

Contamination of an operating theatre by Gram-negative bacteria. Examination of water supplies, cleaning methods and wound infections

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SUMMARY

This paper describes a search for Gram-negative bacteria in an operating theatre and the steps taken to reduce the level of environmental contamination.

A high rate of infection in clean wounds prompted a bacteriological survey. Potential sources of infection found, and the measures employed are described in the hope that others may be encouraged to examine familiar equipment critically and to improve hygiene even in old premises.

The choice, design, use and care of cleaning and sterilizing equipment were open to criticism. In particular, a currently popular floor-scrubbing machine provided a breeding ground for *Pseudomonas aeruginosa* and was distributing it in the theatre environment.

INTRODUCTION

During the first 3 months of 1970 the rate of Gram-negative infection of clean wounds increased from 10% to 18% (Table 1) among patients operated upon in a single theatre which was used for both clean and dirty cases. Johnstone's (1970) definition of a dirty operation as one performed in the presence of sepsis, or procedures such as anal operations and colostomy, is followed.

The information concerning infected wounds was gathered from data accompanying pus and swabs sent to the laboratory at the discretion of the clinicians concerned.

A preliminary inspection of the operating suite in April led to a continuous bacteriological survey during which a series of repairs, improvements and hygienic measures was implemented to reduce the level of bacterial contamination of the environment.

METHODS OF THE SURVEY

Nose and throat swabs were taken from the theatre staff. An initial sanitary inspection of the theatre premises was followed by weekly visits and interviews with the staff. Twenty-one sites were cultured, many of them at weekly intervals (Fig. 1). Cotton-wool swabs, moistened on the medium for dry sites, were rubbed over an area of about 10 cm.² and then on blood agar and MacConkey agar plates incubated overnight at 37° C. Bacteria were identified by conventional methods. A sample of the pseudomonas strains isolated was typed by the Cross-Infection Reference Laboratory at Colindale.

RESULTS OF THE SURVEY

Nose and throat swabs from the theatre staff revealed neither Gram-negative infection nor penicillin-resistant staphylococci.

The theatre suite consisted of a main operating room and six other rooms interconnected and opening to one corridor. The unit was old and some repairs asked for had not been carried out. There was no air conditioning, the floor was cracked and a door and window broken. At the first survey in April, 13 sites in the theatre which were cultured all yielded confluent growth of *Pseudomonas aeruginosa* and other Gram-negative organisms.

Fig. 1. shows diagrammatically the results of cultures from various sites, with some notes on measures taken. Each square on the figure shows the result at one site. Only a sample of the total pseudomonas cultures was typed. Six of the 11 environmental strains typed were of serotype 10, phage pattern (100 RTD) 44/68+ and such strains are shown as 'endemic' in the figure.

Table 1. *Clean procedures in an operating theatre during 10 months with the organisms isolated from subsequent wound infections*

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.
Total procedures	52	50	40	50	36	35	30	20	30	41
Wound swabs sent to laboratory	15	17	10	16	14	19	8	7	10	10
No bacteria found on culture	4	1	1	4	2	5	4	2	4	2
<i>Gram-positive bacteria</i>										
Penicillin resistant <i>Staphylococcus aureus</i>	4	7	3	2	1	3	1	3	0	2
Penicillin sensitive <i>Staphylococcus aureus</i>	0	1	0	2	3	3	0	1	3	3
Other Gram-positives streptococci and skin commensals	2	2	1	3	3	5	1	0	1	1
Total Gram-positives and percentage clean procedures	6 (12%)	10 (20%)	4 (10%)	7 (14%)	7 (19%)	11 (31%)	2 (7%)	4 (20%)	4 (13%)	6 (15%)
<i>Gram-negative bacteria</i>										
<i>Pseudomonas aeruginosa</i>	0	1*	2*†‡	3*†‡	0	0	1	0	0	0
<i>Klebsiella</i> species	0	1	0	2	1*	1	0	1	0	0
Common gut species, <i>Escherichia coli</i> , <i>Proteus</i> species, etc.	5	5	5	1	5	4**	1	0	2	3
Total Gram-negatives and percentage clean procedures	5 (10%)	7 (14%)	7 (18%)	6 (12%)	6 (17%)	5 (14%)	2 (7%)	1 (5%)	2 (7%)	2 (5%)

* *Staphylococcus* also present in one swab.

