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Ward floors and other surfaces as reservoirs of hospital infection

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INTRODUCTION

The floors of hospital wards become contaminated with large numbers of bacteria, including *Staphylococcus aureus*, and are commonly assumed to be important reservoirs of hospital infection. To prevent the dispersal of bacteria from floors into the air, various improvements in methods of cleaning have been introduced, notably oiling of floors, the use of oiled mops and, with most success, the use of special vacuum cleaners (van den Ende, Lush & Edward, 1940; Bate, 1961; Babb, Lilly & Lowbury, 1963). Efforts are also commonly made to reduce the numbers of bacteria on the floors by manual or mechanical scrubbing or disinfection, but the results of such treatment have been disappointingly small (Finegold *et al.* 1962; Vesley & Michaelson,1964). Ayliffe, Collins & Lowbury (1966) found that areas of floor protected against recontamination lost about 80 % of their bacterial flora after mopping or mechanical scrubbing, and a significantly larger proportion (about 99 %) after treatment with certain disinfectants. Since areas which were not protected against recontamination were often as heavily contaminated 1 hr. after scrubbing or disinfection as they were before such treatment, there appeared to be little or no advantage in cleaning floors. On the other hand, frequent scrubbing or the use of disinfectants might be expected to keep the mean level of bacterial contamination lower that that which is present on an uncleaned surface. Even if regular disinfection of floors reduces the mean level of contamination, such treatment cannot be considered useful in preventing infection unless pathogens on the floor are transferred either by air or by contact to patients in the ward.

In this paper we describe studies on the equilibrium levels of floor contamination and the influence of various factors, including disinfection, on these levels. We also describe experiments on the redispersal by air movements of settled dust containing *Staph. aureus* and discuss floor bacteria as a source of infection in the light of the results obtained. Studies on the bacterial contamination of walls and on the use of tacky and antiseptic mats are also described and discussed.

GENERAL METHODS

Contamination of surfaces by a disperser

A carrier and profuse disperser of *Staph. aureus* co-operated in experiments on contamination of surfaces by shedding these organisms into the environment during exercise and by direct transfer from fingers. This subject is subsequently referred to in the paper as 'the disperser'. The staphylococcus isolated from the disperser was not typable by phages at the routine test dilution (R.T.D.) but when tested at 1000 R.T.D. it was found to be of type 80/81; it was sensitive to penicillin and resistant to tetracycline, novobiocin and neomycin (see also Ayliffe & Collins, 1967).

Bacteriological methods

Nutrient agar containing phenolphthalein diphosphate (Barber & Kuper, 1951) was used for settle plates, slit-sampling plates, and impression plates from surfaces (Foster, 1960). Total counts and counts of presumptive *Staph. aureus* were made after incubation for 18 hr. at 37° C. A selection of colonies of presumptive *Staph. aureus* isolated in each experiment was subcultured on blood agar and subsequently confirmed by slide or tube coagulase tests. Strains of *Staph. aureus* were tested for sensitivity to a range of antibiotics by a ditch plate method.

EXPERIMENTAL STUDIES

THE ACCUMULATION OF BACTERIA ON WARD FLOORS AND SURFACES

In a previous study (Ayliffe *et al.* 1966) it was found that floors of surgical wards became contaminated rapidly after cleaning or disinfection. The contamination was probably due both to airborne bacteria and to contact with shoes and trolley wheels. As there was no obvious increase in bacterial floor counts between 1 and 9 hr. after cleaning, it seemed that a 'plateau' may have been reached in which organisms were being removed at about the same rate as they were being deposited. Such a plateau phenomenon has been observed in studies on the contamination of stainless steel surfaces in clean rooms examined over a period of many weeks (Michaelson, personal communication; Favero *et al.* 1966).

In this study, the relative numbers of bacteria deposited on a ward floor from the air and by contact were assessed; the accumulation of bacteria on ward floors and on initially clean squares of vinyl left exposed and unwashed in the same wards was studied for periods up to 4 weeks.

Methods

Sources of contamination of floors

An area of floor in a surgical ward was cleaned with a disinfectant or detergent, and part of the treated floor was immediately covered with a cardboard box open on the underside (Ayliffe *et al.* 1966). Two settle-plates were exposed on top of the box for 1 hr. One hour after treatment of the floor, two impression plates were taken from the covered area and two from the uncovered area of floor. Ten experiments were performed.

Results

Table 1 shows the mean bacterial counts from covered and uncovered areas of floor 1 hr. after cleaning, and the mean counts of settle plates exposed during the same period. The results suggest that airborne contamination accounts for less than half the number of bacteria that were deposited on this floor. The other sources of contamination were probably shoes and trolley wheels; dust blown from adjacent uncleaned areas of floor is another possible source.

Table 1. *Mean bacterial counts from covered and uncovered areas of floor and on settle plates exposed for* 1 *hr.*

	Mean total bacterial counts		
	Impression plates		
Total observations	Covered area	Uncovered area	Settle plates
20	12	*164 ± 21	*63 ± 2·8

* t (18 degrees of freedom) = 4·45. $P < 0{\cdot}001$.

Accumulation of bacteria on surfaces in 7–9 *days*

Methods

Two studies were made in a female geriatric ward containing 13 beds, and one study was made in the open section of a female surgical ward containing 14 beds. The surfaces of two vinyl squares (4 sq. ft. in area) were cleaned by mopping with 70 % ethyl alcohol and exposed in the ward; one square was raised 6 in. above the floor, and the other was placed on the floor. The two squares were not cleaned again during the experiment, and the square on the floor was otherwise treated as part of the ward floor. The ward itself was mopped daily with soap and water. Samples were taken from the two surfaces and from the ward floor with two impression plates at 0, 1, 2, 4 and 6 hr., daily for 4 days, and on the seventh day. Some samples were also taken on the 5th and 9th day. After the first day, samples were usually taken 6 hr. after cleaning the ward, but in one of the experiments, in the geriatric ward, samples were taken 1–2 hr. after cleaning.

Results

The total bacterial and presumptive staphylococcal counts from the two vinyl surfaces and from the floor in the geriatric ward are shown in Fig. 1. Total counts show a gradual rise to a peak in about 24 hr.; the vinyl square raised above the floor shows less contamination than the square on the floor during the first 6 hr. After the first 24 hr, no further progressive rise in bacterial counts occurred on impression plates from either of the squares or from the floor itself until after the fourth day. A considerable rise in counts from the two vinyl surfaces but not from the clean floor was found on the seventh day. There was no obvious reason for this increase; the organisms were mainly aerobic spore-bearing bacilli, whereas in the previous samples micrococci had predominated. Staphylococcal counts did not rise after the first 24 hr.

