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An evaluation of a partial-walled laminar-flow operating room

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SUMMARY

This paper contains an assessment of the physical performance of a permanently installed down-flow laminar-flow operating room at the London Hospital. This system employs partial walls extending 0·76 m (2·5 ft.) from the ceiling, from which the air is allowed to issue freely downwards at an initial velocity of about 0·4 m./sec. (80 ft./min.).

The usefulness of the partial wall, as compared with a free issuing system, was demonstrated and a comparison made with a fully walled system. It was shown that a fully walled system would be more efficient than a partial-walled system as there was a loss in air velocity of about 20–25% with the partial wall due to the nonconstrained flow of air. This loss would be reflected in an increase in airborne bacterial count and would mean that an increase of 20–25% in the air volume would be required to obtain the same conditions as with the full-walled system. Entrainment of contaminated air was demonstrated but it was concluded that this would be of little consequence in the centre of the clean area, i.e. at the wound site. Sterile instruments, etc., however, on the outside of the clean area, would be more liable to airborne contamination.

Bacterial and dust airborne counts taken during total hip operations gave a very low average figure (0·3 bacteria/ft.^{3} or 10·5/m.^{3}) from which we conclude that the system was about 30 times cleaner in terms of airborne bacteria than a well ventilated conventional operating-room. We concluded that although the partial-walled system was slightly less efficacious than a normal full-walled system, the freedom of movement and of communication for the operating team could in some circumstances outweigh this disadvantage.

Sound levels were such that normal conversation was possible with little or no awareness of background noise.

INTRODUCTION

Within the last few years there has been considerable interest shown by surgeons, mainly orthopaedic, in the development of ultra-clean operating-room environments. The stimulation of this interest may be ascribed to two

independent lines of thought – those of Professor John Charnley in this country (Charnley, 1964) and the workers of Sandia Corporation in the U.S.A. (Whitfield, 1962). Professor Charnley was concerned with preventing sepsis after total hip replacement operations, and the U.S.A. workers were interested initially in preventing dust particles contaminating electronic components to be used in the space programmes. These two lines of research have now become intermixed and developed with the ultimate aim of providing medical personnel with bacteria-free environments. However, as this field of work has developed only within the last decade much research and development has still to be carried out before ultra-clean operating-rooms can be satisfactorily designed to as high a building standard as is shown in modern conventional operating-rooms.

A conventional ventilated operating-room is reasonably effective bacteriologically, in that the bacterial count of the air is usually kept below 175 bacteria per $m.^3$ (5 bacteria per cu.ft.), but if cleaner conditions are required it will be necessary to adopt the method of ventilation usually described as 'laminar-flow' (Whyte, Shaw & Barnes, 1973). This system supplies sterile air through an end wall or ceiling in a unidirectional manner at velocities up to 0·5 m./sec. (100 ft./min.). The air is normally supplied through a filter bank on the wall or ceiling which is much smaller than the dimensions of the room, and in order to prevent mixing of this clean air with the room air, walls are provided to constrain the air supplied. This barrier however puts constraints on the surgical team and curtails their freedom of movement and communication. In order to overcome this problem the system at the London Hospital, an assessment of which is reported in this paper, was built initially as a 2·5 m. × 2·5 m. (8 ft. × 8 ft.) ceiling supply system with air being allowed to pass freely into the operating room in, it was hoped, a unidirectional manner. It was subsequently modified with the provision of partial walls which extended 0·76 m. (2·5 ft.) down from the ceiling.

This departure from the normal use of the full walls has obvious advantages and was, as far as we were aware, the first operating room employing laminar-flow methods with a non-constrained downflow of air. Research is, however, being carried out in Holland on a similar idea (Bossers, 1973) and there also exists the Allander system (Allander & Abel, 1968) which is produced commercially and is a low-velocity unidirectional system which supplies air downwards from an area above the table, the periphery of the supply area being provided with air curtains to assist the downward supply of sterile air. A cross-flow non-constrained system is also available commercially in the U.S.A. from Agnew-Higgins Ltd, and is widely used there. Criticism has been levelled at these types of systems because of their relative inability to prevent entrainment from outside the clean area of contaminants which could reach the critical areas. The method of air supply employed at the London Hospital therefore merited investigation. Our findings constitute a major part of this paper.

In our experience most present day laminar flow systems are noisy, because well over 95% of the systems installed in operating-rooms today are of the prefabricated type with the fans installed inside the system and within the operating room. There is usually insufficient room to install silencing. It is doubtful if pre-

