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Protective isolation in single-bed rooms: studies in a modified hospital ward

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SUMMARY

Studies were made in a modified hospital ward containing 19 beds, 14 of them in the open ward, one in a window-ventilated side-room, two in rooms with partial-recirculation ventilators giving 7–10 air changes per hour, and two in self-contained isolation suites with plenum ventilation (20 air changes per hour), ultra-violet (UV) barriers at doorways and airlocks.

Preliminary tests with aerosols of tracer bacteria showed that few bacteria entered the plenum or recirculation-ventilated rooms. Bacteria released inside mechanically ventilated cubicles escaped into the corridor, but this transfer was reduced by the presence of an airlock. UV barriers at the entrance to the airlock and the cubicle reduced the transfer of bacteria from cubicle to corridor.

During a period of 4 years while the ward was in use for surgical and gynaecological patients, the incidence of post-operative sepsis and colonization of wounds by multiple-resistant *Staphylococcus aureus* was lower (though not significantly lower) in the plenum-ventilated rooms than in the open ward, the recirculator-ventilated cubicles and the window-ventilated cubicles. Nasal acquisition of multiple-resistant *Staph. aureus* was significantly less common in the plenum-ventilated than in the recirculator-ventilated cubicles and in the other areas. Mean counts of bacteria on settle-plates were significantly lower in the plenum-ventilated cubicles than in the other areas; mean settle-plate counts in the re-circulator-ventilated cubicles were significantly lower than in the open ward and in the window-ventilated side-room; similar results were shown by slit-sampling of air. Mean settle-plate counts were significantly lower in all areas when the ward was occupied by female patients. *Staph. aureus* was rarely carried by air from plenum-ventilated or other cubicles to the open ward, or from the open ward to the cubicles; though staphylococci were transferred from one floor area to another, they did not appear to be redispersed into the air in sufficient numbers to infect the patients. Ultra-violet irradiation caused a significant reduction in the total and staphylococcal counts from the floors of airlocks, and a significant reduction of total counts in the air.

INTRODUCTION

Isolation in single-bed rooms has been used for infected patients ('source' or 'containment' isolation), and for the protection of those whose susceptibility to infection is increased by disease or by immuno-suppressive treatment ('protective' isolation). Some evidence of the value of source isolation in ward cubicles has been reported (e.g. Lack, Towers & Stevenson, 1962; Williams *et al.* 1962; Turner, Watson & Abbott, 1965), but there is little published evidence of the value of cubicles for protective isolation. In a burns unit, neither the subdivision of an open ward into cubicles nor the installation of partial recirculation air-conditioners into the cubicles without other aseptic innovations led to any fall in the incidence of burn infections (Cason, Jackson, Lowbury & Ricketts, 1966). Burns offer a particularly severe challenge to any method of protective isolation (Lowbury, 1970), and better results might have been obtained in other types of patient. In a unit where leukaemic patients were treated with cytotoxic drugs, the isolation of patients in specially designed single-bed suites was apparently effective in excluding cross-infection (Robertson *et al.* 1968); but in this environment, as in the bacteria-free ward unit of the new Burn Centre described by Burke (1970), additional aseptic and antiseptic measures (e.g. sterile food or topical chemoprophylaxis) may have provided the main protective barriers against cross-infection.

The studies reported here were made in a ward specially modified to allow an assessment of the value of different types of single-bed rooms and of different types of ventilation as factors in the protective isolation of surgical patients.

Structure of the modified ward

A large 30-bed ward with one single-bed room was modified and equipped with four additional single-bed cubicles (see Fig. 1). Two of these cubicles (described below as plenum-ventilated cubicles) are part of self-contained isolation units,

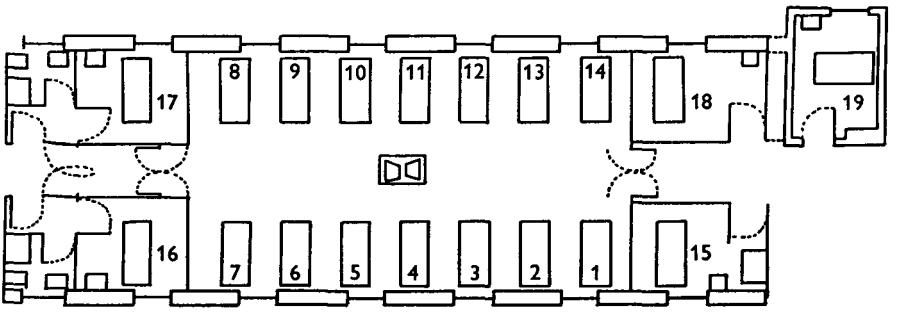

Fig. 1. Plan of ward: 1–14 beds in open ward; 15 and 18 recirculation-ventilated cubicles. 16 and 17 plenum-ventilated cubicles; 19 window-ventilated cubicle.

each having an airlock and an annexe containing toilet, shower and wash-basin. A plenum-ventilation system supplies warmed, humidified and filtered air to both cubicles at a rate of 20 air changes per hour and to the annexes at a rate of

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10 changes per hour. The air is passed through a pre-filter which has an efficiency of 93% for 5 μm. particles and a secondary filter which has an efficiency of 99% for 3 μm. particles. There is also a pre-heater, a capillary washer type of humidifier and a fan which has an output of 1100 ft.^{3}/min and drives the air along ducts to the two cubicles and the annexes. A refrigeration system was not included. Ultra-violet strip-lights were fitted over the door of the cubicle and the door separating the airlock from the outside corridor. The UV lights were 30 watt, giving maximum transmission at 2537 Å at an intensity of 83 μW./cm.^{2} at 1 m. The UV lights were only switched on during the experimental periods described.

