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Bacterial dispersion in relation to operating room clothing

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SUMMARY

The effect of operating clothing on the dispersal of bacterial particles from the wearers was studied in a dispersal chamber. A comparison was made of six gowns as well as four types of trousers. The gowns were of three basic types, namely a conventional cotton type, disposable types made of non-woven fabric and those of the total-body exhaust system (Charnley type). The dispersal chamber could simulate conditions as expected both in down-flow unidirectional ultra-clean systems and in a conventional turbulent plenum-ventilated system. It was found that the disposable gowns would reduce the dispersal rate by about 30 % in the simulated conventionally ventilated system and about 65 % in the laminar flow system. The total-body exhaust system (Charnley) would reduce the count by 10-fold in the conventional ventilated system and by 66-fold in the laminar-flow system.

The poor performance of the gowns in conventionally ventilated systems was caused by the dispersal of bacterial particles from underneath the gown (about 80 %). This was not reduced by the disposable gown and only partially by the Charnley type. This small drop would be further decreased in a conventionally ventilated operating-room as only scrubbed staff would wear the gown. In order to overcome this poor performance in conventionally ventilated operating-rooms impervious trousers would be required. Four types were studied and it was demonstrated that those made either from Ventile or non-woven fabric would reduce the bacterial dispersion fourfold.

As these tests had been carried out in an artificial environment checks were carried out in the unidirectional-flow operating-room during total-hip arthroplasty. This was done by comparing conventional cotton gowns with non-woven gowns and total-body exhaust gowns. The results showed good correlation between the operating room and the chamber with the non-woven fabric gown but the total-body exhaust system did not perform as well in the operating room (12-fold compared to 66-fold) the difference being possibly due to the contribution from the patient. However, as this comparison was that which would be most open to influence from other variables confidence could be placed on the chamber test results.

Values were also obtained for the total number of bacterial particles dispersed by persons during a standard exercise wearing different clothing. This count was

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dependent on the clothing worn but a median count of between 1000 and 1500 bacterial particles/min. would be expected when conventional clothing was worn, with a range of between 300 and 19,000. This count could be reduced to about 100/min. if a total-body exhaust suit was worn (range 30–400).

INTRODUCTION

It has been accepted for some time that operating-room staff shed large numbers of bacteria, normally associated with skin particles, into the air. Duguid & Wallace (1948) estimated indirectly that, depending on activity, a person wearing ordinary clothes disperses between 1000 and 10,000 bacterial particles/min. and that a conventional cotton surgical-gown worn over street clothing did little to reduce the dispersion rate. It has also been demonstrated that the replacement of street clothes with basic operating-room clothing will do nothing to improve this situation (Bethune, Blowers, Parker & Pask, 1965; Doig, 1972).

In a modern plenum-ventilated operating theatre the concentration of bacteria in the air of the unoccupied room is very low and it is only when people are present and dispersing bacteria that significant concentrations of bacteria can be found in the air and therefore be deposited into the wound. Although there is little doubt that post-operative sepsis due to airborne contamination occurs, the frequency with which it does is relatively unknown. However, by developing new methods which prevent dispersion of organisms, it should be possible to assess the importance of airborne infection.

Attempts to reduce the risk from bacteria dispersed from personnel in the operating theatre have been of two kinds; diluting the organisms given off by improving the design of operating room ventilation, or improving the design of operating-room clothing.

Control of the bacteria dispersed into the environment by use of ventilation systems has been either in the conventional way (Report, 1973) or by the use of ultra-clean systems typified by unidirectional-flow units (Whyte, Shaw & Barnes, 1971). By the use of unidirectional-flow systems it is possible to reduce the number of bacterial particles at the wound site by at least 50 times, but this does not result in an environmentally sterile operating-room.

