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Bacterial contamination in a modern operating suite. 1. Effect of ventilation on airborne bacteria and transfer of airborne particles*

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SUMMARY

The effect of ventilation on airborne contamination was studied in a new operating suite containing operating rooms with conventional ventilation (17–20 turnovers/h) and operating rooms with zonal ventilation, where the turnover in the central part of the room was ~ 80/h. The efficacy of the ventilation was first examined with gas tracer experiments and found satisfactory. Experiments using potassium iodide particles showed the transfer between adjacent rooms in the suite to be less than 10^{-3} % with closed doors and from 1 % to $2{\cdot}5 \times 10^{-2}$ % when the doors were opened once a minute. The transfer between two adjacent operating rooms was calculated to be ~ 10^{-4} %. There is thus little risk of spread of airborne infection between operating rooms.

Experiments with potassium iodide particles showed that in operating rooms with zonal ventilation the particle concentration in the centre of the room was about one-tenth that in the periphery; in conventionally ventilated operating rooms the concentration was about one-half. With bacteria-carrying particles generated by human activity the concentration in the centre of operating rooms with zonal ventilation was about half that in the periphery both during experimental activity and operations; in conventionally ventilated operating rooms it was about equal in both cases. Bacterial counts at the periphery were found to be lower in rooms with zonal ventilation (~ 50 c.f.u./m^3) than in conventionally ventilated (~ 70 c.f.u./m^3).

INTRODUCTION

There is general agreement that air supplied to operating rooms should be free from dust and bacteria. For many years operating rooms have therefore been provided with some form of ventilation equipment. The purpose has been to provide comfortable working conditions and to maintain dilution of airborne contaminants derived from human sources inside these areas. The introduction of positive pressure ventilation for operating rooms led to a substantial reduction of the number of airborne micro-organisms and some workers claim that this was accom-

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panied by a reduction in the frequency of wound sepsis (Williams, Blowers, Garrod & Shooter, 1966). Methods for a further reduction of the air contamination by a factor of ten or more (ultra clean air) have been introduced during the last years. The claim is made that the use of these would lead to a further reduction of wound sepsis at least in some kinds of surgery (Charnley, 1964; Charnley & Eftekhar, 1969; Charnley, 1972; Eftekhar, 1973).

In many of these studies, however, the comparisons made have been between the rates of sepsis before the introduction of the ultra clean air systems and those experienced subsequent to the change. Other changes were also made during the period of study and there are those who believe that a conventional plenum system would have given comparable results (Leading article, *Brit. med. J.*, 1975). In order to evaluate the gain derived from the introduction of clean air systems it is, in our opinion, necessary to have a direct simultaneous comparison of the new and old systems.

The new operating department at the University Hospital in Uppsala is equipped with positive pressure ventilation systems of two different kinds. In order to investigate the effectiveness of the ventilation in this new unit we have studied the airborne transfer of particles as well as the amount of airborne contamination during activity. When studying transfer of airborne particles we have used a method described by Foord & Lidwell (1972). We have also tried to discover if the layout of this operating unit has contributed to maintaining good working routines within the unit. The results of the clinical study of sepsis rates in operations performed in the suite will be presented in a later paper.

MATERIALS AND METHODS

Operating unit

The operating suite consists of twelve operating rooms. The layout of the unit, i.e. the operating rooms and ancillary rooms, can be seen from Fig. 1. In principle it is a double-corridor system. One corridor is used by clean staff and for clean or sterile supplies only. In this the scrub sink for the operating team is situated. The other corridor is used for transport of patients and other material and for the removal of used and soiled articles. Each operating room has three doors. One leads to the corridor used by the staff, one leads to the anaesthetic room and one to the exit area.

Ventilation

The unit is equipped with a positive pressure ventilation system and the ventilation is normally balanced between all rooms in the operating suite. The extraction of air from the operating room can be increased causing an inflow of air from the corridors. This latter type of ventilation is used during operations classified as septic, contaminated, or infected according to local rules.

