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Ventilation conditions and air-borne bacteria and particles in operating theatres: proposed safe economies

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SUMMARY

Concentrations of air-borne bacteria and particles have been measured in turbulently ventilated operating theatres in full flow, half flow and zero flow conditions. Increased air-borne challenge produced by human activity and by mechanical cleaning procedures is demonstrated: die-away of this contamination is shown to be related to the ventilation rate. Ventilation can be reduced or turned off at night and during weekends, and cleaning can also be carried out, without increased risk of infection if full flow is restored one hour prior to preparation for surgery. Areas surrounding the theatres should remain at positive pressure with regard to the general hospital environment during low or no flow periods. The implementation of such energy-saving policies will substantially reduce theatre running costs without introducing infection hazards.

INTRODUCTION

Air filtration and mechanical ventilation in operating theatres are necessary for two main reasons. First, they enable the environment to be controlled in terms of temperature and humidity, thus ensuring the comfort of the operating team and patient. Secondly, they keep the concentration of air-borne contamination below specified limits to minimize the risk of air-borne cross-infection during surgery (Charnley, 1980; Lidwell, 1981; Lidwell, 1984; Working Party, 1972). The running costs of such systems are considerable, particularly as most theatres are used only during the daytime but have the same ventilation rates throughout the 24 h period.

Ventilation in operating theatres can be achieved in a number of different ways but there are two main systems currently in general use. The majority of theatres are maintained under positive pressure by an inflow of air filtered to remove particles above 5 μm. This air is introduced at high level in the theatre through diffusers that give a general mixing to the total air volume. This is generally called a turbulently ventilated system. For certain operations, e.g. orthopaedic

prosthesis implant and open heart surgery, prevention of wound sepsis is of paramount importance and laminar or unidirectional air flows are used (Howorth, 1984; Lidwell *et al.* 1983). Relatively high-velocity air is introduced from a large area of wall, or from ceiling diffusers to move through the theatre in a well-defined direction. The flow is designed to minimize the entrainment of organisms from the operating team and to lessen the risk of infectious particles entering the wound. The air in these systems is generally filtered to a higher standard than in turbulently ventilated theatres, and particles greater than 0·5 μm are removed by the filtration system.

For reasons of economy there is now much interest in reducing the ventilation airflows or turning them off altogether during periods when the operating theatres are not in use. However, before the implementation of such policies it is necessary to understand the consequences of reducing the airflow, particularly in relation to any increased microbiological hazard. It is also important to determine the time, after changing from lower or zero flow, that the air ventilation system needs to run in normal mode before the air-borne bacterial levels are acceptable for surgery.

In order to determine these factors, and to assess the effects of cleaning procedures on air-borne contaminants, studies have been carried out in the turbulently ventilated operating theatres at Northwick Park Hospital. Air-borne bacteria have been assessed using slit samplers and settle plates in theatres with no airflow, reduced airflow (nominally half normal volume flow rate) and full airflow before, during and after floor cleaning and during vigorous exercise by people. In addition, an electronic light-scattering particle counter has been used to measure concentrations of air-borne particles in several discrete size ranges during the time that air-borne bacterial levels were measured. The re-establishment of full-flow levels of air-borne particles and organisms after the restoration of full flow from either zero or half flow was also studied.

MATERIALS AND METHODS

An air-borne challenge was produced by floor cleaning using a machine (Rotowash RB4) operated by two people for a period of approximately 20 min. This machine cleaned the floor with a detergent solution but did not have added disinfectant. Air-borne bacterial counts were made with a Cassella bacterial slit sampler (700 l/min) operated either remotely or by a hatted, gowned and gloved person before, during and after the cleaning procedure. Samples were for either 1 or 10 min. In addition, a Royco model 245 particle counter coupled to an Epson RX80 FT printer recorded concentrations of air-borne particles in the 0·5–1·5 μm and 5–15 μm ranges every 2 min.

Settle plates (between 4 and 43) were exposed on the floor of the theatre for varying lengths of time during and after cleaning. Contact plates were used to assess the contamination on the floor by aerobic and anaerobic organisms before and after the cleaning procedure.