Two of the other cubicles are equipped with smaller air-conditioning units which recirculate the cubicle air through filters; an additional 20% of air is drawn in from outside. Each cubicle has a different make of air-conditioning plant. A 'Westair Model 300' supplied by Thermotank Limited was fitted in one cubicle (Bed 18, recirculation cubicle 1). The output of the recirculator was approximately 200 ft.^{3}/min. and gave 6–7 air changes per hour in the cubicle; a washable fibre-glass filter with an efficiency of 95% for 5 μm. particle size was fitted. The other cubicle (bed 15, recirculation cubicle 2) was equipped with an air-conditioner supplied by Carter Thermal Engineering Company. The output was 300 ft.^{3}/min. and gave approximately 10 air changes per hour in the cubicle; a disposable fibre filter with an efficiency of 95% for 5 μm. particle size was used with the machine. The units provide warmed air; the 'Westair' machine contains a refrigeration unit but no humidifier, and the 'Carter' unit contains an integral humidifier but no refrigeration unit. The filters of both units showed a reduction of air flow at 6–8 weeks and were changed every month. Neither of these cubicles has airlocks, toilets, or showers. The original single-bed cubicle is furthest from the open ward; it has no air-conditioning unit and is ventilated by windows. Fourteen beds are present in the open section of the ward, giving a total of 19 beds.

PRELIMINARY INVESTIGATION

Before patients were admitted to the ward, tests were made on the efficiency of the isolation units and their ventilation systems with aerosols of *Bacillus subtilis* var. *globigii* or of micrococci used as tracers.

Experiments were made to determine the following:

(1) The rate of clearance of organisms from the cubicles.

(2) The escape of organisms from cubicles to the corridor.

(3) The entrance of organisms into the cubicles when released in the corridor.

(4) The effect of UV barriers on the escape of organisms from a plenum-ventilated unit.

General methods

Tracer organisms

B. subtilis var. *globigii* was grown in nutrient broth for 48 hr. at 37° C. The broth cultures were centrifuged and resuspended in water to give an approximate concentration of 10^9 organisms per ml. The suspension was heated to 100° C. for

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10 min. and then kept as the stock suspension at 4° C. In the experiment the stock suspension was diluted 1/100 in nutrient broth containing 0·2% Tween 80.

For the experiments with the UV light barriers, a suspension of a micrococcus was used, since this organism was likely to have a sensitivity to UV irradiation similar to that of *Staphylococcus aureus*. The organism was grown in nutrient broth for 18 hr. at 37° C. The culture was centrifuged and resuspended in nutrient broth containing 0·2% Tween 80 to give a concentration of approximately 10^7 organisms/ml. for the test.

Distribution of organisms

One ml. of the suspension of organisms was dispersed into the air by the use of a spinning disk atomizer (May, 1949). The disk was driven by compressed air at a speed to give aerosol particle sizes of approximately 10–15 μm. over a period of 2 min. During the release of organisms, large hand fans were used to distribute the organisms throughout the room.

Experiments

Clearance of organisms from ventilated cubicles

Aerosols of spores of *B. subtilis* var. *globigii* were released in the cubicles by the technique described and the air was sampled on nutrient agar plates with a slit-sampler over a period of 30 min.; viable counts were made after incubation of the plates for 18 hr. at 37° C. Tests were made in one of the plenum-ventilated cubicles and in the two recirculation-ventilated cubicles; replicate tests were made with the ventilation switched off, and with the ventilation switched on during and after the release of the organisms.

Table 1. *Clearance of* B. subtilis *var.* globigii *from ventilated cubicles*

Time after release (min.)	Cubicle	Number of *B. subtilis* var. *globigii* in 12 ft.³ of air		
		Ventilation switched on after release of organisms	Ventilation on throughout	Ventilation switched off
1	Plenum	267	70	150
5		101	35	156
10		20	11	146
20		2	2	119
30		1	1	80
1	Recirc. 1	260	130	150
5		168	94	110
10		120	65	91
20		60	31	82
30		30	20	80
1	Recirc. 2	378	317	185
5		245	160	189
10		189	106	160
20		80	50	141
30		48	8	121

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Results. These are shown in Table 1. Clearance of *B. subtilis* var. *globigii* occurred more rapidly and completely in all cubicles when the ventilation was switched on. A lower peak count and more rapid clearance were obtained if ventilation was on during the release of organisms than if the ventilation was switched on after the release of the organisms. A more rapid and complete clearance was obtained in the plenum-ventilated cubicles than in the other two cubicles. This corresponded to the higher rate of flow in the plenum-ventilated than in the recirculation-ventilated cubicles.

