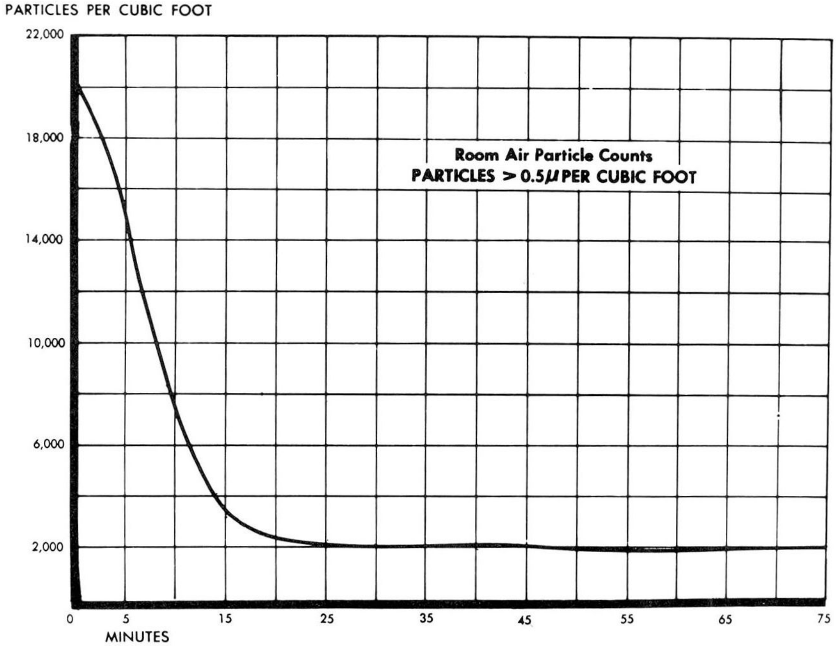


Fig. 7. Graph showing particle counts made over back instrument tables.

left too dry and very little growth will result.

Because of these problems, a new type of air sampler was designed *(Fig. 8)*. It consists of a sterile chamber into which a standard petri dish containing blood agar is placed. Incoming air at the rate of 1 cubic foot per minute is passed into a pressure plenum. This plenum has many minute holes in its interior surface through which air is directed onto the agar face. Although some airborne bacteria are certain to skip across the agar and not be impinged, the system proves to be quite effective, simple to use, and has the advantage of being able to sample large volumes of air. Since comparison was only made between samples with the same air monitor, it was felt that the results were valid despite the loss of some bacteria from the agar surface. Air was drawn through broth samplers by a small, standard vacuum pump.

The experimental samples were taken with the air unit on and the control samples aspirated from the same region with the filter turned off. *Figures 9 and 10* graphically demonstrate the differences in the bacteria counts. An average of 1.2 bacteria were found per 10 cubic feet within the air flow and 19 bacteria per 10 cubic feet in the control series. With the millipore sampler, an average of 0.83 bacteria per cubic foot were found within the air flow as compared to 12.5 per cubic foot without the air flow.

Discussion

The present report describes the effectiveness of locally directed clean air for the protection of surgical wounds from airborne contamination. It was felt during the study that the low particle counts in other areas of the operating room with the air system turned on would significantly decrease

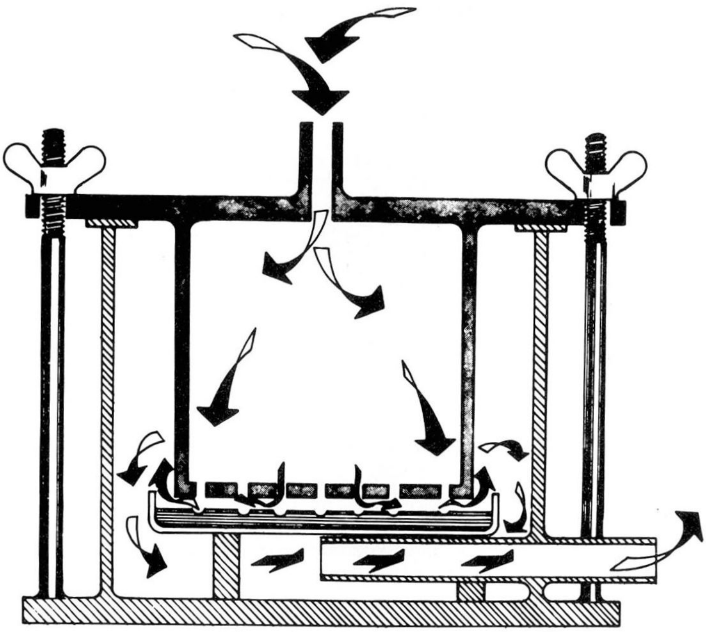


Fig. 8. New type air sampler.