The ventilation rate in the operating rooms is about 17–20 air changes per hour. In some rooms there is a special zonal ventilation (Fig. 2) where a clean air inlet is installed in the ceiling over the operating table. This inlet consists of a perforated area $2{\cdot}4 \times 3{\cdot}4$ m enclosed by two parallel 2 mm wide slits. By this system

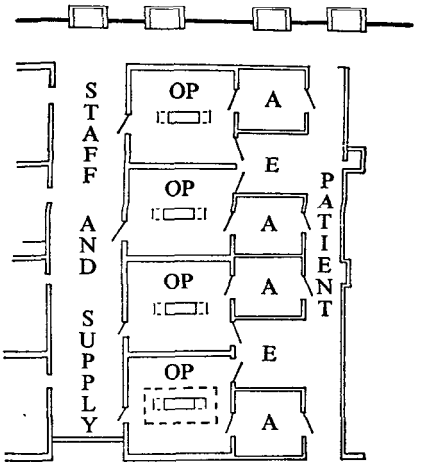

Fig. 1. Layout of the operating suite. OP, Operating room. The broken line indicates the position of the zonal ventilation; A, anaesthetic room; E, exit area.

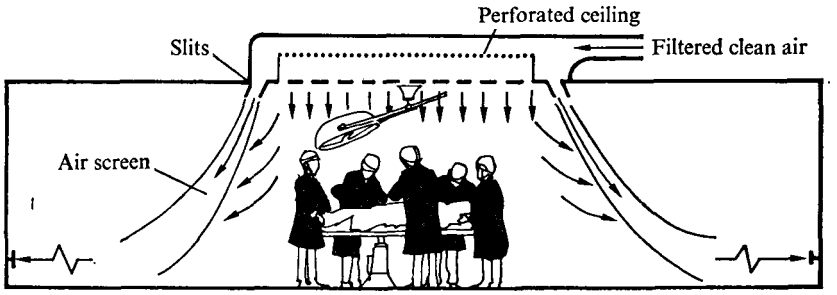

Fig. 2. Design of operating room with zonal ventilation.
Broken arrows symbolize evacuation grilles.

the operation area is provided with a ventilation corresponding to 80 air changes per hour. According to the designers (Abel & Allander, 1966) the clean air is almost completely prevented from being mixed with the peripheral room air by the air jets derived from the parallel slits.

Gas tracer experiments

Before the particle tracer experiments were performed the ventilation plant was examined by using nitrous oxide as a tracer gas (Lidwell, 1960). The gas was liberated in measured amounts and samples were taken continuously in the operating rooms. The gas concentration present in an air sample was determined by infra-red absorption. All experiments were made with the doors closed. This part of the investigation was done in collaboration with Dr Olander and Dr Faxvall at the Institute of Technology in Stockholm.

Tracer particle experiments

A spinning disk particle generator was used to produce an aerosol of particles (Foord & Lidwell, 1975). With the help of an external fan the particles were mixed

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with the air in the room. Potassium iodide dissolved in ethyl alcohol was used at a concentration giving an aerosol with particles with a sedimentation rate close to 0·3 m/min. In all experiments the generator was run for 30 min and, if possible, adjusted to reach a steady state of about 500 particles/l at the source. Air sampling and determination of particle size was carried out as described earlier (Hambraeus & Sanderson, 1972).

Bacteriological experiments

Airborne bacteria-carrying particles were sampled using a Casella slit sampler sampling 700 l/min. Blood agar plates were used. The plates were incubated at 37 °C for 48 h before being examined. The total count of c.f.u. of bacteria was estimated and presumptive *Staph. aureus* c.f.u. were tested for deoxyribonuclease activity.

RESULTS

Gas tracer experiments

In more than three-quarters of the experiments with balanced ventilation there was no detectable transfer of air from adjacent rooms into the operating theatre and only once did the concentration in this room exceed 3% of that in the (adjacent) room in which the gas was being liberated.

When there was a forced exhaust of the air in the operating theatre transfer of air into the operating room was detected in half these experiments and the concentration in the operating room was between 2 and 20% of that in the room where the gas was liberated.

When tracer gas was liberated in the operating room transfer from the operating room to adjacent rooms was detected in half the experiments with the ventilation in the balanced conditions and in as many as one-third of the experiments when there was increased extraction of air from the operating room. On no occasion did the concentration found in any room exceed 10% of that in the operating room.