The transfer of organisms released inside cubicles to the corridor outside

Aerosols of *B. subtilis* var. *globigii* spores were released in a plenum-ventilated cubicle. Simultaneous samples were obtained on nutrient agar plates with one slit-sampler inside the cubicle and another slit-sampler placed in the corridor immedi-

Table 2. *Transfer of* B. subtilis *var.* globigii *from a plenum-ventilated cubicle to an airlock or to outside corridor*

Time after release of organism (min.)	Number of *B. subtilis* var. *globigii* in 12 ft.³ of air			
	Inside cubicle	In corridor outside cubicle	Inside cubicle	In airlock
1	292	8	265	115
2	318	20	230	160
	Doors opened*		Inner door opened (30 sec.)	
3	220	32	152	144
4	133	18	120	119
5	120	12	68	84

* The inner door was opened for 30 sec., closed and outer door was opened for 30 sec.

Table 3. *Transfer of* B. subtilis *var.* globigii *from ventilated cubicle (recirculation 1) to corridor*

Time after release of organism (min.)	Number of *B. subtilis* var. *globigii* in 12 ft.³ of air			
	Inside cubicle		In corridor outside cubicle	
	Vent off	Vent on	Vent off	Vent on
1	240	208	5	42
2	260	140	2	38
		Door opened (30 sec.)		
3	222	120	50	72
4	184	109	23	68
5	160	80	20	62

ately outside the door of the unit. To simulate a person leaving the unit, the inner door of the airlock was opened for 30 sec., 2 min. after the release of the organisms; the inner door was then closed and the outer door was opened for 30 sec. The experiment was repeated with the second slit-sampler placed in the airlock and the inner door only was opened for 30 sec. at 2 min. Spores were similarly released in

one of the cubicles ventilated with a recirculation unit. Samples were collected with one slit-sampler inside the cubicle and the other outside the door of the cubicle. The door was opened at 2 min. for 30 sec. Separate experiments were made with the ventilation switched on and off.

Results. Table 2 shows that some organisms escaped from the cubicle through the airlock into the corridor. The numbers of organisms increased slightly when the doors were opened. Many more organisms were obtained from the airlock than from the outside corridor. Table 3 shows that when the ventilation was off in the recirculation cubicle, few organisms escaped until the door was opened. With the ventilation on, more organisms escaped with the door closed and numbers increased when the door was opened. These experiments demonstrate that there is a risk of airborne organisms escaping from ventilated cubicles, but this may be reduced by the presence of an airlock.

The transfer of organisms from outside to inside of cubicles

An aerosol of *B. subtilis* var. *globigii* spores was released in the corridor outside the plenum-ventilated cubicle. Simultaneous air samples were taken outside and inside the cubicle. Separate experiments were made with the ventilation switched on and off. The doors were opened for 30 sec. at 2 min. A similar experiment was made with one of the recirculation-ventilated cubicles.

Table 4. *Transfer of* B. subtilis *var.* globigii *from corridor outside a plenum-ventilated cubicle with airlock to inside of cubicle*

Time after release of spores (min.)	Number of *B. subtillis* var. *globigii* in 12 ft.³ of air			
	Inside cubicle		Outside cubicle	
	Ventilation off	Ventilation on	Ventilation off	Ventilation on
1	1	0	174	145
2	3	4	160	122
	Doors opened for 30 sec.			
3	7	8	155	100
4	11	5	149	75
5	16	4	104	53
6	26	1	68	28
7	22	0	72	22
8	21	0	52	21
9	20	3	35	12
10	21	1	37	14

Results. Tables 4 and 5 show that few organisms entered either the plenum-ventilated or recirculation-ventilated cubicles with the ventilation system switched on even when the doors were opened as in the previous experiment. More organisms entered when the doors were opened and the ventilation was switched off. The experiments demonstrate that few airborne organisms are likely to enter the ventilated cubicles, particularly the plenum-ventilated cubicle with the ventilation on.

Table 5. *Transfer of* B. subtilis *var.* globigii *from corridor outside ventilated cubicle (recirculation* 1*) to inside*

Time after release of spores (min.)	Number of *B. subtilis* var. *globigii* in 12 ft.³ of air			
	Inside cubicle		Outside cubicle	
	Ventilation off	Ventilation on	Ventilation off	Ventilation on
1	0	1	400	500
2	1	2	200	300
	Door opened for 30 sec.			
3	0	1	180	242
4	12	4	132	202
5	8	3	140	184
6	8	8	159	105
7	5	6	143	132
8	12	5	148	120
9	9	1	112	80
10	14	3	75	75

Table 6. *The effect of UV barriers on the escape of organisms from a plenum-ventilated cubicle*