In addition, the effect on air-borne particles and micro-organisms of up to three people entering the operating theatre to perform various tasks was measured during the time of their activity and in the die-away period following.

Air-borne particulate and bacterial levels were determined during and following the restoration to full airflow from no flow and half flow conditions. Pressures in the theatres were monitored with respect to the theatre corridor in order to identify any occurrences of reversed flow which could bring contaminated air into the theatres.

RESULTS

Figures 1 and 2 show the rise and die-away of air-borne bacteria assessed by slit sampling and settle plates before, during and after the cleaning procedure in theatres with no flow, half flow and full flow ventilation. It is seen that the bacterial levels rise steeply during the cleaning process but that the die-away has produced baseline values within 35 min in the full and half flow conditions and after some 65 min in zero flow.

Figures 3 and 4 show similar curves for the air-borne particle levels in two size ranges (0·5–1·5 μm and 5–15 μm) during the cleaning procedure for the three theatre ventilation configurations. The individual peaks on the curves were found to be directly related to specific activities during the cleaning procedure (i.e. the part of the theatre or ancillary room being machine cleaned). In addition, the particle concentration curves for the larger particles show particle accumulation (upon which the activity details are superimposed) related to the theatre ventilation rate. In the full flow conditions the discrete cleaning events were quickly 'purged' to give a lower mean concentration over the whole cleaning period than in either the half or no flow conditions. The die-away curves for small particles are relatively smooth, whereas the curves for the large particles and, to some extent, the air-borne bacteria sampled with the slit sampler, reflect the activity of people within the theatres during the die-away period.

Figure 5 shows the air-borne particle concentrations in the size ranges 0·5–1·5 μm and 5–15 μm when three people entered a theatre and moved around to produce an air-borne challenge of particles shed from skin and clothing. These results are in contrast to those seen in Figs. 3 and 4, in that the rise in particle levels for human activity alone is pronounced for the larger particles but only shows a minor change in the small particle concentrations. During the machine-cleaning process large particles together with a great number of small ones were aerosolized, the latter apparently by the cleaning machine. These particles will have included naked bacteria and desiccated human skin scales from the floor.

Figure 6 shows the die-away of large particles when the half flow and zero flow theatres were returned to full flow. It is seen that the full flow baseline values were reached after some 15 min.

Contact plate samples of the floor contamination showed that the initial level of $2{\cdot}4 \times 10^4$ c.f.u./m^2 was reduced after the cleaning process to an average of $1{\cdot}4 \times 10^4$ c.f.u./m^2. However, after a period of several hours it was found that the floor contamination had risen to $2{\cdot}6 \times 10^4$ c.f.u./m^2, thereby indicating that the bacterial cleanliness provided by the cleaning process was short-lived. No anaerobic organism was isolated from the theatre floors.