As normal operating-room clothing does little to prevent the dispersal of bacterial particles by the operating team, the second approach is to reduce the number of organisms by use of impervious clothing (Blowers & McCluskey, 1965). Use of an operating suit made from a cloth (Ventile) almost impervious to bacterial particles gives a large drop in *Staph. aureus* dissemination. This is caused particularly by the use of trousers with tight ankle fittings which reduce the shedding of *Staph. aureus* from its principal source, the perineal area. These Ventile materials have however proved uncomfortable to wear and Ventile underpants have been suggested (Hill, Howell & Blowers, 1974).

Both these approaches, i.e. the ultra-clean air system and impervious clothing, have been advocated by Charnley (1973). A downflow unidirectional ventilation system is used along with a one-piece Ventile gown, which is worn in conjunction with a helmet, exhaust ventilation being provided to keep the surgeon cool. Little is known of the contribution of this total-body system in reducing the number of airborne bacteria in the operating room.

The object of this study therefore was as follows:

(*a*) to design and test operating clothing in a dispersal chamber in order to assess and improve on operating-theatre clothing,

(*b*) to test the best and most practical of such clothing in a laminar-flow operating theatre in order to check the validity of the experiments carried out above,

(*c*) to assess the contribution of total-body exhaust-system clothing in a laminar-flow operating-room.

In view of the occurrence of infection by coagulase-negative staphylococci in implant operations (Speller & Mitchell, 1973; Holt, 1969) it would appear that at least as valid an approach in assessing the effectiveness of operating clothing is by considering, not just the number of *Staph. aureus* dispersed, but the total bacterial count.

METHODS

Dispersal chamber studies

Fig. 1 is a diagram of the dispersal chamber used in this study. This chamber was made up of plastic-coated chipboard ('Contiboard'). The overall height of the box was 2·7 m. but as the top contained a H.E.P.A. filter (*a*) the free space was 2 m. Bacteria-free and dust-free air was supplied through this filter at 0·035 m.^{3}/sec. (75 ft.^{3}/min.) in a downward direction. A shelf (*d*) 25 cm. wide was situated at a point 90 cm. high in order to simulate an operating table. A 0·017 m.^{3}/sec. (25 ft.^{3}/min.) sample of air was taken just above this shelf, thus simulating a sample of the number of bacterial particles to be found at the wound site in a unidirectional flow system. The remaining air passed down the box and when one of the subjects was in the box it passed him at a speed associated with ultra-clean systems – around 0·35 m./sec. (70 ft./min.). A further air sample of 0·017 m.^{3}/sec. (25 ft.^{3}/min.) was taken at floor level, the remaining air either passing out through the exhaust ports (*g*) or when the total-body exhaust system was being used, through the total body clothing exhaust (*J*). A slight positive pressure in the chamber was ensured. In order to prevent re-entrainment of bacterial particles from the floor a plastic mat soaked in disinfectant was used.

Three subjects were tested: two males and a female. The males stripped to their underpants and socks and the female to her undergarments. All clothing, including a conventional operating-suit, was donned along with surgical gloves, disposable mask, hood and shoe covers. The subjects exercised to the beat of a metronome (*b*) (1 beat/sec.). This exercise was standardized in order to achieve consistency of results and was: marking time on the spot by touching the bridge of the foot on the underside of the exercise bar (*e*) and at the same time crossing arms to touch shoulders with the hands and then dropping the hands to the corners of the shelf (*d*). This exercise was carried on for 30 sec., the air sampling

