J. Hyg., Camb. (1979), **82**, 7
With 1 plate
Printed in Great Britain

A garment for use in the operating theatre: the effect upon bacterial shedding

By J. DANKERT, J. B. ZIJLSTRA AND H. LUBBERDING

Laboratory of Medical Microbiology, State University of Groningen, and the Department of Hospital Epidemiology and Hospital Infections, University Hospital Groningen, The Netherlands

(*Received* 24 *January* 1978)

SUMMARY

In operating theatres the air is mainly contaminated with bacteria shed from the human skin. The emission of bacteria can be prevented by wearing clothing of impervious material, while normal cotton clothing does not decrease the shedding of bacteria.

In this study shedding of viable bacteria from 20 test-persons wearing an operating theatre suit, composed of 65% polyester and 35% cotton (Diolen), was investigated in a test-chamber and compared with that when normal clothing was worn. The use of this operating-theatre suit resulted in a significant reduction (50–75%) in the number of bacteria-carrying particles in the air of the test-chamber and in an operating room when everyone present wore this suit. A combination of the suit with knee-high boots showed a further reduction in the dispersal of colony forming units.

The dispersion from female subjects wearing an operating-theatre frock was significantly higher than when wearing an operating-theatre suit.

INTRODUCTION

In modern surgery the number of microorganisms in the air of operating theatres should be as low as possible. To achieve this the contamination of the air by the personnel, by dust from the floor and other surfaces and by air from adjoining rooms has to be prevented by control measures, while the bacterial load in the air can be diluted by using a ventilation system.

Since every human being carries an immense number of bacteria (Noble & Somerville, 1974), shedding from the upper respiratory tract, oral cavity, skin and hair of every person present in the operating-theatre will occur (Wells & Wells, 1936; Duguid & Wallace, 1948; Noble & Davies, 1965; Bethune *et al.* 1965). Contamination of the air by these microorganisms is reduced by wearing a face-mask, a cap and special clothing (Duguid & Wallace, 1948; Blowers & McCluskey, 1965, Bernard *et al.* 1965; Mitchell & Gamble, 1974).

Shedding of bacteria from the beard where *Staphylococcus aureus* can be isolated in high numbers (Huysman-Evers, 1974) may be prevented by use of a mask similar in shape to that worn by apiarists. Operating suits made of Ventile L 19 or L 34

0022–1724/79/0012–1978 $01.00

are effective but are uncomfortable when worn for longer periods (Hill, Howell & Blowers, 1974). To adapt this clothing for longer operations Charnley (1973) has developed an exhaust ventilation system. This system, however, is only suitable for stationary subjects.

In the Department of Surgery of the University Hospital Groningen for the last four years special operating-theatre clothing has been worn not only by members of the surgical team but also by all other persons present, including visitors.

The results of the bacteriological monitoring of the air in an operating-room showed a significant reduction in the number of bacteria after the introduction of this regulation.

Since no other factors, e.g. the ventilation system, the cleaning and disinfection procedure or the number of subjects present in the operating theatre were altered, we ascribed the reduction to the effect of the special clothing on the sheddding of bacteria. We have studied this effect and present the results here.

MATERIALS AND METHODS

Test persons

The investigation was carried out upon 20 technicians from our laboratory (10 female and 10 male) with an average of 24·6 years (19–33 years); none suffered from skin diseases, nor used antimicrobial agents during the previous 3 months or during the period of investigation.

Clothing

The clothing under investigation consisted of a frock or a trouser suit (Plate 1) and knee-high boots (45 cm high), composed of 65% polyester and 35% cotton (Diolen, Enka Glanzstoff). The weave-pattern of the frock and the suit has a warp of 42·5 and a weft of 22·8 threads/cm with a pore size of 10–30 μm and the material weighs 168 g/m^2, the air transmission is 12100 l/m^2. The weave-pattern of the slippers and boots has a warp of 21·7 and a weft of 24·4 threads/cm, while the pore size is 10–30 μm. The weight and the air transmission of this material is 230 g/m^2 and 15 600 l/m^2 respectively. The dispersal from every participant wearing normal daily clothing or the freshly cleaned trouser suit, in each case in combination with a face-mask (Bardic^R disposable face mask (C. R. Bard Inc., Murray Hill, N.J., U.S.A.)), a cap and ankle-high cotton slippers was determined within the same week. The shedding of bacteria by the 10 females wearing the freshly cleaned operating-theatre frock was investigated. The female test subjects did not wear stockings or tights during the experiments. To study the dispersion from test persons (5 males and 5 females) wearing the operating theatre suit for a longer time period (8 h), air sampling was carried out at 0, 1, 2, 4, 6 and 8 h after putting on the suit. These same subjects wearing normal daily clothing were investigated twice with a time interval of 8 h. In another experiment the effect of wearing the trouser suit without boots and in combination with ankle-high slippers or with knee-high boots was studied.

