A systems analysis approach to postoperative wound infections

Phase I. Evaluation of a horizontal wall-less laminar air flow system

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Is the environment a significant factor in a postoperative wound infection, and if so, is laminar air flow an effective control? A problem of this magnitude can only be solved by the amalgamation of three basic interdisciplinary sciences: engineering, microbiology, and medicine. Working together, a systems analysis approach was developed to solve just such a problem.

Engineering

A conventional 20 by 20 foot operating room was first equipped with a horizontal wall-less laminar air flow unit.* This unit was selected because of the relatively low cost and ease of installation and modification. The floor of the operating room was marked with locating spots at the nodes of 1 foot squares. Planar air velocities were measured with a single wire constant temperature, hot wire anemometer (DISA S & B Inc., Model 55D01). The anemometer probe was mounted in an indexing head attached to a locating stand. The anemometer was calibrated before and after each set of data was obtained. Ten readings, each separated by five time constants, were recorded over each locating spot with the indexing head set at each setting of −45°,

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neutral, and +45°. The same readings were obtained for each locating spot throughout the room. All measurements were at the 4-foot level (wound height). The results showed, that with the room empty there was a 6-foot wide area in which the air was directed away from the filter module, and at a speed of about 300 feet per minute (*Fig. 1*). When the room was manikin staged, the air speed was reduced to about 150 feet per minute at the region of wound site, and the area of unidirectional air was widened to approximately 10 feet (*Figs. 2 and 3*). This can be determined by noting the lines

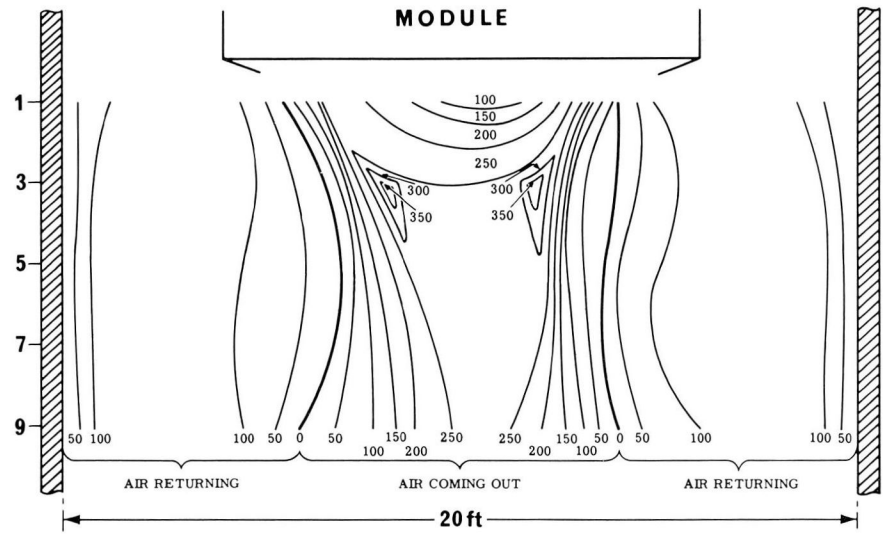

Fig. 1. Constant velocity plot-room unoccupied.

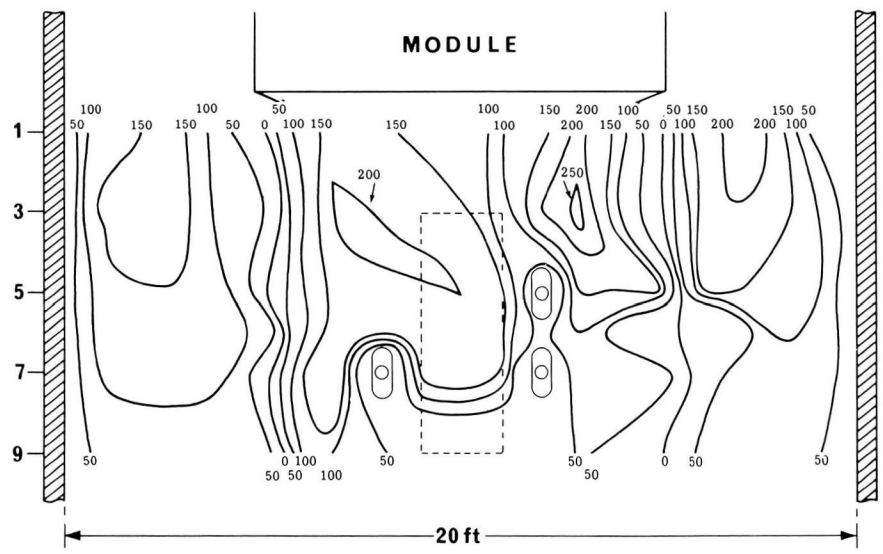

Fig. 2. Constant velocity plot-room occupied.

