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Attempts to control clothes-borne infection in a burn unit, 2. Clothing routines in clinical use and the epidemiology of cross-colonization*

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SUMMARY

Previous investigations have shown that cross-contamination in a burn unit is mainly clothes-borne. New barrier garments have been designed and tried experimentally. The aim of the present study was to investigate the effects of different clothing routines on cross-contamination. In a long-term study, the rates and routes of colonizations with *Staphylococcus aureus*, *Streptococcus* groups A, B, C, F, and G and *Pseudomonas aeruginosa* were examined. The exogenous colonization rates were, with *S. aureus* 77%, with *Streptococcus* species 52% and with *Ps. aeruginosa* 32%. The colonization rate with *Ps. aeruginosa* was higher in patients with larger burns. Patients dispersed *Streptococcus* and *Ps. aeruginosa* as well as *S. aureus* into the air of their rooms in considerable amounts, but dispersers were not more important as sources of cross-colonization than non-dispersers. In comparison of clothing routines, there was no difference in overall colonization rates. The newly designed barrier garment that was made from apparently particle-tight material did not reduce the transfer of bacteria from patient to patient. A less rigid routine than that previously used did not increase the risk of cross-contamination. A thorough change of barrier dress after close contact nursing delayed the first exogenous *S. aureus* colonization from day 6 to day 14 after admission. This routine might be recommended for clinical use. Otherwise, methods must be developed for adequate selection of materials intended for barrier garments.

INTRODUCTION

Infection causes at least 50% of the deaths among burn patients today (Feller & Jones, 1973). The main causative bacteria are *Staphylococcus aureus*, beta-haemolytic *Streptococcus* and *Pseudomonas aeruginosa* (Cason *et al.* 1966; Thomsen, 1970; Wickman, 1970; Wormald, 1970).

Cross-colonization, at least with *S. aureus*, is probably more often clothes-borne than airborne (Hambraeus, 1973*a*; Lidwell *et al.* 1975). Many attempts have been made to develop better clothing for barrier nursing to interrupt this route of bacterial transfer (Alford *et al.* 1973; Bernard *et al.* 1965; Whyte, Vesley & Hodgson, 1976). Most of these attempts have been purely experimental. Very

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little has been done in clinical trials. As shown in a previous paper (Hambraeus & Ransjö, 1977) the results of experimental evaluation of clothing are conflicting. The efficacy of clothes in the prevention of cross-contamination in experimental nursing cannot be predicted from simple particle penetration tests. Fabrics that in particle tests seemed to be 100 times better than ordinary cotton did not perform more than 5–10 times better when tried in experimental nursing.

In this paper the results of clinical trials of the clothes previously tested experimentally are presented. The effects of different clothing routines on environmental contamination and cross-colonization have been studied in an isolation ward for burn patients.

MATERIALS AND METHODS

The ward

The burn unit where the investigations were performed had five rooms with conventional beds and one room with an air bed. One patient, or occasionally two, were nursed in each room.

Ventilation

The ventilation rate in the rooms was approximately four air changes per hour. Each room had an individual air lock with negative pressure versus patient room and corridor and exhaust via the lavatory (Hambraeus & Sanderson, 1972). During this investigation, the air currents in the air lock were traced once a week with titanium tetrachloride (Williams *et al.* 1960). The ventillation was correctly balanced in only 32–49 % of the measurements. In all periods (see below) flow from patient rooms into the corridor was twice as common as in the reverse direction.

Sampling and identification of bacteria

Bacterial contamination of clothes was measured by a wash method (Hambraeus, 1973*c*).

Airborne bacteria were collected on 13·5 cm blood agar settle plates. These were exposed in occupied patient rooms for 4 h/day on 5 days/week. Assuming a sedimentation rate of 0·3 m/min for the bacteria-carrying particles (Noble, Lidwell & Kingston, 1963) each plate collected the bacteria from approximately 1 m^3 of air.

Patients' cultures were taken on admission from nose, throat, skin, perineum, urine and stool if possible, and twice weekly from sampling sites at every 5 % of burn wound surface area.

Staff nose and throat swabs were taken once a week.

Samples from respiratory tract, skin and wounds were plated on haematin, mannitol salt and blood agar. Broth enrichment media were also used. Stool samples were also plated on cetrimide agar. Plates were incubated aerobically. Bacteria isolated were identified according to current methods. Presumptive *S. aureus* colonies were examined for DNase, and positive strains phage-typed according to the international test system (Blair & Williams, 1961). On settle plates,

colonies up to a maximum of 8 per plate were typed. *Streptococcus* colonies with beta-haemolysis were Lancefield-grouped serologically (Cars, Forsum & Hjelm, 1975). *Ps. aeruginosa* colonies, identified by fermentation tests, were phage-typed by L. Sjöberg, The National Bacteriological Laboratory, Stockholm (Sjöberg & Lindberg, 1968).

Some definitions used

Strain = phage pattern of *S. aureus* or *Ps. aeruginosa*; Lancefield group of beta-haemolytic streptococci. Whether a strain appeared several times or only in one culture was not taken into account. A strain was considered as the same if it had the same phage and colony characteristics, even if it had been absent from cultures for several weeks after it first appeared.

Source room = occupied ward room where a certain strain was found on the patient nursed.

Recipient room = occupied ward room where a strain was found in settle plate but not on the patient nursed or on staff working only in that room.

