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AIRBORNE CONTAMINATION AND POSTOPERATIVE INFECTION AFTER TOTAL HIP REPLACEMENT

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The results of 163 hip replacements at the Uppsala University Hospital are presented. Deep infection occurred in ten cases and was caused by Staphylococcus aureus in four early or intermediate infections and by anaerobes in four late infections. The remaining two infections (both of which were late) were probably associated with Staphylococcus albus—in one case possibly also with alpha streptococci. Two superficial infections not affecting the operative result were caused by Staphylococcus aureus and betahaemolytic streptococci. The results of environmental analyses of staphylococci and the total number of bacteria in the air during 77 operations did not indicate that airborne infection is a major cause of postoperative infections—there was no difference between the number of bacteria found in the air during operations after which infection occurred and uninfected operations, and the use of special zonal ventilation with high rates of air exchange in the operating area had no effect on the infection frequency.

Key words: airborne bacteria; arthroplasty of hip; postoperative infection; ventilation

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Hospital infections have again been the object of much attention and intensive debate. However, surprisingly little is known as yet about the real significance of various ways of transmission and what the most suitable control measures should be.

This subject has been much discussed in orthopaedic surgery, particularly in cases of deep infection after total hip replacement. The frequency of infection varies in different investigations from only a few per cent up to 12 per cent or more (Charnley & Eftekhar 1969, Amstutz 1970, Lindberg 1976). According to Charnley (1972) this infection is mostly airborne and transmission takes place in connection with the operation; in operation suites with conventional ventilation it is hardly possible to have less than four per cent deep infections, but if "ultraclean air" ventilation is introduced it is possible to reduce the incidence to below one per cent (Charnley 1964, 1972, Charnley & Eftekhar 1969, Eftekhar 1973). During the years that Charnley has carried out his tests he has, however, also introduced other protective measures, such as special clothing, changes in operation technique, double surgical gloves, etc. This renders the evaluation of a separate measure like ventilation difficult.

In this paper a bacteriological and epidemiological study will be reported which was undertaken in the operation suite of a department of orthopaedic surgery during operations of total hip replacement. Special attention was given to transmission of infection in connection with operation.

PATIENTS AND METHODS

Patients

One hundred and forty-nine patients were subjected to total hip replacement with the Charnley prosthesis from 1972 to 1974. In 14 patients, double-sided replacement was carried out. Altogether 163 hip replacements were thus performed. The majority of the patients were over 60 years of age. The number of males and females was about the same. The shortest observation period was one year and the longest three years. For 77 patients the observation period was more than two years.

Bacteriological investigation

During the investigation period, routine samples from nose and throat were taken once a week from all operating staff. Specimens were taken from all patients with clinical signs of wound infection and on re-operation.

Prospective study

Eighty-four patients were included in a prospective study. On the day of operation samples were taken from the throat, nose, perineum, and the skin of the forearm of the patients.

During 77 operations, four sedimentation plates were placed in different parts of the operation room. The plates were exposed for eight hours.

Cultural technique

All samples were taken with cotton swabs. Before the skin test was carried out, the swab was moistened in peptone water. The swabs were transported in agar slants. Stuart transport medium was used for wound specimens.

Nose, throat, and skin specimens were cultivated on sheep-blood agar plates only. Perineum specimens were also cultivated on phenolred-mannitol agar.

Wound samples were cultivated on blood agar plates with and without gentian violet, on haematin agar, phenolred-mannitol agar plates, and on anaerobic-blood agar plates with the addition of yeast extract, vitamin K, and haemin. The plates were incubated at 37° C and read after 24 and 48 hours. Anaerobic culture plates were observed for five days and culture was performed according to modern techniques (Anaerobe Laboratory Manual 1973).

Sheep-blood agar plates were used as sedimentation plates and read after 48 hours incubation. The total number of bacteria and Staph. aureus was determined. The number of bacteria-carrying particles/m^3 was calculated from the number found on the sedimentation plates assuming a sedimentation rate of 0.3 m/min (Noble et al. 1963).

Isolated bacteria were verified according to current techniques. All Staph. aureus were phage typed according to Blair & Williams (1961). Resistance to penicillin was determined with the disc-diffusion method according to Ericsson & Sherris (1971).