Dispersal investigations

Test persons. During the dispersal investigations the subjects performed standardized exercises. These exercises were (*a*) keeping feet on the floor while bending knees (10 times), (*b*) crossing the arms so that hands touch the shoulders (10 times), (*c*) running movements (30 sec), (*d*) shrugging shoulders and dropping hands at the sides (30 sec). This set of exercises was repeated once.

Colony-forming units. Aerial dispersal of bacteria was investigated in a test chamber measuring 71 × 82 × 193 cm similar to that described by Bethune *et al.* (1965). The test chamber was disinfected with aerosolized ethanol (96 %) after each investigation and evacuated for 10 min. Bacteria-carrying particles are withdrawn from the upper and lower part of the chamber by two suction pumps (Electrolux, model 274) for 5 min. The capacity of each pump is 1500 l/min. At a distance of 10 cm from the chamber a filter of sterilized face-mask material (Bardic; diameter 12 cm) is inserted into the suction tube. The efficiency of this filter in removing bacteria-carrying particles from the air was found to be 99·98 %. The total number of bacteria-carrying particles upon the filters and on sedimentation plates placed within the chamber was determined. The filter was shaken (Yankee Kahn Shaker, B-D, U.S.A.) for a short period (2 min) in 25 ml peptone broth (Oxoid, Ltd.). Five samples of 1 ml were pipetted into 5 petri dishes and pour plates were made. The number of colonies were counted after an incubation period of 48 h at 37 °C and the number of colony-forming units (c.f.u.) dispersed per minute was calculated. The sedimentation plates (blood agar) were exposed while each test subject was in the test chamber (5 min) and for the following 15 min. Four plates were located in the upper and four in the lower compartment. The plates (65 cm^2) were incubated at 37 °C for 48 h.

The number of c.f.u. which were sedimented per minute upon the floor surface of the upper and lower compartments was calculated. The total number of c.f.u dispersed per minute was the sum of the c.f.u. isolated from the filter and the c.f.u. sedimented on the blood agar plates.

Bacteriological monitoring of the air in the operating-room

In the operating-room for open-heart surgery, samples were taken each hour for 5 min during operations. Two Bourdillon samplers and two Anderson samplers, connected to a central suction line to avoid the high noise level, were located in the immediate vicinity of the wound area at the end of the operating table, under the table and at two of the corners of the operating-room. Sedimentation plates were located at the same sites for the whole operation period.

Statistical analysis

The paired Student *t* test was used. A significance level of ± 5 % was adhered to.

https://doi.org/10.1017/S0022172400025419 Published online by Cambridge University Press

Table 1. *Mean number of c.f.u. in 1 cubic foot of air in an operating-room during open-heart operations*

Sample site	Staff wore normal clothes with ankle slippers	Staff wore trouser suits with ankle slippers
Wound area	10·1*	5·2**
Head-end of the operating table	16·4	4·8
Below the operating table	17·8	7·1
Corner of the operating room	5·3	3·9

* Samples were taken with Bourdillon samplers and Andersen samplers each hour for 5 min during operations. Results from 46 operations are given. Per site, 196 samples were taken.

** Samples were taken with Bourdillon samplers and Andersen samplers each hour for 5 min during operations. Results from 85 operations are given. Per site, 383 samples were taken.