Isolate on settle plate = all colony-forming units (c.f.u.) of one strain found on one settle plate.

Carrier = a person with a demonstrable strain of *S. aureus*, beta-haemolytic streptococci and/or *Ps. aeruginosa* in nose, throat, skin or perineal cultures.

Endogenous colonization = colonization in the burn wound with a strain of which the patient was a carrier, or colonization already present on admission.

Exogenous colonization = colonization in the burn wound with a strain not previously found on the patient.

Disperser = a patient whose strain was discovered on a source room settle plate, even in single colonies.

Epidemic strain = a strain causing at least two exogenous colonizations, where it was possible to follow the chain of colonization from patient to patient.

Clothes

Three garments were used, a cotton suit, a cotton gown and a semidisposable polyethylene fibre coverall. Data of the general properties of the fabrics in these garments have been published in a previous paper (Hambraeus & Ransjö, 1977).

The cotton suit consisted of jacket and trousers of cotton/polyester. It was the working dress in the ward, and the only dress worn in the non-patient area. It was laundry clean each morning.

The cotton gown was an ordinary sterile operating gown, made of green cotton.

The coverall (Fig. 1) was a coverall with tightly fitting neck, cuffed sleeves and legs, made of non-woven polyethylene fibre (Tyvek 1442 Du Pont).

Clothing routines in the ward

Four different clothing routines were tried in alternating periods (Table 1). Cap, mask, and gloves were used every time a barrier garment was worn.

Control period. In the control period, everybody had to dress in a cotton gown

Table 1. *Periods: clothing and time distribution*

Year	Weeks	Period
1973	36–48	Control
	49–51	Strip
1974	2–24	Strip
	33–43	Tyvek
	45–51	Control
1975	2–3	Green
	5–8	Tyvek
	9–10	Green
	11	Tyvek
	13–14	Green
	51–17	Tyvek
	20–26	Green
	38–42	Green
	43–51	Control
1976	2–20	Green (without settle plates)

	Clothing	
Period	Cotton suit	Barrier dress
Control	All day	Gown, every visit, all day
Strip	Changed	Gown, close nursing, discarded
Tyvek	All day	Coverall, close nursing, discarded
Green	All day	Gown, close nursing, all day

on top of the cotton suit, which was worn throughout the day, before entering a patient room. The cotton gown was sterile each morning and was kept hanging in the air lock between use during the day.

Strip period. In the strip period, a sterile cotton gown was used only during close nursing procedures that could give contact contamination, such as wound dressing, bed-making and physiotherapy. The gown was discarded after each use together with the cotton suit worn underneath. People who entered the patient room on brief visits, without touching the patient or his bed, did not use a barrier gown but wore the cotton suit only, not changing the latter afterwards.

Tyvek period. In the Tyvek period, a sterile Tyvek coverall was worn during close nursing procedures and was discharged after each use. The cotton suit worn underneath the coverall was kept on all day. The coverall was washed as directed by the manufacturers, autoclaved and re-used twice. On brief visits to the patient, a cotton suit only was worn.

Green period. In the green period, nursing staff wore a cotton gown only during close nursing procedures. The gown was sterile once a day and was kept in the air lock when not used. The cotton suit was kept on all day. For brief visits to the patient room, a cotton suit only was worn.

Periods and patients

The three new routines were alternated at about 10-week (Table 2) intervals with a control period between each of the new dress periods. The tyvek and green

Table 2. *Periods and patients*

Period ...	Control	Strip	Tyvek	Green
(i) Number of weeks	29	25	18	17+18
(ii) Number of burn patients admitted	36	31	27	39
(iii) Number of patients nursed	42	37	36	62
(iv) Number of patients admitted, cultured at least twice	29	27	22	33
(v) Deaths	5	6	5	8

periods were interchanged at shorter intervals than intended owing to difficulties in the supply of Tyvek coveralls. The total number of weeks were: control period, 29; strip, 25; tyvek, 18; and green period, 17+18 weeks without settle plates. Thirty-five per cent of the patients were under 16 years of age and 20% were over 45; 31% were in hospital for 1 week or less, and 47% for more than 2 weeks; 51% had burns over less than 15% of body area, and 30% had burns over 30% or more of body area. These proportions did not differ significantly for the periods covered by the different nursing procedures.

Statistical analysis

Each patient was considered only in the period during which he was admitted. In the calculations of colonizations, only patients who stayed in the ward long enough to be cultured at least twice were included.

For calculations of first exogenous *S. aureus* colonization, however, all patients admitted were included. It was assumed that patients who did not acquire an exogenous *S. aureus* colonization before their discharge would have done so if they had stayed in the ward for one more day.

Analysis of covariance on *S. aureus* data was performed by Gunnar Ekbohm, Ph.D., and Ulf Thorsson, M.A., Swedish University of Agricultural Sciences, Uppsala.

RESULTS

Staphylococcus aureus

Patient colonization

Of the 111 patients included in the study 109 (98%) developed a colonization with *S. aureus* (Table 3). The exogenous colonization rate was 68% in carriers, and 88% in non-carriers. Patients with an endogenous colonization had an exogenous colonization rate of 71%, as compared to a rate of 94% in patients without endogenous colonization (Table 3, rows i–iv).