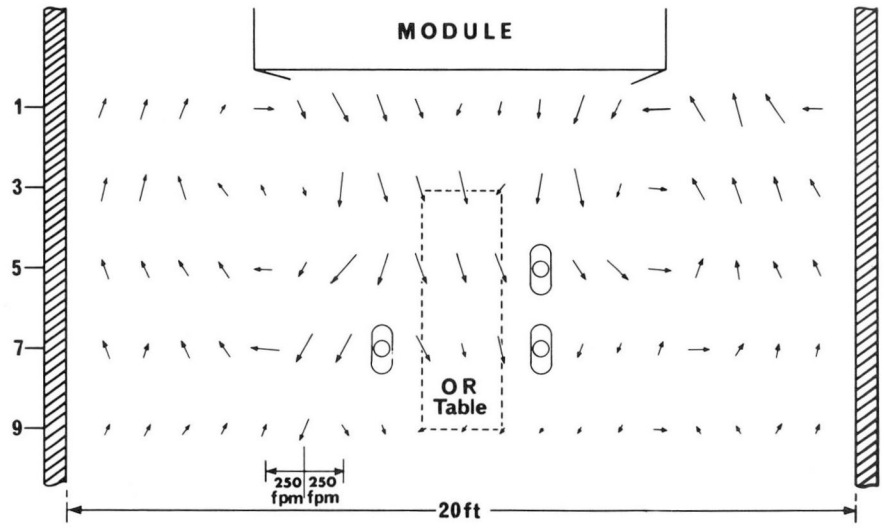

Fig. 3. Velocity vector plot-room occupied.

with the 0 velocities. Thus, by introducing people and equipment into the path of the air, the area of safety widened.[1]

Particle counts

Because the term class 100 has been used to denote a clean room we moved a Coulter particle counter (Coulter Electronics model number 550) across the same locating spots with the room empty. At each spot 10 readings were recorded. Each reading consisted of the number of particles greater than 0.5μ in diameter per cubic foot of air. Where the counts dropped precipitously below 100, a mark was made upon the floor. These marks coincided with our previously determined 0 velocities (*Fig. 1*) perpendicular to the module. The floor was then permanently marked with white lines over the previously mentioned spots, inside of which we refer to as our clean zone, and outside of which all nonsterile equipment and personnel remain (*Fig. 4*).

Running the particle counter (4 feet high) 1 foot to either side of the midline of the clean zone and 6 feet from the plenum (the area where the operative site might be) we found: (1) The activity outside of the clean zone had no effect on the counts within the zone. (2) The activity in the clean zone on the opposite side of the midline had a minimal effect on the counts on the other side of the clean zone. The counts never went above 100. (3) Counts rose drastically if one stood upwind of the counter; however,

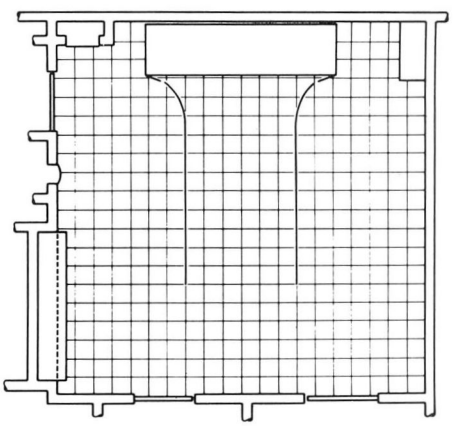

Fig. 4. Projected clean area.

when standing 1 foot from the plenum, 5 feet upwind of the counter, they rose only slightly. This indicated that not only was the air moving away from the plenum, but away from the midline.

Smoke and bubble tests

Smoke bombs were released and the area was photographed. This was totally unsuccessful in our hands.

