

## Wound infections after surgery in a modern operating suite: clinical, bacteriological and epidemiological findings

By STELLAN BENGTTSSON, ANNA HAMBRAEUS AND  
GUNNAR LAURELL

*Institute of Clinical Bacteriology, University of Uppsala, Uppsala, Sweden*

### SUMMARY

A prospective study of 2983 operations in general and orthopaedic surgery during 3 years performed in four operating theatres in a modern operating suite was carried out in order to evaluate the importance of airborne infection. Weekly nose-and-throat samples were taken from the surgical staff and pre-operative samples were taken from the nose, throat, skin and perineum of the patients. The air contamination was followed by using settle plates, which showed low mean counts of total bacteria of between 9 and 15 c.f.u./m<sup>2</sup>/min, with mean counts of *Staph. aureus* of between 0.03 and 0.06 c.f.u./m<sup>2</sup>/min. No correlation was found between the total number of bacteria and the incidence of post-operative infections or between the amount of *Staph. aureus* in the air and post-operative *Staph. aureus* infections. It was concluded that further increases in ventilation could, at best, only marginally affect the incidence of post-operative infection.

The post-operative wound-infection rate was 9.0%. In various types of surgery, the infection rates varied from 5.3% in clean operations to 47.6% in dirty surgery. About one third of the infections were classified as moderate or severe.

Adverse patient factors, such as immunodeficiency, steroid treatment, intensive care, etc., increased the rate to 15.0%; in 'normal' patients it was 3.8%.

Among the bacteria isolated, gram-negative bacilli (31% of wounds), often together with other bacteria, and *Staph. aureus* (28%) predominated, but in 25% no specimens were taken.

Of 76 post-operative *Staph. aureus* infections, 32 were caused by the patients' own strains, and of the remaining 44 infections, 22, or 8% of all infections, could be traced to strains present in the air and/or the respiratory tracts of staff during the operation.

The length of pre-operative hospital stay had no influence on the carrier rate of *Staph. aureus* in patients. The incidence of post-operative wound infection was significantly higher in patients carrying *Staph. aureus* and was even higher if these bacteria were found on the skin.

Patients with wound infections stayed, on an average, 15 days longer than patients without infections. In serious infections the increase in duration of stay was > 20 days. Although infections were commoner in older patients, the average additional hospital stay of infected patients did not increase with age. If the post-operative infections studied in a concurrent retrospective study are taken into account more than 12 000 bed-days were due to post-surgical wound infections

in the period studied or, in other words, some 12 beds (corresponding to 5.5% of the total) were always occupied by infected patients.

#### INTRODUCTION

Hospital infections are still an important problem in hospital care and many attempts have been made to determine the most important transmission routes and to find the most effective prophylactic measures. It is not possible to make a detailed review but some large investigations published during the last 10–15 years are worth mentioning. In two large studies from the U.S. the infection rates were 7.4% (Ad Hoc Committee, National Research Council, 1964; Altemeir, 1971) and in two recent studies from England (Ayliffe *et al.* 1977; Shaw, Doig & Douglas, 1973) the infection rates were 15.4 and 17%, respectively. In Scandinavia several extensive investigations have also been published during the last 10-year period. In a Danish study (Jepsen, Olesen-Larsen & Thomsen, 1969) the infection rate was as high as 19.1%, and from Norway a rate of 13.1% was reported in 1970 (Bruun). In Sweden a well-controlled study in 1976 (Bröte) reported an infection rate of 7.4%. The general impression is that the infection rates vary, but in well-controlled large studies during the last 15 years they have been about 7–8%. There does not seem to have been any substantial improvement during this period.

Many clinicians and bacteriologists, especially in the mid-years of the century (Bourdillon & Colebrook, 1946; Hart, 1938; Wells, 1955), believed that airborne bacteria in the operating room are very important as a source for post-operative infections and several investigators have reported epidemics of post-operative wound infection apparently due to airborne transfer of staphylococci from a carrier in the operating room (Ayliffe & Collins, 1967; Payne, 1967). Improved ventilation should then reduce infection rates and in one study by Blowers *et al.* (1955) the infection rate fell from 10.9% to 3.9% when controlled ventilation was installed. During the last years orthopaedic surgeons like Charnley have published results favouring the idea that at least in hip surgery most infections are airborne and that transmission takes place in connexion with the operation (Charnley, 1964, 1972; Charnley & Eftekhari, 1969). In operating suites with conventional ventilation it is hardly possible to have less than 4% deep infections, but if ultra-clean-air ventilation is introduced it is possible to reduce the incidence below 1%. One disadvantage with several of these investigations is that other changes have been introduced at the same time.