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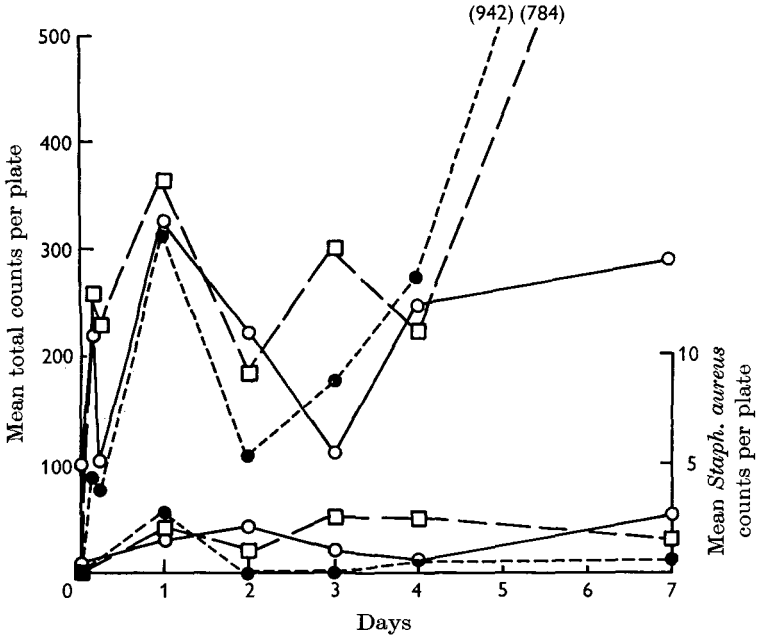

Fig. 1. Mean total and mean *Staph. aureus* counts on impression plates taken at intervals after cleaning a floor in a female geriatric ward during the course of one week. ○——○, Floor; ● - - - ●, vinyl off floor; □ - - - □, vinyl on floor.

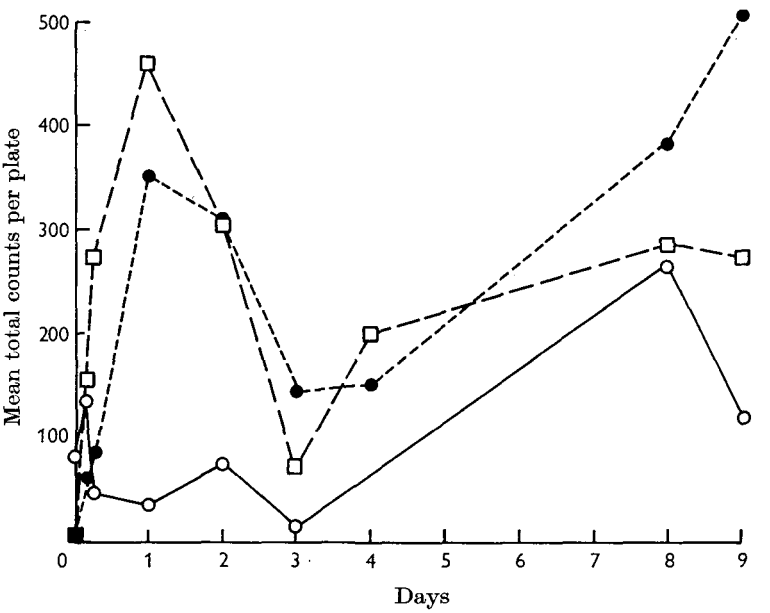

Fig. 2. Mean total counts on impression plates taken at intervals after cleaning the floor in a female geriatric ward during the course of nine days. ○——○, Floor; ● - - - ●, vinyl off floor; □ – – □, vinyl on floor.

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The results of a similar experiment are shown in Fig. 2. Counts from the vinyl squares again rose to a peak in 24 hr.; after the peak there was a fall in counts, followed by an increase on all surfaces after the third day. In this experiment samples were taken between 1 and 2 hr. after cleaning the floor; this shorter interval between cleaning and sampling was associated with lower counts on the floor than on the vinyl squares.

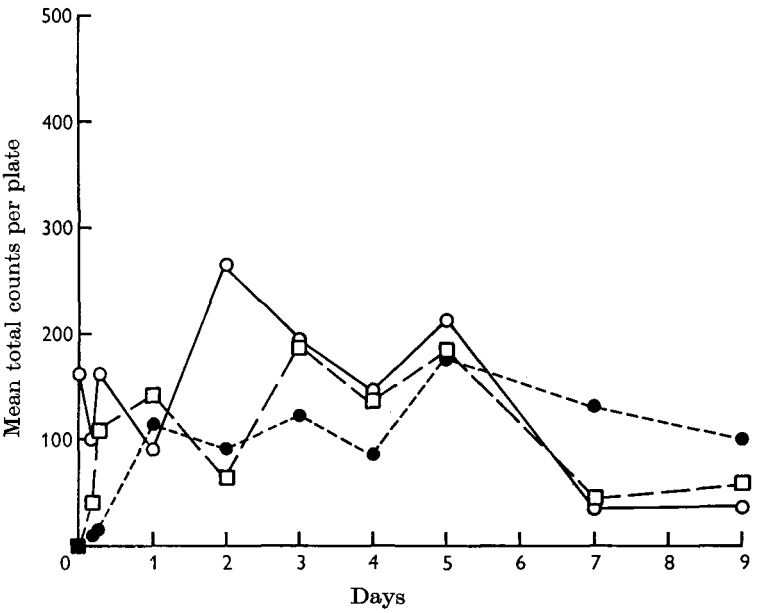

Fig. 3. Mean total counts on impression plates taken at intervals after cleaning the floor in a female surgical ward during the course of nine days. O——O, Floor; ● - - - ●, vinyl off floor; □ – – □, vinyl on floor.

Figure 3 shows the result of a similar experiment in a female surgical ward. Counts from the two vinyl squares again rose to a peak after 24 hr., and on all three areas they remained at about the same level for 9 days. The count from the floor showed an increase on the second day, due to Gram-negative bacilli surviving on a damp area. Apart from this, most of the counts were less than 200 per plate, which was lower than those usually obtained in the geriatric ward.