Soap bubbles one-eighth inch in diameter, filled with helium to maintain their buoyancy, were generated so we could visually see air flow patterns in areas of concern. We found that there were many areas of turbulence but few had an effect on the wound area. Our largest problem was air returning from the area of the anesthesiologist. This occurred when the surgical personnel would lean into the center over the operating site, creating a negative pressure downwind. This corrected itself instantly when the air had a chance to pass directly over the wound site without interference.

Proper utilization of the room

All operating room personnel were then trained as to proper use of the clean zone and how to avoid interfering with the air stream.[2] When instruments were to be passed across the midline they were done so rapidly and with the gowned arm and gloved hand (*Fig. 5*). Mayo stands could be used, but they had to be high enough to allow the air to pass easily beneath them and across the wound (*Fig. 6*). All equipment was to be placed upon instrument tables between the plenum and operating room table (*Fig. 5*). All observers and nonsterile operating personnel were to remain outside the clean zone (*Fig. 7*).

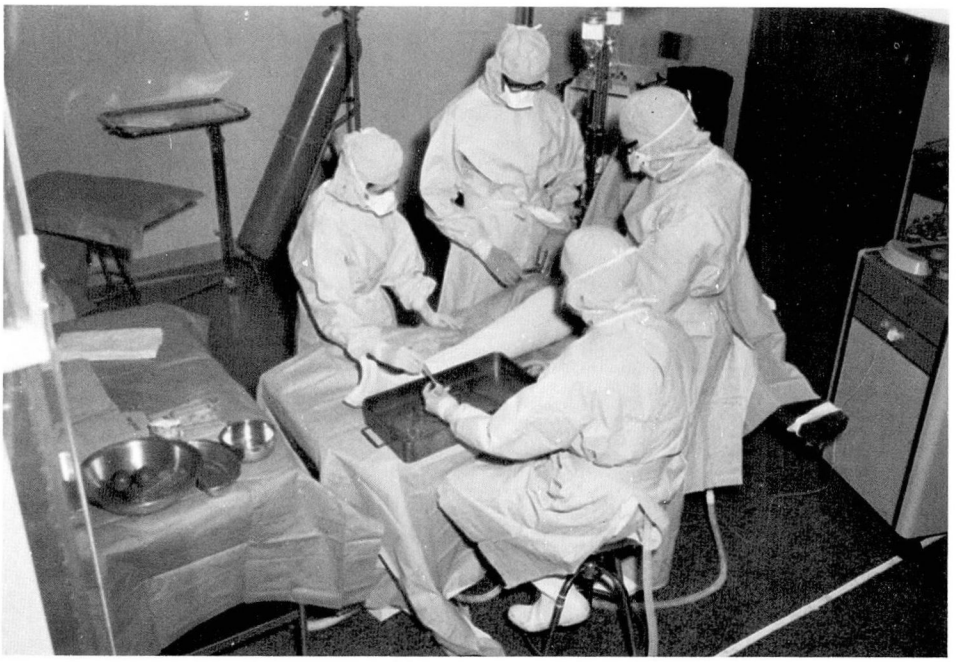

Fig. 5. The positions of operating room table, back table, and means of passing instruments. The plenum is to the left.