Other workers do not believe that airborne infection is so important and claim that there is no conclusive evidence at this time that improved conventional ventilation or ultra-clean-air systems in itself has a favourable influence on the incidence of surgical wound infections (Clark *et al.* 1976; Laufmann, 1973, 1976; Lidwell, 1976; McLauchlan *et al.* 1976; Nelson, 1975; Nelson, 1976; Seropion & Reynolds, 1969). In a large U.S. study (Ad Hoc Committee, National Research Council, 1964) it could be shown that although ultraviolet irradiation reduced the number of airborne bacteria in the operating room by 51 to 63%, the post-operative wound infection rate was the same in irradiated and unirradiated rooms.

Several other attempts to relate the numbers of airborne bacteria to the incidence of post-operative sepsis have also failed and the importance of air spread compared to other modes of spread has not been determined.

Shaw, Doig & Douglas (1973), who carried out an investigation in an operating suite for general surgery, concluded that the evidence appears to be incompatible with the view that airborne infections play an important role in general surgery.

In Uppsala a new operating department was opened in 1972. It was constructed with regard to the principles laid down by the Operating Theatre Hygiene Subcommittee of the Medical Research Council in England (1962). This unit has been studied from a hygienic point of view and the results have been published in a series of papers (Hambraeus, Bengtsson & Laurell, 1977, 1978*a-c*). The aim of this investigation is to report the infection rates and the results of bacteriological and epidemiological studies during the first 3 years of use. In connexion with this some of the factors of importance for the infections and the economic consequences of a prolonged hospitalization caused by a post-operative wound infection will be discussed.

#### MATERIAL AND METHODS

The study started in January 1972, when a new operating suite was opened at the University Hospital, and went on for three years. During this time 2983 patients were included in a prospective study where details about the patient and the operation were registered and pre-operative samples collected from the patients. A full-time nurse followed the post-operative course of the patients. Any post-operative infection was noted and, if possible, a specimen taken for culture.

Another 600 patients with post-operative infections were included in a retrospective study. In this study no pre-operative cultures could be taken, but an attempt was made to find out as many details as possible about the patient and his operation.

##### *Operating suite*

The operating suite has been described in detail in earlier papers (Hambraeus *et al.* 1977, 1978*a*). It is independent of the general traffic and air movement in the rest of the hospital. In principle, it is planned as a double corridor system. One corridor is used by staff only. In this the scrub sink for the operating team is situated. The other corridor is used for transport of patients and material. The operating theatre has three doors. One leads to the corridor used by the staff, one leads to the anaesthetic room and one to the exit area. There are 12 operating theatres. The rooms of the suite are arranged so that there is a continuous progression from the entrance to the suite through zones that are increasingly cleaner. The unit is equipped with a positive-pressure ventilation system and the ventilation is normally balanced between all rooms in the operating suite. The ventilation rate in the operating room is about 17–20 changes/h. In some rooms there is a special zonal ventilation (Abel & Allander, 1966) where a clean-air inlet is installed in the ceiling above the operating table. By this system the operating area is provided with a ventilation corresponding to 80 changes/h.

The operating department is used mainly for general and orthopaedic surgery.

The prospective investigation was carried out in 4 of the 12 operating theatres. Three of these had normal positive pressure ventilation and the fourth had zonal ventilation.

#### *Definition of wound infection*

Wound infections have been defined as wounds with pus visible to the naked eye, whether or not organisms could be cultured from the purulent material. In some cases no wound culture was done, but if the criteria of pus and clinical signs of infection were fulfilled they have been regarded as infections.

#### *Classification of wound*

The classification of wounds was the same as that used by the American Ad Hoc Committee, National Research Council (1964), in the study of post-operative wound infection. They are as follows:

*Clean.* All clean operations such as thyroid, mammary, hernia, fractures, etc., have been included. No break in technique occurred. No inflammation was encountered. The gastrointestinal or respiratory tracts were not entered. Operations with entrance of the GU or biliary tracts were considered clean in the absence of infected urine or bile.