The exogenous colonization rates were: 76% in control, 74% in strip, 77% in tyvek, and 82% in green periods (Table 3, rows i, iii, and iv). The time from admission to first exogenous colonization (Table 3, row v) was mean 6·9, 6·3, and 6·1 days in control, tyvek and green periods, but 14·0 days in strip. To correct for possible variations in the patient ages and burn sizes, these were taken into account in

Table 3. Staphylococcus aureus *colonizations*

Period ...	Control	Strip	Tyvek	Green
(i) Patients admitted, cultured twice	29	27	22	33
(ii) Patients with endogenous colonizations only	5	7	5	6
(iii) Patients with exogenous colonizations only	8	8	4	9
(iv) Patients with endogenous and exogenous colonizations	14	12	13	18
(v) Time from admission to first exogenous colonization (days)				
Mean	6·9	14·0	6·3	6·1
Adjusted mean	6·8	13·9	6·2	6·3
(vi) Number of typable exogenous colonizations/ patient				
Mean	1·9	1·9	1·8	2·1
Range	1–6	1–4	1–5	1–6
(vii) Source of typable exogenous colonizations (per cent of traced)				
Patients	13 (42%)	13 (59%)	8 (40%)	22 (58%)
Staff	9 (29%)	7 (32%)	4 (20%)	9 (24%)
Patients and staff	9 (29%)	2 (9%)	8 (40%)	7 (18%)
Not traced	12	6	3	19
(viii) Patients exposed to air-borne spread (nursed in a recipient room during admission period)	22	20	14	7
(ix) Patients acquiring an exogenous colonization in a recipient room	20	14	11	4
(x) Patients acquiring a colonization with their recipient room strain	5	7	3	2

analysis of covariance to produce the adjusted means (Table 3, row v). These differed very little from the actual means. The differences between the strip and the other three periods were statistically significant ($P < 0{\cdot}005$).

Sources of colonizations

Of all typable exogenous *S. aureus* colonizations 67–87% could be traced (Table 3, row vii). Staff were the only source of 20–32% of these traceable colonizations. All the others could be derived from patients. Of the patients who were possible sources of colonization (Table 4), 59% had burns of 30% or less of the surface, as compared to 70% of the patients admitted (Table 2). However, recipient room strains did not appear to be more frequently derived from patients with the larger area burns and the sources of colonization with strains found in the air of the patient room followed a similar distribution in relation to the burned area of the source. Seventy-five per cent of the 111 exogenous colonizations for

Table 4. *Patients colonized with* Staphylococcus aureus, *as sources*

Burn size	All patients (%)	Sources of: All exogenous colonizations	Sources of: Recipient room strains	Colonization with recipient room strains
> 15%	51	18 (37%)	24 (46%)	6 (35%)
16–30%	19	11 (22%)	16 (25%)	5 (29%)
31–60%	23	14 (29%)	14 (22%)	5 (29%)
> 60%	7	6 (12%)	4 (6%)	1 (6%)

which a source could be assumed were due to 31 strains. One strain was responsible for 11 colonizations, but no other strain caused more than 5.

Routes of transfer

Staphylococcus aureus from other patients were found in the air of rooms of 63 of the 92 patients nursed during periods with settle plates. Forty-nine of these 63 (78%) acquired an exogenous colonization, but only 17 of the 49 (35%) did so with the strain previously found in the air of their room.

Recipient room strains were possible causes of typable exogenous colonizations on 8/43 (19%) occasions in control, 12/28 (43%) in strip, 3/23 (13%) in tyvek, and 3/16 (19%) in green periods. The numbers of c.f.u./m^3 of recipient room strains exceeded two when the strains caused a recipient room patient colonization in one of eight times in control, three of twelve times in strip, none of three times in tyvek and one of three times in green period.

Recipient room strains were delivered from patients, or both patients and staff, in 68%, 64%, 84%, and 88% of the traced strains on control, strip, tyvek and green periods respectively.

The burn size distribution of the 63 patients whose strains were found on recipient room settle plates (but not necessarily on source room plates) was the same as that of all the patients admitted (Table 4).

One or more dispersers were nearly always in the ward, and their strain was found in other rooms (recipient rooms) on about 2 out of 3 such days. The median count in the source rooms on these occasions was about three times the overall median count.

Beta-haemolytic streptococci

Patient colonizations (Table 5)

Of the 111 patients 79 (71%) developed a colonization with beta-haemolytic streptococci. Thirty-four patients were colonized with *Str. pyogenes* (31%), and 59 patients were colonized 69 times with beta-haemolytic streptococci from other serogroups. In all, 29 patients had an endogenous colonization (26%). The exogenous colonization rate among these was 8/29 (28%), and among those without endogenous colonization 50/82 (61%) (Table 5, rows i–iv). The exogenous colonization