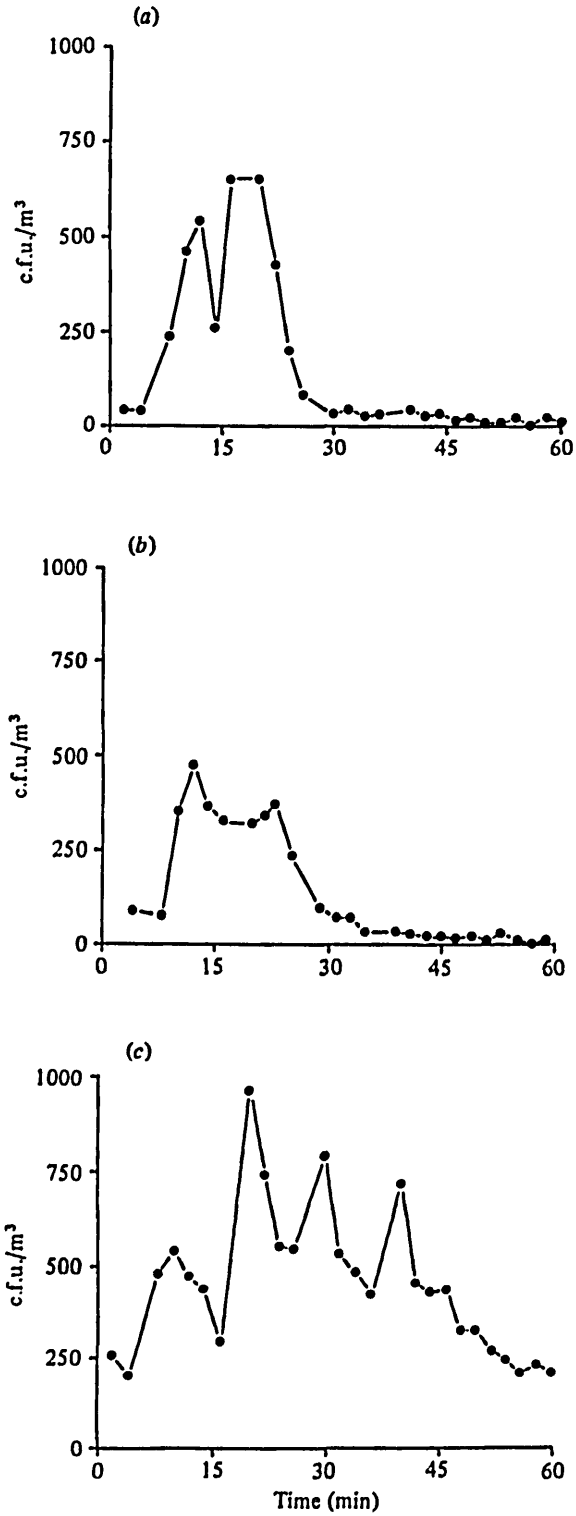

Fig. 1. Variation of air-borne bacterial concentration (assessed with a slit sampler) with time during a machine cleaning period (8–28 min) in an operating theatre in full (*a*), half (*b*) and zero (*c*) flow conditions.

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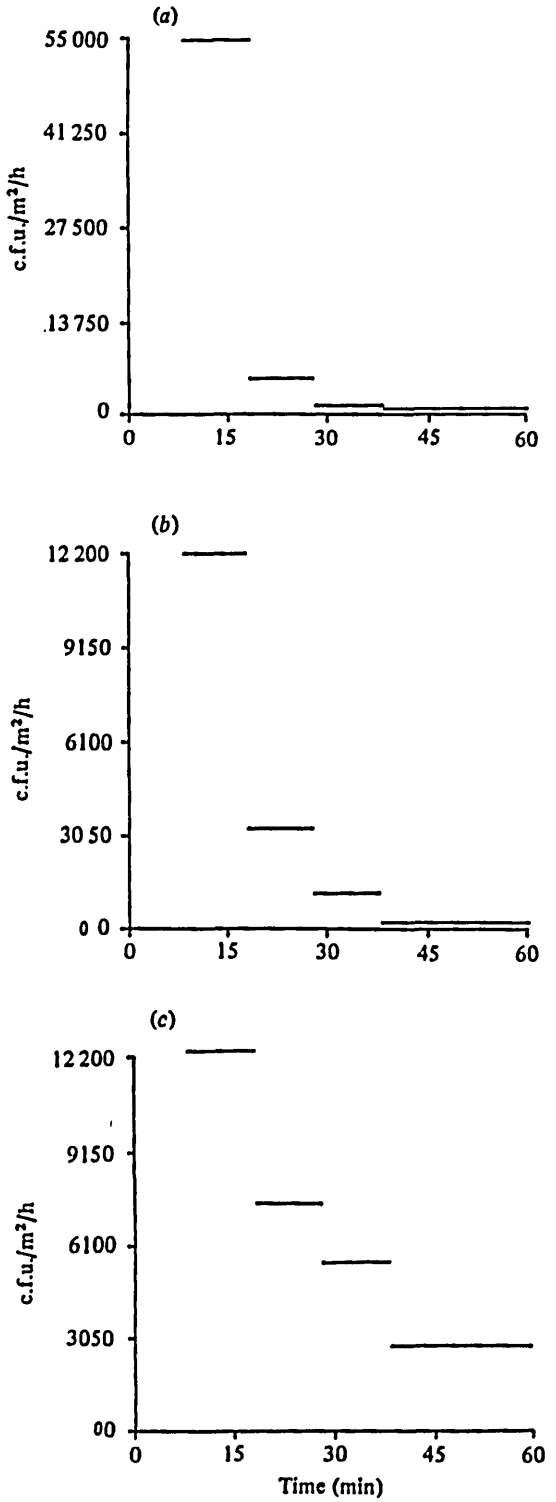

Fig. 2. Variation of settled bacterial contamination with time during a machine cleaning period (8–28 min) in an operating theatre in full (*a*), half (*b*) and zero (*c*) flow conditions.