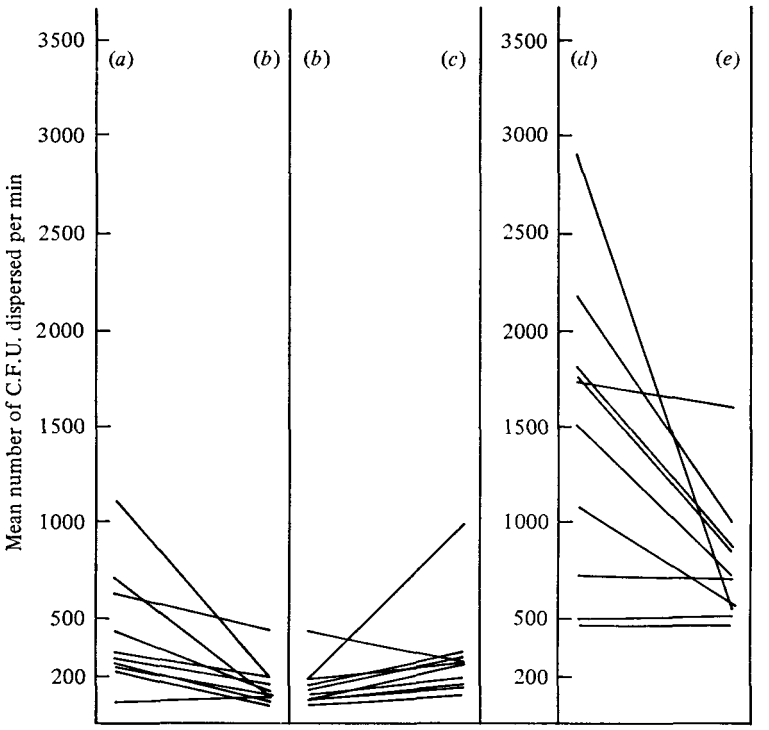


Fig. 1. The effect of wearing the trouser suit upon the shedding of skin flora by ten female and ten male test subjects. The number of c.f.u. shed/min. is given individually. (*a*) Female test subjects wearing normal clothes. (*b*) Female test subjects wearing trouser suits. (*c*) Female test subjects wearing operating-theatre frocks. (*d*) Male test subjects wearing normal clothes. (*e*) Male test subjects wearing trouser suits.

https://doi.org/10.1017/S0022172400025419 Published online by Cambridge University Press

Table 2. *Mean number of c.f.u. shed per min. by ten female and ten male test subjects wearing normal clothes, trouser suits or operating-theatre frocks*

Sex	Normal clothes (*a*)	Trouser suit (*b*)	Operating-theatre frock (*c*)	Statistical analysis: Comparison	Statistical analysis: *t* value
Females ($n = 10$)	483 (112–1176)	191 (93–490)	340 (146–1018)	(*a*)–(*b*)	3·18 ($P < 0·05$)
				(*a*)–(*c*)	1·36 ($P > 0·05$)
				(*b*)–(*c*)	−2·89 ($P < 0·05$)
Males ($n = 10$)	1531 (510–2948)	755 (503–1646)	—	(*a*)–(*b*)	2·66 ($P < 0·05$)

Table 3. *Mean number of c.f.u. shed per minute by 5 female and 5 male test subjects wearing normal clothes or the trouser suit; shedding was determined over a period of 8 h*

Sex	Clothing	Wearing time (h): 0	1	2	4	6	8
Female	Trouser suit	191	212	90	108	92	85
	Normal clothes	460	—	—	—	—	360
Male	Trouser suit	314	240	275	247	232	196
	Normal clothes	1165	—	—	—	—	670

Table 4. *Mean c.f.u. shed per min by 10 male test subjects while wearing the trouser suit with and without slippers, and with slippers or knee-high boots*

Trouser suit: Without slippers (*a*)	Trouser suit: With ankle-high slippers (*b*)	Trouser suit: With knee-high boots (*c*)	Statistical analysis: Comparison	Statistical analysis: t value
1036 (608–2408)	956 (540–2305)	318 (113–1098)	(*a*)–(*b*)	0·84 ($P > 0·05$)
			(*a*)–(*c*)	3·67 ($P < 0·05$)
			(*b*)–(*c*)	3·55 ($P < 0·05$)

RESULTS

The mean number of colony forming units (c.f.u.) found in the air during operations where normal clothes were worn was significantly higher than at operations where the special suit was worn (Table 1).

The results of the shedding of c.f.u. from 10 females and 10 males in the test chamber are shown individually in Fig. 1. These values represent the sum of c.f.u.s found on sedimentation plates and the filters in the upper and lower compartments. The latter was found to be higher than the former by a factor of 3–4. Nine females showed a reduction when the trouser suit was worn (Fig. 1*b*), but while wearing a frock of the same material shedding increased (Fig. 1*c*). Seven males wearing the suit showed a decrease in the dispersal of c.f.u. (Fig. 1*e*). Table 2 summarizes the results of Fig. 1 and shows that the trouser suit significantly decreases shedding of c.f.u. in both sexes. Wearing the frock reduced the number of c.f.u. compared with normal clothing but not to a significant degree. The

https://doi.org/10.1017/S0022172400025419 Published online by Cambridge University Press

experiments concerning the shedding at different time intervals over 8 h show that the reduction in c.f.u. by wearing the suit remained (Table 3). It is apparent that shedding decreases over the investigated time period. Knee-high boots in combination with the trouser suit significantly reduced dispersal of c.f.u. (Table 4).