The design of the operation unit

The design of the central part of the suite, i.e., the operation room with surrounding area,

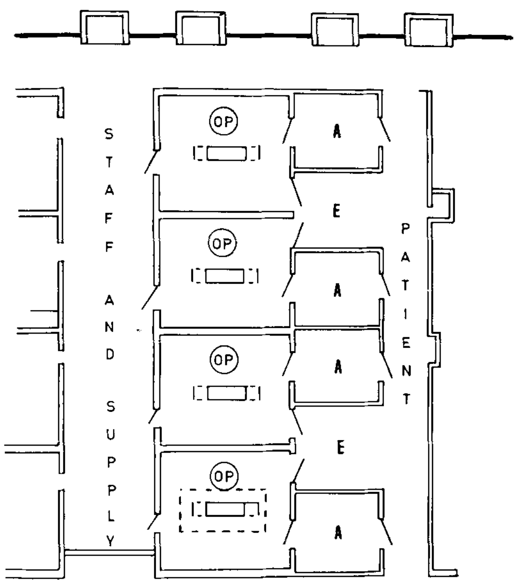

Figure 1. General outline of one block of four operation theatres.
OP: Operation room. The room with the broken line is equipped with zonal ventilation.
A: Anaesthetic room.
E: Exit area.

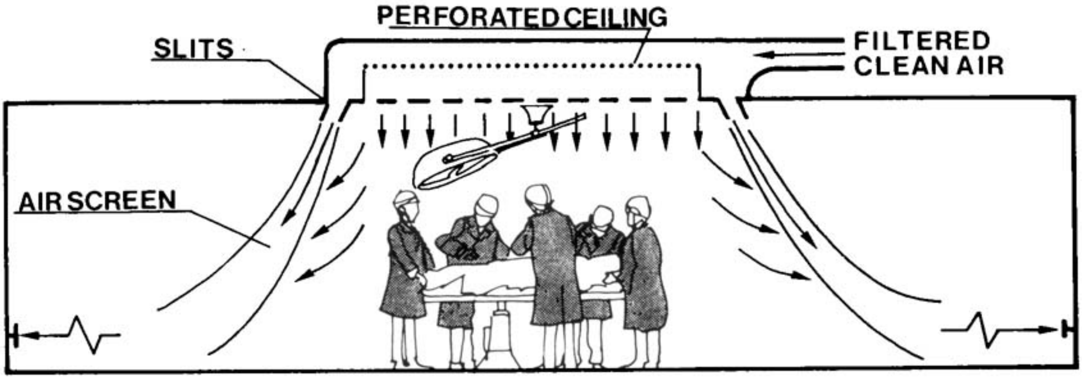

Figure 2. Design of operation room with zonal ventilation.

is shown in Figure 1. As can be seen, it is a two-corridor system in which patients are brought from one of the corridors into the operation room via an anaesthetic room. After operation the patient is transferred to an extubation area which is shared by two operation rooms, and then leaves the unit via the same corridor. The other corridor is used by the staff and for incoming clean goods.

There are two ventilation systems for the operation rooms. One is conventional with up to 18 to 20 changes of air per hour. In the other system the main part of the air is introduced above the operation table, a so-called zonal ventilation (Figure 2). A higher exchange of air is thus achieved—about 80 changes per hour in the central part of the room (Abel & Allander 1966).

Criterion of infection

In addition to bacteriological findings the criteria listed by Ericson et al. (1973) have been considered.

RESULTS

A. Infections

During the study there were ten deep infections involving the area of prosthesis. These cases are presented in Table 1.

Cases 1 to 3 where Staph. aureus was isolated were early onset infections. The

Table 1. Ten cases of deep infection after total hip replacement.

Case no.	Sex	Age	Months before sign of infection	Infecting agent	Type of ventilation
1	M	71	0	Staph. aureus 6/42E/47/53/54/75/83A	CV*
2	F	65	3	Staph. aureus 3 C	CV
3	M	46	2	Staph. aureus 29/52	ZV*
4	M	75	6	Staphylococci?	ZV
5	F	74	14	Propionibacterium sp.	ZV
6	F	54	16	Peptococcus sp.	CV
7	M	70	17	Peptococcus sp.	CV
8	M	65	19	Peptococcus magnus	ZV
9	M	63	13	Staph. albus	ZV
10	F	44	11	Staph. albus? Alpha streptococci?	CV

* CV = Conventional Ventilation.
ZV = Zonal Ventilation.