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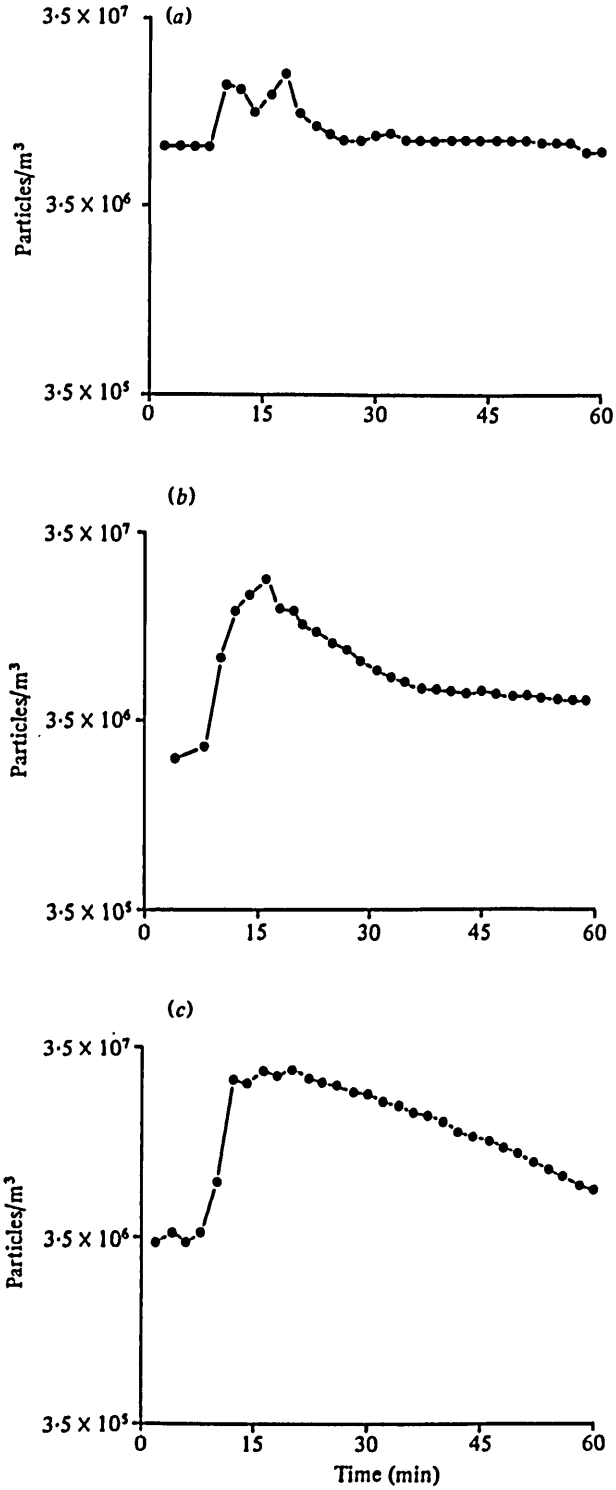

Fig. 3. Variation of air-borne particle concentrations (0·5–1·5 μm) with time during a machine cleaning period (8–28 min) in an operating theatre at full (*a*), half (*b*) and zero (*c*) flow conditions.