† Haemolytic streptococcus also present in one swab.

‡ Endemic strain of *Pseudomonas aeruginosa* also present in one swab.

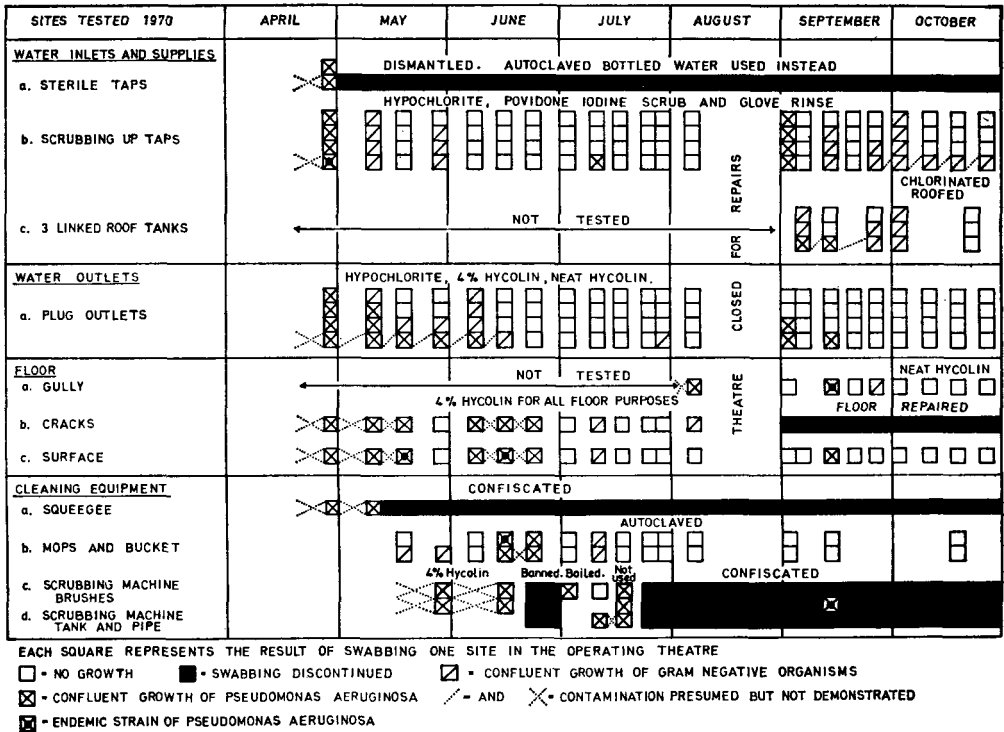


Fig. 1. Sites in the operating theatre contaminated by *Pseudomonas aeruginosa* and other gram-negative organisms.

Five main potential sources of infection were discovered.

1. Plumbing supplies and outlets.
2. The floor.
3. Floor-cleaning methods.
4. Instrument sterilizing methods.
5. Maintenance of premises.

Plumbing

Sterile water

Fixed in the wall of the main theatre were taps from a 'sterile' water supply used for moistening swabs and rinsing instruments. Profuse Gram-negative bacilli were isolated from these taps. The 'sterile' water apparatus was removed and bottled autoclaved water supplied by the dispensary instead.

Washing

Eight washing sinks in the suite had mixer taps for cold and hot water, which was often tepid. Cold water was drawn from linked roof tanks which were not inspected until September when they were found to be bird-fouled, without covers and containing two dead pigeons. The tanks were cleaned out and superchlorinated and the temperature of the hot water supply was increased. Profuse pseudomonas

and other Gram-negative bacteria were isolated from all the taps. Spray roses were removed and a syringe and catheter was used to inject 40 ml. of a 2% solution of hypochlorite (20,000 parts per million available chlorine) into each tap each evening. This treatment produced negative cultures in general, but contamination recurred occasionally. Broken contaminated hexachlorophane dispensers were replaced by a povidone iodine dispenser beside each hand-washing sink.

Water outlets

Stagnant water lay in U-bend waste traps below each plughole and four sinks also had inbuilt overflow traps. An outflow trap leading from a gully in the floor of the main theatre was unclean. Swabs taken from plugholes and U traps produced, as had been expected, a confluent growth of Gram-negative bacilli. An attempt was therefore made to find whether contamination might have spread upward from plugholes. Blotting paper cards were fixed over several taps so that the faucet protruded. Methylene blue was put in and around the plughole and the tap turned on. Blue splashes appeared on the blotting paper showing that water from the plughole area could be splashed up inside the faucet.