The three experiments showed that the bacterial flora of ward surfaces gradually increased over a period of 24 hr. In one experiment the counts remained at approximately the same level for at least 9 days. In the two other experiments, this 'plateau' was rather less obvious because of some unexplained irregularities, but the results over the first 4 days suggest a similar phenomenon, and the counts of *Staph. aureus* in one experiment show the establishment of an equilibrium. The female surgical ward was less crowded than the geriatric ward, and the differences in the equilibrium levels probably correspond with differences in contamination.

Accumulation of airborne bacteria over a period of 5 weeks

Methods

A vinyl square was exposed for 34 days in the female ward, and a similar square was exposed in a male surgical ward during the same period. The squares were raised 3 in. above the floor and were therefore contaminated only with airborne bacteria; they were cleaned with 70 % ethyl alcohol before exposure, and not again during the experiment.

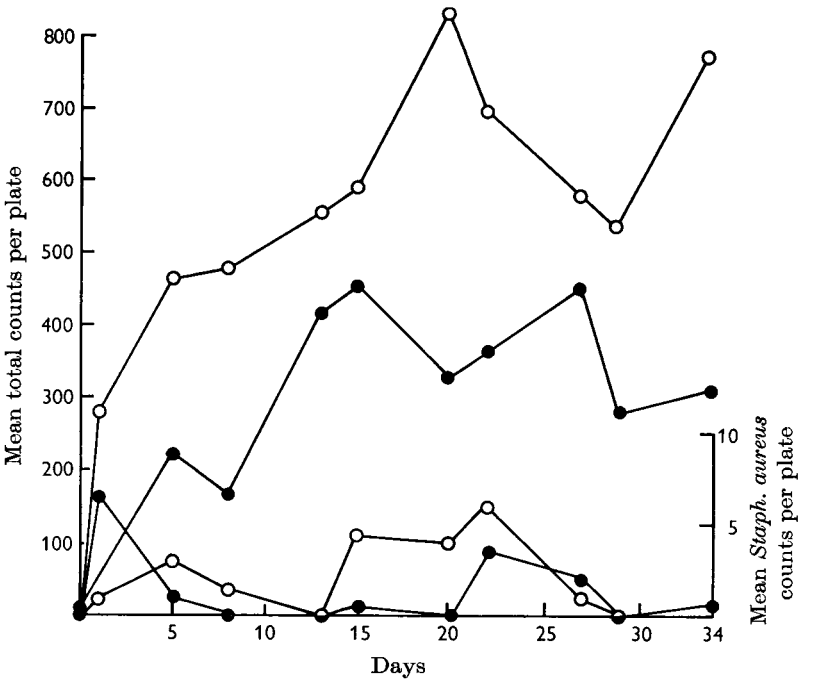

Fig. 4. Mean total and mean *Staph. aureus* counts on impression plates taken from exposed vinyl squares in male and female surgical wards during the course of 5 weeks. ○——○, Male surgical ward; ●——●, female surgical ward.

Results

Figure 4 shows the results. The counts increased gradually over a period of 2–3 weeks, and then remained, with some fluctuation, at approximately the same level. A high proportion of aerobic spore-bearing bacilli was isolated after the first week. It seems that an equilibrium between death (or removal) and deposition of vegetative organisms occurs within 24 hr., and a second equilibrium occurs at a later stage with a predominance of spore-bearing bacilli. Counts of *Staph. aureus* also showed the establishment of a fluctuating equilibrium, but without the further rise shown by counts of total organisms. The difference in bacterial counts in the two wards was associated with differences in the numbers of patients and in activity.

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The effect of disinfection of a ward floor on bacterial counts over a three-week period

In a previous study (Ayliffe *et al.* 1966) cleaning with an effective disinfectant (Sudol 1/100) killed or removed 99% of bacteria from a surgical ward floor, while soap and water killed or removed only about 80% of the bacteria. Although the effects of both methods of cleaning were apparently annulled by rapid recontamination, it might be expected that cleaning a floor daily with a disinfectant would result in a lower equilibrium level of contamination that that which occurred when soap and water was used for cleaning. A comparison was therefore made of bacterial counts on an area of floor mopped with Sudol 1/100 and an area mopped with soap and water.

Table 2. *Floor bacteria 24 hr. after cleaning with Sudol or with soap and water over a period of 21 days*

Method of cleaning	No. of samples	No. of plates	Mean bacterial count per plate
Soap and water	9	18	824
Sudol 1/100	9	18	848

Methods

Two squares of vinyl were placed on the floor of a female surgical ward in an area where traffic was heaviest. Samples were taken after 24 hr. exposure, two impression plates being taken from each square. For a period of 3 weeks one square was mopped daily with Sudol (1/100) while the other square was mopped at the same time with soap and water. Nine samples were taken from each square before cleaning during the period.

Results

Table 2 shows that there was no appreciable difference in mean counts from the square mopped with Sudol and the square mopped with soap and water.

Death-rate of *Staph. aureus* on surfaces

In a previous section, the establishment of an equilibrium between the death or removal of bacteria and the deposition of bacteria on the surface is described. There are great differences in the death rate of different types of bacteria; Gram-negative bacilli die more readily than Gram-positive cocci when their suspending medium dries, which explains the preponderance of the latter in dry environments (Lowbury & Fox, 1953; F. Pettit, personal communication). Staphylococci can survive for long periods in dust (Lidwell & Lowbury, 1950), but disappear much more rapidly from exposed surfaces in a ward (Skaliy & Sciple, 1964).

In the experiment described here the survival of staphylococci which settled on a vinyl surface from a disperser of the organism was assessed.

Methods

A vinyl square was placed on the floor and cleaned with 70 % alcohol. The disperser exercised for 2 min. near the square, which was then sampled with two impression plates 1 hr. after contamination, daily for 4 days and on the seventh day. The vinyl square was exposed to daylight but not to direct sunlight during the experiment. Four other similar experiments were made, but in two of these experiments a disk of vinyl was contaminated by the disperser and was sampled by the agar cylinder method of Ten Cate (1965) (using 'Agaroid Oxoid') at similar times after contamination.

Results

Table 3 shows a progressive reduction in numbers of *Staph. aureus* isolated from vinyl surfaces in all experiments over a period of 7 days. Although there was some variation between experiments, an appreciable reduction occurred after 24 hr. in four experiments, and few staphylococci were isolated after 4–7 days.