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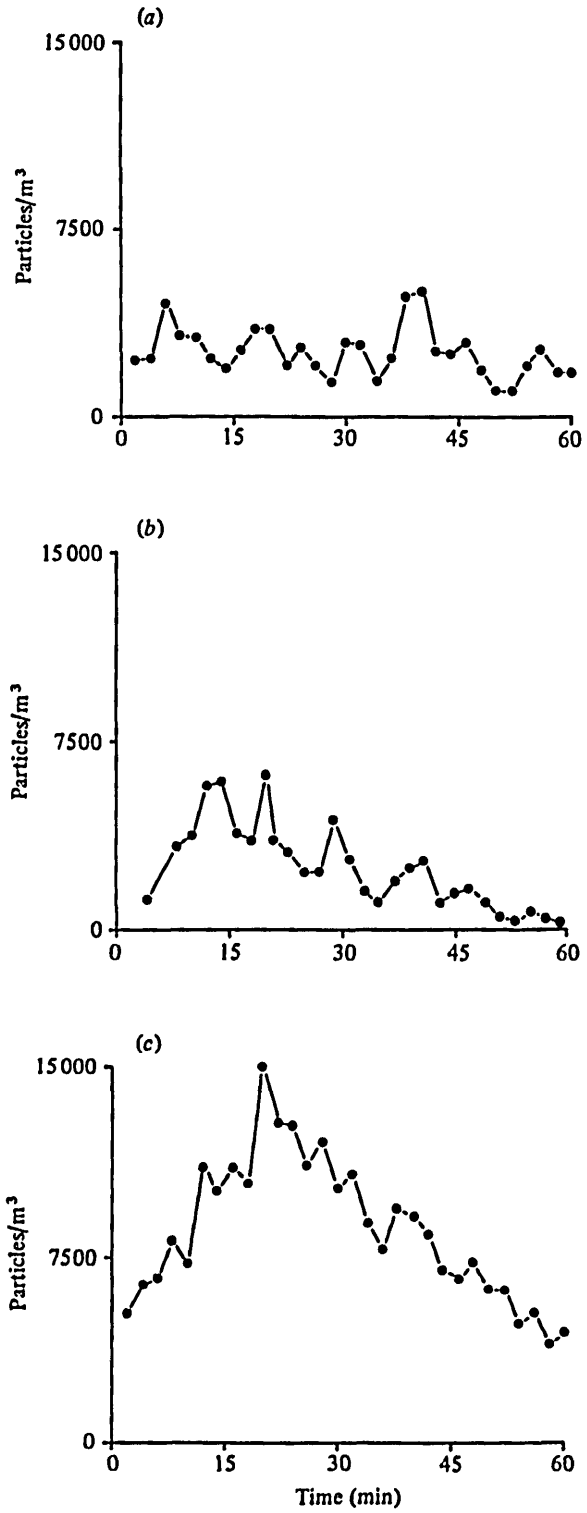

Fig. 4. Variation of air-borne particles (5–15 μm) with time during a machine cleaning period (8–28 min) in an operating theatre at full (*a*), half (*b*) and zero (*c*) flow conditions.

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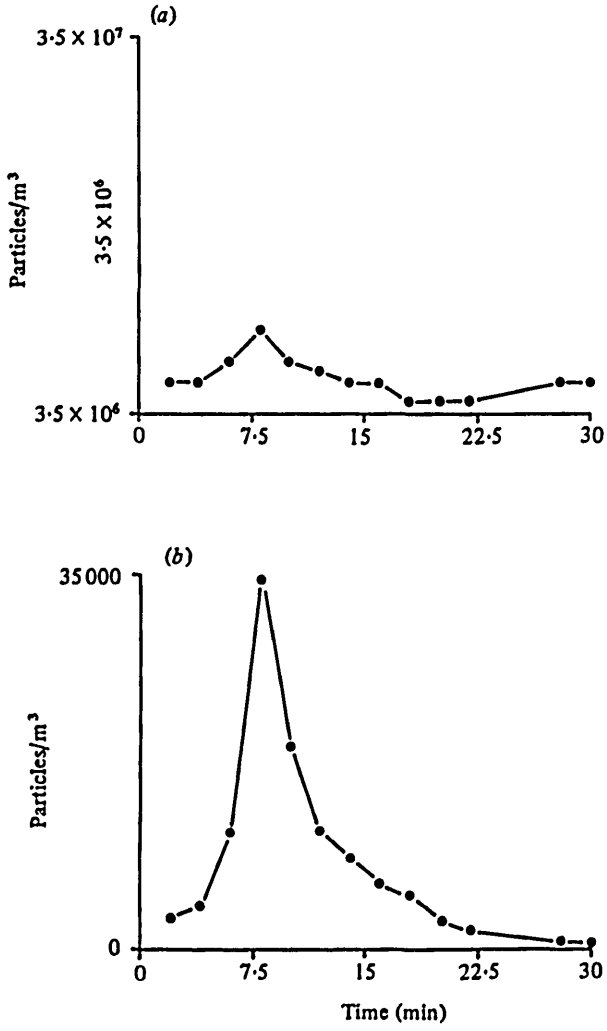