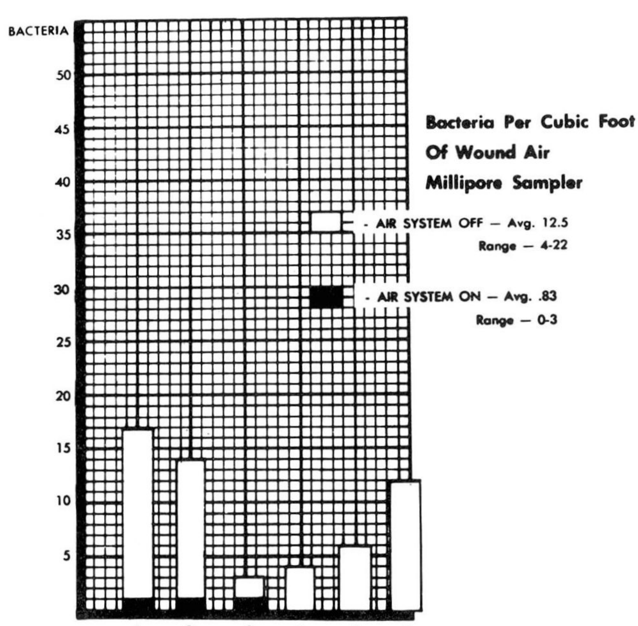


Fig. 9. Millipore sampler, bacterial count.

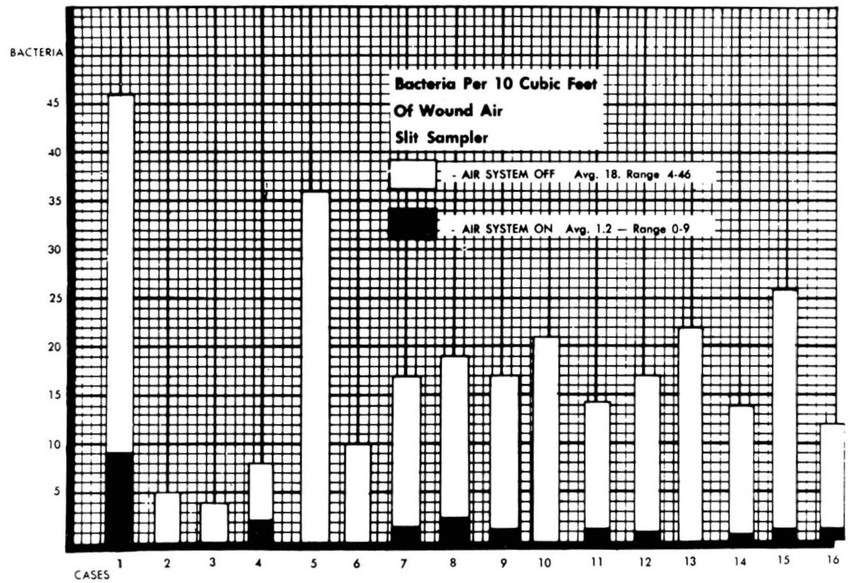


Fig. 10. Slit sampler, bacterial count.

bacteria fallout on the instrument tables; however, bacteriologic sampling of these areas in a controlled fashion was not carried out. Studies are presently in progress which suggest that such is the case. However, insufficient data have been collected to reach any definite conclusion.

The core area of true laminar flow across the wound was found to form a very effective barrier to prevent particles dropped into it from reaching the wound. Particulate matter generated by the surgical team and entrained in this flow could, however, be carried away and deposited on the open instrument tables. To minimize this possibility, we are now covering the back table instruments with a sterile, clear plastic drape sheet and using bacteria-impenetrable cloth or paper hoods for the surgical team. The surgeon's expelled breath is exhausted via a small vacuum system into the air unit's HEPA filter where it is isolated from the ambient environment. It may be that these additional steps are unnecessary, as the total room counts are quite low. On the other hand, it may eventually be proven that isolating the surgical team and the patient from the operating room atmosphere will result in such low air bacterial counts that no special air filtration system may be required.

Summary

A portable air filtration unit for use in hospital operating rooms has been described. Prospective studies of its effectiveness in controlling airborne particles and bacteria were presented. It is concluded that this system has certain advantages over other existing air filtration systems.

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