DISCUSSION

The results show a reduction of 50–75 % in the c.f.u. from male and female volunteers wearing the trouser suit composed of 65 % polyester and 35 % cotton. This positive effect may be the result of wearing freshly cleaned clothing and the short duration of the investigation (5 min) in the test chamber. Our results obtained from test persons wearing the suit and frequently tested over a period of 8 h even show a decrease in the number of c.f.u. dispersed. This may imply that the suit plays the role of a rather effective barrier for longer periods and that clothing as a source of shed c.f.u. is negligible. The latter is in agreement with the findings of May & Pomeroy (1973) that sterile clothing did not decrease the emission of viable particles in comparison with normal clothes. We cannot provide a suitable explanation for the decrease in c.f.u. during the test period up to 8 h, but perhaps the increase in sebum on the skin surface as the day progresses influences the dispersal (W. C. Noble, personal communication). The finding that air contamination in industrial clean rooms was greater in the morning than in the afternoon (Favero *et al.* 1966) may be due to the decline in the shedding of skin bacteria throughout the day.

The bacterial skin flora resides in the outer layers of the epidermidis and is regularly disseminated. As known from the work of Holt (1971) and Somerville & Noble (1973), bacteria form microcolonies containing sometimes up to 10^4 bacteria. Dispersal of microorganisms into the air occurs mainly on particles of skin of which only a few harbour viable microorganisms. May & Pomeroy (1973) determined the number of c.f.u. dispersed from the skin by sampling the air with a large-volume air sampler and found a mean output of 1000 and 750 c.f.u./min from their clothed male and female subjects respectively. Our standard method involved the use of a filter for collecting the c.f.u. from the air of the test chamber. The filter was immersed in peptone broth, which possibly causes partial disruption of the viable units. We have therefore compared our standard method with results obtained in experiments in which a high-volume air sampler (Casella Ltd.) was used for 30 sec. We found no significant difference. However, with the filter method the whole volume of air in the test chamber is sampled every minute, while with the high-volume air sampler only a fraction of the whole volume could be sampled.

It is well known that males disperse more organisms than females owing to heavier colonization of skin surface (Noble *et al.* 1976). We found as others (Noble & Davies, 1965; May & Pomeroy, 1973) that this difference remained when both sexes wore identical trouser suits. When female subjects wore the operating-theatre frock a significant increase in the dispersal was found in comparison with the trouser suit. Our test subjects did not wear stockings or tights which cause the 'cheese-grater' effect upon the skin as described by Mitchell & Gamble (1974).

Therefore our finding may support the suggestion of Noble *et al.* (1976) that in females the dispersal is correlated with the normal flora of the shin. In males the thighs and abdomen are heavily colonized and this is reflected in the amount of dispersal, which is three to four times higher below the waist than above. Blowers & McCluskey (1965) suggested the closure of the trousers openings at the ankles with Velcrotape to obtain a reduction in the emission of particles. However, in practice the use of zip and Velcro fasteners appeared to be uncomfortable (Mitchell & Gamble, 1974). Shedding was also reduced by wearing Ventile drawers (May & Pomeroy, 1973; Hill *et al.* 1974). Mitchell & Gamble (1974), however, reported that these drawers were less effective under other clothing. In our experiments the use of knee-high boots (made of a similar material to the suit) in conjunction with the trouser suit decreased dispersal by a further 80%.

We intend that the trouser suit should be used by every person in the operating room to minimize shedding of skin flora. Most investigations concerning shedding only deal with the emission of *Staph. aureus*. However, asepsis in surgery means keeping possible sources of contamination to a minimum, since some of the micro-organisms normally present in the resident skin flora and in the air are isolated from infected lesions (Charnley & Eftekhar, 1969; Blakemore *et al.* 1971; Speller & Mitchell, 1973).

The suit has now been in use for 4 years and although it is less effective than Ventile L 19 and Ventile L 34 clothing in preventing dispersal, it is more appropriate for general use in the operating-theatre. Total airborne c.f.u. counts in an operating room sampled during open-heart operations decreased by 50–70% when everyone present in the operating-theatre wore this suit, while the ventilation system, the cleaning and disinfecting procedures and the number of persons in the room were unchanged. A further reduction of airborne concentrations of bacterial particles can be obtained using total-body exhaust clothing in conjunction with a unidirectional flow-system (Whyte, Vesley & Hodgson, 1976).