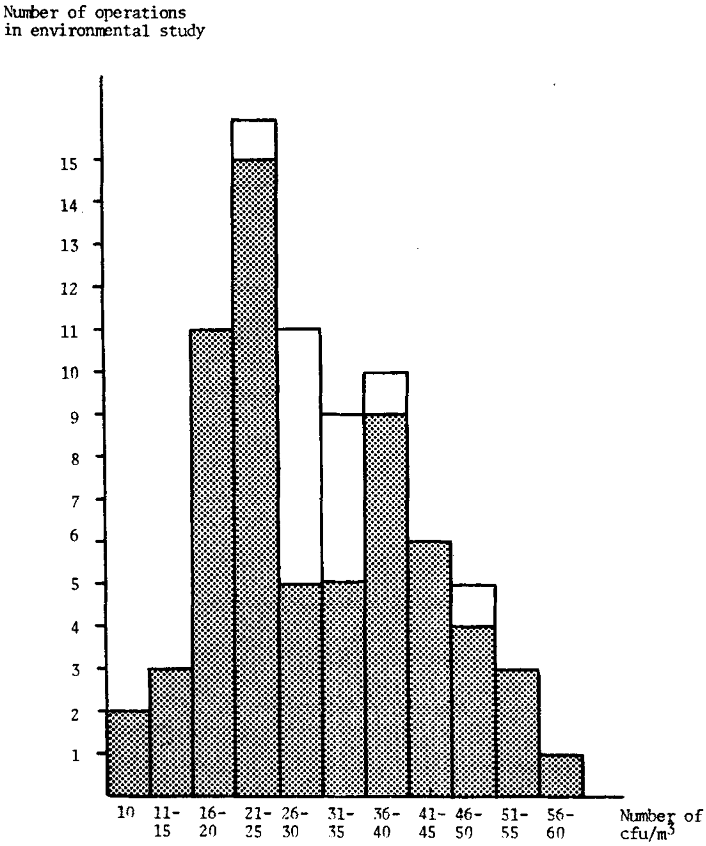

Figure 3. Open bars: operations performed in rooms with conventional ventilation. Shaded bars: operations performed in rooms with zonal ventilation.

staphylococci all had different phage patterns.

Case 4 was an intermediate onset infection where an increase in anti-staphylolysin titre indicated the possibility of a staphylococcal infection.

Cases 6–10 were all late infections. In 4 cases anaerobic bacteria were isolated: in three cases peptococci and in one case propionibacteria.

From the two remaining patients with late infections Staph. albus was isolated in one case and Staph. albus and alpha streptococci in the other. The staphylococci and alpha streptococci in case 10 were isolated on different occasions and their role in the infection is difficult to establish.

There were two superficial infections, one was caused by betahaemolytic streptococci and engaged the operation wound. The infection was treated with V-penicillin and healed. This patient (case 9) later developed a deep infection. The other superficial infection, from which Staph. aureus was isolated, occurred in a pressure wound caused by a plaster cast.

B. *Prospective study*

Staff

Staph. aureus was isolated from the respiratory tract in 43 per cent of the 169 individuals who took part in operations. Phage typing showed that 79.8 per cent of isolated strains were typable. Group I was the most common with 40 per cent, followed by group III with 18.9 per cent, and group II with 15.8 per cent. Determination of resistance to penicillin

Table 2. Four cases of

Case no.	Staph. aureus, c.f.u./m³	Total bacteria, c.f.u./m³	Carriers of Staph. aureus Patient	Staff
1	0.13	23	ND*	See text
2	ND	ND	ND	See text
3	1.0	37	No	5
Superficial infection	0.38	28	Nose–throat + perineum	4

* ND = Not Done.

showed that 62 per cent of the strains formed penicillinase.

Patients

Respiratory tract. Staph. aureus was isolated from the nose and throat in 22 of the 84 patients, thus giving a carrier frequency of 26 per cent. The distribution of strains between the various phage groups was the same as for the staff group. Twenty-eight per cent appeared to produce penicillinase.