Time of Sampling	Doors	Total micrococci in 12 ft.³ of air			
		Inside cubicle		Corridor outside cubicle	
		UV off	UV on	UV off	UV on
Before release of organisms	Closed	21	10	4	13
2 min. after release		532	497	17	15
4 min. after release		461	534	17	14
6 min. after release		231	284	39	13
8 min. after release		212	270	30	11
Before release of organisms	Open	13	10	14	58
2 min. after release		370	293	484	153
4 min. after release		114	76	275	73
6 min. after release		50	46	103	57
8 min. after release		41	31	84	34

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The effect of UV light barriers on the escape of organisms from a plenum-ventilated cubicle

An aerosol of micrococci was released in one of the plenum-ventilated cubicles. Simultaneous air samples were collected with one slit-sampler in the cubicle and another in the corridor outside the airlock. The experiment was repeated with the UV light barriers switched on. Similar experiments were made with the doors closed and with the doors open.

Results. Table 6 shows that larger numbers of organisms escaped from the cubicle during the period of sampling when the UV was off than when it was switched on.

When both doors were opened with the ventilation on and the UV barriers off, more organisms were obtained outside the cubicle than within. The number of organisms outside the cubicle was less when the UV barriers were switched on. The results demonstrate that two UV light barriers irradiating the airlock cause some reduction in the numbers of organisms escaping from the cubicle.

CLINICAL STUDY

The ward was studied from October 1965 to December 1969, apart from several periods during which it was either closed or used for patients whom we did not include in our series. A total of 1674 patients were included in the study. The type of patient was changed at approximately yearly intervals throughout the period; female surgical and gynaecological patients were admitted for 2 years and male surgical patients for a rather shorter period. Patients who were likely to remain in hospital for 10 days or longer were randomly selected for admission to the isolation cubicles and to the open ward; those admitted to cubicles remained in them throughout their stay, although during the later stages of the investigation a few patients were admitted either for special protection or because they were staphylococcal dispersers. Occasionally patients refused to remain in the cubicles and were transferred to the open ward.

The ward was used mainly as an ordinary surgical ward, but during the first 2 years few patients were admitted for emergency surgery. Beds in the open ward were not moved unless there was a medical indication, which was rare. Patients in side-rooms were treated as other patients and no special precautions were taken (e.g. the use of mask, gowns, overshoes, and special hand-washing techniques) except for a few patients requiring protective isolation. Visiting was not restricted. Patients in the self-contained plenum-ventilated units remained in them throughout their stay in hospital, but patients in the recirculation and window-ventilated rooms walked through the open ward to bathroom and w.c.'s. Information on all patients admitted to the ward was entered on special record cards. After the first year the information was transferred to forms suitable for transfer to punch cards. In addition to personal details the information included bed-site in ward, days in hospital, diagnosis, operation, wound and other sepsis, factors predisposing to infection, antibiotics given and bacteriological results. All ward records were examined when the patient was discharged and information on sepsis was obtained

daily from the ward sister by the laboratory staff and entered in a day book. Wounds were classified as septic if there was any evidence of clinical infection irrespective of the presence or absence of pus. Swabs were taken daily for 6 days a week from patients' noses and weekly from the staff. Nose swabs were taken from patients on admission by the staff at weekends and placed in Stuart's transport medium. Swabs were taken from drained or moist wounds at the first dressing and at subsequent dressings whenever possible, also from any other infected lesions. Settle-plates (see below) were exposed for 2 hr. on 5 days a week; two plates were exposed in each side-ward and seven in the open ward. The plates were placed on bed-side lockers and bed tables, approximately 3 ft. above the floor. Slit-sampling studies were also made twice weekly. This routine was continued throughout most of the period, but the frequency of sampling was reduced for limited periods because of other laboratory commitments. Counts of bacteria on floors were made, initially with gauze-impregnated agar (Foster, 1960) and later with Alne plastic contact plates (Hall & Hartnett, 1964), when information on floor contamination was required.

Bacteriology

Nasal swabs were cultured on nutrient agar containing 1% serum and phenolphthalein diphosphate (Barber & Kuper, 1951). The same medium was used for settle-plates, surface sampling plates and slit-sampling studies. Counts of total organisms and presumptive *Staph. aureus* were made after 18 hr. incubation at 37° C. Either four colonies or 10% of colonies of presumptive *Staph. aureus* (whichever was the higher) were confirmed by slide or tube coagulase tests. Wound swabs were cultured aerobically on blood agar, McConkey medium and in cooked meat broth, which was subcultured aerobically and anaerobically at 48 hr. Tests of antibiotic sensitivity on *Staph. aureus* were made by a ditch plate method (Topley, Lowbury & Hurst, 1951). Antibiotic sensitivity tests were made on strains grown from the environment and the first strain grown from a nose and wound and then at weekly intervals. If a change in sensitivity was noted, strains collected during the previous week also were examined. Phage typing (Blair & Williams, 1961) was carried out on environmental strains resistant to at least two antibiotics, on the first strains isolated from nose or wound and again subsequently if there was a change in antibiotic resistance.