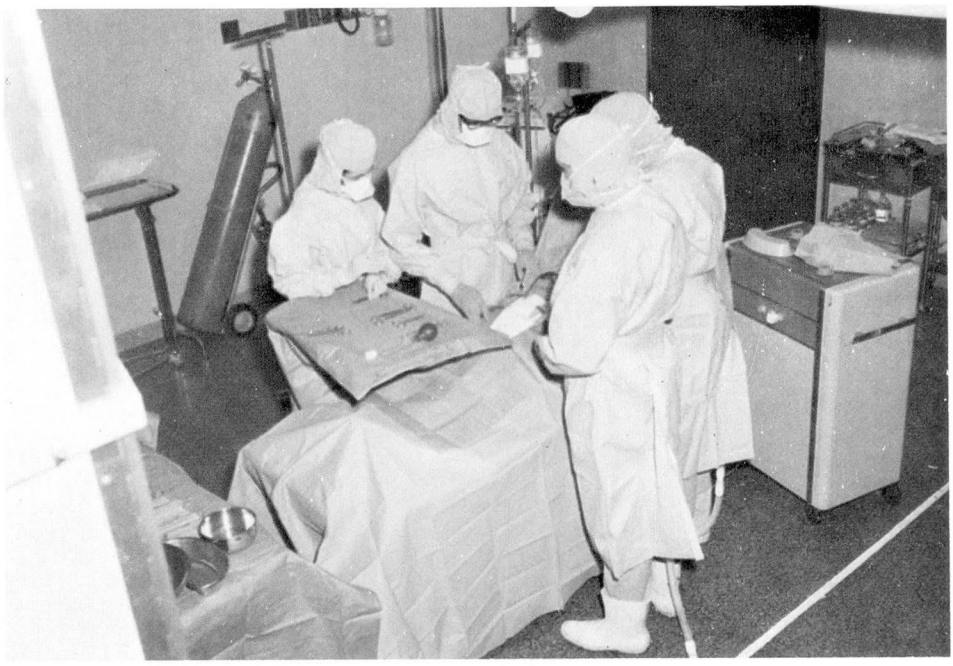

Fig. 6. The position of the back table, operating room table, and Mayo stand. The Mayo stand should be a few inches higher than the wound to allow the air to blow beneath it and over the wound.

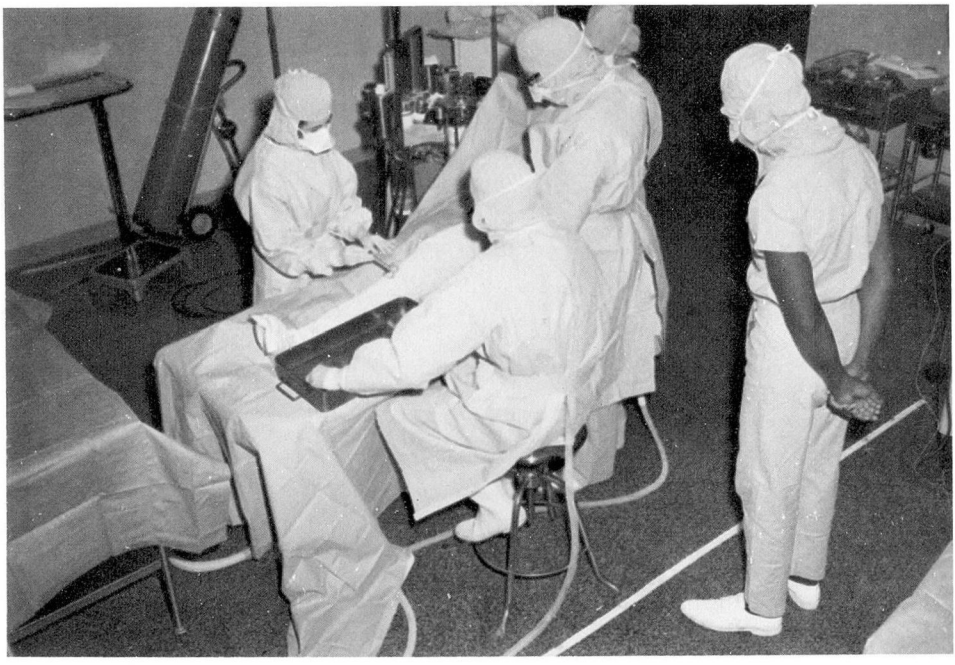

Fig. 7. All sterile equipment and personnel are to remain inside the white lines, and observers are to remain outside the white lines.