However, an ideal suit for surgical-team members has not yet been found (Hill *et al.* 1974; Mitchell & Gamble, 1974); a combination of the suit with knee-high boots and a gown made from the same fabric is comfortable and prevents the dispersal of bacteria-associated skin particles to a high degree. A gown is probably preferable since Hambraeus & Ransjö (1977) have recently shown that in comparison with loose fitting garments, such as a gown, close coveralls tended to spread more bacteria to the air by rubbing them off the jacket of the suit.

REFERENCES

Bernard, H. R., Speers, R., O'Grady, F. & Shooter, R. A. (1965). Reduction of dissemination of skin bacteria by modification of operating-room clothing and by ultraviolet irradiation. *Lancet* ii, 458.

Bethune, D. W., Blowers, R., Parker, M. & Pask, E. A. (1965). Dispersal of *Staphylococcus aureus* by patients and surgical staff. *Lancet* i, 480.

Blakemore, W. S., McGarrity, G. J., Thurrer, R. J., Wallace, H. W., MacVaugh III, H. & Coriell, L. L. (1971). Infection by air-borne bacteria with cardiopulmonary bypass. *Surgery* **70**, 830.

Blowers, R. & McCluskey, M. (1965). Design of operating-room dress for surgeons. *Lancet* ii, 681.

CHARNLEY, J. (1973). Clean air in the operating-room. *Cleveland Clinic Quarterly* **40**, 99.

CHARNLEY, J. & EFTEKHAR, N. (1969). Postoperative infection in total prosthetic replacement arthroplasty of the hip-joint. *British Journal of Surgery* **56**, 641.

DUGUID, J. P. & WALLACE, A. T. (1948). Air infection with dust liberated from clothing. *Lancet* ii, 845.

FAVERO, M. S., PULEO, J. R., MARSHALL, J. H. & OXBORROW, G. S. (1966). Comparative levels and types of microbial contamination detected in industrial clean rooms. *Applied Microbiology* **14**, 593.

HAMBRAEUS, A. & RANSJÖ, U. (1977). Attempts to control clothes-borne infection in a burn unit. Experimental investigations of some clothes for barrier nursing. *Journal of Hygiene* **79**, 193.

HILL, J., HOWELL, A. & BLOWERS, R. (1974). Effect of clothing on dispersal of *Staphylococcus aureus* by males and females. *Lancet* ii, 1131.

HOLT, R. J. (1971). Aerobic bacterial counts on human skin after bathing. *Journal of Medical Microbiology* **4**, 319.

HUYSMAN-EVERS, A. G. M. (1974). In *Microbiology of Human Skin* (ed. W. C. Noble and D. A. Somerville), pp. 268–9. London: W. B. Saunders.

MAY, K. R. & POMEROY, N. P. (1973). Bacterial dispersion from the human body. In *Airborne Transmission and Airborne Infection* (ed. J. F. Ph Hers and K. C. Winkler), p. 426. Utrecht: Oosthoek.

MITCHELL, N. J. & GAMBLE, D. R. (1974). Clothing design for operating-room personnel. *Lancet* ii, 1133.

NOBLE, W. C. & DAVIES, R. R. (1965). Studies on the dispersal of Staphylococci. *Journal of Clinical Pathology* **18**, 16.

NOBLE, W. C. & SOMERVILLE, D. A. (1974). *Microbiology of Human Skin*. London: W. B. Saunders.

NOBLE, W. C., HABBEMA, J. D. F., VAN FURTH, R., SMITH, I. & DE RAAY, C. (1976). Quantitative studies on the dispersal of skin bacteria into the air. *Journal of Medical Microbiology* **9**, 53.

SOMERVILLE, D. A. & NOBLE, W. C. (1973). Microcolony size of microbes on human skin. *Journal of Medical Microbiology* **6**, 323.

SPELLER, D. C. & MITCHELL, R. G. (1973). Coagulase-negative staphylococci causing endocarditis after cardiac surgery. *Journal of Clinical Pathology* **26**, 517.