Results

Comparability of groups of patients

Patients in the open ward and cubicles were comparable both in their length of stay and in numbers receiving antibiotics. Patients admitted during 1965, totalling 433, were excluded from this comparison, since information on their length of stay and administration of antibiotics was not available for that period. In an analysis of 1241 patients admitted between 1966 and 1969 the average length of stay of patients was 10·9 days in the open ward, 10·7 days in the plenum-ventilated and recirculator-ventilated cubicles and 9·3 days in the window-ventilated cubicle. Thirty-four per cent of patients in the open ward and recirculator-ventilated cubicles, 31% in the plenum-ventilated cubicles and 32% in the window-ventilated cubicle were treated with antibiotics.

Wound sepsis and staphylococcal infection

The overall incidence of wound sepsis in the cubicles and the open ward from 1966 to 1969 was 62/744 (8·3%); the incidence was 41/610 (6·7%) in undrained wounds and 21/134 (15·7%) in drained wounds.

The incidence of wound sepsis was lower in the plenum-ventilated wards (2/68 = 2·9%) than in the open ward (53/596 = 8·9%), the recirculator-ventilated cubicles (4/52 = 7·7%) or the window-ventilated cubicle (3/28 = 10·7%). However, the number of wounds in which there was a special hazard of infection in the wards after operation was too small for comparison of cubicles with the open ward; e.g. the incidence of sepsis in drained wounds was 15/104 in the open ward, 3/12 in the recirculator-ventilated cubicles and 1/12 in the plenum-ventilated cubicles. Table 7 shows the incidence of staphylococcal infection from 1965 to 1969 and includes colonized as well as septic wounds. Multiple-resistant strains (i.e. resistant to two

Table 7. *Colonization of wounds with* Staph. aureus *1965–69*

Site	Incidence of colonization with multiple-resistant strains	Incidence of colonization with sensitive or penicillin-resistant only strains
Open ward	16/722 (2·2%)	20/722 (2·8%)
Recirculation cubicles	2/61 (3·3%)	1/61 (1·6%)
Plenum cubicles	0/78	3/78 (3·8%)
Window-ventilated cubicle	1/26 (3·8%)	0/26

Table 8. *Acquisition of multiple-resistant* Staph. aureus *in noses (1965–69)*

Site	Total patients	Number of acquisitions
Open ward	1325	51 (3·8%)
Recirculation cubicles	134	8 (5·9%)
Plenum-ventilated cubicles	143	1 (0·7%)
Window-ventilated side-ward	72	3 (4·2%)
Significant differences: comparison of:		
Plenum with open ward		$t = 1{\cdot}94$ $P \simeq 0{\cdot}05$
Plenum with recirculation cubicle		$t = 2{\cdot}47$ $P < 0{\cdot}05$

or more antibiotics) are likely to have been acquired in the ward, since patients usually had operations on the day after admission and theatre staff infrequently carried multiple-resistant strains. There were no infections (0/78) with these strains in the plenum-ventilated cubicles but this incidence was not significantly lower than in any of the other areas.

Nasal acquisition of multiple-resistant Staph. aureus

Isolation of multiple-resistant strains from noses of patients who carried sensitive, penicillin-resistant strains only or no *Staph. aureus* on admission were considered to be acquisitions in the ward. The acquisition of multiple-resistant *Staph. aureus* is shown in Table 8. The number acquiring strains in the plenum-ventilated cubicle was less than in the open ward and also less than in the recirculation cubicles,

both differences being significant. The other differences are not significant; there was no significant difference in the frequency of acquisition of multiple-resitant strains in the recirculation-ventilated cubicles, open ward and non-ventilated side-ward.

Airborne organisms

The mean counts of total organisms on settle-plates over a period of 2 years are shown in Table 9. The ward was occupied by female patients from October 1965 to September 1966 and by male patients from October 1966 to September 1967; there

Table 9. *Settle-plate counts*

Period of study	Sex of patients in ward	Site of sampling	Number of plates	Mean/total count/plate /h. and S.E.
October 1965 to September 1966	Female	Window-ventilated cubicle	262	$10{\cdot}8 \pm 0{\cdot}90$
		Recirculation cubicles	726	$8{\cdot}8 \pm 0{\cdot}41$
		Open ward	1421	$14{\cdot}5 \pm 0{\cdot}27$
		Plenum-ventilated cubicles	569	$3{\cdot}9 \pm 0{\cdot}25$
October 1966 to September 1967	Male	Window-ventilated cubicle	295	$23{\cdot}6 \pm 1{\cdot}45$
		Recirculation cubicles	752	$15{\cdot}9 \pm 0{\cdot}64$
		Open ward	1568	$26{\cdot}0 \pm 0{\cdot}50$
		Plenum-ventilated cubicles	563	$12{\cdot}6 \pm 0{\cdot}59$