Particle transfer between the operating room and adjacent areas (with balanced ventilation)

In this series of experiments the following sequences of experiments were used.

(1) Generation of particles in the operating room measuring the transfer to: (*a*) the anaesthetic room; (*b*) the exit area and adjacent parts of the patient corridor; (*c*) the staff corridor.

(2) Generation of particles in the anaesthetic room and staff corridor, measuring the transfer to the operating room.

(3) Generation of particles in the anaesthetic room, measuring the transfer to the corridor outside.

In all experiments the doors to the operating room were closed during the first 10 min of particle generation and no activity was carried out. During the following 20 min one person walked from the site of the source to the receiving room and back again every other minute, i.e. the activity corresponded to 60 door openings

Table 1. *Particle transfer within the operating suite**

Source/receiving room		Ratio source/receiving room: No activity (median value)	Ratio source/receiving room: Activity (log mean value)
Operating room / Anaesthetic room		$1{\cdot}1 \times 10^5$	$9{\cdot}6 \times 10$
Operating room / Exit area		$> 2 \times 10^5$	$4{\cdot}8 \times 10^2$
Operating room / Patient corridor	Just outside exit area	$> 2 \times 10^5$	$2{\cdot}3 \times 10^4$
	≈ 4 m along the corridor	$> 2 \times 10^5$	$5{\cdot}5 \times 10^4$
Operating room / Staff corridor	Just outside the door	$> 2 \times 10^5$	$7{\cdot}9 \times 10^2$
	≈ 4 m along the corridor	$> 2 \times 10^5$	$2{\cdot}4 \times 10^3$
Anaesthetic room / Operating room		$> 2 \times 10^5$	$2{\cdot}1 \times 10^3$
Staff corridor / Operating room		$> 2 \times 10^5$	$1{\cdot}3 \times 10^3$
Anaesthetic room / Patient corridor	Just outside the door	$> 2 \times 10^5$	$1{\cdot}5 \times 10^3$
	≈ 4 m along the corridor	$> 2 \times 10^5$	$4{\cdot}0 \times 10^3$

* On an average 11 experiments were made of each kind.

per hour. Air samples were taken at the source for 1 min periods at 2 min intervals. In the receiving rooms samples were taken continuously for 10 min during the period of no activity and for 4 min every 5 min during the period of activity. The transfer of airborne particles from one place to another will be presented as the ratio of the particle concentration at the source site to that at the receiving site. The results of the experiments are shown in Table 1. When there is no activity there is a detectable transfer of particles only from the operating room to the anaesthetic room. During activity the lowest ratio $9{\cdot}6 \times 10$ is found for transfer from the operating theatre to the anaesthetic room. Transfers to the exit area and the staff corridor were of the same order with ratios of $4{\cdot}8 \times 10^2$ and $7{\cdot}9 \times 10^2$ respectively. The transfer into the operating room is much the same for the two doors tested, ratios being $2{\cdot}1 \times 10^3$ and $1{\cdot}3 \times 10^3$, mean value $1{\cdot}7 \times 10^3$. As the third door was of the same size, particle transfer through this door was not measured. In some experiments the concentration of particles was measured simultaneously just outside the source room and about 4 m along the corridor. As can be seen the concentration fell to between $\frac{1}{2}$ and $\frac{1}{3}$ between these two points.

The risk of transfer from one operating room to the adjacent one of a pair, under the experimental conditions, can be calculated as follows. For transfer via the exit area:

$$S/R = S/E \times E/R = 4{\cdot}8 \times 10^2 \times 1{\cdot}7 \times 10^3 = 8{\cdot}2 \times 10^5,$$

where S represents the particle concentration in the operating room, acting as the source room, R that in the receiving operating room and E that in the exit area. For this calculation the mean of the two experimental values for transfer into an

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Table 2. *Transfer of tracer particles within an operating room; see Fig.* 3

(Ratio of concentration to that close by source, 1.)