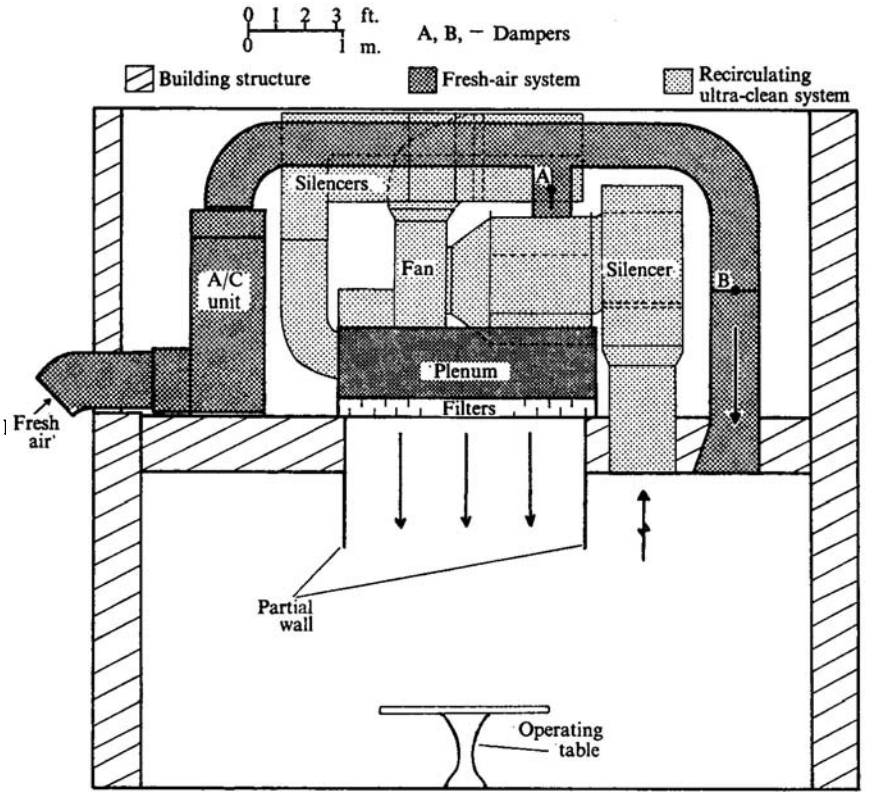

Fig. 1. Sectional elevation of operating-room at the London Hospital, with associated ventilation system dampers set at laminar flow position.

fabricated systems will ever be fully satisfactory as far as noise is concerned, and although they will continue to be installed into theatres which require upgrading, it is likely that the trend will be to install unidirectional-flow systems permanently.

The system in the London Hospital was the first to be permanently installed in this country, but it certainly will not be the last, and for this reason it was necessary to investigate its performance and report on any design problems which could be avoided in subsequent installations.

DESCRIPTION OF THE ULTRA-CLEAN OPERATING ROOM

Ventilation system

A sectional elevation of the operating room and its associated ventilation system is shown in Fig. 1. This shows the two alternative ventilation systems which may be selected in the operating room, one being a fresh air supply and the other a unidirectional air flow system. The two alternative systems were installed to permit direct comparisons to be made in the future between ventilation with ultra-clean air and conventionally filtered air in the same theatre.

When the full fresh air system is selected the air conditioning system draws

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1·42 m.³/sec. (3000 ft.³/min.) of fresh air from outside, conditions the air and then ducts 0·85 m.³/sec. (1800 ft.³/min.) of this air to the operating room via two ceiling grilles. The remaining 0·57 m.³/sec. (1200 ft.³/min.) of this system is supplied to the anaesthetic room, which is adjacent to the operating room, through a ceiling grille.

When the unidirectional ultra-clean system is selected flap B closes the fresh air supply to the operating room and flap A is opened to allow the fresh air to mix with the recirculated air from the operating room. The ultra-clean recirculation system, draws approximately 2·20 m.³/sec. (4700 ft.³/min.) through the ceiling extract grille. This extract air is made up with 0·85 m.³/sec. (1800 ft.³/min.) of fresh air from the air conditioning unit which now follows the alternative route into the ultra-clean system. The total designed air volume supplied is therefore 3·05 m.³/sec. (6500 ft.³/min). which would give a velocity of 0·5 m./sec. (100 ft./min.) through the 2·5 m. × 2·5 m. (8 ft. × 8 ft.) filter ceiling. These design values were not reached however during this study. The excess air in the room (0·85 m.³/sec. or 1800 ft.³/min.) finds its way out of the operating room by flap dampers in the utility room and through cracks in the theatre doors, thus pressurising the operating area.

After being extracted from the theatre, the recirculated air is drawn through a set of silencers and into a large centrifugal fan. Once through the fan the air is ducted in twin systems to a plenum, again being passed through sets of silencers on the way. The air then passes through the H.E.P.A. filters mounted in the ceiling and hence into the operating-room via the constraints of the partial walls. Both the plants are controllable from the operating-room itself.

The pre-filter before the air conditioning plant and the secondary filters of the 100 % fresh air system are of the efficiency as recommended by the Department of Health and Social Security for fresh air, but the H.E.P.A. filters are not less than 99·97 % efficient against 0·5 μm. particles.

Internal construction

The internal construction of the operating room may be seen from Plate 1 which shows an actual operation in progress. The partial glass walls can be seen protruding approximately 0·76 m. (30 in.) into the room. Within this area it is possible to see the structural beams and twin light tracks which hold the twin Amsco operating-lamps. At the far end of the enclosure is a rectangular dark area which is the recirculated-air extract-grille. A drape can be seen hanging from the far end partial wall in order to prevent short circuiting of the supply air into the badly sited extract grille and to separate the anaesthetist and his equipment from the sterile area. One of the fresh air supply grilles is also shown on the extreme right-hand side of the ceiling. The operating team work within the vertical plane confines of the partial walls, the instrument trolleys being kept as tight round the working area as possible in order to keep the instruments in the sterile air flow.

RESULTS

Visualization of the air flow produced by the laminar-flow system

In order to study and report the flow of air at the London Hospital we adopted a method recently developed by the National Institute of Agricultural Engineering in Britain, and now described by Carpenter & Moulsley (1972). This system uses an air supply mixed with helium and a bubble generator to produce a flow of neutral-buoyancy detergent-bubbles of 3 mm average diameter. Plates 2 and 3 were achieved by photographing the bubble mass as a time exposure of 1 sec.

The light source was a series of spot lights set up in a duct, the light being projected through a slit facing the flow of air to be studied. The bubbles were illuminated and the background kept dark with a backcloth. Two bubble generators were used in our studies and it may be seen that the bubble movement is shown up as a streak, its length being proportional to the velocity of the streamline. Knowing the actual length of the bubble streak by reference to an object of known size in the photograph and the exposure time of the camera, the velocity of the air stream may be ascertained.