Comparison of:	Female		Male	
Plenum with open ward	$t = 28{\cdot}60$	$P < 0{\cdot}001$	$t = 17{\cdot}32$	$P < 0{\cdot}001$
Plenum with recirculation cubicle	$t = 10{\cdot}08$		$t = 3{\cdot}79$	
Plenum with window-ventilated cubicle	$t = 7{\cdot}34$		$t = 7{\cdot}01$	
Recirculation with open ward	$t = 11{\cdot}49$		$t = 12{\cdot}46$	
Recirculation with window-ventilated cubicle	$t = 2{\cdot}01$	$P < 0{\cdot}05$	$t = 4{\cdot}85$	
Window-ventilated cubicle with open ward	$t = 6{\cdot}03$	$P < 0{\cdot}001$	$t = 1{\cdot}57$	Not significant

was considerable variation in counts on individual plates and on single days. For both years the results obtained showed the same order, counts in the open ward being highest and counts in the plenum-ventilated cubicle being lowest. The differences between all but two of these mean counts for both years showed highly significant results. For the males only the difference between the window-ventilated cubicle and the open ward was not significant. The difference between the window-ventilated and recirculation-ventilated cubicles for females was just significant ($P < 0{\cdot}05$). All the other results were highly significant at the level $P < 0{\cdot}001$. The counts in the open ward and cubicles were twice as high during the period of *male occupation as during the female; the difference was highly significant in all* areas ($P < 0{\cdot}001$).

The slit-sampling studies showed similar differences; e.g. from October to

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December 1967 the total mean count was 8·1 per ft.^{3} for the window-ventilated cubicle, 6·5 per ft.^{3} for the recirculation cubicles, 3·5 per ft.^{3} for the plenum-ventilated cubicles and 12·4 per ft.^{3} for the open ward.

Transfer of Staph. aureus *in the air to and from cubicles*

The assessment of this was difficult owing to the small number of dispersers and because more than one patient in the ward at one time carried a strain of similar phage and antibiotic sensitivity pattern. *Staph. aureus* was usually present on settle-plates or on slit-sampling plates in small numbers and there was little evidence of transfer either from cubicles to the open ward or vice versa.

The presence of a few staphylococcal dispersers enabled some observations to be made. On one occasion, when a disperser was present in a plenum-ventilated cubicle, 89 colonies were isolated on settle-plates in the cubicle over a period of 6 days; 10 colonies were phage typed and showed a similar phage pattern and only three colonies of similar type were isolated in the main ward. Slit-sampling counts on another day showed 13 colonies of *Staph. aureus* in the cubicle and none in the corridor or in the other plenum-ventilated cubicle. The evidence suggests that few organisms escaped from the plenum-ventilated cubicle into the open ward.

When a disperser of a strain of *Staph. aureus*, phage type 84/85, was in a re-circulation cubicle, 258 colonies of *Staph. aureus* were grown on settle plates, each exposed for 2 hr., during a 3-day period; 77 colonies of *Staph. aureus* were grown in the main ward, and of 16 colonies typed, 9 were of the same type as those in the recirculation cubicle. Two colonies of similar type were grown from the other recirculation cubicle and none from the plenum-ventilated cubicles.

On another occasion, when smaller numbers of *Staph. aureus* were grown from a recirculation cubicle (23 colonies) on 1 day, only one colony of similar type was grown from settle-plates in the open ward. At another time when 42 colonies were grown from settle-plates in the window-ventilated cubicle, only 1 colony of similar type was grown in the main ward on the same day. The relative absence of airborne transfer from the main ward to the cubicles is shown in the following examples: (1) 27 colonies of *Staph. aureus* grown on slit-sampling plates in the open ward and none in any of the cubicles; (2) 65 colonies in the open ward and one colony in one of the plenum-ventilated cubicles; (3) 22 colonies in the open ward and none in the cubicles.

The results confirm an interpretation of the original studies with artificially released organisms. Few staphylococci entered the cubicles by air from the main ward, but when the level of contamination was high, organisms did escape from the recirculation cubicle into the open ward, possibly because of the absence of an airlock. The window-ventilated cubicle was further than the other cubicles from the open ward and sampling showed that organisms were less likely to be transmitted from it in the air to the open ward.

Distribution of Staph. aureus *on floors*

Heavy floor contamination of the open ward was often associated with contamination of the floors of cubicles with the same phage type of *Staph. aureus*.

On one occasion 19/20 contact plates taken from the main ward showed *Staph. aureus* resistant to penicillin, tetracycline and erythromycin of phage type 80/81 (at R.T.D.). The same strain was found on 3/10 contact plates taken in a recirculation cubicle and on 6/10 plates taken in a plenum-ventilated cubicle. Mean counts of *Staph. aureus* were 12·8/plate in the open ward, 2·5/plate in the recirculation cubicle and 2·0/plate in the plenum-ventilated cubicle. One colony was grown on settle-plates in the recirculation cubicle and none in the plenum-ventilated cubicle. Similar results were obtained on several other occasions when floor contamination of the open ward was heavy. Patients in the cubicles did not acquire the strain in the nose or wound. When floor contamination was light, staphylococci of the same phage type were rarely found in the cubicles. The results suggest that although organisms were transferred from one floor area to another, probably on the soles of shoes, they were not transferred from the floor to the air in sufficient numbers to infect or colonize the patients.