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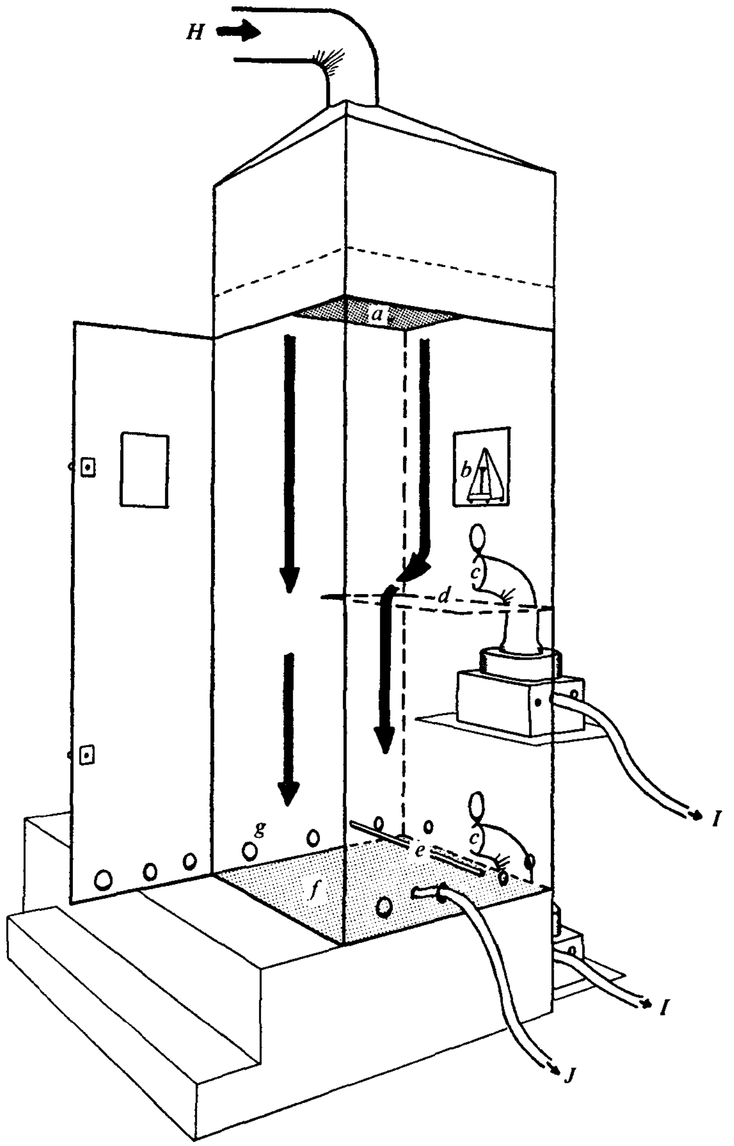

Fig. 1. Diagram of dispersal chamber. *a*, H.E.P.A. filter; *b*, metronome; *c*, sampling points; *d*, shelf; *e*, exercise bar; *f*, antiseptic mat; *g*, exhaust ports; *H*, air supply; *I*, bacterial sampler exhaust; *J*, impervious-clothing exhaust.

started, and the exercise continued through an air-sampling period of between 30 sec. and 6 min., depending on the expected bacterial dispersal rate.

The bacterial samplers used were high-volume samplers (Casella Ltd). In the experiments with gowns, samples were taken simultaneously both above the shelf and at floor level. In the trousers experiments samples were taken at floor level only. This sampling was designed to provide the best imitation of conditions in an operating theatre. In experiments with gowns we considered that the number of bacterial particles dispersed in a unidirectional-flow operating room would be best simulated at shelf level. However, in a conventionally ventilated theatre this concentration would be best expressed as the total number of bacterial particles given off by the person, which remained in the air. This was determined by adding the airborne count at shelf level to twice the count of the floor level sample (the remaining air being exhausted at floor level and presumably being the same concentration as the floor-level bacterial-sample).

When trousers were compared, air sampling was carried out only at floor level, as it was considered that trousers would be of greatest use in a conventionally ventilated theatre. The floor level sample would be one-third of what would be expected to be disseminated by the person into the operating-room air.

In order to assess the total number of bacterial particles disseminated into the air Petri dishes were placed occasionally on the floor of the box.

