

A bacteriological evaluation of laminar-flow systems for orthopaedic surgery

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SUMMARY

An evaluation has been undertaken of the efficiency of laminar-flow ventilation in operating-rooms in which conventional operating-room clothing was used. It has been demonstrated that velocities in the region of 0.3–0.4 m./sec. will give maximum returns for effort in both down-flow and cross-flow systems. At this velocity the laminar-flow system, in terms of airborne bacteria measured at the wound site, was about 11 times more efficient using horizontal air-flow and 35–90 times more efficient using vertical air-flow than a plenum-ventilated operating-room.

INTRODUCTION

An ever-present problem in hospitals is the control of hospital infection, and in spite of much medical research in the past few decades wound sepsis remains one of the chief hazards.

There is, however, reasonable evidence that in general surgery some reduction in wound infection is obtained by positive-pressure ventilation of conventional operating rooms (Blowers, Mason, Wallace & Walton, 1955; Shooter, Taylor, Ellis & Ross, 1956). Recently, however, systems have been evolved which use large quantities of sterile air introduced through an entire end wall or ceiling in a unidirectional manner at velocities of up to 0.5 m./sec. (100 ft./min.) (Scott, 1970). These are normally known as laminar-flow systems.

Although there is no convincing evidence to show that this type of ventilation will result in a reduction of wound sepsis, it would seem reasonable that in 'clean' operations of long duration with implant of foreign material, as for example in a total prosthetic replacement of the hip, some reduction in wound sepsis should be possible. In a previous article (Whyte, Shaw & Barnes, 1971) we described the construction of an experimental operating-room with laminar-flow ventilation. This has now been subjected to a bacteriological evaluation which is described in this paper.

EXPERIMENTAL DESIGN

The experimental laminar-flow system was installed in one room of a twin-theatre suite which was built during the last war and solely served the Professorial Orthopaedic Unit of Glasgow University. Various types of elective orthopaedic surgery were carried out but we confined ourselves to observations on operations of the spine and total prosthetic replacement of the hip and knee.

One of the theatres was of conventional design, 0.7 m.³/sec. (1500 c.f.m.) of heated, filtered air being supplied to the operating-room through four ceiling diffusers. The other identical theatre contained our laminar-flow unit and was served by the same staff and provided with the same instruments, clothing, etc. The sterilizing room was situated between the two theatres.

The experimental ventilation unit was built so that during an operation the direction of air could be changed from cross-flow to down-flow and the speed of the air could be varied in the case of the cross-flow from 0 to 0.6 m./sec. (120 ft./min.) and from 0 to 0.5 m./sec. (100 ft./min.) with the down-flow.

Measurement of the velocity was by a hot-wire anemometer placed 1 m. away from the filter face. If an obstruction influenced this measurement, velocity readings were calculated from the velocity of air issuing from the system.

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 air-borne contamination. It may be considered that it would have been best to expose agar settle plates in order to obtain a direct indication as to the number of bacterial particles which would fall into the wound. This we did on a limited number of occasions, but even with the use of a large diameter Petri dish (15 cm.) the sample of bacteria was too low (about 2 bacterial particles/plate/hr.) to obtain significant results in a satisfactory time. We therefore used a High-Volume Slit-Sampler (Casella Ltd., London) with an air flow of 700 l./min. (25 c.f.m.). This was connected by a 0.6 m. (2 ft.) long bend of 10 cm. diameter (4 in.) flexible ducting to a metal cone 43 cm. (17 in.) long. This cone, which was sterilized between operations, was constructed to converge to a hole of 4 cm. diameter (1.5 in.) through which 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 halfway along the incision and 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, when appropriate, of dust particles 0.5 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.

The operating personnel were of course aware of the purpose of these studies and attempts were made at the start to place the team in the best position for good airflow. This was not pursued, however, during the observations reported here,