Plate 2A shows a typical photograph that was obtained by releasing bubbles outside the unidirectional air-flow area and observing the number that penetrated into the area which it was intended to keep free of contamination. It should be noted that the partial walls were not in position but notwithstanding this, the air movement was such as to prevent any great number of bubbles passing into the clean zone. Plate 2B shows a typical photograph obtained by releasing bubbles outside the clean area when the partial walls are in place. It may be observed that once again there is little entrainment of the outside air. Although slight differences may be observed in these two photographs, no conclusions should be made as there was as much variation within a set of photographs taken with or without the partial wall as between these two sets of photographs.

Plate 3A shows the situation that existed at the point where the light tracks, which passed across the sterile air supply area, were attached to the ceiling. This situation only existed, however, when the partial walls were not present. The negative pressure created under the tracks caused contamination to pass into the sterile zone to a large extent. It is obvious that these tracks would be better sited outside the clean sterile air supply area.

Plate 3B shows clearly the bad positioning of the exhaust system which is adjacent to the unidirectional supply. It is very clear that this is extremely unsatisfactory and the exhausts should have been sited at ground level, preferably an exhaust grille on each wall.

Particle challenge tests

In order to supplement the observations made with the bubble generator technique, further tests were carried out on the ultra-clean system. These were done with and without the partial walls and carried out by releasing smoke on the outside of the system and measuring the concentration of smoke that was found to have penetrated into the clean area. Almost any type of smoke source could

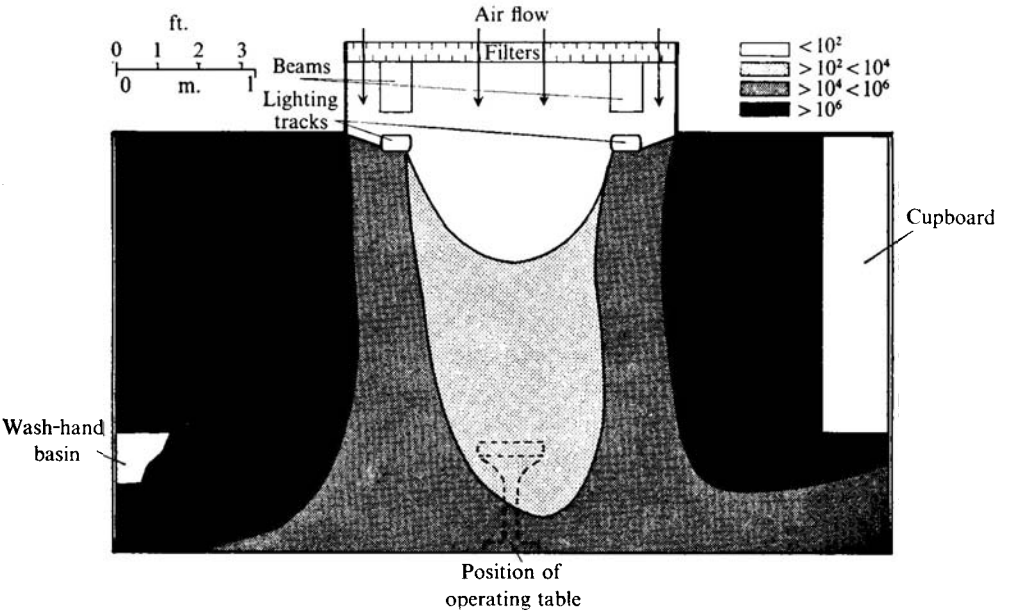

Fig. 2. Isopleth diagram of the non-constrained laminar-flow system.

have been used, but we have found that either joss sticks or cigarettes were simple and convenient. In this case we used joss sticks. The amount of smoke generated was adjusted by increasing or decreasing the number of burning joss sticks and by positioning them in order that the concentration outside the clean area of particles $\geqslant 0{\cdot}5$ μm. was just over 10^6 particles per ft.^{3} as measured by a Royco Particle Counter. In a given plane particle counts were taken and zones of equal contamination determined. These zones were $< 10^2$; between 10^2 and 10^4, between 10^4 and 10^6, and greater than 10^6 particles per ft.^{3} This type of diagram is used elsewhere, e.g. in the pollution research field where the lines of equal concentration are called isopleths. This name we have retained.

Fig. 2 shows an isopleth diagram obtained by studying the penetration of smoke particles at a plane half way across the supply face. The partial walls were removed for this test and the section studied in a plane such that the exhaust would not interfere with the air flow. The only thing therefore that prevented an ideal representation as to what should happen in a well constructed system was the interference of the light tracks, which not only drew in smoke along their length from outside the clean area (as shown in Plate 3A) but caused the air flow to curve inwards to the negative zone induced by them. This caused greater contamination than would have been achieved in the perfect situation.