*Clean contaminated.* Respiratory and stomach tracts entered without significant spillage. Minor break in technique. Entrance of GU or biliary tracts in the presence of infected urine or bile.

*Contaminated.* Surgery of colon and rectum. Acute bacterial inflammation encountered without pus. Fresh traumatic wound from relatively clean source.

*Infected or dirty.* Pus encountered. Perforated viscus. Traumatic wound, old, or from dirty source.

#### *Sampling routines*

*Patients.* From the patients specimens were taken on the day of operation from the nose and throat with a dry cotton swab, and from the skin of the forearm and the perineum with a wet (physiological saline) cotton swab. Wound specimens were usually collected by the ward staff on the day an infection was discovered.

*Staff.* About 100 persons worked in the operating suite every week. Nose and throat swabs were taken once a week from all staff members, who usually took their own specimens. A total of 11 200 specimens were taken from 1250 persons.

*Environment.* Four settle plates were placed in the periphery of each operating room and two each in the adjacent anaesthetic room and exit area.

#### *Bacteriological methods*

Wound samples were cultivated on sheep-blood agar plates with and without gentian violet, on hematin agar, and phenol-red mannitol salt agar and on anaerobic blood agar plates. The plates were incubated at 37 °C and read after 24 and

48 h. During the latter part of the investigation a modern technique was used for anaerobic cultures (Anaerobe Laboratory Manual, 1973).

For nose, throat, skin and settle plates only sheep-blood agar plates were used. Specimens from the perineum were also cultivated on phenol-red mannitol agar. The plates were incubated at 37 °C and read after 24 and 48 h. From the settle plates both the total number of bacteria and the number of *Staph. aureus* were determined. Isolated bacteria were verified according to current techniques. All *Staph. aureus* were phage-typed according to the methods of Blair & Williams (1961).

### Registration

For all patients included in the study a form (see Appendix) containing information about the patient and his operation was completed. It included data on underlying disease, e.g. diabetes and malignancy, treatment with steroids or antibiotics, etc., as well as existing infections. The type of operation and anaesthesia and the identity of the surgical staff was also noted, together with the type of post-operative treatment, such as intensive care, central venous catheter, etc. Any infection occurring was also noted. All this information was collected by one person, a full-time registered nurse. It should be noted that only infections that made their appearance during the stay in hospital were registered. A schematic outlay of the form used is given in the Appendix. All this information was transferred to punch cards and computer-processed. Details about bacterial cultures were entered on optical mark recognition sheets. The data system used, a modification of the routine laboratory system we use, has been described earlier (Bengtsson, Bergqvist & Schneider, 1975).

The data-technical aspects of the computer analysis of the collected data have been discussed elsewhere (Bergqvist & Bengtsson, 1978). AID (Automatic Interaction Detector) analysis (OSIRIS users manual, 1973) was used for some analyses.

## BACTERIOLOGICAL FINDINGS

### Staff

The frequency of nose and throat carriers of *Staph. aureus* in different staff categories varied from 34 % to 47 %. It varied slightly from year to year, but there were no significant differences. It was highest among doctors and medical students and lowest among nurses and assistant nurses. Phage typing showed that 67 % of isolated strains were typable. Strains within group I constituted 38 %, within group II 8.7 % and group III 18 %. No special phage type dominated. As in many other investigations there were two types of carrier, persistent and intermittent, and non-carriers. The type of carrier state in the individual person was remarkably constant. In many cases the same type of *Staph. aureus* could be found in a persistent carrier during the whole 3-year period of the investigation.

*Beta-haemolytic streptococci*. These occurred sporadically and were found in only 2.4 % of all specimens; 12.4 % of the staff were positive on one or several occasions. Grouping showed that group A, C and G were commonest and 89.5 % of the strains

Table 1. *Influence of length of pre-operative stay on occurrence of Staph. aureus in patients*

Pre-operative stay (days)	Number of patients	% carrying <i>Staph. aureus</i> in:		
		Nose/throat	Skin	Perineum
≤ 3	1,899	33	6	9
4-8	720	35	7	9
9-15	215	34	8	9
≥ 16	137	34	9	10

Table 2. *Mean number of total bacteria and Staph. aureus in c.f.u./m<sup>2</sup>/min in theatres and ancillary rooms 1972-1974*

Theatre*	Anaesthetic room		Operating theatre		Exit area	
	Total	<i>Staph. aureus</i>	Total	<i>Staph. aureus</i>	Total	<i>Staph. aureus</i>
9	8.4	0.06	10.8	0.04	8.3	0.02
11	10.6	0.04	11.3	0.04	12.28†	0.04†
12	12.3	0.06	9.0	0.04		
14	12.6	0.05	14.3	0.05	13.8	0.06

\* Theatre 11 had zonal ventilation, the others conventional.