	Expt.	Conventional ventilation	Zonal ventilation
At periphery near source, 2	1	0·30	0·83
	2	0·53	0·45
	3	2·50	0·11
Mean*		0·74	0·34
At centre, 3	1	0·27	0·18
	2	0·31	0·14
	3	1·25	0·05
Mean		0·47	0·11
At periphery opposite source, 4	1	0·24	1·43
	2	0·32	0·91
	3	1·67	0·21
Mean		0·51	0·65

* Means are geometric.

operating room through a door has been taken as the value of E/R. For transfer via the staff corridor:

$$S/R = S/C_R \times C_R/R = 2{\cdot}4 \times 10^3 \times 1{\cdot}3 \times 10^3 = 3{\cdot}1 \times 10^6,$$

where C_R represents the particle concentration in the staff corridor outside the receiving operating room door, i.e. 4 m from the source room door.

The overall transfer ratio between the two operating theatres is then

$$1/(1/(8{\cdot}2 \times 10^5) + 1/(3{\cdot}1 \times 10^6)) = 6{\cdot}5 \times 10^5.$$

Particle transfer within the operating room

Transfer of potassium iodide particles

Experiments were made in rooms with and without zonal ventilation. The arrangement of the tests can be seen from Fig. 3 and the results in Table 2. In order to create a normal turbulence in the operating rooms one person was moving around in the periphery during the experiments.

As might be expected there is considerable variation in the distribution of particles from experiment to experiment. In rooms with conventional ventilation the ratios between the particle concentration at the different sampling sites to that at the source site varied between 2·5 and 0·24. In rooms with zonal ventilation the corresponding range was from 1·43 to 0·06. However, the mean peripheral concentration ratios were similar for both types of ventilation, 0·74 and 0·51 with conventional ventilation compared with 0·34 and 0·65 with zonal ventilation. The mean concentration ratio at the centre was, however, much less with zonal ventilation, 0·11 compared with 0·47.

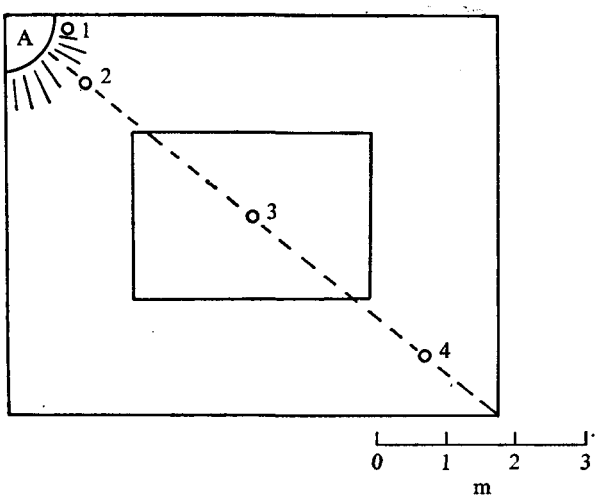

Fig. 3. OP 72. Transfer of potassium iodide particles in an operating theatre. Position of generator and samplers. A, Generator. Sampling points: 1, at the source; 2, periphery near source; 3, in the centre; 4, periphery opposite source.

Table 3. *Transfer of bacteria-carrying particles during standard activity in operating rooms*

(Ratio of concentration to that in the source area.)

Source area	Receiving area	Conventional ventilation (means of 4 experiments)	Zonal ventilation (means of 9 experiments)
Periphery	Centre	0·83	0·59
Centre	Periphery	0·83	2·00

Transfer of bacteria-carrying particles generated by standard activity

The distribution of airborne bacteria-carrying particles generated by human activity was also measured in the two operating rooms with different types of ventilation. Five technicians performed a standardized activity for 30 min (rapid walking) either in the centre or in the periphery of the operating room. The bacteriological samples were taken in the centre and in the periphery. The mean value of the ratios between bacterial concentration at the sampling points to that in the source area are given in Table 3. The experimental activity was sufficiently high to create airborne contamination of between 31·7 c.f.u./m^3 and 74·4 c.f.u./m^3 with an average of 41 c.f.u./m^3. Whether standard activity was taking place in the centre or in the periphery of operating rooms with zonal ventilation the concentration of bacteria within the zone was about half that in the periphery. In rooms with conventional ventilation the particles were almost evenly distributed in the room, mean ratios being 0·83 for both kinds of experiments.