UV light barriers

The effect of the two UV light barriers on bacteria in one of the airlocks was investigated when the plenum-ventilated cubicles were occupied by patients. In one series of experiments a comparison was made between the two cubicles and

Table 10. *The effect of UV light barriers in an air lock*

Slit-sampling studies in plenum-ventilated units.

	Mean bacterial counts in 50 ft.³/air					
	UV on			UV off		
Site of sampling	No. of plates	Total organisms	Total *S. aureus*	No. of plates	Total organisms	Total *S. aureus*
Cubicle	16	434·6 ± 121·7	6·3	13	309 ± 103·9	2·8
Airlock	16	120 ± 19·9	0·4	13	250·6 ± 35·3	1·5

their airlocks; the UV lights were switched on in one airlock but not in the other. In the other series, the same cubicle and airlock were investigated, both with and without UV irradiation of the airlock. UV lights were switched on at least 24 hr. before each set of observations. The air of the cubicles and airlocks was sampled with a slit-sampler and floors were examined with 8–10 contact plates for each experiment. Bacteriological techniques were as described in the general methods.

The overall results of the slit-sampling studies are shown in Table 10. Total counts of organisms were significantly lower ($t = 3{\cdot}3$, $P = < 0{\cdot}01$) and *Staph. aureus* were lower (but not significantly so) in the irradiated than in the unirradiated airlock; mean counts were lower in the airlocks than in the cubicles by 75% with the UV irradiation on, but by only 19% with the UV off. In the airlock with the UV off 9/13 bacterial counts were higher than in the corresponding cubicle, but only 2/16 airlock counts were higher than the cubicle counts when the UV lights were switched on. Table 11 shows that counts of total organisms and *Staph. aureus* on the floor of the airlock were significantly reduced (total organisms: $t = 9{\cdot}57$, $P < 0{\cdot}001$) when irradiated with UV lights.

Table 11. *The effect of UV light barriers in an airlock*

Contact plates from floors of plenum-ventilated units

Site of sampling	Mean bacterial count/plate: UV on — No. of plates	UV on — Total organisms	UV on — Total *S. aureus*	UV off — No. of plates	UV off — Total organisms	UV off — Total *S. aureus*
Cubicle	71	106·8 ± 18·8	3·6	68	269·9 ± 28·1	3·5
Airlock	81	12·8 ± 2·2	0·02	75	190·8 ± 19·1	3·6

DISCUSSION

In these studies on a modified hospital ward we have examined the role of structural separation of patients, with or without the additional aid of mechanical-ventilation and UV barriers, as a component of protective isolation; isolation in a cubicle was assessed in patients who were not also receiving protection by other means, e.g. gowns, masks or a special hand-washing routine.

Preliminary studies with tracer organisms showed that the movement of bacteria between the isolation rooms (cubicles) and the corridor was reduced by mechanical-ventilation, that the presence of an airlock added to this control of bacterial movement, and that UV irradiation of the airlock, whether plenum-ventilation was in use or not, caused a further reduction in the numbers of airborne bacteria which escaped from the cubicle to the corridor. The results of floor sampling obtained in the experiments on UV irradiation with a patient in the cubicle should be interpreted with caution, since organisms on the floor of the airlock are unlikely to be relevant in the spread of infection. The reduction in the count of airborne bacteria in the irradiated airlock suggests that UV barriers might be useful where plenum-ventilation is not used, but in a ward with little contamination, plenum-ventilation alone was effective in preventing airborne organisms from entering from outside. Multiple-resistant strains of *Staph. aureus* were frequently grown from the floor of the cubicles when contamination of the main ward with those organisms was heavy, probably transferred on the shoes of the staff. The absence of colonization of wounds or staphylococcal sepsis with these strains in patients in the cubicles and the absence of these organisms in the air confirm experiments previously reported that organisms on the floor were not easily redistributed into the air (Ayliffe *et al.* 1967).

The mean counts of total airborne bacteria were reduced in proportion to the number of air changes, i.e. settle-plate and slit-sampling counts were lowest in the plenum-ventilated cubicles, higher in the recirculation-ventilated rooms and highest in the open ward or window-ventilated cubicle. There were considerable day-to-day variations in counts in all areas and occasionally counts in one of the cubicles would be unusually high, presumably due to the presence of a heavy disperser of coagulase negative staphylococci. Counts in all areas were consistently higher when the ward was occupied by male patients than when it was occupied by females; it seems likely that males disseminate more organisms into the environ-

ment. This applies also to dispersal of *Staph. aureus* (Bethune, Blowers, Parker & Pask, 1965; Emslie, 1966) and has been confirmed by other observations of our own. A comparison of the total numbers of *Staph. aureus* in the open ward and in the cubicles is not shown, since their presence in the air of a cubicle was almost always related to the presence of a carrier or infected patient in the cubicle; some nasal carriers were always present in the open ward.