Fig. 3 is an isopleth diagram of the system with the partial walls in place. These tests were carried out through the same plane as that used when the partial walls were not in place. The unusual feature in this diagram is the discovery that the air was being induced from outside the clean area, up the inside of the glass to a height level with the ceiling. The smoke was then blown down and across the clean area. This unfortunate effect was caused by a lower air velocity at that side of the

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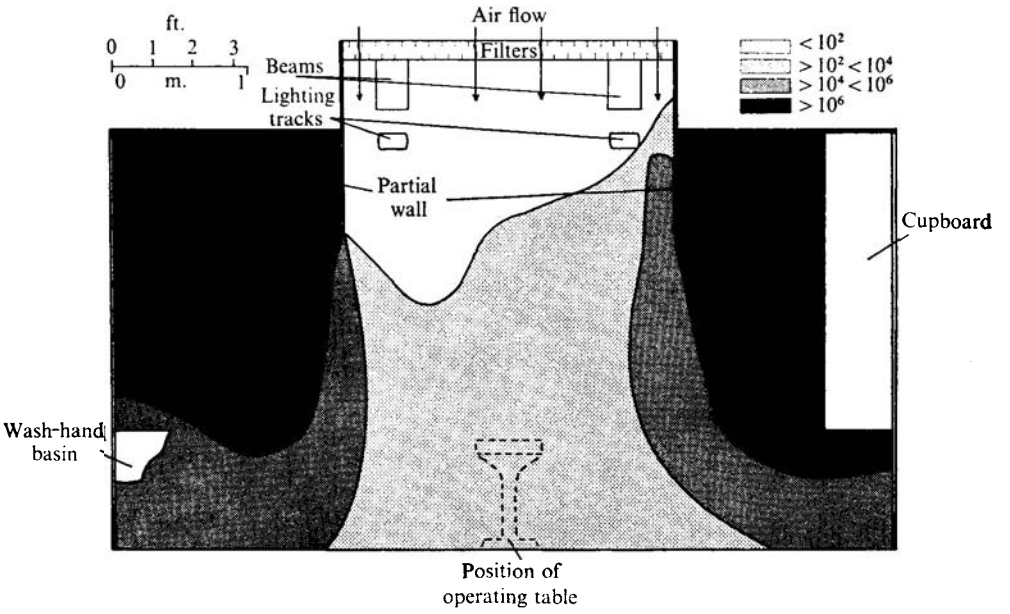

Fig. 3. Isopleth diagram of the partial-walled laminar-flow system.

supply area, so that the velocity was not great enough to overcome the effect of the areas of negative pressure produced by obstructions at the filter face. This would also appear to be the reason why this phenomenon was only exhibited with the partial walls in place, as the air velocity at the height of the glass from the floor was shown to be lower than that of ceiling height.

Although the positioning of the light tracks and the non-uniformity of the air velocity across the delivery area leads to disturbances of airflow which confuse assessment of the value of the partial walls, a larger clean area is produced at table height when the partial walls are used. Over an area approximately the same size as that of the air supply face ($2{\cdot}5 \times 2{\cdot}5$ m.) the particle concentration was between 10^2 and 10^4 times less than that outside, the value at the wound site being near the lower of these ($1/10^4$).

Bacterial and particle concentrations in the operating room during several total hip operations.

Counts at the wound site. Samples of air were taken from the vicinity of the wound, rather than the theatre environment, as the latter may bear no relationship to the risk of airborne contamination. We therefore employed a method described previously (Whyte, Shaw & Barnes, 1973) and used a High-Volume Slit-Sampler (Casella Ltd., London) with an air flow of 700 l./min. (25 ft.³/min.). This was connected by a bend to a long metal cone, which was sterilized between operations, and a sample was taken at a maximum of 15 cm. (6 in.) from the wound site. Because of the very large sample of air around the wound (25 ft.³/min. or 700 l./min.) and the fact that the sampling point was half way along the incision and

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Table 1. *Mean and standard deviation of bacterial concentrations at Killearn Hospital during total hip operations*

Velocity (m./sec.)	Mean (bact/m.^{3})	Standard deviation
0·2	34·8	34·8
0·3	10·2	7·3
0·4	2·8	1·04

below it, we felt that good sampling conditions were established. Bacterial samples were incubated for 36 hr. at 37° C. before counting.

Samples were also taken of dust particles of 0·5 μm. and over in diameter and of 5 μm. and over. This was done by means of a Royco Particle Counter, the sterile tube being clipped to the sampling cone and samples taken at the same spot as the bacterial sample. It was considered that as very few dust particles would pass through the high efficiency filters, any dust particles collected would normally be generated by potential sources of contamination, i.e. by the operating team.

Five total-hip replacement operations by three different operating teams were monitored. A total of thirty 10 min. airborne bacterial samples were taken, thereby sampling a total of 214 m.^{3} (7500 ft.^{3}) of air. The average bacterial count for each operation was 7·0, 14·0, 10·8, 13·3, 12·2 bacteria/m.^{3} (0·20, 0·40, 0·31, 0·38, 0·35 bacteria/ft.^{3}), the mean count of the 30 samples taken throughout the operations being 10·8/m.^{3} (0·31/ft.^{3}) with a standard deviation of 5·95 (0·17). One minute dust samples were taken throughout the period and gave an average dust concentration of 230,000/m.^{3} (6600/ft.^{3}) for particles $\geqslant 0{\cdot}5$ μm. and 13,000/m.^{3} (370/ft.^{3}) for particles $\geqslant 5{\cdot}0$ μm.

Given in Table 1 for comparison are the results obtained at Killearn Hospital, Scotland during a series of total-hip operations carried out in a completely enclosed down-flow laminar-air system (Whyte, Shaw & Barnes, 1973). Concentrations are given for downward velocities (measured 1 metre away from the filter face) of 0·2, 0·3, 0·4 m./sec. (40, 60 and 80 ft./min.).

Inspection of the results shows that at a down flow velocity of 0·3 m./sec. (60 ft./min.) the bacterial concentrations are very similar. The bacterial concentration was 10·8/m.^{3} (0·31/ft.^{3}) in the partial-walled system compared with 10·2/m.^{3} (0·29/ft.^{3}) in the full wall situation at Killearn Hospital. Inspection of the mean and standard deviation of the bacterial counts and a statistical comparison of the results (*t*–test) shows that the results obtained at the London Hospital are significantly different from those at Killearn Hospital at velocities of 0·4 m./sec. ($P \leqslant 0.01$) and 0·2 m./sec. ($P \leqslant 0{\cdot}05$).