Table 5. *Patient colonizations with beta-haemolytic streptococci*

Period	Control	Strip	Tyvek	Green
(i) Patients admitted, cultured twice	29	27	22	33
(ii) Patients with endogenous colonizations only	7	5	3	6
(iii) Patients with exogenous colonization only	13	9	9	19
(iv) Patients with endogenous and exogenous colonizations	1	2	1	4
(v) Time from admission to first exogenous colonization (days)				
Mean	5·5	11·0	4·3	6·0
SD	4·1	10·9	3·3	4·0
Range	2–18	3–41	1–11	2–17
(vi) Number of colonizations/ patient				
Mean	1·2	1·4	1·4	2·2
Range	1–3	1–3	1–3	1–3
(vii) Sources of colonizations				
Lancefield group A				
Endogenous	3	5	2	1
Exogenous:				
Patients	2	1	—	2
Staff	—	—	—	2
Patients and staff	3	2	—	7
Not traced			3	1
Lancefield groups B, C, F, G				
Endogenous	7	2	3	9
Exogenous:				
Patients	1	6	2	3
Staff	—	1	2	2
Patients and staff	7	—	2	14
Not traced	2	3	3	—
(viii) Patients nursed in a recipient room during admission period	1	1	1	2
(ix) Patients acquiring an exogenous colonization in a recipient room	0	0	0	0

rates were: 48 % in control, 41 % in strip, 45 % in tyvek, and 70 % in green periods (Table 5, rows i, iii and iv). The average time from admission to first exogenous colonization was 5·5 days in control, 4·3 days in tyvek, 6·0 days in green periods but 11·0 days in strip period.

Sources of colonizations (Table 5, row vii)

Lancefield group A. Of the 30 traceable colonizations with *S. pyogenes*, 11 were endogenous. Staff were the only identifiable source of 2/19 (11 %) of exogenous colonizations. The remaining 17 (57 %) of traced colonizations with beta-haemolytic streptococci group A could be derived from patients. Four colonizations were not traced.

Table 6. Pseudomonas aeruginosa *colonizations*

Period	Control	Strip	Tyvek	Green
(i) Patients with wound colonizations during admission period	6	10	2	13
(ii) Source of wound colonizations				
Endogenous	1	4	—	—
Exogenous	—	4	—	8
Not traced	5	2	2	5
(iii) Time from admission to first colonization (exogenous or not traced (days)				
Mean	10·8	13·2	—	16·3
Range	6–19	5–31	7–62	5–21

Lancefield groups B, C, F and G. Of the 61 traced colonizations with *streptococci* groups B, C, F and G, 21 (34%) could be proved to be endogenous. Staff were the only identifiable source of 5/40 (13%) traced endogenous colonizations. Eight colonizations were not traced. The remaining 35 (57%) colonizations could be derived from patients.

Although patients whose burns were colonized with streptococci dispersed considerable numbers into the air of their rooms the numbers found in recipient rooms were very small. Examination of the results obtained from the settle plates did not provide any evidence that the airborne route was that effecting the exogenous colonization observed. Recipient room streptococci could always be related to carriers among the staff.

Pseudomonas aeruginosa

Patient colonizations

Of the 111 patients in the study 31 (28%) were colonized with *Ps. aeruginosa* (Table 6, row i). The colonization rate in patients with burns larger than 30% of body area was 24/40 (60%). Five patients had proved endogenous colonizations (14%). From the 14 patients with colonizations that were not traced, stool cultures were available in four, all negative for *Ps. aeruginosa*. The average time from admission to first non-endogenous colonization (Table 6, row iii) was 10·8, 13·2 and 16·3 days in control, strip and green periods, respectively, These means are not significantly different. One patient in control, four in strip, two in tyvek and three in green were colonized with more than one, usually two, strains of *Ps. aeruginosa*.

Sources of colonizations

Traceable exogenous *Ps. aeruginosa* colonizations of patients in admission period occurred only in strip and green periods (Table 6, row ii). Twelve colonizations could be traced, all from patients. Staff became transient nasal carriers of a disperser's strain once in control, once in strip and twice in tyvek periods, but this was not shown to cause any patient colonizations.

Epidemic strains, causing at least two exogenous colonizations each, did not occur in control. In strip, three strains caused 3–4 exogenous colonizations each. In tyvek, one strain overlapping from control and one from green periods caused one colonization each. In green period, one strain caused six exogenous colonizations.

Patients that could have been the cause of colonization never had burns less than 16% of body area. Five of the eight colonized patients with burn sizes from 16 to 30%, and 6 of 22 of those colonized with larger burns were possible causes of colonization.

Routes of transfer

Pseudomonas aeruginosa was dispersed by 16 of the 24 patients who were colonized during periods with settle plates. Thirteen of these had burns larger than 30%. The seventeenth disperser was a 1-year-old girl with a burn of less than 15%. She was the only perineal carrier found. Her strain never colonized her burn, nor any other patient.

Dispersal started within 2 days before or after the demonstration of a colonization in 11/16 patients and lasted for 8 days or less in 13/16 patients. Dispersers were present in the ward on 19%, 13%, 8% and 19% of the days in the four periods. The amounts dispersed varied between one and 78 c.f.u./m^3 with a mean of 14 in control and two to three in the other periods.

The numbers of colonizations were few, and no relation to air dispersion could be inferred.

DISCUSSION

Clothes

There is reason to believe that the nurses' working dress worn underneath a barrier garment is an important vehicle for cross-contamination from patient to patient (Hambraeus, 1973*c*; Lidwell *et al.* 1975). The purpose of this investigation was to evaluate the importance of clothing routines in the prevention of such cross-contamination.

Four different clothing routines were tried. In the control period, conventional barrier nursing, with staff wearing full operating room dress on every visit to the patient, was practised, the barrier garment used was the common cotton gown. In the three experimental periods, strip, tyvek and green, the occasions when barrier garments were worn were restricted to times of close contact with the patient. This was done as the wearing of many layers of clothing increases the dispersal of bacteria-carrying particles from the clothes (Hambraeus & Ransjö, 1977; Rubbo & Saunders, 1963). Less rigid routines make nursing easier and have not been proved to increase the risk of cross-contamination in isolation wards for newborns (Evans, Akpata & Baki, 1971).