Table 3. *Survival of* Staph. aureus *on a vinyl surface contaminated by a staphylococcal disperser*

Time of sampling after contamination	Total counts of *Staph. aureus* per sample (impression plate) in experiments					Mean % survivors
	1	2	3	4	5	
1 hr.	15	43	29	28	15	100
1 day	6	19	17	2	16	46
2 days	—	17	5	0	1	22
3 days	10	—	3	0	0	12·5
4 days	—	6	0	0	1	6·7
7 days	0	3	0	0	0	1·9

CONTAMINATION OF FLOORS BY SHOES: THE EFFECT OF TACKY AND DISINFECTANT MATS

It has been shown that recontamination after cleaning a floor may occur from settlement of airborne bacteria or from other sources. Barber & Dutton (personal communication) have shown that *Staph. aureus* can be transferred from one area to another on the soles of shoes; they found that organisms were removed from shoes by walking on a mat with a slightly sticky surface ('Takimat'). On the other hand, it has also been found (E. J. L. L., unpublished results) that organisms could be transferred from a contaminated Takimat to clean trolley wheels. In the following experiment, the effect of Takimat and disinfectant mats on the transfer of bacteria by shoes was assessed.

The removal of organisms from a shoe by a Takimat

Methods

Two squares of vinyl, cleaned with 70 % alcohol, were placed one on each side of a Takimat. A subject wearing smooth, rubber-soled shoes walked on an area of

floor contaminated by the disperser, and then stepped on one of the clean surfaces. One shoe was then pressed on the clean Takimat and the other was pressed on the clean area of vinyl. A third step with each shoe was then taken on a clean area of vinyl. The six areas were then sampled with impression plates. The experiment was repeated twice.

Results

Table 4 shows that many organisms were deposited by shoes on the Takimat, but also on the control area of clean vinyl. Larger numbers of *Staph. aureus* were deposited on the mat than on the vinyl surface, but many bacteria were deposited by the third step after treading on the mat; in Expt. 3, more *Staph. aureus* was transferred to the clean floor after stepping on the mat than after stepping on the control area of vinyl.

These experiments also confirm that bacteria, including *Staph. aureus*, may be transferred to floors by contaminated shoes.

Table 4. *Removal of bacteria from a shoe by a Takimat*

(Three experiments)

Floor areas sampled by impression plate	Total bacterial count per plate			*Staph. aureus* per plate		
	1	2	3	1	2	3
Site of first step (on vinyl before stepping on Takimat)	185	76	320	10	3	28
Site of second step (Takimat)	394	145	196	18	7	25
Site of third step (on vinyl after stepping on Takimat)	199	10	194	6	0	26
Controls						
Site of first step on vinyl	358	75	79	9	7	30
Site of second step on vinyl	283	35	82	9	0	3
Site of third step on vinyl	95	20	80	1	0	10
Clean Takimat	16	8	15	0	0	0

Table 5. *The effect of a Takimat at entrance on bacterial counts in room*

	No. of plates	Mean bacterial count per impression plate	
		In air lock	In cubicle
Takimat in air lock	17	120	*68 ± 14·6
No Takimat in air lock	13	125	*105 ± 27·0

* t (28 degrees of freedom) = 1·29. $P > 0·1$.

The effect of a Takimat on bacterial counts in a side ward

A Takimat was placed in an airlock at the entrance to a plenum-ventilated, single-bedded cubicle, so that anyone entering or leaving the cubicle walked on the mat. The floor of the cubicle and airlock were disinfected daily, 4 hr. before sampling. Two floor impression plates were taken in the airlock at positions 2 ft. proximal to the mat, and two plates were taken in the cubicle at positions 2 ft.

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distal to the mat. Samples were also taken in similar positions in another plenum-ventilated cubicle without a Takimat. Four series of samples were taken during one period of 7 days and five series of samples were taken during another period of 7 days after putting down a fresh Takimat. Table 5 shows a slightly (but not significantly) lower mean bacterial count from the floor of a cubicle with a Takimat at the entrance than from the control cubicle without a Takimat.

Transfer of organisms from a contaminated Takimat to a clean floor

A Takimat which had been walked on in the airlock of a ventilated cubicle for 7 days was used in this experiment. The sole (smooth rubber) of a shoe was cleaned with 70% ethyl alcohol and allowed to dry without touching the floor. The subject wearing the shoe stepped on a clean area of vinyl and then on the contaminated Takimat. Four further steps were then taken on another clean area of vinyl flooring. Samples were taken with impression plates from the floor after a step with the clean shoe; the areas trodden on the first and fourth steps after contamination of the sole of the shoe by the Takimat and the mat itself were also sampled.

Table 6 shows that, although the Takimat was heavily contaminated only a small number of bacteria were transferred on a clean shoe to a clean floor by treading on the dirty mat.

Table 6. *The transfer of bacteria from a contaminated Takimat to a clean floor*

Area sampled by impression plate	Total organisms per impression plate
Floor after contact with clean shoe	2
Contaminated Takimat	1000
Floor after contact with shoe:	
(1) First step after Takimat	31
(2) Fourth step after Takimat	12

Protection of a clean floor by a disinfectant mat in the doorway

A honeycomb type of mat ('Recticel') containing numerous small cells which were filled with a phenolic disinfectant (Hycolin 2%) was used in the experiment. A subject wearing smooth, rubber-soled shoes walked over an area of floor contaminated by the disperser, and then stepped on an area of floor previously cleaned with 70% alcohol. He then stepped on the disinfectant mat, and finally took 10 steps on a clean vinyl floor. Impression plates were taken from areas of clean floor on which the subject stepped before he walked on the mat, and also from the areas trodden on his first and tenth steps after walking on the mat. Since the shoes were wet immediately after stepping on the mat and left wet patches on the floor, samples were taken 1 hr. later when the floor was completely dry.

Table 7 shows that the transfer of organisms from a shoe to the floor was reduced on the first step after walking on the mat. An increase was obtained on the 10th step which showed that not all of the bacteria remaining on the shoe were killed. The floor was quite wet under the first tread after stepping on the mat, but much

less so after the tenth tread. The time required for the floor to dry was correspondingly longer after the first tread, which would allow more time to kill the organisms transferred from shoe to floor.

Table 7. *The effect of treading on a disinfectant mat on the contamination of a clean floor by shoes*

Floor area sampled by impression plate	Total bacterial counts and counts of *Staph. aureus* per impression plate from floor			
	Left foot		Right foot	
	Total	*Staph. aureus*	Total	*Staph. aureus*
Before stepping on mat	127	62	194	70
First step after mat	3	0	3	0
10th step after mat	40	7	46	16

The contamination of floors during cleaning

The effect of using contaminated mop-water

In an investigation on the cleaning of ward floors, the use of soap and water was not much less effective in reducing the numbers of bacteria than a disinfectant solution (Ayliffe *et al.* 1966). These results were obtained with a clean mop and water; Walter & Kundsin (1960) have shown that floors may become contaminated if the mop and water are dirty. Gram-negative bacilli are often isolated in large numbers from wet floors but rarely from dry floors.