Thus for a bacterial concentration of 10·8/m.^{3} the average concentration found at the London Hospital, it would be expected from our results at Killearn that the air velocity in the London Hospital system would be about 0·29 m./sec. This figure agrees well with our observations of air velocity as the measured velocity in the partial walled operating-room at operating table height was 0·23 m./sec. This figure was measured without a curtain present to screen the exhaust, and

therefore a slightly higher velocity could be expected when the curtain was present. This would bring the measured velocity closer to the predicted value.

Although no observations were made of these surgical teams operating in a conventionally plenum-ventilated operating-theatre it has been our experience in taking bacterial counts that average concentrations in the order of 315 bacteria/m^3. (9 bacteria/ft.^{3}) are associated with total hip operations. This would make the London Hospital's ultra-clean theatre about 30 times cleaner than modern conventionally ventilated operating-rooms.

It is interesting to consider the cleanliness of the air in terms of how many bacteria would be liable to be deposited from the air into an open wound. Using a simplified version of Stokes equation ($d^2 = Vg/0{\cdot}006$) the settling velocity (Vg) in ft./min. can be determined for particles of known equivalent diameter (d), where the equivalent diameter is the diameter of a sphere of unit density which has a settling rate in air equal to the particle in question. Noble *et al.* (1963) showed that the median diameter of bacteria-carrying particles in hospitals was about 13 μm. and using this figure it may be calculated that the number of particles being deposited on 1 ft.^{2}/min. would be equivalent to the number of particles in one cubic foot of air. This means that in the ultra-clean system a wound of area 1 ft.^{2} would have about 0·3 bacteria-carrying particles deposited per min. or 18 per hr.

Bacterial counts round the operating room periphery. It has been demonstrated in previous sections of this paper that a major consideration in assessing the capability of an ultra-clean system is its ability to prevent the ingress of contaminated material from the periphery of the operating room into the clean area. This ability has been assessed in previous sections but it is necessary to find out the dimension of the challenge, that is to say the amount of contamination that is present in the peripheral area. The less contamination that is present, the less important is the question of entrainment.

In order to carry out sampling in the area round the outside of the room the same type of bacterial sampler was used. This was placed on a trolley which was wheeled round the room in order to sample at various positions round the room. The sampling position was 2 m. (6 ft.) high. No particle counts were taken.

Twenty-five 2 min. air samples were taken during several operations. These samples varied from 11·2 to 315 bacteria per m.^{3} (0·32 to 8·98 bacteria per ft.^{3}) with a mean value of 70·7 per m.^{3} (2·02/ft.^{3}).

Velocity measurements

A comparison was necessary of the air velocity produced by a full-walled laminar-flow system and the partial-walled system from the same air supply. As we have demonstrated in previous experiments (Whyte, *et al.* 1973) that the efficiency of a laminar-flow system depends on its velocity it followed that if the velocity in the partial-walled system was considerably lower than in the full-walled system this would result in a significant drop in bacterial efficiency.

Measurements were made of the velocities from the filter face to the operating table height. These results are shown in Fig. 4. It may be seen from this figure that the velocity falls very quickly in the first few centimetres (Zone A) from

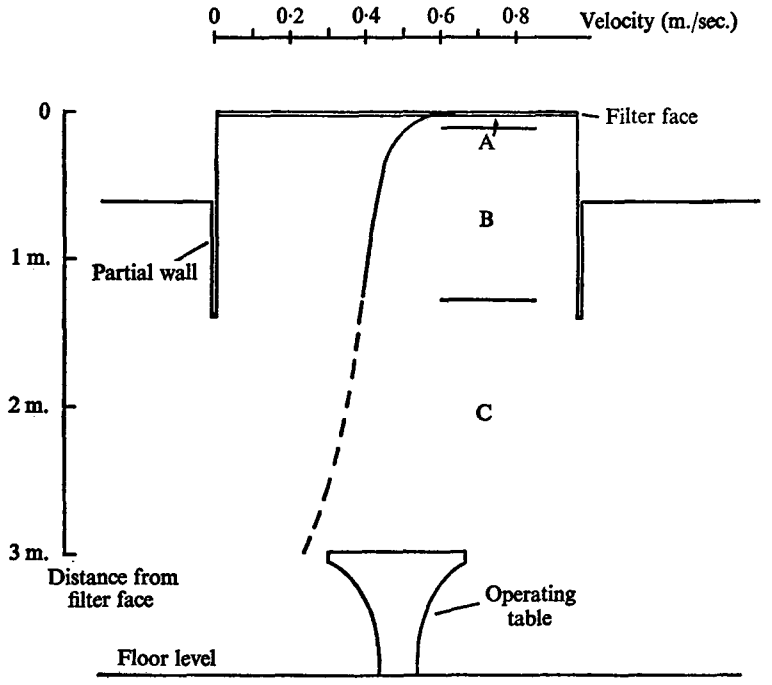

Fig. 4. Air velocity reduction from filter face to operating table.

0·63 m./sec. at the filter face to 0·50 m./sec. at 10 cm. distance. This initial drop may be attributed to jetting from the filter face producing high velocity areas which were picked up by our instruments.