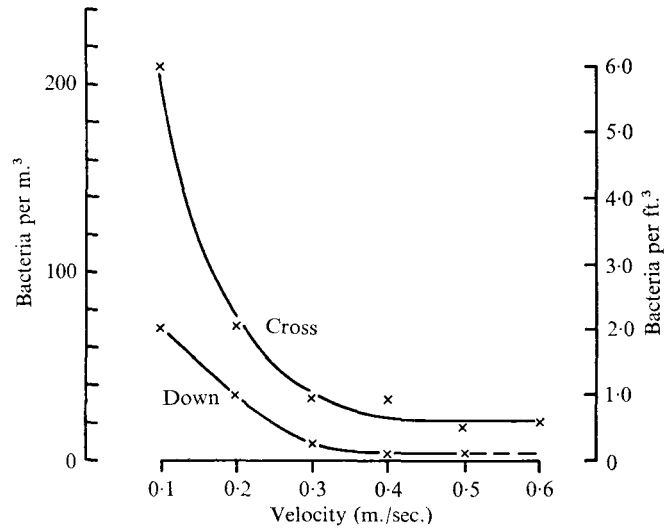


Fig. 1. Airborne bacterial counts at different velocities under cross- and down-flow conditions.

and positions were taken up which were more suitable to surgery. Although discipline was enforced by the physical shape of the system and the position of the anaesthetist at the end away from the filter, no artificial positions were adopted. All the surgery was done in a standing position and the clothing was of a conventional type; that is to say, it was of 'balloon cloth' which is known to do little to prevent the dispersion of bacteria from personnel.

RESULTS

Comparison of down-flow with cross-flow and the effect of velocity

Bacterial counts

Fig. 1 shows the average bacterial concentration that was found at the wound site at different air velocities under both down-flow and cross-flow conditions.

These results were obtained by sampling during 20 operations under cross-flow (13 hips, 5 spines and 2 knees) and 16 operations under down-flow (10 hips, 4 spines, 2 knees). Depending on the expected concentrations, samples were taken for 7–10 min. at a given velocity; in all a total of 270. The velocity was then randomly changed and another sample taken. This meant that the range of velocities was covered at least once during an operation. It may be seen that, at all velocities, down-flow ventilation gives a lower average concentration of bacteria than cross-flow. The difference in concentration was statistically significant at an F -level of 0.1% at all velocities except 0.2 m./sec. where it was significant at 1%.

Particle counts

Particle counts were taken at 1 min. intervals during the time the bacterial sampler was running. When, however, diathermy or a high-speed saw was being used, as well as when swabs were vigorously shaken, the particle counts increased

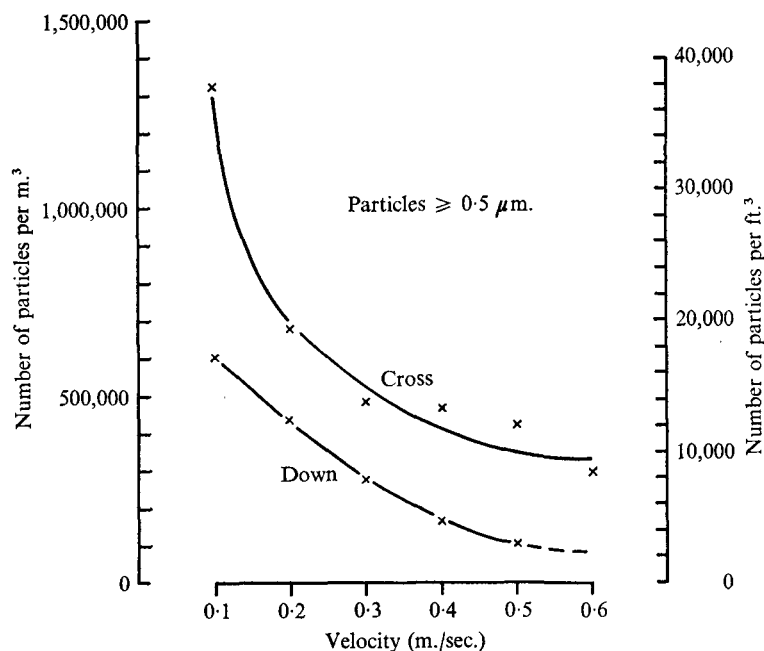


Fig. 2. Dust-particle counts ($\geq 0.5 \mu\text{m}$) at different velocities under cross- and down-flow.

tremendously. These counts were removed from the calculations and the counts averaged. The particle counts were not taken during as many operations as bacterial counts, but 18 operations were studied.

Fig. 2 shows the count of dust particles of $0.5 \mu\text{m}$. or greater under down-flow and cross-flow conditions at different velocities. It may be seen that substantially the same graph is obtained from dust particles as bacterial particles.