† Theatres 11 and 12 shared the same exit area.

belonged to these groups. The streptococci were mostly found in healthy carriers but there were a few clinical infections.

### Patients

The frequency of *Staph. aureus* from different sampling areas related to pre-operative nursing time can be seen in Table 1, which stresses that the carrier rate was not influenced by the pre-operative nursing time. There was no increase in the number of tetracycline-resistant strains. In 3.2% the perineum was the only place from which *Staph. aureus* was isolated. There seemed to be an increase of skin carriers with a longer pre-operative nursing time but the difference was not significant. *Staph. aureus* was isolated from the skin in 6.5%, and in 1.8% from skin only.

### Environment

The mean values for total bacterial air count in four operating theatres with adjacent anaesthetic room and exit area can be seen in Table 2.

In the periphery of the operating theatres it varied between 10.8 and 14.3 c.f.u./m<sup>2</sup>/min and there were no marked differences between the theatres. If earlier experiments with dispersal were used as a base it could be calculated to be lowest in the central part of zonal-ventilated theatres, i.e. 6.6 c.f.u./m<sup>2</sup>/min.

The number of bacteria in the anaesthetic rooms and exit areas was more or less the same as in the theatres. There were variations from day to day but they



were usually small and there were no broadcasting effects. There were no differences in the air counts in different types of surgery. The mean was  $\sim 10$  c.f.u./m<sup>2</sup>/min in contaminated surgery on colon and rectum and 12.5 c.f.u./m<sup>2</sup>/min in clean or clean-contaminated surgery of the gall-bladder or kidney. This does not differ from the mean counts in the whole investigation.

The number of *Staph. aureus* in the air was generally low, being between 0.04 and 0.05 c.f.u./m<sup>2</sup>/min. There was at least one broadcasting period with *Staph. aureus* of phage type 42D. During this period, which lasted for 10 weeks, this strain was isolated in the air during 85 operations. The highest number of *Staph. aureus* found in the air during this period was 0.97 c.f.u./m<sup>2</sup>/min. Two infections were caused by *Staph. aureus* of this type. In general, however, the count of *Staph. aureus* c.f.u./m<sup>2</sup>/min could not be correlated to an increased risk of infection.

#### *Incidence of wound infection in various operations*

The number of patients in the prospective study was 2983. In more than three-quarters of the patients with an infection this appeared within 8 days of the operation. In 12 patients where the infection occurred after more than 3 weeks the records were excluded from the study. Of those remaining, 268, i.e. 9.0%, had a post-operative wound infection during their stay in hospital. In Table 3 the infection rates in the different wound classes are shown.

In 'clean' operations the infection rate was 5.3%. In certain clean operations it was, however, much lower, for instance in 200 operations on the thyroid or the parathyroid no infection occurred. In operations for inguinal hernia the infection rate was 1.5%.

In 'clean contaminated' operations it was 22.5%. The infection rate varied within the group and was for instance 16.7% in operations on the kidney and ureter, and 22% in gastric surgery.

As can be expected the infection rate was high in contaminated and dirty operations being 33.6% and 47.6%, respectively. These operations were mainly on the colon and rectum.

Clinically, 35% of the infections could be classified as moderate or severe with tissue necrosis and/or abscesses in addition to pus formation.

#### *Host factors*

The influence of adverse host factors on the infection rate can be seen in Table 3. When studying patient groups with these risk factors, i.e. pre-operative infection, pre-operative antibiotic treatment, predisposing factors and post-operative treatment (as listed in the Appendix), it can be seen that the infection rate after clean operations is between 2 and 3 times higher in patients with one or several risk factors.