After 10 cm. (Zone B) the velocity decreased gradually to a value of about 0·40 m./sec. at a plane level with the bottom of the partial wall, 1·25 m. from the filter face. This decrease in velocity of 20 % from the 10 cm. level to that of the partial wall is almost certainly caused by an increase in cross-sectional area of the opening. At the 10 cm. level there is a blockage area of approximately 20–25 % due to beams and main frames of the filters but once the air has passed these obstructions it opens out to the full area of the opening and hence the air speed drops. This velocity at the level of the bottom of the partial wall must be regarded as the *actual* air velocity the system is producing. Measurement of the air velocity at the filter face would be exaggerated both by the jetting of the air and failure to take into account the obstruction of the airstream. The supply velocity of the system should therefore be regarded as 0·4 m./sec. (80 ft./min.). This means that the volume of air supplied by the laminar-flow module was 2·5 m.^{3}/sec. (5100 ft.^{3}/min.) compared to the design figure of 3·05 m.^{3}/sec. (6500 ft.^{3}/min.).

On passing the bottom of the partial wall (Zone C) there is no constraint on the air and the air speed drops even further, reaching a value of approximately 0·23 m./sec. at operating table level, a reduction of 42·5 %.

These findings may be compared with those in a fully walled system. Velocity readings similar to the above series were taken in a down-flow laminar-flow system. We found that there was also a change in the velocity from a point 2 to 3 ft. from

the filter down to table height. The air velocity was found to drop from 0·4 m./sec. to 0·32 m./sec., a reduction of 20 %. This was caused by the fact that the air flow at table height was tending to veer away from the centre of the system in readiness to passing out at floor level round the periphery. It would appear therefore that the system with the partial wall is 20–25 % less efficient in terms of velocity achieved at table height than was the fully-walled system.

Sound measurement

It was expected that the sound levels found at the permanently installed London Hospital system would be much less than had been previously found in prefabricated systems built in this country, due to remoteness of the air-movement equipment and the opportunity for the inclusion of more silencing. This was the case at the London Hospital.

Measurements were taken in the empty room when the air was being supplied by the laminar-flow module and were an average of two readings taken on separate days. These results reflect accurately the noise generated by the laminar-flow system, as background noise was minimal. The operating room was close to a main trunk road but the fitting of double glazing had reduced the traffic noise to a very low level. The sound level for the theatre was N.C. 50 and except for a low-frequency rumble, possibly from the fan, at the 63 Hz. octave band, would have reached N.C. 45.

Comparative readings taken at the Princess Margaret Rose Hospital, Edinburgh in a prefabricated system gave an N.C. level of 65 whereas our own system at Killearn, which is also prefabricated, has an N.C. level of 60.

These readings are for a velocity as measured 1 metre from the filter face of about 0·45 m./sec. (90 ft./min.).

Subjective assessment by the surgeons showed the system not to be noticeably noisier than conventionally ventilated operating-rooms that they were used to and that normal conversation was possible with little or no awareness of background noise.

DISCUSSION AND CONCLUSION

It is our opinion that the partial-walled laminar-flow system at the London Hospital is a success. The success of the system may be considered in two ways – the access and convenience to the staff and its physical performance.

An obvious advantage of the partially walled system is that normal access is available at all times to the operating area and to the patient. Instruments, X-ray equipment, anaesthetic equipment and personnel can enter and leave the sterile area freely and in a conventional manner. The scrubbed team can also talk to other people in the theatre in a normal fashion; an important consideration especially in a teaching hospital.

From the engineering point of view several design faults existed which have in the main been overcome. However, as the laminar-flow room was the first to be permanently installed in the U.K., the building of the system could be considered

a research project and several lessons can be learned. These we should like to pinpoint in order that future designs may benefit from these mistakes.

Theoretically in terms of air cleanliness, a laminar-flow system without complete walls can not achieve the air cleanliness that one with walls can. However, we were interested to see how closely the partially walled system approached the fully walled system and whether or not it approached sufficiently to be acceptable. This question, the highlighting of the possible faults in the system, and the lessons to be learned were the main objects of our assessment.

Environmental conditions achieved and possible design faults

General design points. The height of the operating room ceiling was 10 ft. It was envisaged before installation that the air issuing from the 8 ft. square supply-area would be contaminated by some entrainment, but that at table height there would be a near particle-free zone where the operation could take place. After installation this was found not to be the case because (1) the distance from the air opening above to the required clean area below was excessive, (2) the filter face was obstructed by beams, (3) the light tracks which were fitted to these beams were so positioned as to fit flush with the ceiling and cause particles to be induced into the clean area and (4) the exhaust system was very badly sited adjacent to the air supply. All these factors came together to give a flow of air which was anything but unidirectional or particle free. Partial walls were therefore installed to overcome these effects. On testing the system with and without these walls we found that the walls produced substantial improvement; they completely prevented the contamination caused by the negative pressure induced under the light tracks and in part overcame some of the other faults.

No walls or partial walls? Because of the filter obstruction, light track and the exhaust, it was impossible to make an exact comparison of the flow of air with and without the partial walls. Theoretically it would seem that one would get a better air flow with less entrainment using the partial wall, but bubble generator and particle challenge indicated that in practice this was not a particularly obvious effect. However, apart from the possible theoretical advantage, the partial walls brought the sterile air supply closer to the critical area before the effect of entrainment and other forces could act on it. For this reason their use should be encouraged.

By challenging the laminar-flow system with smoke particles when the partial walls were fitted and then taken away, further evidence was obtained of the effectiveness of the system. The adverse effect of the lighting track and also the usefulness of the partial walls in extending the clean zone closer to the critical area were once again shown. We observed at one point a backflow of contamination up the inside of the partial walls towards the filters which reduced the effectiveness of the system. Conversation with staff at the London Hospital had led us to expect this phenomenon which was caused by obstruction of the air supply by beams and light tracks. It had been observed by smoke tests when the system was being first commissioned that this phenomenon was very noticeable and much greater than we had observed. However, in order to improve this the air velocity had been

increased and made more uniform across the filter face. This had been carried out before we tested the system and had obviously caused a great improvement.