Types of operating theatre clothing studied

Gowns

Six types were studied. These gowns could be grouped into three types: conventional, disposable and total-body exhaust gowns. The conventional gowns used were a wrap-round type made from a cotton fabric, 136 g./m.^{2} (4 oz./yd.^{2}), woven with 40×40 threads/cm. (100×100 threads/in.) similar to those found in most British hospitals. Two of the disposable gowns were manufactured from a non-woven fabric (Johnson & Johnson Ltd), one being their British product, the other American. A third type was made from a spun-bonded olefin material (Tyvek) which is distributed by C. R. Bard International Ltd. The total-body exhaust gowns were identical in design to those used by Professor Charnley and were worn in accompaniment with an air-exhaust helmet and visor. They were made up from (*a*) 'Ventile L24', (*b*) non-woven fabric laminated with plastic to give a material which was absolutely impervious.

Trousers

These were of four types: (i) a conventional type made from cotton (as described above) with no ankle fastening, (ii) trousers made from a heavier cotton of a weight 197 g./m.^{2} (5·8 oz./yd.^{2}), woven with 23×18 threads/cm. (58×45/in.), the tapered ankle being fastened under the foot by elastic (ski-pant design), (iii) trousers made from 'Ventile L24' material with the ankle secured by a stockinette fastening, (iv) trousers made from the same non-woven fabric as the gown (J & J), the ankles being again secured by stockinette fastening. For all four types, alternate evaluations were carried out with the trouser-leg bottom secured by a rubber band.

Operating theatre studies

These were carried out in a down-flow laminar-flow unit located at Gartnavel Hospital, Glasgow. The air velocity was set at 0·35 m./sec., the same as in the dispersal chamber. This system is almost identical with the system we have described previously (Whyte, Shaw & Barnes, 1971). Air sampling was carried out only during total-hip arthroplasty. It was carried out throughout the operation

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Table 1. *Dispersal of bacteria through gowns in simulated conventional conditions (median rate per minute for* 18 *tests on* 3 *subjects)*

	Dispersal/min.		Change in dispersion rate
	Median	Range	(%)
Conventional operating suit	1338	334–5212	—
Conventional cotton gown	893	317–5455	0
Disposable gowns			
Non-woven fabric (U.K.)	725	263–3671	−19
Non-woven fabric (U.S.A.)	568	217–2844	−36
Tyvek	538·5	265–3450	−40
Total body gowns			
Ventile	119·5	29–394	−87
Laminated plastic	67	30–247	−92

using a high-volume air-sampler. The sampling rate was 0·017 m.^{3}/sec. (25 ft.^{3}/min.) and the samples taken at a position no more than 10 cm. from the wound site. This sampling device is described elsewhere (Whyte & Shaw, 1973).

RESULTS

Settle plate sampling

As the air sampling carried out with the bacterial samplers would only give the number of organisms suspended, at least temporarily, in the air it was thought that settle plates should be laid on the floor of the dispersal chamber to evaluate the number of bacterial particles which would, because of their size, fall to the floor, thus obtaining the total number of bacterial particles dispersed by an individual. Results showed that these bacterial particles amounted to less than 3% of the bacterial particles dispersed and this method of sampling was therefore discontinued. The results of bacterial dispersion are therefore reported only in terms of counts obtained by the volumetric samplers.

Comparison of gowns in dispersal chamber

Conventional operating-room air-flow simulation. Table 1 shows the dispersal rate of bacteria per minute for different gowns. These results are drawn from 18 tests carried out with gowns worn over a sterile conventional cotton suit (short sleeve shirt plus trousers) by two male subjects (W.W. and P.B.) and one female (M.McM.), each result being expressed as a median of the 18 results collected. In order to simplify the table individual results collected are not shown, but it should be noted that although there was excellent consistency in the rate of change of dispersion with different clothing carried out on one subject during the same day, the difference in the rate of dispersion between subjects and also from day to day was very large indeed. If an example is taken of the dispersal rate of subjects wearing a conventional gown we find the difference in total dispersal rate between two subjects to be between 326 bact./min. (M.McM.) and 3912 bact./min. (P.B.) (a 12-fold difference). Similarly a large difference could be shown on a day-to-day basis with the same individuals, this difference varied with individual and was as follows:

P.B.	1654 bact./min. – 19,200 bact./min.	(12-fold difference),
W.W.	367 bact./min. – 3,840 bact./min.	(10-fold difference),
M.McM.	317 bact./min. – 1,374 bact./min.	(4-fold difference).