There was a highly significant correlation ( $P < 0.001$ ) between the presence of pre-operative antibiotic treatment, predisposing factors and post-operative treatment (as listed in the Appendix), and post-operative wound infection. It was, however, not possible to analyse the correlation between infection and individual risk factors, since many risk factors occurred together and were also commoner in

Table 3. Frequency of wound infections in different wound classes

Wound class	Total no.	Infected		Risk patients			No risk		
		No.	%	No.	No. inf.	% inf.	No.	No. inf.	% inf.
Clean	2478	132	5.3	987	81	8.2	1491	51	3.4
Clean-contaminated	320	72	22.5	239	64	26.8	81	8	9.9
Contaminated	131	44	33.6	121	43	35.5	10	1	10.0
Infected or dirty	42	20	47.6	31	19	61.3	11	1	9.1
Total	2971	268	9.0	1378	207	15.0	1593	61	3.8

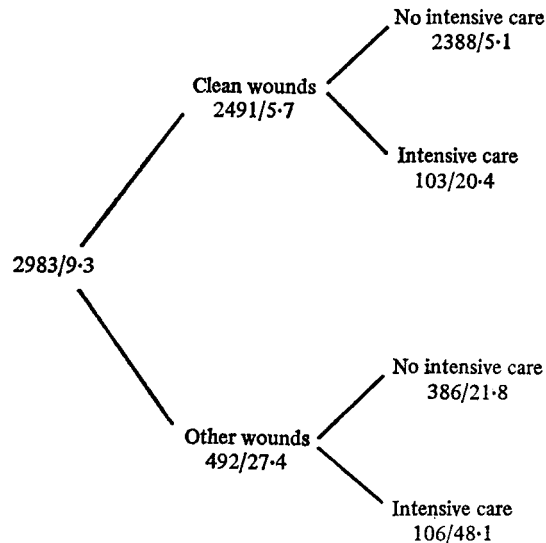


Fig. 1. Automatic interaction detector analysis of factors affecting the occurrence of post-operative wound infections. The factors taken into account were patient age, wound class, predisposing factors (as listed in the appendix), preoperative infection, preoperative antibiotic treatment, intensive care and presence of drain. The diagram shows number of patients and frequency of postoperative wound infections in all prospective patients.

contaminated surgery. Also, for central venous catheter treatment it was obvious that this was more often a consequence than a cause of infection.

By the use of the AID (Automatic Interaction Detector) analysis as shown in Fig. 1 it was found that the wound class was the most important determining factor and that intensive care treatment came next in importance. No reason for the increase in infection rates in patients treated in the intensive care unit could be found when the records for the infected patients were analysed. When the analysis continued, various predisposing patient factors alone or in combination were found to influence the infection rate, but in the eight alternatives chosen for the analysis all were found both as positive and negative predictors in the groups studied.



Table 4. Average length of post-operative stay and mean age for infected and non-infected patients after some common operations

Type of operation	Post-operative stay (days)		Mean age (years)	
	Infected	Non-infected	Infected	Non-infected
Inguinal hernia	8.3	3.9	64	59
Breast	20.3	6.3	81	63
Cholecystectomies	14.4	7.2	63	52
Colonic	28.9	10.5	48	49
Rectal	31.6	12.0	64	58

Table 5. Organisms identified in wound infections\*

	Wound class				Total
	Clean	Clean contaminated	Contaminated	Infected or dirty	
Number of infections	132	72	44	20	268
No specimens	34	15	12	7	68
No growth	8	1	1	1	11
$\beta$ -haemolytic streptococci	4 (2)	2 (1)	2 (1)	0	8 (4)
Enterococci	4 (2)	5 (3)	3	0	12 (5)
<i>Staph. aureus</i>	44 (39)	16 (8)	9 (5)	7 (5)	76 (57)
<i>Staph. albus</i> †	(15)	(5)	0	0	(20)
Anaerobes	8 (6)	7 (2)	5 (3)	0	20 (11)
Gram neg. bacilli	22 (15)	34 (17)	21 (13)	7 (4)	84 (49)
Others†	(3)	(3)	0	0	(6)
Mixed	8	17	9	3	37
Fungi	0	3	0	1	4

\* The number of cases where no other organisms were isolated are shown in parentheses.

† For *Staph. albus* and other organisms only pure cultures have been noted.

### Age

Age is known to influence the infection rate. This can be seen for some common operations in Table 4, where the post-operative hospitalization time is also included. For some operations such as those on the breast the age is much higher in infected patients than in non-infected. In others, such as operations on the colon, the difference in age is small.