Another test was made with blotting paper attached above waist level at the front of a gown. Blue splashes appeared at distances up to 18 in. above the plughole and across a width of 17 in. More sophisticated splash tests have been made by Kohn (1967). Following this evidence, sink plugs were discarded and plugholes and overflow pipes were treated with 40 ml. neat Hycolin each evening, which eliminated bacterial growth. Previously 2% hypochlorite and then 4% Hycolin solutions had been ineffective. The four sinks with overflow fittings are to be replaced.

Floor

Although repairs had often been requested, a cracked terrazzo floor had broken vulcanite fillets and an attempt had been made to bridge cracks with sticking plaster to prevent accidents. The surface, the cracks, and the plaster were heavily contaminated with *Ps. aeruginosa* of the endemic type (Fig. 1). This was traced to cleaning equipment (see below).

The floor was re-surfaced.

Footwear

Sterile booties were placed outside the theatre suite, to slip over outdoor footwear. A bin was provided for those discarded after leaving the theatre. This simple arrangement needed careful supervision to prevent the mixing of clean and dirty booties.

Floor-cleaning methods

Cleaning of the operating suite was the responsibility of a theatre sister, not the domestic superintendent. It was carried out by a domestic worker and theatre porters.

Mops

The disinfectant policy of the hospital recommended mops with heads which could be autoclaved, but unsterilizable string mops and squeegees were still being used in the theatre. A string mop was used with detergent each morning and also for mopping up spilt blood. After use it was returned to a bucket of Hycolin. No one was prepared to name the age or concentration of this disinfectant, which yielded a confluent growth of the endemic pseudomonas (Fig. 1).

Mops with detachable heads were introduced. These were supposed to be autoclaved daily, but persistent contamination made it clear that, initially, this was not being done. Considerable effort was required to ensure that the mop heads were actually autoclaved. Bacteria then ceased to live on the mops.

Scrubbing machines

The floor was scrubbed daily by a modern machine and then partially dried with a squeegee and mop. A second modern machine of another make had stood unused for some time. It had been tried once, when the tank was found to be too heavy for one person to empty.

The scrubbing machine in use was examined in detail. Three revolving brushes were supplied with water through a long narrow bent junctioned pipe, leading through a plastic valve from a fibreglass tank with a smooth outer surface and rough inner surface. The brushes were washable and could be autoclaved, but the feedpipe and tank could not.

Before the survey, Teepol detergent had been used in the machine. This was replaced by 2% Hycolin and then because floor contamination persisted, by 4% Hycolin, which is twice the recommended concentration. The machine brushes, nevertheless, showed very heavy contamination with *Ps. aeruginosa* and other bacteria, so they were autoclaved, but after return to use they were found to be as heavily contaminated as before. Only then was the fluid inside the tank, nominally 4% Hycolin, cultured. More than 10^5 bacteria per ml., mainly pseudomonas, were counted (Plate 1). Since it was not feasible to sterilize the tank or feedpipe, the use of the machine in the operating theatre was stopped. Autoclavable mops and scrubbing brushes, each detachable from its long handle, were obtained and the floor was cleaned with 4% Hycolin.

The scrubbing machine was studied further in the laboratory. The tank and the feedpipe leading to the brushes contained a sludge of micro-organisms, predominantly *Ps. aeruginosa*, and the endemic strain was still present when the machine had been out of use for 7 weeks (Fig. 1). Experiments showed that a spray of dirty water could be collected at a distance of 2 ft. from the machine, both at floor level and 1 ft. up the wall. Gram-negative organisms were grown on plates exposed in both these positions. Fig. 2 shows the direction of the spray thrown out by the machine. A sink at a distance greater than 6 ft. from the machine might receive organisms in the spray, depending on droplet size and incident draughts.

With the help of Mr R. Barfield of the Maintenance Department a machine provided by the manufacturers for experimental purposes has been reconstructed.