Skin. Staph. aureus was isolated from the skin of only two patients. One of them had a strain of the same phage type on the skin as in the nose/throat, whereas the other patient had non-typable Staph. aureus on the skin and typable staphylococci in the respiratory tract.

Perineum. In eight cases Staph. aureus was isolated from the perineum. In six of these Staph. aureus was also isolated from the respiratory tract, but in two cases they could only be isolated from the perineum. One of the patients had the same Staph. aureus in the respiratory tract, on the skin, and in the perineum. In another two cases the isolated strains were of the same phage type in respiratory tract and perineum, whereas they were of different types in one case. Strains from three cases were non-typable.

C. Environmental investigation

Operation rooms

More operations were carried out in rooms with zonal ventilation than in rooms with conventional ventilation. Since some patients had been treated with antibiotics it was difficult to compare infection frequencies among patients operated on under these different conditions. Of the patients who were not given any kind of antibiotics, 46 were operated on in rooms with zonal ventilation. There were five infections in both groups.

Environmental investigation

The results of the analyses of the air from 77 operations included in the prospective study are shown in Figure 3. As can be seen from the figure, the bacterial content was low in both types of operation rooms. The highest figure was 56 colony-forming units (c. f. u.) of bacteria/m³, and the lowest 10 c. f. u./m³. The average total amount of bacteria was 31 c. f. u./m³ in operation rooms with zonal ventilation, measured outside the highly ventilated area, and 30 c. f. u./m³ *staph. aureus infection.*

Patient	Phage pattern of Staph. aureus isolated from Staff	Operating theatre	Infection
		29/52	6/42E/47/53/54/75/83A
	29/53/80/88		3 C
	52	29/52/77	29/52
	52	NT	
	52/52A		
	52/52A/80		
	NT		
52A/54	29/80	52A/80/54	53/54/77
	6/47/53/54/75/83A	53/54/75	6/47/53/54/75
	3C/55/71	6/47/53/54/75/83A/88	52/52A
	NT		

air in rooms with conventional ventilation. No difference was found in the average number of bacteria between operations followed by infection and uninfected operations.

The occurrence of Staph. aureus was low and it was isolated at only 26 out of the 84 operations in the prospective study. The total number of colonies found during the whole investigation was 44 and not more than three colonies were isolated on one operation day. The average occurrence, as estimated from the entire number of operations, was 0.08 c. f. u./m^3 air. If the mean value is calculated for operations where Staph. aureus was present, it is shown to be 0.25 c. f. u./m^3 air.

Possible transmission routes for infections caused by Staph. aureus were studied. In 15 operations Staph. aureus with the same phage pattern could be isolated from the environment and from the staff. The importance of this with regard to transmission routes in the four patients with Staph. aureus infections is demonstrated in Table 2. In case nos. 1 and 2 no preoperative cultures were taken from the patients. Among the staff, cultures were taken only from the operating surgeon. In case 1 the infection was caused by staphylococci belonging to group III with the phage pattern 6/42E/47/53/54/75/83A. The staphylococci isolated from the environment belonged to group I with the phage pattern 29/52. The operator was not a carrier of staphylococci. In case 2 the infection was caused by staphylococci group II with the phage pattern 3C. The surgeon was a carrier of staphylococci but of another phage type. No environmental investigation was made. Case no. 3 had a postoperative infection caused by staphylococci group I, phage pattern 29/52. The patient was himself not a carrier of staphylococci. Staphylococci with the same phage pattern were isolated from the air during the operation. In four out of five of the staff taking part in the operation, staphylococci within group I, with a similar phage pattern, were also isolated. The total amount of bacteria was 37 c. f. u./m^3 air which is somewhat higher than the mean value. The amount of staph. aureus was 1 c. f. u./m^3 air which is considerably higher than the mean value 0.08 c. f. u./m^3.

The superficial infection was a mixed infection with three different types of staphylococci. The source of one of them was probably the patient; staphylococci with a similar phage pattern were isolated from the patient's respiratory tract and perineum as well as from the environment. One of the other types had a pattern similar to staphylococci isolated from one of the operating team and from the environment.

No attempts were made to isolate anaerobic bacteria from the environment and it has therefore not been possible to establish the ways of transmission for these bacteria. The total number of bacteria in one of the anaerobic infections was 42 c. f. u./m^3 which is higher than the mean value. In one infection the amount was 24 c. f. u./m^3 air and in two other infections no analysis of the environment were made.