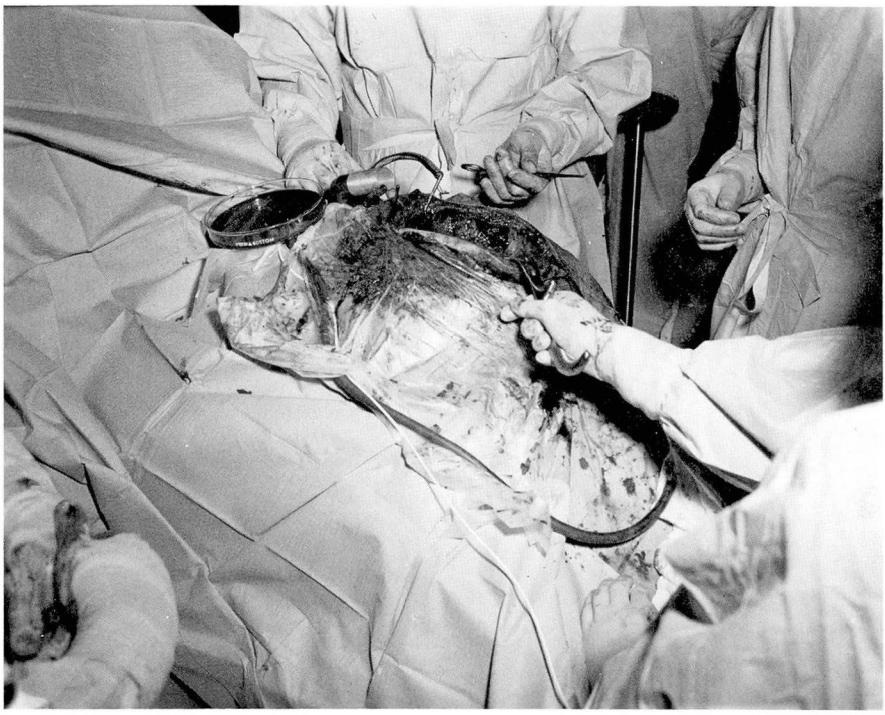

Fig. 8. Air settle plate and isokinetic sampling from the wound site. Note the nozzle for the isokinetic sampling between the air settle plate and the wound.

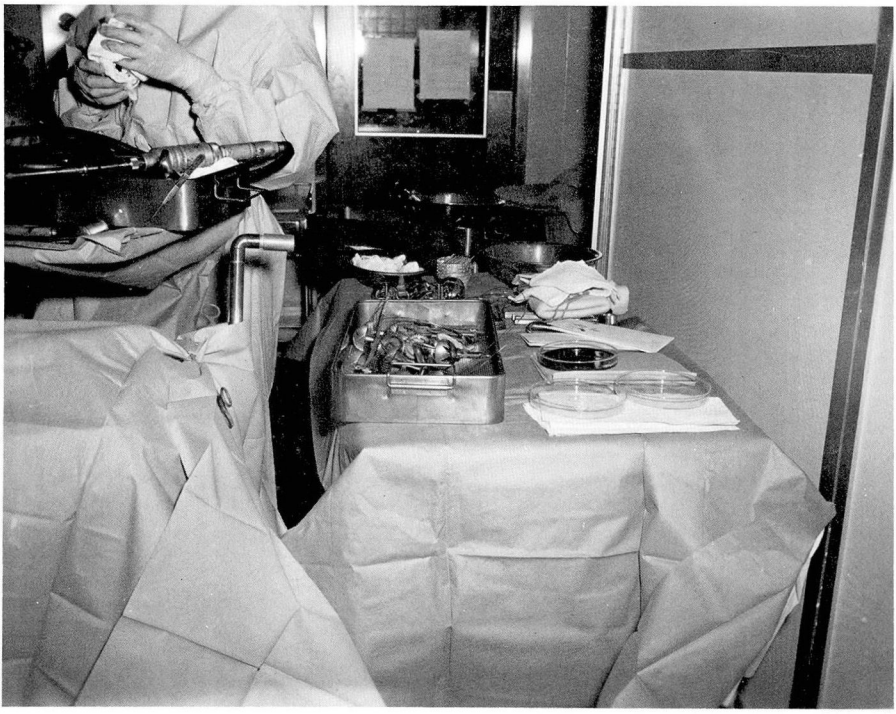

Fig. 9. Air settle plate and isokinetic sampling from the back table. Note the nozzle for the isokinetic sampling at the foot of the operating room table and the air settle plate on the instrument table.