In the tyvek period, a new garment that had proved useful in nursing experiments was introduced. It was made from a polyethylene fibre material which was originally designed for wear in clean rooms in industry. This material performed well in particle penetration tests. Garments made from the material protected

a mock patient somewhat better than common operating room gowns in nursing experiments (Hambraeus & Ransjö, 1977).

In the strip and green periods, the common cotton gown was used as barrier garment. In the strip period, the working dress and the sterile cotton gown were both discarded after close contact nursing. This was done to completely eliminate the working dress as a vehicle for cross-contamination. The green period finally differed from the control period only in that barrier garment was worn only during close contact nursing.

The four varieties of barrier dress were to be interchanged at about 10-week intervals. This plan could not be followed strictly, for practical reasons. Despite this, the patient populations were comparable as to age, burn size, length of stay in hospital and mortality rate.

Patient colonizations

Ninety-eight per cent of the patients developed a colonization with *S. aureus*. The exogenous colonization rate was 74–82 %. About two thirds of these colonizations were caused by epidemic strains. *Ps. aeruginosa* colonizations appeared in 32 % of the patients. The colonization rate in patients with burns larger than 30 % of body area was 60 %. Beta-haemolytic streptococci colonized 71 % of the patients, and half of these were colonized with *Str. pyogenes*. These figures are all about the same as those found in other units (Barclay & Dexter, 1968; Cason *et al.* 1966; Thomsen, 1970; Wickman, 1970; Wormald, 1970).

The exogenous colonization rates with *S. aureus* in patients who already had an endogenous colonization with a strain with another phage pattern, was three quarters of the rate in those who were not previously colonized. Many patients had more than one colonization with *S. aureus*, median value just below two, and several had as many as six colonizations with different phage patterns. Colonization with one strain, then, did not seem to protect against another colonization, which has been postulated (Hughes, 1970; Aly *et al.* 1974). For beta-streptococci, the exogenous colonization rates among those already colonized was half that in those not colonized before. As streptococci were not M-typed, the possibility of more than one colonization with the same Lancefield group was not considered. Patients were possible sources of 70–80 % of the *S. aureus*, 87–89 % of the beta-streptococcal and all the *Ps. aeruginosa*-traced colonizations.

Comparison between periods

Staphylococcus aureus

The exogenous colonization rates with *S. aureus* did not differ significantly in the four periods. Epidemic strains caused 44–50 % of the exogenous colonizations in control, strip and green periods, but 78 % of those in tyvek period, which may have biased the comparison. The time from admission to first exogenous colonization was 14 days in strip, as compared with 6–7 days in the other periods. This difference was statistically significant ($P < 0{\cdot}005$) in analysis of covariance when

differences in the composition of the patient groups were taken into account. This may be of clinical importance, as a delay of colonization from the first to the second week after the burn might give the patient some time to recover from the disturbances of the early post-burn phase. The greatest impairment of neutrophil leukocyte functions as defences against infection also occurs in the second post-burn week (Ransjö, Forsgren & Arturson, 1977).

Staff as the only source of exogenous colonization were of low importance in all periods, 20–32%. This might mean that the four dress routines did not alter the dispersal from carriers among the staff, but this was not studied.

Patients nursed in rooms where strains from other patients were found in the air had the same exogenous colonization rate as all patients, and only 25% of these colonizations were caused by the same strains as those found in the air. The numbers of c.f.u./m^3 of a strain found in the air was two or less on 80% of the occasions when the same strain caused a patient colonization. If each c.f.u. consisted of an average of four viable *S. aureus* cells (Lidwell, Noble & Dolphin, 1959) and dispersal was equally large night and day, this would be an infective dose from the air of less than 3500 cells/m^2/24 h. This dose is about 30 times less than that of 10^5 cells/m^2 needed for experimental infections in abraded skin (Marples & Kligman, 1975). It is unlikely to be sufficient to cause a colonization, and an additional dose by contact would be needed even in burn patients.

The median count of a strain in a source room when the strain was transferred into the air of another room was three times as high as the median count of all source room strains. Previous experiments have shown that direct airborne spread could account for only a small proportion of *S. aureus* transfer between patient rooms (Hambraeus & Sanderson, 1972). The majority of *S. aureus* isolates in the air of recipient rooms must have originated from redispersal by rubbing of contaminated clothes (Hambraeus & Ransjö, 1977; Rubbo & Saunders, 1963).

That patients disperse more *S. aureus* into the air if their burns are large has been shown previously (Hambraeus, 1973*b*). The patients who were possible causes of cross-colonization and the patients whose strains were transferred to the air of other rooms, however, had the same burn size distribution as all patients.

The degree of contamination on nurses' clothes is not necessarily related to dispersal in source rooms and thereby to burn size, but is more likely to depend on the degree of contact. Some patients, such as children and those with electric burns, may need much handling although their burns are small.

The mean transfer to the air of recipient rooms was the same in strip as in the other periods. If median values are compared the transfer of strains seemed to be about five times higher in this period than in the others. One reason for this may be technical. The counts in the air of the source rooms were three to four times lower in strip than in any other period. As only eight colonies per settle plate were phage-typed, a very large isolate may mask the presence of an isolate consisting of only a single colony in the periods with high *S. aureus* counts. Recipient room strains seemed to play a relatively greater part in the cross-colonization of exposed patients in strip than the other periods. This could be because the recipient room strains were easier to detect, as the total counts per plate were lower in that

period. To some extent, it may also be a reflection of the reduction of direct clothes-borne transfer as a cause of cross-contamination in this period.