DISCUSSION

During the period of study 10 deep infections occurred. Four were associated with Staph. aureus. Anaerobic bacteria probably caused four infections. This agrees with the results in some other Swedish reports (Kamme et al. 1974). It seems likely that the significance of anaerobic bacteria has been underestimated because of defective isolation techniques.

The environmental investigation showed that the occurrence of Staph. aureus in the respiratory tract of the staff was 43 per cent which is somewhat above normal, and 29 per cent in patients which is somewhat below normal. Phage typing showed that strains within group I were the most frequent among both staff and patients, but no special phage type was predominant. The frequency of penicillinase-producing staphylococci was nearly twice as high in the staff group.

Air analyses in the operation suites showed that the total number of bacteria was low; the mean was 31 c. f. u./m^3 and there was no difference between the number of bacteria in operations where postoperative infections occurred and uninfected operations. There was no difference between operation rooms with conventional ventilation and rooms with zonal ventilation. In rooms with zonal ventilation the determinations were performed outside the "curtain". We have shown experimentally that the relation between the amount of bacteria outside and inside the zone is not less than 2:1 (Hambraeus et al. 1976). This means that the amount of bacteria inside the zone should have been 15 c. f. u./m^3 or less. These are low figures and not considerably higher than those found in operation suites with "ultra-clean air" ventilation (Charnley & Eftekhar 1969, Cook & Boyd 1971, McDade et al. 1968, Scott 1970).

The amount of Staph. aureus in the air was very low with a mean value of 0.08 c. f. u. of staphylococci/m^3 air. In two thirds of the operations no staphylococci were isolated from the air. When Staph. aureus is isolated from the perineum the risk of transmission is considered to be greater than when it is found only in the respiratory tract. At only one of the eight operations, where the patient was a perineal carrier of Staph. aureus, was increased transmission to the air established. On the basis of these findings the risk of airborne transmission of staphylococci during operation seems small. Unfortunately, no attempts were made to isolate anaerobic bacteria in the operation environment. It is thus not possible to comment on transmission in these cases.

There was no correlation between the amount of Staph. aureus in the air and the total amount of bacteria. This is in agreement with other reports and confirms the opinion that the total number of bacteria is not a good indicator of the occurrence of possible pathogenic bacteria in the air (Reid et al. 1956, Lidwell 1974, Bourdillon & Colebrook 1946).

Phage typing of the staphylococci in the operation room showed that in 60 per cent they were of the same phage types as those carried by the staff in the respiratory tract. Only in a few per cent could the same phage types be found in the patients. For 40 per cent of the staphylococci found in the air the origin could not be established. This can partly be explained by the fact that the air analyses also covered operations other than those belonging to this study. Another explanation is that the staff may carry the staphylococci on their clothes, thereby introducing them into the air (Hambraeus et al. 1976). A comparatively large number of environmental staphylococci were also non-typable.

Ventilation does not seem to have affected the incidence of infection to any great extent as the number of postoperative infections was the same in patients operated on in rooms with conventional ventilation and in patients operated on in rooms with zonal ventilation. However, the material is small and does not allow any definite conclusions to be drawn.

The investigation showed that there is a need for comprehensive analyses in order to establish transmission. In the four staphylococcal infections the way of transmission could be explained in two cases. Two were probably airborne and acquired during operation. One of these two patients also had an endogenous infection. In two cases the analysis was too incomplete to allow a final estimation of the way of transmission. When attempting to establish the way of transmission it also seems necessary to study the occurrence of anaerobic bacteria in the operation environment.

Neither the results of environmental analyses of staphylococci nor the total number of bacteria found in this study indicate that airborne infection should have been of any great importance for the observed infections. In two of the 15 operations where Staph. aureus was found in the environment infection occurred. In this respect, the results agree with those of other investigators (Shaw et al. 1973), but the problem is controversial and needs further study.

Continued and careful tests will be necessary in order to establish the ways of transmission of all bacteria of importance for these infections and to obtain a better basis for choosing the best prophylactic methods. This is important, especially with regard to the complicated and expensive ventilation systems and other measures that have been introduced for this kind of surgery.

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