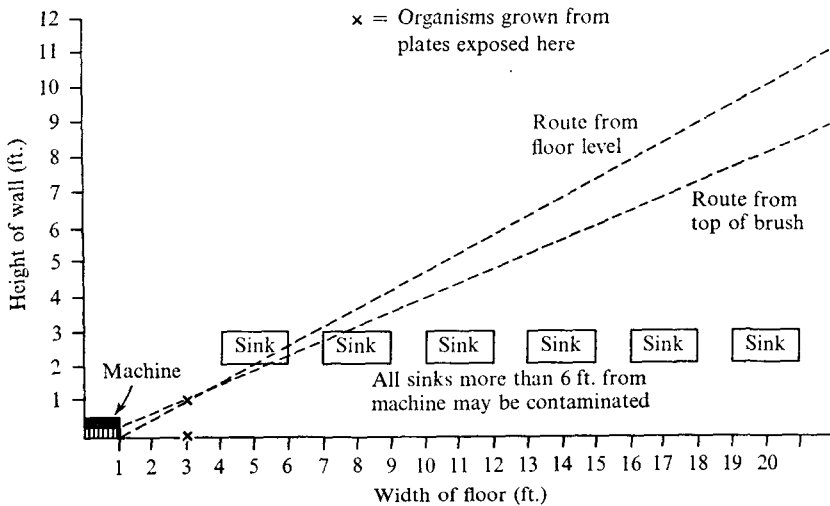


Fig. 2. Possible route of micro-organisms from scrubbing machine to sinks.

The modification has a stainless-steel tank and valve connected to a short length of transparent tubing. These are easily removed as a unit for washing and autoclaving. A rubber mudguard around the floor unit reduces the height of splash from the rotating brushes to under 3 in.

Instrument sterilizing methods

Although inspected regularly by the makers, an obsolescent autoclave in the operating suite was not working efficiently. Centralized steam pressure varied but it has now been controlled by a new regulator. It has been agreed that every autoclave in use shall be tested daily and maintained as described in *Hospital Technical Memorandum* No. 10 (1968). A central sterile supply department service for porous loads is being arranged.

A boiling water 'sterilizer' was in use for bowls and some instruments, producing steam which condensed on surfaces. The use of this apparatus for instruments in the theatre was discontinued as recommended by the Department of Health (1969). In any case it was found to be uninsurable.

Maintenance of premises

In addition to the dilapidated floor and water tanks described above, a broken door and window permitted draughts from a pigeon-fouled area. Discarded dressings and wrappings were in dustbins obstructing a fire escape. Ill-fitting lids allowed the contents to scatter as litter.

The floor, door and window were repaired and the tanks cleaned and roofed. The fire escape was cleared and arrangements made for theatre refuse to be collected in plastic bags and taken directly to the incinerator.

Table 2. Number of operating theatre sites found contaminated by Gram-negative bacteria

Number of sites	Apr.	May	June	July	Aug.	Sept.	Oct.
Swabbed	13	36	38	66	13	63	48
Contaminated by Gram-negative organisms	13 (100)	24 (67)	17 (45)	11 (17)	2 (15)	22 (35)	10 (21)
Contaminated by <i>Pseudomonas aeruginosa</i>	13 (100)	12 (33)	13 (34)	6 (9)	1 (8)	12 (19)	0 —

The figures in parentheses are percentages.

Table 3. Wound swabs examined before and after implementation of hygienic measures in operating theatre environment

	Jan. to June	July to Oct.
Clean incisional operations	263	121
Wound swabs sent to laboratory	91	35
Gram-positive organisms found	45 (17)	16 (13)
<i>Staphylococcus aureus</i> found	29 (11)	13 (11)
Gram-negative organisms found	36 (14)	7 (6)
<i>Pseudomonas aeruginosa</i> found	6 (2)	1 (1)

Figures in parentheses are percentages of the total operations in each group.

RESULTS OF HYGIENIC MEASURES

Details of the growth of Gram-negative organisms from a variety of sites in the operating theatre are shown diagrammatically in Fig. 1 and summarized in Table 2. Apart from the repair of the theatre floor, and the treatment of the water tanks on the roof, most improvements in hygiene were introduced before or during July. Perhaps some of the increased contamination in September came from the pigeon-fouled water supply and as a result of floor repairs. Table 3 shows the numbers of operations and of wound swabs sent to the laboratory before and after the introduction of these measures, and is a summary of the detailed information set out in Table 1. During the period from January to October, inclusive, 384 clean procedures were undertaken in this theatre and 43 Gram-negative wound infections including seven with pseudomonas present were diagnosed in the laboratory (Tables 1 and 3).