Beta-haemolytic streptococci

The exogenous colonization rates with beta-haemolytic streptococci were 41–48 % in control, strip and tyvek but 70 % in green periods. These figures do not differ significantly. The time from admission to first exogenous colonization was 4–6 days in control, tyvek and green, but 11 days in strip. The burn size distribution among patients causing a colonization with beta-haemolytic streptococci was the same as that of the whole population of patients. Dispersal of beta-haemolytic streptococci was demonstrated from two thirds of the colonized patients. Only one third of these dispersers had burns larger than 30 %, which corresponds to the total patient population. The mean value for dispersal was 20–25 c.f.u./m^3 in all periods. Dispersers were present on about half the days in control and green periods and on one quarter of the days in strip and tyvek.

No transfer of beta-streptococci from source rooms to the air of recipient rooms was found in any period. Recipient room strains did not occur but could always be derived from carriers among the staff. Long-term studies of air contamination with beta-haemolytic streptococci are rare.

All the patient-caused colonizations with group A streptococci were traced to dispersers. With other serogroups, eight-ninths of the patient-caused colonizations were caused by dispersers. Exposure to beta-streptococci in the air of recipient rooms was never shown to cause a patient colonization. Thus, cross-contamination with beta-haemolytic streptococci appeared to be by contact only. This may be due to the facts that at least *Str. pyogenes* seems to lose its virulence very rapidly in air and that very large infective doses are needed to cause a colonization (Perry, Siegel & Rammelkamp, 1975).

Pseudomonas aeruginosa

The rate of traced exogenous colonizations with *Ps. aeruginosa* was zero in control and tyvek, 15 % in strip and 24 % in green. The majority of these colonizations were caused by a few epidemic strains. Therefore, any valid comparisons between the periods in this respect are difficult to make.

The mean time of first exogenous/not traced *Ps. aeruginosa* colonizations was in the second week during the three periods when more than five patients were colonized. The burn size of patients causing colonizations with *Ps. aeruginosa* was no different from that of the whole population in the study. Three of seven patients causing *Ps. aeruginosa* colonizations and nursed during settle plate periods were dispersers. This proportion did not include any of those colonized with burns smaller than 15 %, but all those with burns over 60 % of the surface. The mean values of dispersal were between two and three c.f.u./m^3 in all periods except control where it was 14 c.f.u./m^3. Airborne dispersal of *Ps. aeruginosa* has been little emphasized before (Kominos, Copeland & Grosiak, 1972; Liljedahl *et al.* 1972;

MacMillan *et al.* 1973), although the problem has been recognized (Barclay & Dexter, 1968). Strains were transferred to the air of recipient rooms twice, but on one of these occasions no patient in the ward dispersed his strain. One patient, exposed once to a strain found in the air of his room in a concentration of 1 c.f.u./m^3, developed a colonization with this strain which was an epidemic one. Thus, the important route of cross-colonization with *Ps. aeruginosa* seems to be by contact rather than by air (Lowbury, Babb & Ford, 1971).

CONCLUSIONS

Burn patients disperse not only *S. aureus* but also beta-haemolytic streptococci and *Ps. aeruginosa* to the air of their rooms, as has been shown in this investigation. Dispersal is heavier from patients with larger burns for all these species of bacteria. In contrast, colonized patients with small burns were as likely sources of cross-colonization with *S. aureus*, beta-haemolytic streptococci and *Ps. aeruginosa* as those with large burns. This discrepancy between dispersal and cause of colonization clearly indicates that contact transfer is the most important route of cross-contamination between patients.

The effects of different clothing routines on this transfer were compared. None of the four routines were superior as judged by overall colonization rates, which were comparable to those found in other studies.

A routine which was less rigid than usual barrier nursing, and which permitted easier access to the patient room, in no way increased the risk of cross-contamination to the patient. In another routine, a new type of barrier dress was tried. This new dress was made from a material that was 100 times less permeable to particles than cotton and had given five times better results in experimental nursing than common cotton. In spite of this, it gave no improvement in cross-contamination whatsoever. Thus, the results of particle penetration tests did not correlate with the findings in clinical trials. In the routine where a more thorough change of dress after close contact with the patient was practised, the first exogenous colonization with *S. aureus* was significantly delayed from the first to the end of the second week after admission, which may be of clinical importance.

These results suggest that a reduction in the clothes-borne cross-contamination is possible. To achieve this, better clothes nust be developed, made from more bacteria-tight materials. The methods for selecting such materials are not yet available. Barrier garments used in the nursing of burn patients are stretched and rubbed against clothes and skin underneath them, and they often become wet with wound secretions. The investigation of such mechanisms may be necessary. The tighter a material is, the more uncomfortable it is to wear. Charnley (1972) solved this problem by ventilating the barrier garment. This would be cumbersome in daily patient nursing. Perhaps the only remaining alternative is to enclose either staff (Poplack, Penland & Levine, 1974) or burn patient (Burke, 1972) in an isolator. Such devices are costly and difficult to handle. For the time being, a routine where not only the barrier garment but also the clothes worn underneath are discarded after the nursing of infected patients might be more practicable.