It can be clearly seen in Table 1 that, notwithstanding the wearing of sterile clothing, people disperse large numbers of bacteria. The median number of bacterial particles given off by our three subjects wearing a sterile cotton suit typical of many used in the operating theatre was 1338/min. Even when a sterile cotton wrap-round gown was worn the dispersal rate was reduced only to 893/min. (this difference was shown not to be statistically significant). As this gown was typical of what may be expected in practice in an operating room, comparison was made between it and the other gowns used. This increase in efficiency of the new type of gowns is given in Table 1.

Statistical analysis of the results demonstrates that, with a probability level of less than 0·05, a difference could be shown between the total-body exhaust gowns and all other gowns, and between the conventional gown and all others. However, it was also possible to demonstrate a difference between the two types of gowns used in the total-body exhaust-system and between one of the conventionally designed gowns made from non-woven fabric and one of non-woven plastic. This difference may well be real but it is our view that for all practical purposes the gowns may be grouped into three similar types, i.e. (*a*) the conventional cotton gown, (*b*) the disposable gowns and (*c*) the total-body gowns. If this is done it may be expected that when *all* personnel are using these gowns in a conventional operating-room reductions in the airborne bacteria could be in the region of 25 % for disposable gowns and 90 % using the total-body exhaust system. However, as it is neither practical nor possible for all personnel, i.e. the non-scrubbed as well as the scrubbed, to use these gowns, the drop in airborne count in operating-rooms will be considerably less than that calculated above.

Unidirectional-flow operating-room simulation. Table 2 shows the number of bacterial particles given off per minute from a person, which would find their way to a simulated wound position in laminar-flow conditions. A comparison of the gowns with a conventional theatre gown is given and it may be seen that differences are much more dramatic than in the conventional ventilation situation. Use of a cotton gown halves the number of bacteria given off and a comparison between the cotton gown and the others shows an approximate halving again when disposable gowns are used.

Use of the total body system as compared to the cotton gown shows an approximate 70-fold reduction.

Statistical analysis demonstrates that the gowns fit neatly into the three groups mentioned above. No difference ($P \geqslant 0{\cdot}02$) could be demonstrated between the two total-body gowns or between any of the disposable gowns but differences were demonstrated between the total-body gowns and all others and between the disposable gowns and all others.

Table 2. *Dispersion of bacteria through gowns in simulated laminar-flow conditions (median rate per minute for* 18 *tests on* 3 *subjects)*

	Dispersal/min.		Change in dispersion rate (%)
	Median	Range	
Conventional operating suit	429	102–1866	—
Conventional cotton gown	152	54–591	0
Disposable gowns			
Non-woven fabric (U.K.)	73	12–261	−52
Non-woven fabric (U.S.A.)	38	15–300	−75
Tyvek	47	9–411	−69
Total body gowns			
Ventile	1·7	0–12·99	−98·9
Laminated plastic	2·7	0·48–14·49	−98·2

The difference between the results, as found in the simulated conventional and unidirectional flow systems, is explained in the way the air is supplied and where the bacterial particles are dispersed from. It appears from our results that around 80 % of bacterial particles are disseminated from the waist down and the down-flow of air ensures that few of these are sampled above the shelf. The disposable gowns, however, do little to prevent these 80 % of the bacteria being dispersed out from under the gown and similarly the total-body system appears to allow a lesser number of bacterial particles to flow out from beneath the gown. This being so, the greatest reduction in airborne dispersion, in the case of the disposable and total body gowns, is caused above the waist and hence the greater beneficial effect in the laminar-flow simulation.