After June the percentage of swabs yielding Gram-negative organisms was halved (from 14% to 6%) as was the proportion yielding *Ps. aeruginosa* (from 2% to 1%) (Table 3). The temporal correlation of Gram-negative organisms found in the environment and in wound swabs is shown in Fig. 3. As the sources of Gram-negative organisms in the environment became fewer, a smaller proportion of wound swabs yielded Gram-negative organisms, but there was no change in the proportion of swabs yielding *Staphylococcus aureus*.

The endemic strain of *Pseudomonas aeruginosa*, serotype 10, phage pattern (100 RTD) 44/68+ was grown from a scrubbing-up tap in April, the floor surface

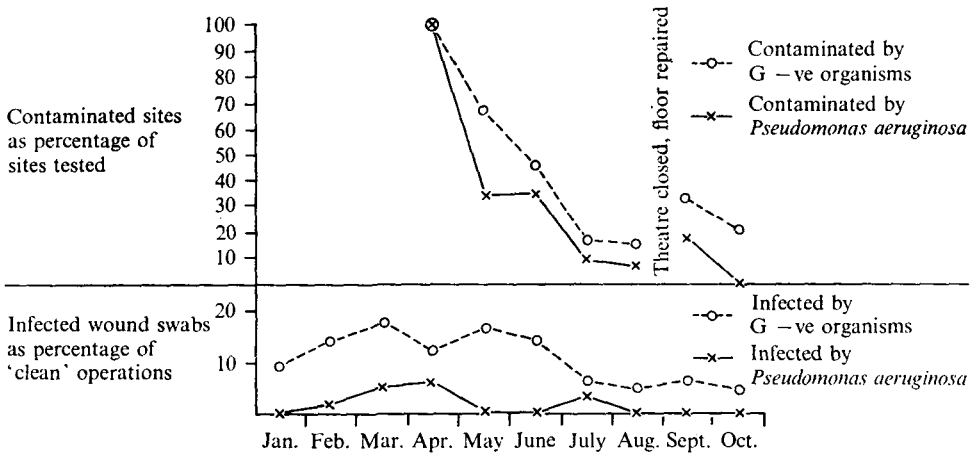


Fig. 3. Correlation between contaminated sites in operating theatre and infections in 'clean' incisional wounds.

in May and June, the floor mop in June, the floor outlet and the scrubbing machine tank (out of use) in September. The same strain was grown from one wound swab in March and two in April. The remaining four patients' strains were not typed.

DISCUSSION

It should not be accepted that a heavily contaminated environment is inevitable in an old hospital building nor that any improvement in hygienic standards will be costly. The part played by age and dilapidation in this case was limited, although there were serious failures of maintenance. Major faults lay in poor design or unsuitable choice of comparatively new equipment, and in failure to appreciate the nature of the risk of infection in various practices. Improving conditions in the operating theatre was not simple. Communication between members of the staff was incomplete, advice was not always understood or carried out and there had to be some changes of plan. Ayliffe, Brightwell, Collins & Lowbury (1969) found frequent discrepancies between methods thought to be in use and what was actually done in hospital wards, and they advocated systematic training in the control of infection at several staff levels.

The present work was not planned in advance as a scientific study, but arose from the practical need to reduce wound infection and was co-ordinated by the Control of Infection Committee. The entire co-operation of the hospital secretary, pharmacist, surgical teams, theatre sister and staff and maintenance staff, and reliable advice received informally from many outside quarters combined to achieve worthwhile improvements.

The aims of this work, which were to reduce the number of infections and to improve working conditions in the theatre were achieved, and at comparatively small cost, which was probably soon covered by a saving on antibiotics and treatment, since an excess stay in hospital of 7.3 days for patients with sepsis has been estimated (P.H.L.S. Report on surgical wound infection, 1960). The bacteriological

survey was neither detailed nor costly. It was carried out amid the routine of a small hospital laboratory, except for the typing of pseudomonas strains which was undertaken by the Cross-Infection Reference Laboratory, Colindale. When cost is being considered, it is worth noting that expensive equipment may be worse than cheaper methods. A new scrubbing machine was dirtier than mops, and an elaborate 'sterile' water apparatus in use was contaminated. In 1959, a Medical Research Council Working Party, and in 1964, Kelsey & Beeby, emphasized that water for use in operations should be autoclaved in bottles.