Tests on airborne contamination during operations

The same type of sampling in the centre and the periphery was also done during actual operations on ten occasions in rooms with zonal ventilation and five times

Table 4. *Comparison of activity and airborne contamination in operating rooms with zonal ventilation and operating rooms with conventional ventilation*

	Zonal ventilation	Conventional ventilation
Mean length of operation	80 min	90 min
Minutes between door openings (mean value)	1·4	1·2
No. of people present (mean value)	13	15
Total number of bacteria		
Mean of all samples	46·3 c.f.u./m³	74·4 c.f.u./m³
Mean of means/operation	48·9 c.f.u./m³	70·9 c.f.u./m³
No. of *Staph. aureus* mean per operation	0·03 c.f.u./m³	0·24 c.f.u./m³

in rooms with conventional ventilation. When sampling in the centre the slit sampler was placed as close to the patient as possible. The level of airborne contamination in rooms with zonal ventilation was about half that found in rooms with conventional ventilation. In the centre of the rooms the mean values per operation were 31·5 c.f.u./m³ and 73·2 c.f.u./m³ for rooms with zonal and conventional ventilation respectively. The corresponding values for samples from the periphery were 53·9 and 89·0 c.f.u./m³. The mean ratio between bacterial concentration in the centre and the periphery for rooms with zonal ventilation was 0·6 (range 0·5–0·8), for rooms with conventional ventilation it was 0·8 (range 0·7–1). The difference, although small, is significant ($P < 0{\cdot}01 > 0{\cdot}005$).

Observations concerning working routines and airborne contamination during operations

During a period of 1·5 months a study was made of ten operations in operating rooms with each type of ventilation. Two hundred and sixty-eight air samples were taken in operating rooms with zonal ventilation and 141 in operating rooms with conventional ventilation. All the samples were taken at the periphery of the operating rooms. Notes were made concerning length of operation, number of people present, frequency of door openings, etc. As can be seen from Table 4 there was no significant difference between length of operation, which usually lasted between 1 and 2 h, or number of door openings; at least one door was opened almost every minute. The average number of people present during an operation was also about the same being 13 and 15, respectively, in the two operating rooms. However, in this investigation it was not possible to randomize the staff involved. In operating rooms with zonal ventilation 122 different persons were present at one time or other during the ten operations studied. The corresponding figure for conventional operating rooms was 125. Of these people only 46 were the same for the two series of observations. The mean number of bacteria of the total samples taken in rooms with zonal ventilation was 46·3 c.f.u./m³ and for rooms with conventional ventilation it was 74·4 c.f.u./m³. This difference is highly significant ($P < 0{\cdot}001$). The mean of the mean number for each operation was almost the

same: 48·9 and 70·9 c.f.u./m^3, respectively. The mean number of *Staph. aureus* found per operation was less in rooms with zonal ventilation 0·03 c.f.u./m^3 as compared to 0·24 c.f.u./m^3 in rooms with conventional ventilation.

DISCUSSION

The aim of the investigation was mainly to study transfer of airborne particles and airborne contamination in a modern operating unit with positive pressure ventilation. The initial experiments with tracer gas showed that the ventilation system functioned in agreement with the plans drawn up for this unit. The transfer of inert particles from one space to another was very low when there was no activity. When particles were generated in the operating room the highest concentration outside it was found in the anaesthetic room. During activity the ratio of particle concentration between the two rooms was about 100. This was due to the fact that the anaesthetic room is a small closed area from which particles disappear more slowly than from the large open corridors.

The transfer from the outside into the operating room was assumed to be the same for all three doors and therefore only transfer through two of the doors was tested. The mean value of the two ratios found was $1{\cdot}7 \times 10^3$ and this was used in calculations including the third door, i.e. transport from exit area to operating room. As two operating rooms share the same exit area, the transfer of particles from one operating room to the other via the exit area was calculated. Under experimental conditions the ratio of particle concentration between the source and the receiving operating rooms was $8{\cdot}2 \times 10^5$ for transfer via the exit area only, and $1/(1/(8{\cdot}2 \times 10^5) + 1/(3{\cdot}1 \times 10^6)) = 6{\cdot}5 \times 10^5$ if transfer via the staff corridor with the same rate of door opening, 60/h, is included.