REFERENCES

ALFORD, D. J., RITTER, M. A., FRENCH, M. L. V. & HART, J. B. (1973). The operating room gown as a barrier to bacterial shedding. *American Journal of Surgery* **125**, 589.

ALY, R., MALIBACH, H. I., SHINEFIELD, H. R., MANDEL, A. & STRAUSS, W. G. (1974). Bacterial interference among strains of *Staphylococcus aureus* in man. *Journal of Infectious Diseases* **129**, 720.

BARCLAY, T. L. & DEXTER, F. (1968). Infection and cross infection in a new burns centre. *British Journal of Surgery* **55**, 197.

BERNARD, H. R., SPEERS, R., O'GRADY, F. & SHOOTER, R. A. (1965). Reduction of dissemination of bacteria by modification of operation room clothing. *Lancet* ii, 458.

BLAIR, J. E. & WILLIAMS, R. E. (1961). Phage-typing of staphylococci. *Bulletin of the World Health Organization* **24**, 771.

BURKE, J. F. (1972). The management of contamination in burns. A new look at isolation techniques. *Journal of Saint Barnabas Medical Centre* **9**, 11.

CARS, O., FORSUM, U. & HJELM, E. (1975). New immunofluoresence method for the identification of group A, B, C, E, F, and G streptococci. *Acta pathologica et microbiologica scandinavica*, B **83**, 145.

CASON, J. S., JACKSON, D. M., LOWBURY, E. J. L. & RICKETTS, C. R. (1966). Antiseptic and aseptic prophylaxis for burns: Use of silver nitrate and of isolaters. *British Medical Journal* ii, 1288.

CHARNELY, J. (1972). Postoperative infection after total hip replacement with special reference to air contamination in the operating room. *Clinical Orthopaedics* **87**, 167.

EVANS, H. E., AKPATA, S. O. & BAKI, A. (1971). Bacteriologic and clinical evaluation of gowning in a premature nursery. *Journal of Pediatrics* **78**, 883.

FELLER, I. & JONES, C. A. (1973). *Nursing the Burned Patient*, p. 11. Ann Arbor, Mich.: Braun-Brumfield Inc.

HAMBRAEUS, A. (1973*a*). Studies on transmission of *Staphylococcus aureus* in an isolation ward for burned patients. *Journal of Hygiene* **71**, 171.

HAMBRAEUS, A. (1973*b*). Dispersal and transfer of *Staphylococcus aureus* in an isolation ward for burned patients. *Journal of Hygiene* **71**, 787.

HAMBRAEUS, A. (1973*c*). Transfer of *Staphylococcus aureus* via nurses' uniforms. *Journal of Hygiene* **71**, 799.

HAMBRAEUS, A & RANSJÖ, U. (1977). Attempts to control clothes-borne infection in a burn unit. 1. Experimental investigations of some clothes for barrier nursing. *Journal of Hygiene* **79**, 193.

HAMBRAEUS, A. & SANDERSON, H. F. (1972). The control by ventilation of air-borne bacteria transfer between hospital patients and its assessment by means of a particle tracer. III. Studies with an airborne particle tracer in an isolation ward for burned patients. *Journal of Hygiene* **70**, 299.

HUGHES, W. H. (1970). The irreducible minimum in cross-infection control and isolation nursing. *Journal of Hygiene* **68**, 379.

KOMINOS, S. D., COPELAND, C. E. & GROSIAK, B. (1972). Mode of transmission of *Pseudomonas aeruginosa* in a burn unit and an intensive care unit in a general hospital. *Applied Microbiology* **23**, 309.

LIDWELL, O. M., NOBLE, W. C. & DOLPHIN, G. W. (1959). The use of radiation to estimate the numbers of micro-organisms in airborne particles. *Journal of Hygiene* **57**, 299.

LIDWELL, O. M., BROCK, B., SHOOTER, R. A., COOKE, E. M. & THOMAS, G. E. (1975). Airborne infection in a fully air-conditioned hospital. IV. Airborne dispersal of *Staphylococcus aureus* and its nasal aquisition by patients. *Journal of Hygiene* **75**, 445.

LILJEDAHL, S. O., MALMBORG, A. S., NYSTRÖM, B. & SJÖBERG, L. (1972). Spread of *Pseudomonas aeruginosa* in a burns unit. *Journal of Medical Microbiology* **5**, 473.

LOWBURY, E. J. L., BABB, J. R. & FORD, P. M. (1971). Protective isolation in a burns unit: the use of plastic isolators and air curtains. *Journal of Hygiene* **69**, 529.

MACMILLAN, B. G., EDMONDS, P., HUMMEL, R. P. & MALEY, M. P. (1973). Epidemiology of *Pseudomonas* in a burn intensive care unit. *Journal of Trauma* **13**, 627.

MARPLES, R. R. & KLIGMAN, A. M. (1975). Experimental staphylococcal infections of the

skin of man. *Zentralblatt für Bakteriologie, Parasitenkunde, Infektionskrankheiten und Hygiene*. I. Abteilung, suppl. **5**, 755.

NOBLE, W. C., LIDWELL, O. M. & KINGSTON, D. (1963). The size distribution of airborne particles carrying microorganisms. *Journal of Hygiene* **61**, 507.