Gram-negative bacteria have often been demonstrated in hospital sink outflows, and careful observers have come to different conclusions. Kohn (1966) associated *Ps. aeruginosa* in outflows with infected burns, whereas Jellard & Churcher (1967) in a neonatal unit, and Lowbury *et al.* (1970) in a study of tracheostomies, concluded that patients were seldom infected from this source. Wormald (1970), also in a burns unit, found concordance of patient and basin outflow pseudomonas strains so infrequent that he discontinued a waste-trap sterilizing procedure. But he noted that a serotype 10 imported in a patient became firmly established in the wash-basin. Simple splash tests indicated that a danger exists if a susceptible victim and an infective dose of pathogens coincide. Bacteria from the bottom of a sink can splash onto a surgeon's gown and also enter and colonize scrubbing-up taps. Plug outlets here have been dosed with neat Hycolin at the end of each day. This method is expensive but has shown considerable success. Contamination of the washing taps was reduced by daily injection of hypochlorite solution. In addition the water supply tanks were put in order and the hot water temperature increased. The neglect of the tanks exemplifies a common failure to inspect and maintain old installations in hospitals. However, hospital plumbing design needs radical re-thinking to reduce the hazards of stagnant water.

Gross contamination of the theatre suite was traced to a modern scrubbing machine which provided a breeding ground for Gram-negative organisms and sprayed bacteria around the theatre. Draughts between a broken south door and an open north window sometimes aided this dispersion. Spray could reach the sinks as shown in Fig. 2. It was impossible to clean or sterilize the inside of the scrubbing machine tank or, because of a projecting filter, to empty it completely. When Hycolin replaced a detergent in the tank, the heavy load of micro-organisms was too great for chemical disinfection. No disinfectant could be depended upon to render safe a machine of this design. Indeed, Gram-negative organisms may multiply in disinfectant solutions. Maurer (1969) has described an increase in the numbers of pseudomonads in some disinfectant solutions. The findings indicate that the hygienic design of scrubbing machines needs attention. Brushes, tanks and feedpipes should be easy to remove and sterilize. Internal surfaces should be smooth, pipes short and the whole easy to clean. Brush splash should not rise at a high angle from the floor. One machine was reconstructed to meet these requirements.

Although there was no evidence to show that autoclave failure contributed to wound infection in this hospital, it was disturbing to find that adequate written instructions in the use of the autoclave had not been given and that it was not working reliably although regularly inspected by the manufacturers.

Many patients included in this survey were given antibiotics before pus was sent to the laboratory. In the last decade there has been a steady increase in the use of ampicillin which tends to be prescribed for rises of temperature regardless of any bacteriological findings. No doubt this explains the failure to grow bacteria from some wound swabs (Table 1). It has been suggested that a rise in Gram-negative infections may be due to increased use of broad spectrum antibiotics (Johnstone, 1970). Hexachlorophane preparations, which were in use at the start of the survey, have been considered a potential source of Gram-negative infection (Collins & Deverill, 1971).