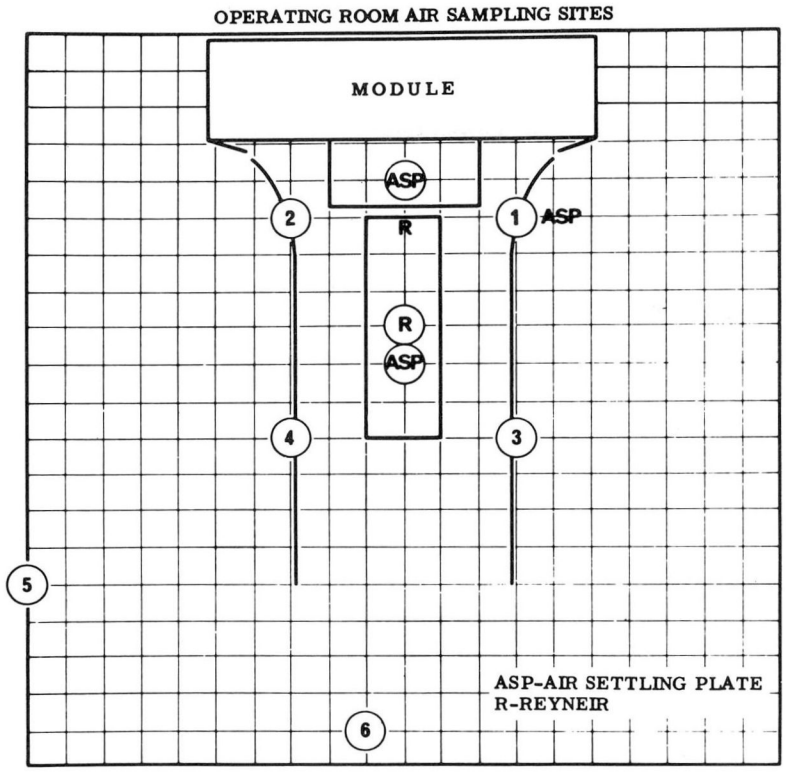

Fig. 10. Room air sampling sites.

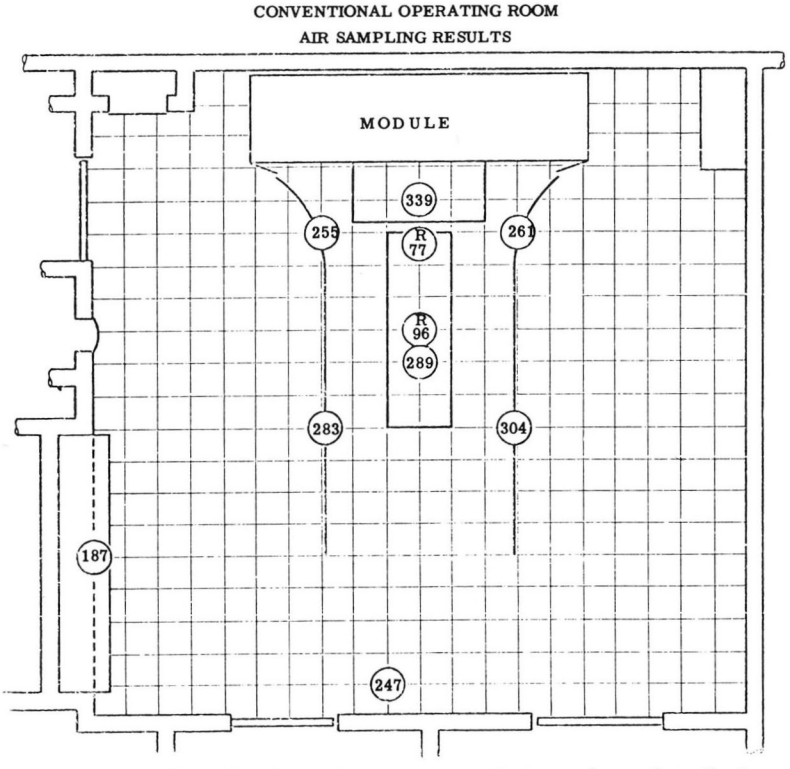

Fig. 11. The average colony forming units per square foot per hour for all air settle plate sampling and colony forming units per cubic foot per hour for (R) isokinetic sampling.