Fig. 5. Variation of air-borne particle concentrations in two size ranges (0·5–1·5 μm (*a*), and 5–15 μm (*b*)) with time after three people had entered an operating theatre on half flow ventilation and performed 3 min of vigorous exercise (between 3 and 6 min).

DISCUSSION

From the die-away curves of bacteria and particles in the various ventilation airflow configurations, it is seen that an air-borne challenge falls to baseline levels in approximately 60 min in the no flow situation compared with approximately 20 min in the full flow mode. Allowing a margin for safety, it would therefore seem to be satisfactory if theatre ventilation is restored to full flow for a minimum period of one hour prior to preparing the theatre for surgery, irrespective of the ventilation state before that time or of the human or machine cleaning activities.

If operating theatre ventilation is to be turned off for long periods the corridors and ancillary areas should remain at some degree of positive pressure with filtered air in order to avoid the ingress of potentially contaminated air from general hospital areas.

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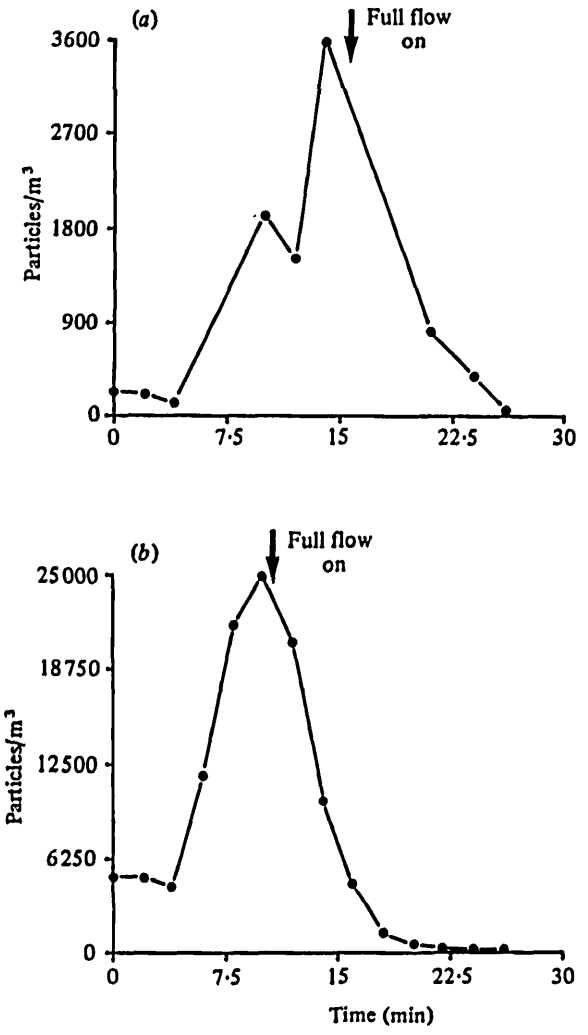

Fig. 6. Variation of large particles with time after restoration to full flow from half flow (*a*) and zero flow (*b*). The peak seen on both curves was a 'challenge' produced by the activity of two people in the theatre prior to the restoration of full flow.