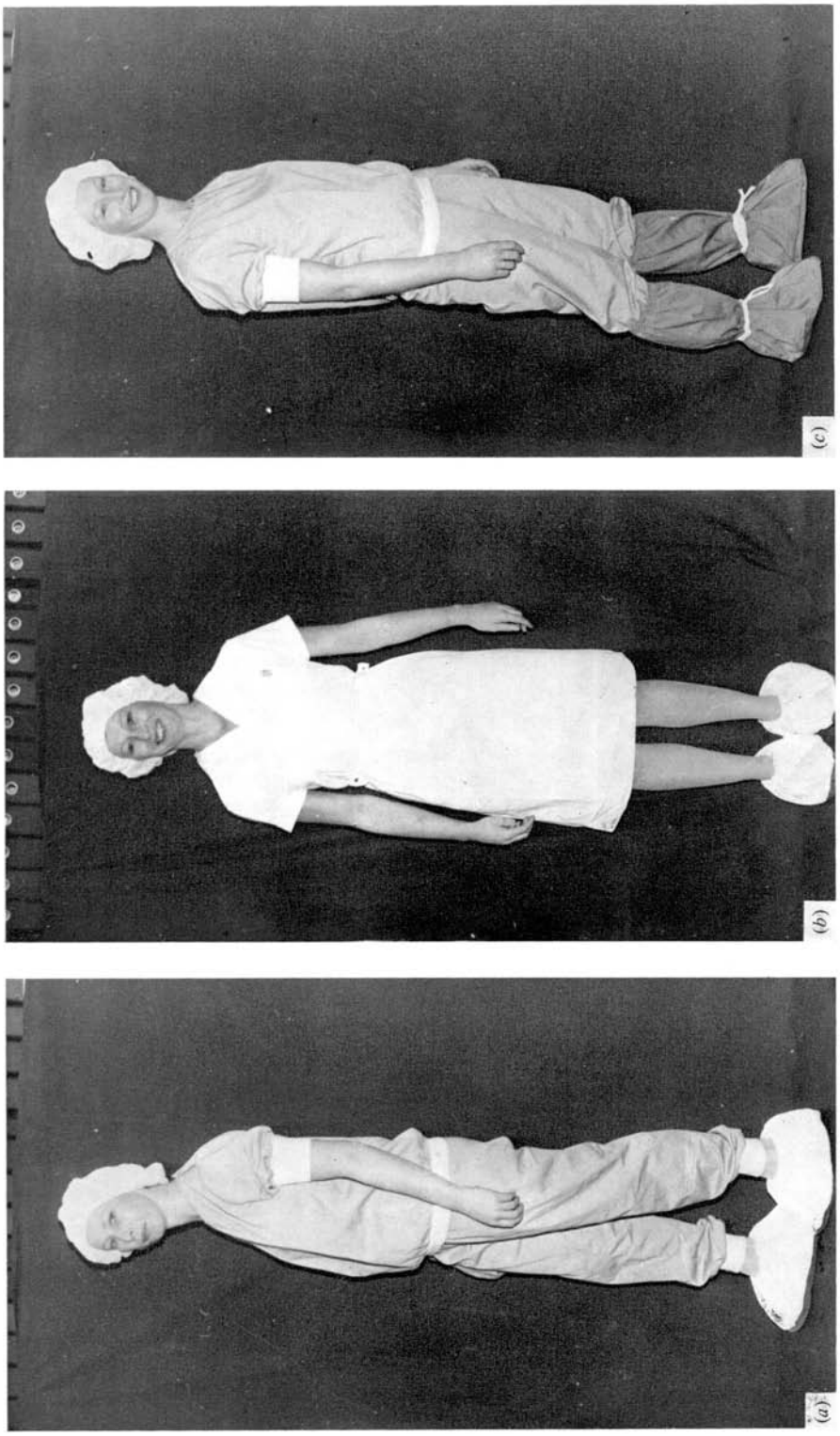
WELLS, W. F. & WELLS, M. W. (1936). Airborne infection. *Journal of the American Medical Association* **107**, 1698.

WHYTE, W., VESLEY, D. & HODGSON, R. (1976). Bacterial dispersion in relation to operating room clothing. *Journal of Hygiene* **76**, 367.

EXPLANATION OF PLATE

PLATE 1

(*a*) A test subject wearing the trouser suit and ankle-high slippers.
(*b*) A test subject wearing the operating-theatre frock.
(*c*) A test subject wearing the trouser suit and knee-high boots.



J. DANKERT, J. B. ZIJLSTRA AND H. LUBBERDING

(*Facing p.* 14)

https://doi.org/10.1017/S0022172400025419 Published online by Cambridge University Press