The effect of using contaminated mop water on bacterial counts from the floor was assessed in the following experiment.

Methods

A male geriatric ward (24 ft. × 48 ft.) containing 13 beds was mopped with soap and water. The mop and bucket were thoroughly rinsed in hot water before use. The ward floor was sampled with six impression plates before cleaning. Three areas (15 in. × 9 in.) of floor were chosen for sampling after cleaning. The first area chosen was cleaned immediately with the clean mop and water, the second after cleaning one-third of the ward, and the third after cleaning two-thirds of the ward. Each area was covered immediately after cleaning with an inverted cardboard box to prevent recontamination by airborne and other bacteria, and sampled with six impression plates after 1 hr. The mop water became increasingly dirty during the cleaning of the ward; total bacterial counts were made from the water before cleaning, and again after cleaning one-third, two-thirds and the complete ward. Five experiments were made with soap and water and one with Sudol (1/100).

Results

Table 8 shows that the mean bacterial count from the floor, cleaned with soap and water, was higher on areas cleaned last than on areas cleaned first. On the floors cleaned with disinfectant, counts were low on all areas. The floor contamina-

tion occurred from the mop or mop water, since the areas were protected from recontamination with bacteria from the air and from shoes.

Table 9 shows an increasing bacterial count in water from the mop bucket during the course of cleaning with soap and water; no comparable increase in total counts occurred when a disinfectant was used.

Table 8. *Bacterial floor counts after mopping ward floor*

	Mean total impression plate counts on covered floor 1 hr. after cleaning with:			
	Soap and water		Sudol 1/100	
Time of sampling floor	No. of plates	Mean total count	No. of plates	Mean total count
Before cleaning	30	337	9	325
After cleaning first area	18	6	6	4
After cleaning one-third of ward	24	32	6	5
After cleaning two-thirds of ward	30	104	6	4

Table 9. *Bacterial counts from mop water during and after mopping a ward floor*

	Mean viable counts on treatment of floor with:			
	Soap and water		Sudol 1/100	
	No. of samples	Mean total counts per ml.	No. of samples	Mean total counts per ml.
Before cleaning	5	10	1	20
After cleaning one-third of ward	5	650	1	10
After cleaning two-thirds of ward	5	15,000	1	30
After cleaning complete ward	4	34,000	1	20

The transfer of bacteria to floor by a contaminated mop

Methods

An area of vinyl floor was 'cleaned' with clean water and a sponge mop that was known to be contaminated with *Pseudomonas aeruginosa*. Impression plates were taken immediately before and after the floor was mopped and at $\frac{1}{2}$, 1, 2 and 3 hr. after mopping. The experiment was repeated on two further occasions. A similar experiment was made after rinsing the mop in a phenolic disinfectant (Hycolin 2 %) and after immersing the mop for 10 min. in the disinfectant.

Results

A heavy confluent growth of *Pseudomonas aeruginosa* and other Gram-negative bacilli was found on plates taken immediately after mopping with a contaminated mop. The counts were considerably reduced in all three experiments during the drying of the floor, and a few colonies were isolated after 3 hr. Rinsing the mop five times in the disinfectant reduced the number of Gram-negative bacilli isolated from the floor, but immersion for 10 min. was required to kill all the organisms.

Redispersal of bacteria from floors into the air

Since it is difficult, and often impracticable, to prevent rapid recontamination of the floors of busy wards, the role of bacteria on floors as a potential source of cross-infection requires consideration. Bacteria-carrying particles on the floor may be redispersed into the air by natural draughts, traffic, or procedures such as bed-making, drawing curtains, sweeping or the use of vacuum cleaners with no filters or with inadequate filters. In the present investigation attempts were made to measure the numbers of bacteria redispersed from a contaminated floor by three methods of disturbance: (1) controlled air movements (blowing with a jet of air from an electric hair dryer), (2) sweeping with a broom, and (3) vigorous movements of a subject who did not disperse *Staph. aureus*.

Methods

An area of vinyl floor (4 ft.^{2}) in a small room was cleaned with 70% ethyl alcohol, and a preliminary sample of air (50 ft.^{3}) was taken with a slit-sampler. The floor was then contaminated, either by shaking for 2 min. a blanket brought from the bed of a patient with burns colonized by tetracycline-resistant *Staph. aureus*, or by exercise of the disperser near the cleaned area. A second air sample was taken during the period of contamination, and four settle plates were exposed (period 0–30 min.): the settle plates were then replaced by fresh settle plates which were also exposed for 30 min. (period 30–60 min.). One hour after contamination an air sample was taken, and six impression plates were taken from the floor.

Redispersal of bacteria from the floor was then attempted by directing a jet of cold air from an electric hair dryer at the area of maximum contamination for 2 min. ('blowing'); the velocity of the air stream was measured with an anenometer and found to be approximately 245 ft./min., which was greater than any natural air movements found in the wards or the laboratory. Air samples were taken for 1 min. during and 1 min. after blowing. Four settle plates were again exposed (period 60–90 min.) and six impression plates were taken from the floor immediately after blowing. Settle plates were again changed after 30 min. (period 90–120 min.) and a final air sample was taken 1 hr. after blowing. All air samples were of 50 ft.^{3}. To avoid contamination of air by *Staph. aureus* from the clothing of the operator, samples were taken by different members of the laboratory staff during the period of contamination of the floor and during the period of redispersal. None of these operators was a disperser of *Staph. aureus*.

Similar experiments were carried out on terrazzo flooring, and other methods of redispersal were studied—sweeping with a dry broom, and exercise (jumping for 2 min.) by a non-disperser.