Comparison of the laminar-flow system with a conventionally ventilated operating room

Samples of dust particles and bacteria were taken at the wound site in the conventional room using the same methods as described above. Bacterial samples were taken for a much shorter period (1 or 2 min.) because of the higher concentration in the air and hence a much larger number of samples could be taken during the operation. A total of 86 samples was taken. Ten operations were monitored (6 hips and 4 spines) and the average bacterial count in the theatre was found to be $350/\text{m}^3$ ($9.8/\text{ft}^3$). The average bacterial count for each operation varied from 165 bacteria/ m^3 ($4.7/\text{ft}^3$) to $665/\text{m}^3$ ($19.0/\text{ft}^3$), individual samples varying from 35 bacteria/ m^3 ($1.0/\text{ft}^3$) to $880/\text{m}^3$ ($25/\text{ft}^3$). The average number of people in the operating room during these tests was eight.

Dust particle counts in the conventional theatre were in the region of $1,750,000$ – $14,000,000$ particles/ m^3 ($50,000$ – $400,000/\text{ft}^3$) for particles $\geq 0.5 \mu\text{m}$. (average $5,250,000/\text{m}^3$ or $150,000/\text{ft}^3$).

A comparison of the airborne count in the conventional operating room as

Table 1. *Percentage reduction of bacterial and particle count at different velocities of laminar-flow compared with conventional ventilation*

		Air velocity (m./sec.)					
		0.1	0.2	0.3	0.4	0.5	0.6
Bacteria	Downflow	79.5	90.0	97.1	98.9	98.8	—
	Crossflow	39.0	79.4	90.2	90.5	94.6	93.9
Particles ≥ 0.5 μm	Downflow	88.6	91.7	94.8	96.9	98.0	—
	Crossflow	74.8	87.1	90.1	91.1	92.0	94.5

opposed to the laminar-flow one is dependent on the velocity at which the laminar flow was being run. Table 1 is drawn up to show this comparison.

These results show that a velocity of 0.3 m./sec. (60 ft./min.) would reduce the bacterial airborne count by 97% using a down-flow of air and 90% using a cross-flow. Increasing the air velocity above this figure is accompanied by further reductions but these are small in comparison to the initial reduction achieved by a velocity of 0.3 m./sec. (60 ft./min.). Very similar results are achieved in reducing the dust particle counts.

DISCUSSION

Few systematic evaluations of the use of laminar-flow systems in operating theatres have been done, and the advice and results obtained by people involved in the industrial field are at present being used to build laminar-flow systems. What we have attempted to do is to evaluate laminar flow in such a way that systems may be designed for operating rooms to a predicted performance.

As in so many situations, the effort (and hence costs) expended in achieving very low airborne bacterial counts in an operating room is not proportional to results. This means that a point must be drawn where moderate effort and good design will achieve a highly efficient system. We consider such a point exists with an air velocity in laminar-flow systems of 0.3 m./sec. (60 ft./min.). An increase in velocity to 0.4 m./sec. (80 ft./min.) would give an additional margin of safety. At this speed 0.3–0.4 m./sec. (60–80 ft./min.) one would achieve a reduction in bacterial count of around 90% with the cross-flow and between 97–99% with the down-flow. It is accepted industrial practice (Federal Standard No. 209a) that the air velocity should be 0.46 m./sec. (95 ft./min.). The use of this recommended speed of between 0.3 and 0.4 m./sec. (60–80 ft./min.) will ensure a quieter system which will be considerably less expensive in capital and running costs.

It may be seen from the above results that in orthopaedic surgery (and almost certainly in most other fields of surgery) the down-flow system appears to be bacteriologically superior to that of cross-flow ventilation.

At velocities of 0.3, 0.4 and 0.5 m./sec. (60, 80 and 100 ft./min.) the down-flow ventilation had 3.5, 9 and 4.5 times less airborne bacteria respectively than cross-flow ventilation. In many ways this reduction is not the result we would have preferred as the design and operation of the cross-flow system has much to encourage its use. With a prefabricated system it is in general cheaper to build and install, and conventional lighting and services may be used without alteration. The

down-flow system is more difficult for the operating team to work with owing to the lack of accessibility caused by the necessity of four sides and often requires a larger surface area of filters. Most of these objections will no doubt be overcome as the technology of building ultra-clean operating rooms becomes more advanced. There will no doubt be compelling reasons for the adoption of one system or the other, but we hope that, with the data provided above, the choice of design of the system may be put on a rational basis.

It is also worth recording that these differences exist when conventional clothing is used. Use of impervious clothes may reduce this difference to practically nil.

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