The ratio between source room and receiving room is inversely proportionate to the frequency of movement through the door (Lidwell, 1972). It is therefore possible to recalculate the experimentally found value into one that would correspond to particle transfer during actual activity according to the following simplified formulae:

$$\alpha'_m = \alpha'_{60} \times \frac{60}{m}$$

$$\alpha''_m = \alpha''_{60} \times \frac{60}{m}$$

$$\alpha'_m \times \alpha''_m = \alpha'_{60} \times \alpha''_{60} \times \left(\frac{60}{m}\right)^2$$

α' denotes $\dfrac{\text{concentration in source room}}{\text{concentration in exit area}}$

α'' denotes $\dfrac{\text{concentration in exit area}}{\text{concentration in receiving room}}$

m = number of movements through the door in each direction

α'_m and α''_m are the ratios at m movements

α'_{60} and α''_{60} are the ratios at 60 door openings per hour (= experimental activity).

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The frequency of door openings between the operating rooms and the exit area was 12 times per hour. For this activity the ratio of particle concentration between source and receiving operating rooms would be $8{\cdot}2 \times 10^5 (60/12)^2 = 2{\cdot}1 \times 10^7$. It would seem that this should provide good protection against airborne transfer of bacteria from one room to the other, since a value of 1 particle/l in the source room would give rise to only 5×10^{-8} particles per litre in the receiving room. The risk of airborne transfer from one operating room to the other through the staff corridor was more than ten times less.

The potassium iodide particle method has earlier proved to be a useful method for estimating transfer of airborne particles in different kinds of patient wards (Hambraeus & Sanderson, 1972; Foord & Lidwell, 1975). It has proved possible to use this technique in a highly ventilated area such as an operating room. A comparison between room to room transfer found in an isolation ward (Hambraeus & Sanderson, 1972) with plenum ventilated rooms with air-locks and that found in the operating suite showed that the airborne isolation provided for the patient in an operating room was more than 1000 times better than that provided for the patient in the isolation ward. Since airborne transfer of bacteria in the isolation ward was found to be far less important than transfer of bacteria by other means such as clothes (Hambraeus, 1973), the airborne room-to-room transfer of bacteria in the operating suite is probably negligible compared with other routes of transmission. The distribution of particles within the operating room itself is therefore more interesting. In this study operating rooms with zonal ventilation were compared with operating rooms with conventional ventilation.

In operating rooms with zonal ventilation experiments with tracer particles as well as bacteria-carrying particles showed that the contamination in the centre was lower than in the periphery. In operating rooms with conventional ventilation both tracer particles and bacteria-carrying particles were almost evenly distributed within the room.

In operating rooms with zonal ventilation only about one-tenth of tracer particles were transferred from the periphery into the centre compared with one half when conventional ventilation was employed. The air currents from the ceiling are too slow to create a completely effective air curtain over the operating table and in experiments with bacteria-carrying particles the difference between centre and periphery and vice versa was substantially less being only about one half. This may be due to the fact that in both these sets of investigations there were people in the centre during the measurements. In the series of experimental activity one person had to attend to the slit sampler in the centre and during operations the entire operating team was in the centre. Since they generate bacteria-carrying particles themselves it is natural that the differences will be smaller than when tracer particles are used.

Airborne contamination was, however, low especially in operating rooms with zonal ventilation. The contamination in these operating rooms was not considerably higher than has been reported in investigations where ultra clean air ventilation systems have been used (McDade, Whitcomb, Whitfield & Franklin, 1968; Scott, 1970; Cook & Boyd, 1971).

This operating unit is planned with two corridors, one for the patients and the other for the staff. The operating and service rooms are situated in the centre. One of the reasons for this arrangement is to minimize the traffic to and from the operating rooms during operations. It was therefore surprising to find that the activity was high during operations, a door being opened almost every minute. According to several workers an intensive traffic in operating rooms is considered to increase the risk of acquiring infections during operations. From observations during operations it was not possible to calculate how much the entrance of one or two more people contributed to air contamination. The variations in activity during the operations were too rapid and frequent. From the experiments in which bacteria-carrying particles were generated by standard activity it is possible to calculate the influence of people and ventilation rate on the amount of airborne contamination. With five people present in a room with a ventilation rate of 20 turnovers per hour the average airborne contamination was 41 c.f.u./m^3.