Results

Table 10 shows the result of slit-sampling in six experiments. No marked increase in airborne organisms (either total or *Staph. aureus*) occurred during blowing on a vinyl surface (Expts. 1 and 2). An increase in airborne organisms occurred after blowing on a terrazzo floor (Expt. 3), but there was more contamination of air by

Table 10. *Studies on the redispersal of bacteria from the floor into the air*

	Total counts and counts of *Staph. aureus* in 50 ft.³ of air (slit-sampler)											
	Expt. 1 (vinyl, blowing)		Expt. 2 (vinyl, blowing)		Expt. 3 (terrazzo, blowing)		Expt. 4 (vinyl, sweeping)		Expt. 5 (vinyl, exercise)		Expt. 6 (terrazzo, exercise)	
Time of sampling	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*
Preliminary sample	358	0	370	0	137	0	720	0	101	0	235	0
During contamination*	†+++	8160	7900	2000	8720	2000	5800	2000	2400	460	1136	288
1 hr. after contamination	652	15	364	1	286	8	432	20	92	7	48	0
During floor disturbance	704	24	332	1	458	27	3004	158	169	7	64	1
1 hr. after floor disturbance	464	0	180	0	97	2	32	0	56	0	2	0

* Contamination by shaken blanket in Expts. 2–6; exercise by staphylococcal disperser in Expt. 1.

† Too numerous to count.

Table 11. *Studies on the redispersal of bacteria from the floor into the air*

	Total counts and counts of *Staph. aureus* on four settle plates exposed for 30 min.											
	Expt. 1 (vinyl, blowing)		Expt. 2 (vinyl, blowing)		Expt. 3 (terrazzo, blowing)		Expt. 4 (vinyl, sweeping)		Expt. 5 (vinyl, exercise)		Expt. 6 (terrazzo, exercise)	
Time of sampling	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*
During and after contamination* (0–30 min.)	2136	1004	638	89	832	65	544	99	129	43	68	12
After contamination (30–60 min.)	20	0	18	0	7	1	30	1	5	1	5	0
During and after floor disturbance (60–90 min.)	41	1	39	2	56	4	222	32	2	0	10	0
After floor disturbance (90–120 min.)	19	1	31	1	6	0	16	0	3	0	3	0

* Expt. 1. Contamination by staphylococcal disperser. Expts. 2–6. Contamination by shaken blanket.

Table 12. *Studies on the redispersal of bacteria from the floors into the air**

	Mean total counts and counts of *Staph. aureus* per floor impression plate											
	Expt. 1 (vinyl, blowing)		Expt. 2 (vinyl, blowing)		Expt. 3 (terrazzo, blowing)		Expt. 4 (vinyl, sweeping)		Expt. 5 (vinyl, exercise)		Expt. 6 (terrazzo, exercise)	
Time of sampling	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*	Total	*Staph. aureus*
Before floor disturbance	+++	1240	105	26	390†	14	97‡	21	104	16	75	1
After floor disturbance	+++	1093	112	34	234†	8	31‡	7	116	15	95	1

* Expt. 1. Contamination by staphylococcal disperser. Expts. 2–6. Contamination by shaken blanket.

† t (10 degrees of freedom) = 2·79, $P < 0{\cdot}02$.

‡ t (10 degrees of freedom) = 5·26, $P < 0{\cdot}001$.

sweeping a vinyl floor (Expt. 4). A small increase in total organisms (probably from the subject exercising), but not *Staph. aureus*, occurred during the exercise of a non-disperser (Expt. 5). A similar result was obtained by exercising on a terrazzo floor. The results of the corresponding settle-plate counts are shown in Table 11 and confirm the slit sampling results. Table 12 shows the mean impression plate counts taken before and after attempts at redispersal. Reductions in total organisms and in *Staph. aureus* on the floor were obtained in Expts. 3 and 4; the reduction corresponded to the increase in counts of airborne bacteria. These results show that, in spite of the heavy initial airborne contamination, few staphylococci were redispersed into the air by blowing on the floor or by a subject exercising, More organisms were raised by blowing on a terrazzo than on a vinyl floor, but this redispersal was much smaller than that obtained by sweeping with a broom.

CONTAMINATION OF WALLS

Wypkema & Alder (1962) and Froud, Alder & Gillespie (1966) found little contamination of walls and even less contamination of ceilings in hospital wards and operating theatres. These findings were supported in general by results of the study summarized below, but we describe certain conditions where walls may become heavily contaminated.

Accumulation of bacteria on the wall of an operating theatre

Methods

After a theatre wall had been thoroughly washed with soap and water, an area of 13·5 ft.^{2} was marked off and left uncleaned for 12 weeks. The remaining area of wall was cleaned weekly with a fresh oiled ('Kex') mop (Babb *et al.* 1963). Ten impression plates were taken each week from the uncleaned wall and from the adjacent area of clean wall.

Table 13. *Bacterial contamination of walls in an operating theatre*

Time of sampling (after washing)	Mean counts from 10 impression plates on area: Left intact after washing — Total	Left intact after washing — *Staph. aureus*	Cleaned weekly with oiled mop — Total	Cleaned weekly with oiled mop — *Staph. aureus*
1 day	2·8	0	3	0
1 week	5·0	0	6·4	0
2 weeks	3·4	0·6	2·8	0
3 weeks	3·4	0·2	7	0·2
4 weeks	3·2	0	1·8	0·2
5 weeks	4·6	0·2	1·6	0
12 weeks	1·2	0	1·4	0
1 day after second wash	1·0	0	0·8	0

Results

Table 13 shows the mean count of organisms and of presumptive *Staph. aureus* on impression plates from the two areas of wall. Counts were low, and there was no

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evidence of an increase in contamination during the period of study or of any significant difference between the cleaned and uncleaned areas of wall. The results suggest that a 'plateau' is obtained on wall surfaces, but with a much lower level of contamination than that found on floors.

Bacteria in areas of bare plaster

Impression plates were taken from areas of clean paintwork under the window of an operating theatre. The walls were moist with condensate and included patches of wet exposed plaster. Plate 1 shows the appearance of this wall and of an impression plate taken from it. After overnight incubation, large numbers of bacteria, including many Gram-negative bacilli, had appeared on the impression plate in areas which corresponded with the position of the bare plaster. Similar samples taken from dry plaster exposed on an inner wall yielded very small numbers of bacteria.

Staphylococcal contamination of a wall by fingers of a disperser and the transfer of organisms from these areas by the fingers of a non-carrier

Walls are often touched by contaminated fingers, and it is possible that pathogens may be picked up from such areas by the hands of others and transferred directly or indirectly to patients. An assessment of this hazard was made in the following experiment.