Assessment of the partial-wall compared with a full-wall system. Smoke tests of the partial-walled system showed that in an area of approximately the same dimension as that of the air supply face (8 ft. × 8 ft.) the particle concentration was reduced to between 1/100 and 1/10,000 of the concentration that exists in the peripheral area of the operating room. This reduction was 100 times at the very outside of the clean area to 10,000 times in the centre. It is worth noting that the entrainment is less in this system than in a free flow jet as the barrier of the floor pushes the clean air out and hence the contamination is partially prevented from entering the clean area by this outwardly flowing air.

Bacterial sampling carried out in the area around the periphery of the ultra-clean system gave an average bacterial concentration of 70·7/m.^{3} (2·02/ft.^{3}) which would mean that entrainment of contamination in the partial-walled system would give an additional contribution of airborne contamination varying from 0·707 bacteria/m.^{3} (0·02/ft.^{3}) at the outside of the clean area to 0·00707/m.^{3} (0·002/ft.^{3}) in the centre.

Airborne bacterial sampling at the wound site during several total hip replacement operations shows that the average concentration would be in the order of 10·5 bacteria/m.^{3} (0·3/ft.^{3}) which would suggest that a negligible number of bacteria, less than 0·1 % of the bacteria in the area of the wound, were present as a result of entrainment. At the outer points of the 8 ft. × 8 ft. clean area, however, where the instruments could be lying exposed to the air, it would be much dirtier than a fully walled system, the majority of the contamination coming from the entrained air.

Although no bacterial sampling was carried out during total hip replacement in a conventionally ventilated plenum system we have no reason to suspect that it would differ from what we have normally observed, namely, an average concentration of 315 bacteria/m.^{3} (9/ft.^{3}). This would mean that the London Hospital system was 30 times more efficient than a good plenum ventilated operating-room.

It is interesting to note that, assuming a median diameter of 13 μm. for the bacterial particles in the air (Noble *et al.* 1963), the number of bacterial particles settling in the ultra-clean system into a wound of 1 ft.^{2} would be about 18 per hour.

The second factor that must be taken into account, apart from entrainment, is the effect of velocity. Because the air is not contained within full walls, the velocity at table height is between 0·80 and 0·75 of what could be achieved with walls. This is confirmed by airborne bacterial sampling where it was shown that the concentration at the wound site was what was expected from a velocity of 0·25 m./sec., the velocity at table level, rather than that from 0·40 m./sec., the velocity of the air issuing from the system. This means that the air volume of a partial-walled system must be increased by about 25 % to obtain similar conditions to those in a full-walled system.

Sound levels were achieved in this system which were much superior to the majority of prefabricated types of laminar flow systems which are installed

throughout the world and normal conversation was possible with little or no awareness of background noise.

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EXPLANATION OF PLATES

PLATE 1

Internal construction of the partial-walled operating room at the London Hospital.

PLATE 2

(A) Penetration of ultra-clean area. No partial wall.

(B) Penetration of ultra-clean area. Partial walls in place.

PLATE 3

(A) The effect of light track straddling the air supply area.

(B) The effect of the adjacent extract system.

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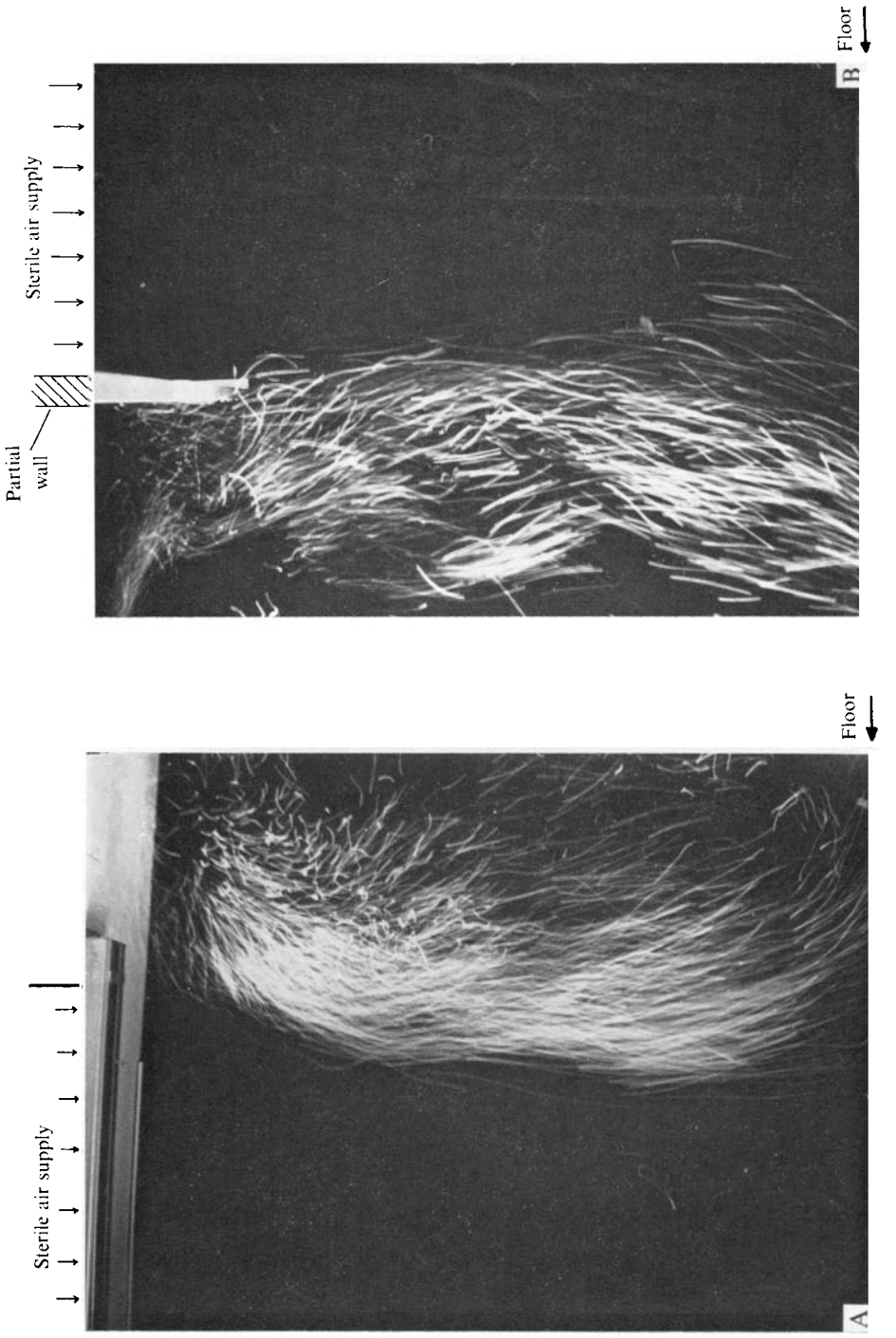