The die-away rate due to sedimentation can be taken as approximately 5·5/h, assuming a particle settling-rate of 0·3 m/min in a room 3·3 m high. The equilibrium concentration in the room is given by Ne = $(nB)/(R \times S)$ (Bourdillon, Lidwell & Lovelock, 1948), with n the number of persons, B the rate of dispersal per person, R the ventilation rate and S the rate of loss due to sedimentation. For the above conditions $B = 41\ (20+5{\cdot}5)/5 = 209$. It is then possible to calculate the equilibrium concentration for any number of persons present and for any ventilation rate assuming the same rates of sedimentation and dispersal per person. Although the mean number present at the operations was 13–15 probably not more than 10 were active. According to this calculation the number of airborne bacteria would then be 82/m^3 in the conventionally ventilated room, the observed mean value was 71.

In a following paper the frequency of infections during a three-year period among patients operated on in this unit will be presented. Attempts will be made to explain the importance of airborne infection and whether routines involving as much movement as those described above may contribute to an increased rate of infection.

REFERENCES

Abel, E. & Allander, C. (1966). Undersökning av nytt inblåsnings system för rena rum. *VVS* No. 8.

Bourdillon, R. B., Lidwell, O. M. & Lovelock, J. E. (1948). Studies in air hygiene. *Medical Research Council Special Report Series* No. 262. London: H.M.S.O.

Charnley, J. (1964). A clean air operating enclosure. *British Journal of Surgery* **51**, 202.

Charnley, J. (1972). Postoperative infection after total hip replacement with special reference to air contamination in the operating room. *Clinical Orthopaedics* **87**, 167.

Charnley, J. & Eftekhar, N. S. (1969). Postoperative infection in total prosthetic replacement arthroplasty of the hip joint, with special reference to the bacterial content of the air of the operating room. *British Journal of Surgery* **56**, 641.

Cook, R. & Boyd, N. A. (1971). Reduction of the microbial contamination of surgical wound areas by sterile laminar air-flow. *British Journal of Surgery* **58**, 48.

Eftekhar, N. S. (1973). The surgeon and clean air in the operating room. *Clinical Orthopaedics* **96**, 188.

Foord, N. & Lidwell, O. M. (1972). An airborne particle tracer for crossinfection studies. *Journal of Hygiene* **70**, 279.

FOORD, N. & LIDWELL, O. M. (1975). Airborne infection in a fully air-conditioned hospital. II. Transfer of airborne particles between rooms resulting from the movement of air from one room to another. *Journal of Hygiene* **75**, 31.

HAMBRAEUS, A. (1973). Transfer of *Staphylococcus aureus* via nurses' uniforms. *Journal of Hygiene* **71**, 799.

HAMBRAEUS, A. & SANDERSON, H. F. (1972). Studies with an airborne particle tracer in an isolation ward for burned patients. *Journal of Hygiene* **70**, 299.

LEADING ARTICLE (1975). Risks and uses of total hip replacement. *British Medical Journal* i, 296.

LIDWELL, O. M. (1960). The evaluation of ventilation. *Journal of Hygiene* **58**, 297.

LIDWELL, O. M. (1972). Ventilation in subdivided isolation units. *Journal of Hygiene* **67**, 649.

MCDADE, J. J., WHITCOMB, J. G., WHITFIELD, W. J. & FRANKLIN, C. R. (1968). Microbiological studies conducted in a vertical laminar airflow surgery. *Journal of the American Medical Association* **203**, 125.

SCOTT, C. C. (1970). Laminar/linear flow system of ventilation. *Lancet* i, 989.

WILLIAMS, R. E. O., BLOWERS, R., GARROD, L. P. & SHOOTER, R. A. (1966). *Hospital Infections, Causes and Prevention*. 2nd ed. London: Lloyd-Luke Ltd.