### Wound cultures

In 200 of the 268 post-operative wound infections cultures were done. In 11 of these (mostly from clean operations) no bacteria could be isolated. In 152 infections only one organism was isolated, the others were mixed infections with two or more micro-organisms. In Table 5 the bacteriological findings in the different wound classes can be seen.

As could be expected normal intestinal bacteria were common in clean con-

Table 6. *Incidence of post-operative wound infection in Staph. aureus carriers*

	No. of patients	No. infected	<i>Staph. aureus</i> infections		Non- <i>aureus</i> infections	
			No.	%	No.	%
Non-carriers	1797	139	23	1.3	116	6.5
Carriers	1174	129	53	4.5	78	6.6
Skin carriers	198	32	15	7.6	17	8.6

taminated and contaminated operations. It is in these wound classes that one finds operations on the colon, rectum, stomach and gall-bladder. Gram-negative bacilli were isolated from 84 patients and in 49 it was the only infecting organism.

Beta-haemolytic streptococci (A, B, C or G) were not very common but were found in 8 cases.

Anaerobic bacteria were only isolated in 20 cases. The explanation for this rather low frequency is probably that modern anaerobic isolation techniques were not used throughout the whole investigation.

*Staph. aureus* was common. It was isolated in 76 cases and in 57 of these it was the only pathogenic microorganism found. It was much commoner in clean operations than in the other wound classes. It could be found after several types of operations but was commonest after operations on the kidney and ureters where it caused about half the infections.

Micro-organisms of doubtful pathogenic importance such as *Staph. albus* and alpha-streptococci were the only micro-organisms found in 26 cases.

#### *Staph. aureus epidemiology*

The correlation between carrier state and wound infection can be seen in Table 6.

Post-operative infections caused by *Staph. aureus* are significantly commoner among patients who were carriers and the risk of infection is increased if *Staph. aureus* can also be isolated from the skin.

As described earlier, *Staph. aureus* was found in 76 cases. In 57 of these *Staph. aureus* was the only pathogen found in the wound culture. The others were mixed infections, mostly with enteric bacteria. Thirty-two *Staph. aureus* infections were considered endogenous, i.e. the patient was a carrier of the strain found in the wound. The remaining 44 infections were exogenous and in 23 cases the infecting strain was present during operation. In 18 cases it was found in the nose/throat of staff members and in 5 of these also in the air. In a further 5 cases it could only be found in the air.

The frequency of infections possibly acquired during operations was thus 30% but only in 13% could it be proved that the transmission route might have been airborne.

Phage typing showed that 21% of the strains were non-typable. Strains of group I were commonest, specially among exogenous infections with a known source where they constituted 57% of strains isolated. Strains in group III were also common.

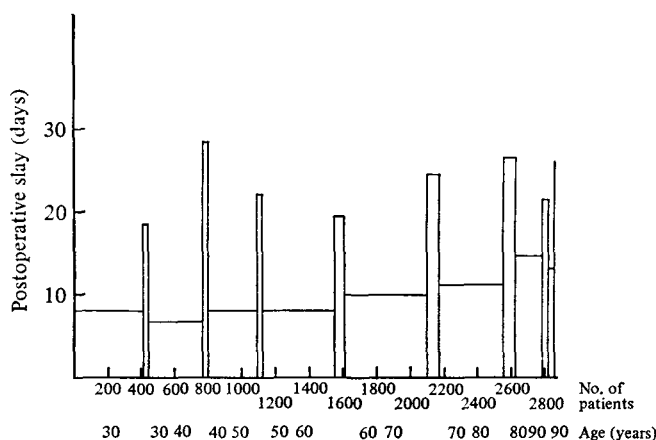


Fig. 2. Influence of infection and age on post-operative hospitalization. Left hand columns non-infected, right hand infected patients.

#### *Incidence of infections in different operating theatres*

A comparison was made between operations performed in operating theatres with conventional ventilation and theatres with zonal ventilation. Of 877 clean operations from orthopaedic surgery 520 were performed in theatres with conventional ventilation and 357 in theatres with zonal ventilation. The infection rates were 6.7% and 10.1%, respectively, but the difference is not statistically significant. No difference in patient age or in incidence of adverse factors among the patients could be found between patients operated on in theatres with conventional and zonal ventilation.