Table 14. *Transfer of* Staph. aureus *from contaminated wall by fingers of non-carrier*

Area of wall sampled	Fingers	Total *Staph. aureus* per plate
Contaminated by disperser	Left 1	21
	Right 2	32
Contaminated by transfer on fingers of non-carrier	Left 3	5
	Right 3	2

Methods

The fingers of both hands of the staphylococcal disperser were sampled directly by impression on an agar plate. Two sets of imprints (L. 1 and L. 2, R. 1 and R. 2) from the four fingers of each hand were made by firm pressure on a tiled wall previously cleaned with 70% alcohol. The disperser's fingers were again sampled on an agar plate. Two of the four contaminated areas were then sampled with an impression plate (L. 1 and R. 2). The fingers of a non-carrier of staphylococci were now sampled on an agar plate, after which the remaining two contaminated areas of the wall were firmly touched by the fingers of both hands of the non-carrier (L. 2 and R. 1). A clean area of the wall was then firmly touched by the contaminated fingers of the non-carrier. These two areas of wall were sampled by impression plates L. 3 and R. 3. Finally the non-carrier's fingers were sampled by impression on an agar plate.

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Results

Table 14 demonstrates the contamination of the wall by the fingers of the disperser (L. 1 and R. 2). *Staph. aureus* was also transferred from the contaminated wall to another area of wall by the fingers of the non-carrier (L. 3 and R. 3), but in much smaller numbers; these staphylococci showed the same antibiotic sensitivity pattern as the organisms isolated from the disperser. Table 15 shows that smaller numbers of *Staph. aureus* were deposited on an agar plate by the disperser after he had touched the wall than before. No staphylococci were isolated from the fingers of the non-carrier either before contaminating the fingers or after transferring staphylococci to a clean area of the wall.

Table 15. *Staphylococcal contamination of fingers of the disperser before and after touching a wall*

Time of sampling	Fingers of disperser	Total *Staph. aureus* per plate
Before contaminating the wall	Left	*ca.* 100
	Right	*ca.* 100
After contaminating the wall	Left	87
	Right	66

Table 16. *Survival of* Staph. aureus *on a wall contaminated by fingers of the disperser*

	Total bacterial counts and counts of *Staph. aureus* per impression plate			
	Expt. 1 (dry fingers)		Expt. 2 (wet fingers)	
Time of sampling (after contamination)	Total	*Staph. aureus*	Total	*Staph. aureus*
1 hr.	12	9	1040	560
1 day	4	0	151	55
2 days	0	0	6	0
3 days	2	0	4	0
4 days	0	0	3	0
7 days	0	0	0	0

Survival of Staph. aureus *on walls*

In view of the heavy local contamination of walls that may occur where they are touched by the hands of the staphyloccocal carrier, experiments were made to assess the survival of *Staph. aureus* on a wall contaminated by the fingers of the disperser.

Methods

Six areas of a glossy tiled wall were contaminated by the fingers of the disperser. Areas 1 to 6 were contaminated in sequence with one hand and the same areas in reverse order 6 to 1 with the other hand so that all areas were contaminated by the fingers of both hands. Dry fingers were used for contaminating the wall in the

first experiment and wet fingers in the second experiment. The areas were sampled in a random order with impression plates 1 hr. after contamination, and then daily for four days and on the seventh day.

Results

Table 16 shows that organisms from fingers, especially *Staph. aureus*, die rapidly on a clean surface. No colonies of *Staph. aureus* were isolated after 2 days. The other organisms isolated were mainly *Staph. albus*. Expt. 2 showed that considerably greater contamination of the wall was obtained with wet fingers.

DISCUSSION

Uncontaminated floors of hospital wards rapidly acquire bacteria from the environment, but after short periods, which vary with the amount of recontamination, the removal and death of bacteria approximately balance the addition of bacteria from the environment. An earlier study (Ayliffe *et al.* 1966) showed that cleaning the floor with a disinfectant (Sudol 1/100) caused a significantly greater reduction in bacterial flora than washing with soap and water when the area was protected from recontamination. Although the effect of cleaning was largely annulled by recontamination, it seemed likely that more effective cleaning would lead to a lower equilibrium level of bacteria on the floor; such a difference was not, however, found in a comparison of contamination levels 24 hr. after cleaning on an area of ward floor cleaned daily with soap and water and a similar area cleaned daily with Sudol (1/100).

From this study we deduce that at most times daily disinfection contributes little or nothing to the bacteriological cleanliness of ward floors. In operating theatres and other areas with less contamination than that which occurs in wards, disinfection or cleaning might be expected to be more effective. The main function of disinfection, however, must be in the removal of sporadic local contamination which occurs when floors or walls become contaminated with sputum, pus, urine and other fluids, or when walls are touched by fingers of a heavy carrier of pathogens. Since the occasions when such contamination occur often pass unnoticed, there is a case for regular disinfection to prevent this sporadic hazard in areas where the risk of contamination is high. Disinfectants also help to prevent a build-up of bacterial contamination in a bucket of water used for cleaning a floor. Gram-negative bacilli are the predominant flora of mop buckets and mops which have not been disinfected after use; though most of the organisms die during the evaporation of the water from the floor, the surface remains wet and heavily contaminated for some time after washing. Neither washing nor disinfection can be expected to remove the heavy bacterial colonization that is found on moist areas of exposed plaster of walls, or on damaged floor surfaces; to remove this hazard the surfaces must be repaired and a new finish applied. In view of the small contamination usually found on walls and the damage that may be caused by frequent washing, there is in fact a case for reducing the frequency of washing walls.

Both contact and airborne contamination of floors were demonstrated in these studies. Since disinfection and other methods of cleaning have limited value in

reducing the numbers of bacteria on floors, it is clearly desirable to prevent contamination of these surfaces. Tacky and disinfectant mats appeared to have very limited value in preventing the transfer of bacteria on shoes; they are clearly no substitute for over-shoes or rubber boots reserved for use in the clean areas. Tacky mats become dirty in a short time, and slippery patches are found on the floor adjacent to disinfectant mats. Transfer of bacteria on hands of carriers to walls and other surfaces can be reduced by washing the hands with antiseptic detergent preparations, and by the use of rubber or plastic gloves in handling infected patients; these measures may, however, fail in the case of heavy dispersers of *Staph. aureus*, who are also likely to contaminate the air with large numbers of staphylococci. In the absence of routine surveillance, a source will not be recognized unless it causes an outbreak of infection; where 'high-risk' patients are under treatment it is clearly desirable to forestall this hazard by surveillance, and also to use various methods to prevent dispersal of staphylococci, including special clothing (Bernard *et al.* 1965), and bathing with hexachlorophane detergent preparations.