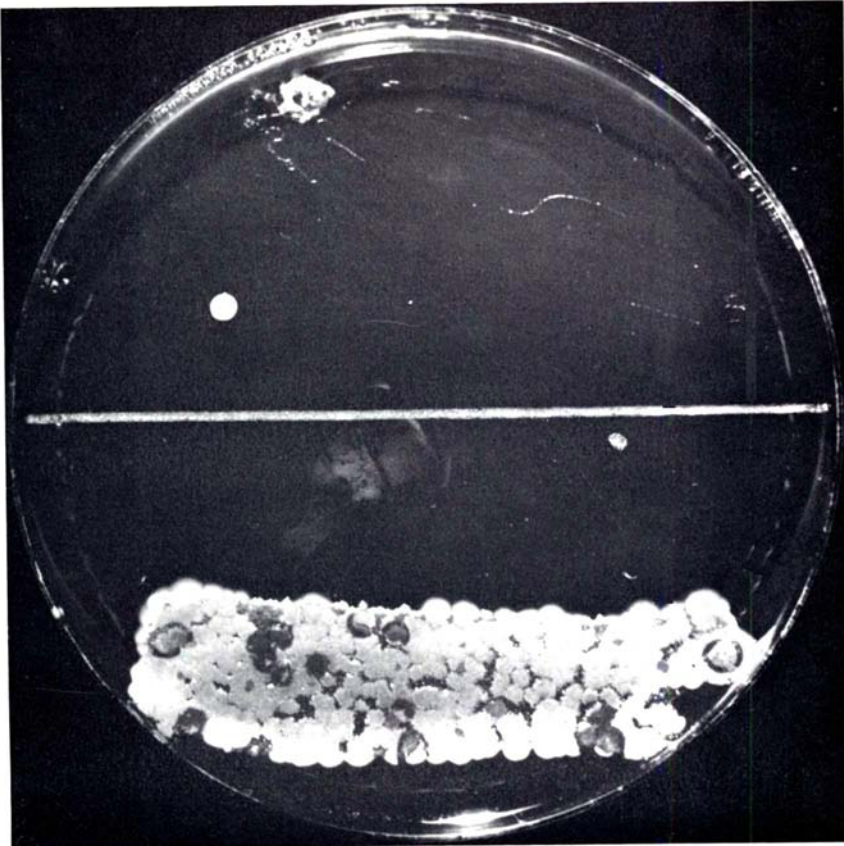
In spite of the high level of Gram-negative contamination in the operating theatre, most patients escaped overt infection. Several hundred operations were performed and only seven pseudomonas wound infections reached the laboratory. Three of the cultures were typed and showed the same phage pattern as the endemic strain in the theatre environment. Although this does not exclude sources of the same organism in food or wards, it makes theatre infection a serious possibility. Factors increasing liability to post-operative infection have been reviewed (McEwin, 1970). Pseudomonas infection was related to poor condition of the patient. Wormald (1970) found that patients with burns of over 30 % body surface became colonized much more often than did those with less injury. Our pseudomonas-infected patients were older (average 65 years) and more ill (4/7 with cancer) than others and their wounds discharged pus for longer (60 days). For comparison, the average age of a similar number of patients with wound infections in which staphylococci alone were isolated was 50 years, 1/7 had cancer and their wounds discharged for 19 days. In no case was *Pseudomonas aeruginosa* isolated in pure culture. A klebsiella, a streptococcus, three *Staphylococcus aureus* and three *Escherichia coli* were isolated in association. *Pseudomonas aeruginosa* may offer little risk to adult patients who are not old and frail or burned. Nevertheless, a theatre is better off without vermin, be they pigeons, cockroaches or bacteria. The recent reports by Powell & Rogers (1971) of a salmonella colonization of a suction pipe system in a premature baby unit and by the Peterborough Public Health Laboratory (1971) of an outbreak of *Ps. aeruginosa* infection in a genito-urinary ward are relevant warnings.

It is obviously impossible to prove cause and effect in a non-experimental setting or to draw firm conclusions from small figures, but the sequence of events here is suggestive. The reduction in contamination in the theatre was accompanied by a reduction in infection. The effect of the survey on methods and decisions was beneficial. Hospital administrators may welcome an opportunity to visit premises under discussion accompanied by an informed source of advice.

In this work exhortation achieved little, but demonstration of correct methods, photographs and bacterial cultures showing the contamination arising from failure to use correct methods made a strong impression on the staff. While a tolerable standard of hygiene was achieved, it is questionable whether this would be maintained without surveillance.

Although this report may appear depressing at first sight, the improvement in standards reflects great credit on all those responsible for the upgrading and in

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particular the members of the Control of Infection Committee. We hope that this description may encourage committees in other hospitals to examine critically, equipment and methods in use in operating theatres, not forgetting those used for cleaning. Mr Barfield's invaluable modification of a scrubbing machine, which it is planned to describe in detail elsewhere, is likely to play a significant part in the reduction of contamination in the environment of hospitals.

We are indebted to Dr J. C. Kelsey, Dr M. T. Parker and Dr T. M. Pollock for constructive criticism and also to some members of the Department of Health and Social Security for detailed technical advice. These include, in particular, Mr G. R. Wilkinson and Mr J. C. T. Williamson of the Scientific and Technical Services Branch of the Supplies Division, with Mrs J. Goodman and Mr I. W. Little of the Hospital Domestic Management Division.

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EXPLANATION OF PLATE

Two-swab plate (July 1970). A. Scrubbing machine brush (boiled). B. Scrubbing machine tank.