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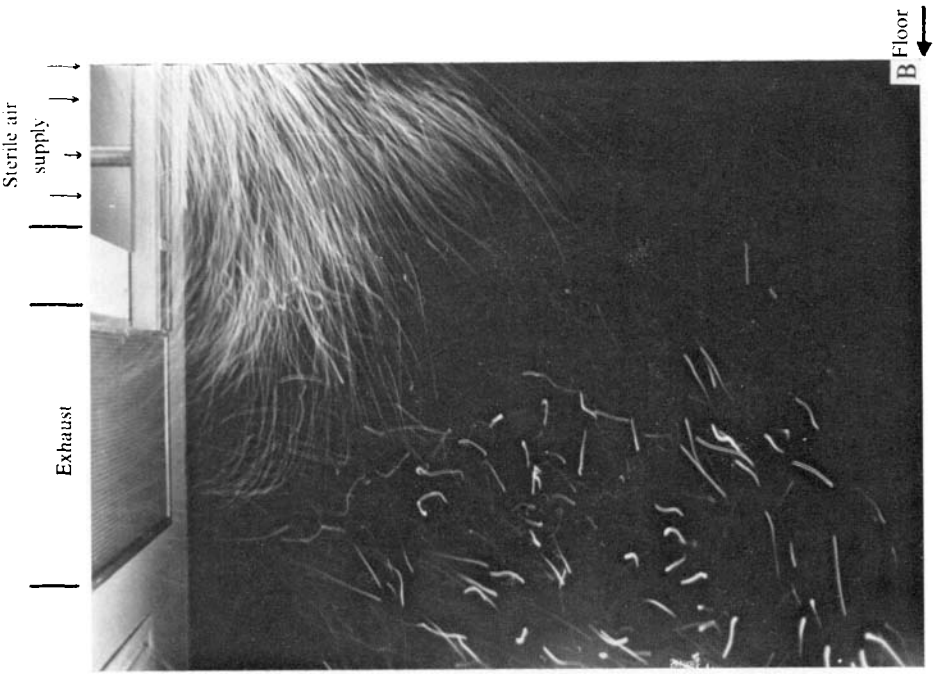

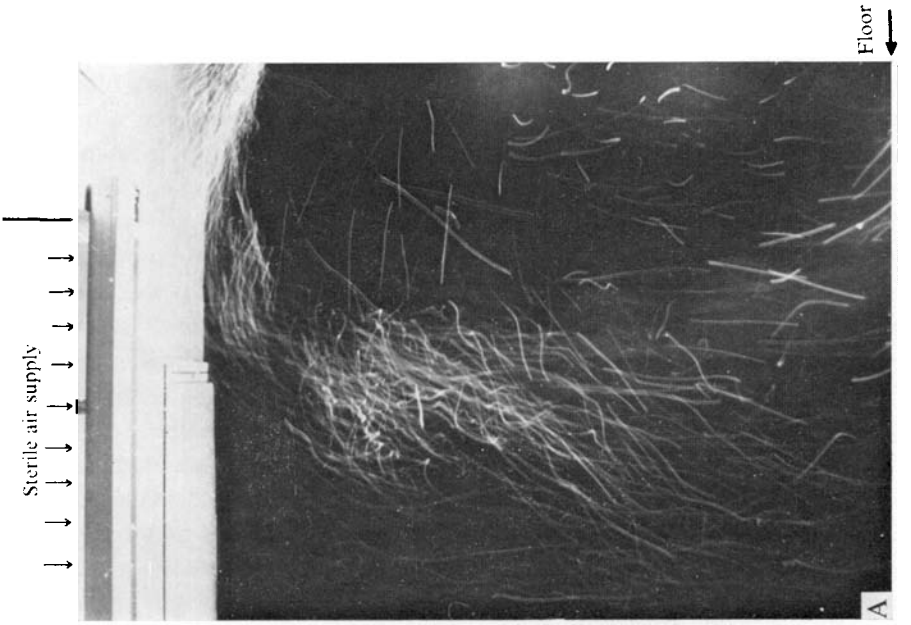

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