Trousers. Table 3 shows a comparison between trousers made of conventional cotton material, linen of a ski-pant design, 'Ventile L24' and non-woven fabric (J. & J.). All trousers were compared with and without an elastic band around the ankles, the band ensuring that no bacteria were disseminated out of the trouser ankles fitting.

It may be seen and confirmed statistically that no difference could be demonstrated between the conventional trouser and those of ski-pant design or between the non-woven fabric and Ventile trousers ($P > 0{\cdot}1$).

A statistical advantage ($P < 0{\cdot}05$) could be demonstrated in all but the ski pants by ensuring good ankle fastening, but most important of all a considerable difference was found between the conventional trousers and the 'Ventile' or non-woven fabric (around 4 times).

Comparison of gowns in the operating theatre

Twenty-two different conditions were studied in the dispersal chamber. These were the dispersal rate of individuals in two types of ventilation wearing six different gowns and also that of four different type of trousers with and without ankle fastening. The application of these results directly to the operating-room environment was checked by comparing conventional cotton gowns with both non-woven fabric gowns and the total-body exhaust system gowns in a unidirec-

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Table 3. *Comparison of dispersal rate through trousers in simulated conventional flow conditions (median rate of dispersion per minute for* 18 *tests on* 3 *subjects)*

	Dispersion/min.		Change in dispersion rate
	Median	Range	(%)
Conventional cotton			
Without band	1599	528–19,200	0
With band	1431	450–15,840	−11
'Ski type'			
Without band	1314	216–17,760	−18
With band	1746	126–19,080	+9
Ventile			
Without band	540	48–6720	−66
With band	465	66–3960	−71
Non-woven fabric			
Without band	360	75–7920	−78
With band	279	45–4020	−83

Table 4. *Comparison of the reduction in the median airborne bacterial concentrations in unidirectional-flow operating room and the dispersal chamber*

	Conventional cotton gown	Non-woven fabric gown	Total body exhaust gown
Bacterial particles per $m.^3$	7·34	2·5	0·63
Reduction in operating room (%)	—	66	91·4
Reduction in dispersal chamber (%)	—	52	98·5

tional air-flow operating-room. This situation was chosen not only because of the intrinsic interest of evaluating the effect of the total-body exhaust system in the laminar-flow situation but by using the ultra-clean situation the effect of the gowns could be more easily studied as the non-scrubbed staff who would not be wearing these gowns would not be shedding bacteria into the area to be sampled.

Table 4 shows the median bacterial particle count found during total-hip replacements under the three test conditions. The reduction achieved by use of the non-woven fabric gowns and the total-body exhaust gowns as compared to the conventional gown is given for both the operating room and the dispersal chamber.

DISCUSSION AND CONCLUSIONS

It was the aim of this study to evaluate the potential of new types of operating clothing in reducing the numbers of bacterial particles dispersed into the operating room. This was carried out in a dispersal chamber and to a much lesser extent in an operating room. In the tests carried out in the dispersal chamber it was possible to draw a distinction between the number of bacterial particles disseminated which would be expected to reach the wound in a downward unidirectional-flow system, and those which would reach the wound in a conventional turbulent-ventilation system. It was also possible to obtain a value for the total number of bacterial particles dispersed per minute for a standard exercise.

The total number of bacterial particles dispersed per minute was found to vary according to the individual, the type of clothing worn and the time of sampling. When a person carried out a standard exercise wearing standard operating clothing the median total dispersal rate as measured by a bacterial sampler was 1338 bacterial particles/min. with a maximum of 19,200 and a minimum of 317. This excluded the small percentage (less than 3 %) of particles which fell to the floor and which must be added to the figure for the total counts referred to in this text. The count varied greatly between individuals and the day of testing and it was possible to show differences of 12-fold, both between subjects and between different sampling days.

These results compare quite well with May & Pomeroy (1973). Exact comparisons cannot be made as the activity, clothing worn and the individuals studied were not the same. Notwithstanding this they found that the total bacterial particle counts varied from 237 to 17,651/min. and that the median count with 'normal' (presumably outdoor) clothing was 1008 for males and 753 for females.