The importance of bacteria on floors and walls as a source of infection is not clearly defined. *Staph. aureus* deposited either by settlement from air or by contact disappeared in a few days from contaminated surfaces, but in that time it may be a source of cross-infection. Experiments with radioactive dust (Brunskill, 1966; Jones & Pond, 1966) and with bacterial markers (Carson, 1966) have shown small amounts of redispersal of settled dust. Our failure to redisperse settled bacteria into the air from a vinyl surface and the small numbers redispersed from a terrazzo surface are in keeping with previously reported failures to reduce infection by the oiling of floors (Clarke *et al.* 1954). But while these experiments support the view that floor dust is not an important source of airborne infection, contact transfer (e.g. by toys dropped on the floor, or to nurses' hands when putting on overshoes) may be a sporadic source of infection. Walls and doors, which acquire much smaller levels of bacterial contamination than floors, may be heavily contaminated by sporadic contact (e.g. with fingers of a staphylococcal carrier); since such contamination is likely to occur in areas touched or handled by many people, it may be an important cause of infection from the inanimate environment.

SUMMARY

Impression plates from initially clean horizontal surfaces and floor areas in surgical wards showed a rapid accumulation of bacteria, mainly micrococci, which reached a fluctuating equilibrium after about 24 h. A later increase in bacterial contamination (mainly with aerobic sporing bacilli) to a higher equilibrium level after about 14 days occurred on uncleaned areas. Walls, even if left unwashed, acquired very few bacteria, but many were deposited locally when the wall was touched by a subject whose skin carried large numbers of staphylococci; moist exposed plaster was also heavily contaminated.

Regular use of a disinfectant ('Sudol' 1 in 100) in cleaning a ward floor did not reduce the equilibrium level of bacteria on the floor.

The transfer of staphylococci from contaminated to clean areas on the soles of shoes was demonstrated; the use of tacky and disinfectant mats did not appreciably reduce the transfer of bacteria by this route.

Staphylococci deposited on a wall by a disperser were shown to be transferred from the contaminated area of wall to the hands of another subject who did not previously carry the organism; this subject was shown to transfer the staphylococcus to a wall which he touched.

Attempts to redisperse by air movement *Staph. aureus* which had been shed by a disperser or by a contaminated blanket on to the floor surfaces had little effect; neither blowing with a hair dryer nor brisk exercise appeared to lift any of the staphylococci from a vinyl surface, and only small numbers were lifted by these measures from a terrazzo surface.

The hazards of infection from the inanimate environment are discussed.

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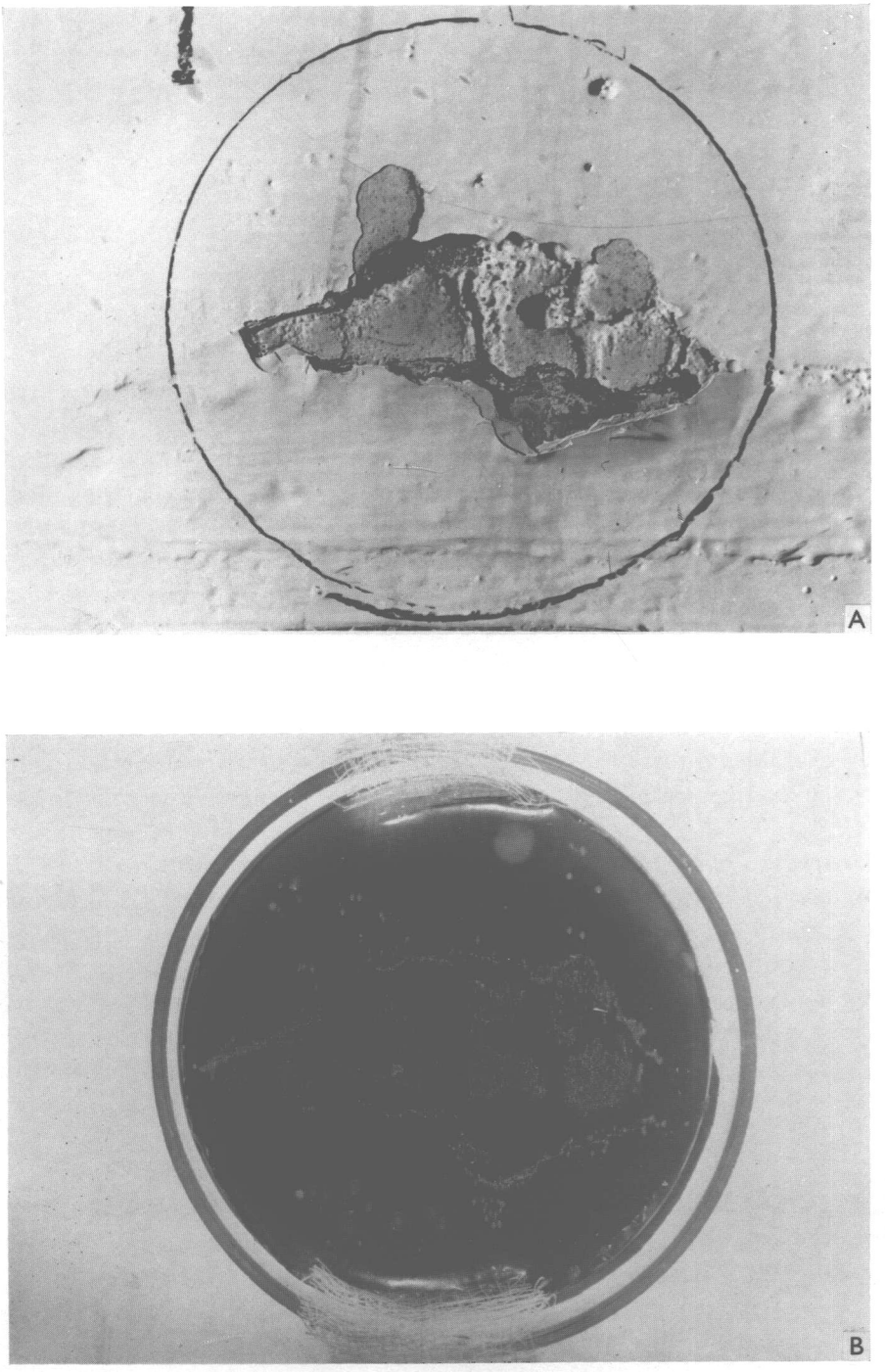
EXPLANATION OF PLATE

A. An area of moist exposed plaster on the wall of an operating theatre from which paint had flaked.

B. An impression plate from the same area showing heavy bacterial growth.



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