PERRY, W. D., SIEGEL, A. C. & RAMMELKAMP, C. H. (1957). Transmission of group A streptococci. II. The role of contaminated dust. *American Journal of Hygiene* **66**, 96.

POPLACK, D. G., PENLAND, W. Z. & LEVINE, A. S. (1974). Bacteriological isolation garment. *Lancet* i, 1261.

RANSJÖ, U., FORSGREN, A. & ARTURSON, G. (1977). Neutrophil leukocyte functions and wound bacteria in burn patients. *Burns* **3**, 171.

RUBBO, S. D. & SAUNDERS, J. (1963). Liberation of organisms from contaminated textiles. *Journal of Hygiene* **61**, 507.

SJÖBERG, L. & LINDBERG, A. A. (1968). Phage typing of *Pseudomonas aeruginosa*. *Acta pathologica et microbiologica scandinavica* **74**, 61.

THOMSEN, M. (1970). The burns unit in Copenhagen. VII. Time of onset and duration of infection. *Scandinavian Journal of Plastic and Reconstructive Surgery* **4**, 61.

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

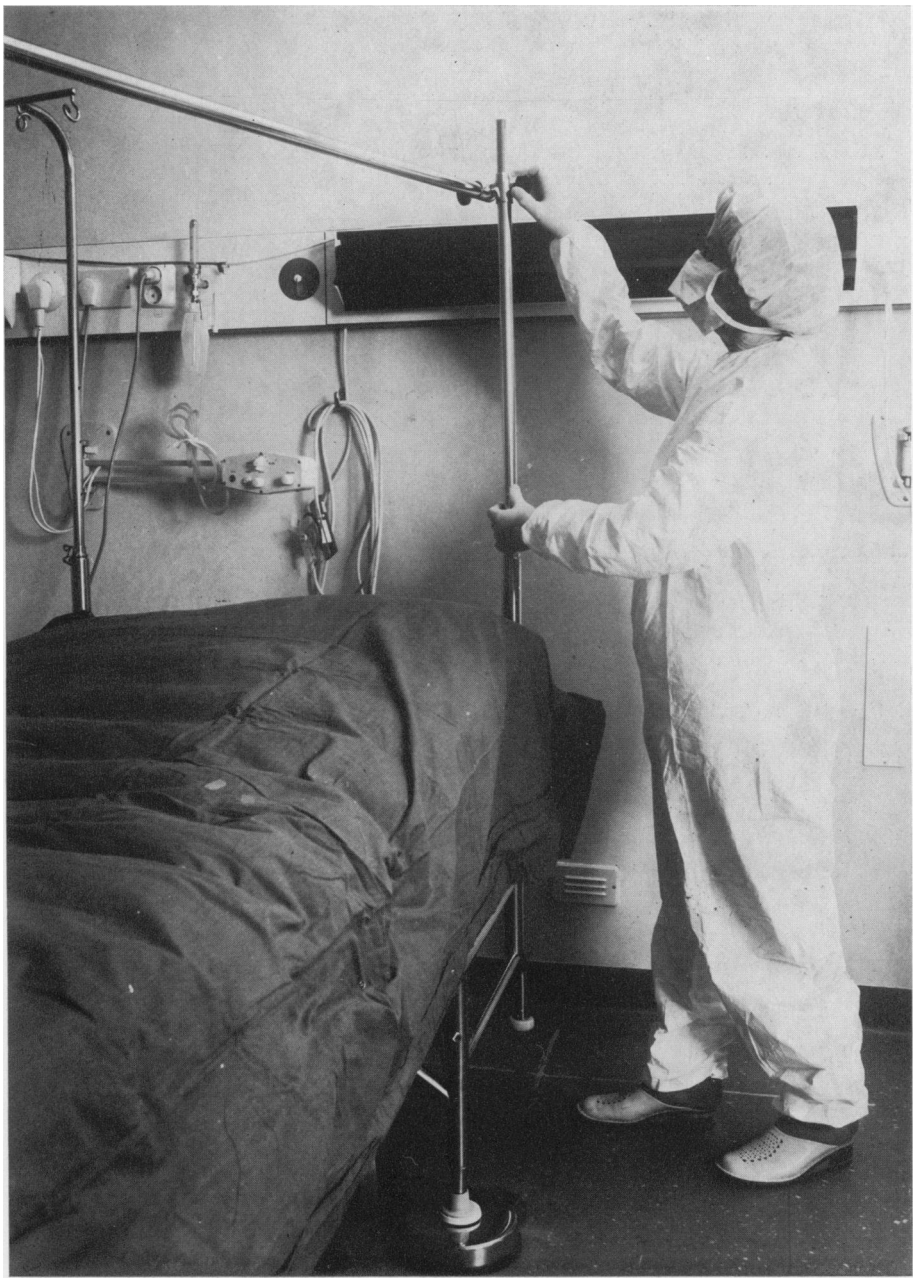
WICKMAN, K. (1970). Studies on burns, XIV. Bacteriology II. *Acta chirurgica scandinavica* **408**, 1.

WILLIAMS, R. E. O., BLOWERS, R., GARROD, L. P. & SHOOTER, R. A. (1960). *Hospital Infection*, p. 292. London: Lloyd-Luke Ltd.

WORMALD, P. J. (1970). The effect of a changed environment on bacterial colonization. *Journal of Hygiene* **68**, 633.

EXPLANATION OF PLATE

The Tyvek close coverall.



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(*Facing p.* 384)