It is normal practice for nursing staff to clean up obvious spills at the end of surgery, thereby leaving the theatres generally and socially clean. However, at Northwick Park the theatre floors are currently cleaned twice in the day and once at night. Such comprehensive routine cleaning procedures obviously maintain a high general standard of cleanliness, but the investigations of floor cleaning described here show that the settling process fairly rapidly increased bacterial levels to the pre-cleaning values. The effect of vigorous floor cleaning procedures, as practised at Northwick Park, on floor bacterial levels is thus of questionable value. However, it should be stressed that clostridia were not recovered from the operating theatre floors whereas some were found ($2{\cdot}1 \times 10^3$ c.f.u./m^2) on floor contact plates taken outside the theatre area when the total count was $6{\cdot}5 \times 10^4$ c.f.u./m^2.

From the results it appears that larger particles (5–15 μm) are associated with

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people and their activity whereas the smaller particles (0·5–1·5 μm) are made air-borne by certain activities such as floor cleaning. The air-borne concentrations of larger particles and of freshly shed bacteria appear to be directly related to the number of people and their activity. This confirms many of the measurements made in recent years during surgery; it is now generally accepted that the greatest risk of air-borne infection comes from the members of the surgical team, who are continually shedding bacteria-carrying skin particles.

Bacteriological assessment of air-borne contamination is time consuming, and the results are not immediately available. This is in contrast to the results that can be obtained from air-borne particle counts using an electronic particle counter such as the Royco 245 used in this study. Such machines readily determine the particulate contamination (which in the future could be related to standards appropriate for clean rooms) within operating theatres. In the theatres of this investigation the filtration was no better than 5 μm. With HEPA filtered ultra-clean air installations there would be reduced levels of particle concentrations in sizes down to 0·5 μm and smaller, which could accurately be measured with an electronic counter. In the absence of aerosols produced by mechanical means, such as the cleaning machine, the results of the bacterial and particle counts clearly indicate that the small particles passing through the filters do not carry micro-organisms. The larger sizes (5–15 μm), shed from people, appear to be the organism-carrying particles, and we consider it reasonable to suggest that immediate assessments of the integrity of the ventilation filtration system could therefore be made in operating theatres with the particle counter rather than with bacterial slit samplers; any excessive concentration of particles in an empty theatre would be indicative of a breakdown in the filtration or ventilation system. During operations, the presence of increased numbers of larger particles at the site of surgery could indicate that entrainment of bacteria was occurring, without the need for slit air sampling.

Settle plate counts, slit air sampling and air-borne particle levels were found to be well related in a number of instances, but on one occasion when air-borne concentrations were estimated from the settle plate harvest in a full-flow theatre they were found to be some five times higher than levels assessed by the other techniques. One explanation for this could be the local disturbances to surface and air-borne contamination produced during the act of placing and uncovering the settle plates. Spurious contamination may therefore be an important factor when using settle plates; this is a problem that can easily be overcome in the other methods by remote activation of the air samplers. Nevertheless, carefully used settle plates can give a rough indication of overall air-borne organism concentrations, although short-term variations due to specific activities cannot be determined as very short settle plate exposures are impracticable.

From the results presented in this paper the following recommendations regarding operating theatre ventilation and cleaning procedures can be made, which may be expected to substantially reduce system running costs without producing an increased risk of cross-infection.

(1) Theatre ventilation can be turned off during periods when the theatres are not in use, provided full flow is restored one hour prior to preparation for surgery. In this event, the surrounding corridor areas within the theatre suite should still

be maintained at positive pressure with filtered air with regard to the general hospital surroundings.

(2) If theatres are reduced to half flow (*neither* giving best economies *nor* suitable for operating) adequate instrumentation (individual manometers) should be provided to ensure that the surgical team have an immediate check on the ventilation status of individual theatres.

(3) Cleaning procedures can be carried out in the theatres without ventilation provided that they cease, and the ventilation is restored to full flow, one hour prior to surgical preparation.

(4) The results show that, as long as generally accepted socially clean standards are maintained in the theatre, floor cleaning procedures have little or no effect on bacterial levels on the floor. However, the short-term effect of cleaning the floors is to increase the air-borne load of both small and large particles as well as bacteria.

(5) In many instances, settle plates can give an indication of overall bacterial load, but more comprehensive evaluation can be obtained using particle counters and air-borne slit samplers. The particle counting devices can produce spectra of particle sizes which will give an indication of the performance of turbulently ventilated and ultra-clean air ventilation systems.

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