They also found that the number of bacteria per bacterial particle was around 4·6. This would explain the apparently high counts of bacteria (3333 → 63,000/min.) dispersed during the tests reported by Sciple, Reimensnider & Schleyer (1967) as their method entailed a washing procedure which would presumably break down the bacterial particles to single cells.

When an ordinary cotton gown was worn this appeared to reduce the number of bacterial particles shed by 33 % with the conventional ventilation simulation and 65 % in the laminar-flow simulation. Further comparisons were, however, made between this conventional cotton gown and six other gowns. These gowns could be divided both in terms of results and physical appearance into two types – the newer disposable type of gown made from non-woven fabric and the total-body exhaust system gowns. The disposable non-woven fabric gowns reduced the dispersal rate in the conventional ventilation compared to the cotton gown by around 30 % and in the laminar flow by twice that (approx. 65 %). The total body exhaust gowns, however, gave a drop of about 10-fold in the turbulent air flow and 66-fold in the laminar air flow, it being interesting to note that the absolutely impervious gown showed no advantage.

It was obvious from the above results that the gowns were performing much better in the laminar flow. This is almost certainly due to the fact that when an operating gown is worn bacterial particles easily find their way out under the bottom of the gown, this not being as important in downward unidirectional flow where the bacterial particles are swept away. In our case around 70 % of the bacterial particles were sampled in the lower part of the sampling chamber when trousers and vest were worn, but more than 90 % were sampled when disposable gowns were used. It was therefore reasonably obvious that in a conventional theatre with only the scrubbed staff wearing gowns the effect of the gowns on the airborne count would be very low. It was therefore apparent that a significant reduction in the bacterial count would be best achieved by impervious trousers.

Tests were carried out on different types of trousers – two were linen, one Ventile and one specially manufactured from non-woven fabric. It was demon-

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strated in agreement with Blowers & McCluskey (1965) that tight sealing of the trousers at the ankle was a distinct advantage and that trousers made out of Ventile could reduce the dispersal rate by about 70 %. However, we also found similar, if not better, results (80 % reduction) from trousers made from non-woven fabric. As Ventile trousers can be extremely uncomfortable to wear, owing to their insulating qualities, the non-woven fabric may be more acceptable.

The results considered above are all derived from dispersal-chamber studies which, it is hoped, simulated operating-room conditions. In order to ascertain the validity of the results two comparisons were made in our laminar-flow theatre between the conventional gown and both a non-woven fabric gown and a total body exhaust gown. These comparisons showed good correlation between the comparison of conventionally designed cotton gowns and non-woven fabric gowns. However, comparison with the total-body exhaust showed the apparent performance of this gown in our operating rooms to be poorer than in the dispersal chamber. The reason for this, we feel, may be the possible contribution of bacteria from the patient's own flora. As such low numbers of bacterial particles were dispersed from people wearing these gowns in the unidirectional flow system the results will be easily affected by extraneous influences. However, it may be assumed that the difference between the results found in the dispersal chamber and those in the operating room will be *worst* with such high efficiency clothing and that comparisons with clothing not as efficient will give less difference. This leads us to place considerable confidence in the chamber tests.

The comparison between the conventional cotton gown and the total-body exhaust system gown had an intrinsic value of its own as we were very interested to ascertain the contribution of the total-body gown to the airborne cleanliness of a laminar flow system. In our present plenum-ventilated operating room using conventional clothing we have found the average airborne concentration of bacterial particles during a total hip implant to be about $450/m.^3$. In a downflow laminar-flow system still using conventional clothing this count was reduced to $7{\cdot}3/m.^3$, a 60-fold drop, but using total-body exhaust clothing in conjunction with the vertical laminar-flow system the bacterial concentration was reduced 12 times to $0{\cdot}63/m.^3$, in all, a 750 times reduction.

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