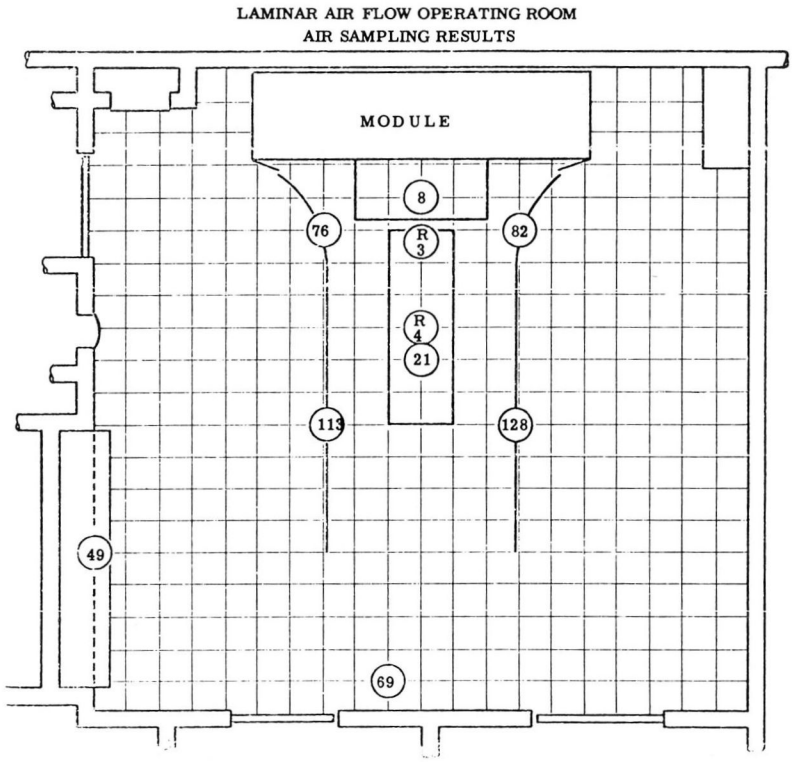

Fig. 12. The average colony forming units per square foot per hour for the air settle plate sampling and the average colony forming units per cubic foot per hour for (R) isokinetic sampling.

MICROBIAL LEVELS OF A CONVENTIONAL OPERATING ROOM
VS
AN OPERATING ROOM WITH HORIZONTAL LAMINAR AIR FLOW

AIR SAMPLING CONDITIONS	CONVENTIONAL ROOM	LAMINAR AIR FLOW	% REDUCTION
* Reyneir at wound	82	5	94
* Reyneir at back table	58	3	95
Air Settle Plate at wound	240	20	92
Air Settle Plate at back table	273	8	97
Air Settle Plate around clean zone	274	105	62
Air Settle Plate - periphery of room	228	60	74

* Colony Forming Units/hour
Colony Forming Units/ft^2/hour

Fig. 13. The percent reduction of microbial levels, of laminar air flow versus the conventional operating room for all sampling sites.

Microbiology

With an understanding of how the room performed, we developed an exhaustive microbiological evaluation of all orthopaedic procedures to be performed within the operating room, both with and without the use of the laminar air flow unit.[3] This was easily accomplished, as the laminar air flow unit could be turned on or off while the conventional ventilation system was continually in operation. Sampling techniques were designed so that we could determine not only the types and numbers of organisms within the room, but possible sources. The following were evaluated: (1) Cultures were obtained from the patients' noses, throats, faces, groins, wound sites prescrubbed, wound sites postscrubbed, and depth of the wounds after incision and prior to closure. All samples were placed in Dey/Engley

neutralizing broth. (2) The noses, throats, faces, and groins of the operating room personnel were cultured. (3) Airborne contamination of the room was determined with the use of isokinetic sampling devices attached to the wound site and back table and 150 mm air settle plates fixed to the wound, back table, and peripherally about the room. The air settle plates were sterilized by autoclaving triple wrapped glass 150 mm petri dishes. These were then opened under a laminar flow hood, filled with 5% sheep blood agar, and allowed to incubate for 2 days before use. The isokinetic sampling was devised by first determining the speed of the air at the wound site and machining a nozzle which would sample at that speed when connected to a Reynier slit sampler drawing 1 cubic foot of air per minute. The nozzle and tubing were then autoclaved before use (*Figs. 8 and 9*). All peripheral air settle plates were placed at wound height (*Fig. 10*). This type of sampling was carried out on consecutive orthopaedic cases whether the laminar air flow was on or off.

A total of 242 cases have been sampled; 125 were with the laminar flow on and 117 with the laminar flow off. As can be seen from *Figure 11* there is little difference in the counts at the wound site or the periphery of the room without the use of laminar flow. However, there was a tremendous difference between the counts about the wound site and the periphery of the room when the laminar air flow was used (*Fig. 12*). *Figure 13* is a summary of *Figures 11 and 12* with the percent reduction of environmental bacteria ($P < 0.005$).

From our studies to date we have been able to learn how the air moves, how we use it correctly, and how effective it is as a control of the environmental bacteria.

Acknowledgment

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References

1. Hart JB, Ritter MA, French MLV: Air flow determination in a horizontal laminar air flow operating room. Trans Biomed Eng. In press.
2. Ritter MA, French MLV, Hart JB: Microbiological studies in a horizontal wall-less laminar air flow operating room during actual surgery. Clin Orthop. In press.
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