In addition to the rarity of *Staph. aureus* in the air of the plenum-ventilated cubicles when no carriers or infected patients were present, there was evidence of protection against airborne spread in the significantly lower nasal acquisition rate of multiple-resistant *Staph. aureus* in patients nursed in these cubicles, when compared with patients nursed in the open ward or in other cubicles. Multiple-resistant strains were used as an index of acquisition since penicillin-resistant strains are now frequently found in the general population and the frequency of acquisition of these strains cannot be assessed with accuracy. The colonization of wounds was also less common (though not significantly so) in patients nursed in the plenum-ventilated cubicles than in those nursed in the open ward or in the other cubicles. The apparent ineffectiveness of the recirculator cubicles in preventing airborne spread was at first sight surprising, in view of the encouraging results obtained in the preliminary bacteriological experiments. It was, however, necessary for these patients (unlike those in the plenum rooms) to walk through the open ward to reach the communal bathroom and w.c., and it is likely that they acquired staphylococci during such excursions into another ward area. The number of multiple-resistant *Staph. aureus* in the open ward was small during most of the period of study, and there was little evidence of cross-infection. The nasal acquisition rate in 1967 was 12/410 (2·9%), whereas in another male surgical ward in the same hospital it was 59/419 (14%) during a 6-month period of the same year. The reason for this difference is not clear, but the smaller number of patients (14 in this ward, compared with 30 in other wards), better bed-spacing, the dilution of surgical with short-stay gynaecological patients when the ward was occupied by female patients, and the high proportion of clean surgery in relatively fit patients admitted from home, may all have contributed to the lower incidence. Since most of the wounds were not drained, the number at risk of acquiring infection in the wards was small; some of the septic drained wounds may have acquired infection in the operating theatre or sepsis may have been due to self-infection by the patient's own flora. Although the wound sepsis rate was lower in the plenum-ventilated cubicles, the numbers were too small for a valid comparison to be made between the cubicles and the open ward.

This study shows that cubicles with plenum-ventilation at 20 air changes per hour, each with associated w.c. and shower and with an airlock, give effective protection against airborne staphylococci in a clean surgical ward. Division of a ward into smaller units, with or without mechanical ventilation, has been associated in some hospitals with a reduced incidence of staphylococcal infection (Edmunds 1970; Smylie, Davidson, Macdonald & Smith, 1971; Davidson, Smylie, Macdonald & Smith, 1971); in other hospitals, however, these conversions have not led to a reduced acquisition of staphylococci and less infection (Whyte, Howie &

Eakin, 1969; Lidwell *et al.* 1970; Cason *et al.* 1966). The use of plastic ventilated isolators which kept out both airborne and personnel-transmitted contaminants achieved only a marginal protection against the acquisition of multiple-resistant *Staph. aureus* in a burns unit (Lowbury, Babb & Ford, 1971); there, however, patients who were more liable to colonization by staphylococci were also exposed to a greater challenge of contamination than in a clean surgical ward. *Pseudomonas aeruginosa* and some other Gram negative bacilli, which are of special importance as pathogens in patients with severe burns or under treatment by immunosuppressive drugs, appear to be transferred almost entirely by contact except at the time of removal of heavily contaminated dressings; isolation techniques aimed at excluding airborne transfer of bacteria cannot be expected to affect the incidence of infection with these bacteria, except in rooms where dressings of burns are changed (Lowbury, 1954; Lowbury *et al.* 1971).

A single-bed room without mechanical-ventilation, though ineffective in controlling cross-infection in a burns unit, may provide adequate structural isolation for most patients requiring special protection, particularly if sited in a gynaecological ward or in other wards where the staphylococcal infection rate is low; though airborne transfer of bacteria to patients in such rooms is not prevented, the numbers of bacteria in unoccupied, window-ventilated rooms are much smaller than those in the open ward, even if the door is left open (Lowbury *et al.* 1971). Where airborne contamination is low, barriers against contact transfer are more important and may be sufficient to exclude most of the pathogens. If it is particularly important to prevent airborne infection (e.g. in an isolation room near a ward where there is much staphylococcal contamination) it is possible to give useful protection in an ordinary side-ward equipped with recirculating-ventilators giving a large turnover of air and a small irradiated airlock, such as that which was found effective in preventing airborne spread of bacteria to kidney transplant patients at the Hammersmith Hospital (Ayliffe, 1963). A window-ventilated room with an airlock, irradiated with UV or equipped with an extractor fan, is a possible and even less expensive alternative. The expensive and elaborate self-contained, plenum-ventilated isolation suite would be appropriate for restricted use in the treatment of some 'high risk' patients (e.g. those treated with cytotoxic drugs) for whom sterile supplies of food and of other materials are also required to ensure the absolute minimum of microbial contamination; such patients, however, are still exposed to the risks of endogenous infection with micro-organisms colonizing the intestinal tract, the skin and other surfaces.

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