#### *Consequences of infection*

A post-operative wound infection usually leads to an increase in the stay in hospital. In this study the mean post-operative stay in hospital was 9.4 days for patients without infections and 24.4 days for patients with a post-operative wound infection – an increase of 15 days. In more serious infections the mean increase in stay was > 20 days. As shown earlier the infected patients are usually older than non-infected and it was suspected that the increase in time in hospital could partly be due to the increase that occurs with age. When the material was analysed as shown in Fig. 2, it was found that although the hospital stay increased with age the additional increase of stay in infected patients was remarkably constant in all age groups.

The increase in stay in hospital caused by post-operative wound infections amounted to ~ 4000 days in the prospective study. In the retrospective study ~ 600 patients with post-operative wound infections had an average increase in stay of approx. 14 days – a total of ~ 8400 days. In the two series wound infection thus led to a total increase of ~ 12400 days during the 3 years studied. If a correction is made for breaks in the study due to holidays, etc., it may be safely stated that, on an average, 12 beds, or 5.5% of the total, were consistently occupied with patients whose infections forced them to stay longer in hospital.

## DISCUSSION

In this final paper the clinical, bacteriological and epidemiological results from an investigation in a modern operating suite based on a zoning system with positive pressure ventilation are presented. *Staph. aureus* was found in the respiratory tract of between 34 and 47% of the staff working in the unit; this figure is a little higher than expected. The carrier state was very stable and the staff seldom changed the strain they carried.

Among the patients *Staph. aureus* was isolated from the nose and throat in 33.7%. A longer pre-operative stay in hospital did not result in a higher carrier rate, but the new wards had good isolation facilities and ventilation which could decrease the risk of cross-infection between patients. *Staph. aureus* was isolated from the perineum in 9%, and from only the perineum in 3.2%. This is of interest since it is known that those who harbour *Staph. aureus* in the perineum are often dispersers and this could increase the risk of self-infection.

It could also be shown that the infection rate was higher among patients carrying *Staph. aureus* than in non-carriers and that this risk increased if they were also found on the skin. This is in agreement with what has been shown by us (Lindbom, Laurell & Grenvik, 1967) and other workers earlier (Miller *et al.* 1962; Williams *et al.* 1962; Calia *et al.* 1969).

The importance of airborne transmission as a source of infection in operating theatres is a controversial question, but there is evidence to support the view that airborne bacteria can cause post-operative wound infections. The mean total number of bacteria in this study was about 9–15 c.f.u./m<sup>2</sup>/min corresponding to 30–50 c.f.u./m<sup>3</sup>, if the sedimentation rate is taken as 0.3 m/min (Noble, Lidwell & Kingston, 1963), in theatres with conventional ventilation. It varied from day to day but there were no broadcasting periods. This is in agreement with what was shown experimentally in an earlier study (Hambraeus *et al.* 1977) that ventilation of this capacity usually eliminates broadcasting effects.

In the theatre with zonal ventilation the total number of bacteria in the centre of the room could be calculated to be 20–25 c.f.u./m<sup>3</sup> if a ratio of 0.6 between the centre and periphery is used (Hambraeus *et al.*, 1977). This means that at least in this theatre the ventilation fulfilled the requirements for Class I ventilation (0–30 c.f.u./m<sup>3</sup>) laid down by the American Academy of Orthopedic Surgery and the National Research Council in 1976 (Beck, 1976).

It was of interest that the air contamination in adjacent rooms such as the anaesthetic room and exit area was only slightly higher than in the operating room. Even if doors to the operating theatres are opened frequently this means that the risk of inflow of bacteria into the operating room is small. This favours the idea that it is important that the hygienic standard is high not only in the operating theatres but also in adjacent areas.

The contamination of the air was not higher after contaminated operations such as those on the colon and rectum. This is in agreement with our earlier findings that neither surfaces such as floors, walls and lamps nor the air are more contaminated after contaminated operations than after clean.

The comparison of infection rates among patients operated on in theatres with conventional and zonal ventilation showed no significant difference. For the comparison material from clean orthopaedic operations was chosen where exogenous infections are more common and air transmission might be important.

The post-operative wound infection rate in this investigation was 9.0%. This is higher than in some large American studies (Ad Hoc Committee, National Research Council, 1964; Altemeir, 1971) but lower than has been reported from Denmark (Jepsen *et al.* 1969) and from Norway (Bruun, 1970). It is also higher than reported in Sweden by Bröte (1976), who noted an infection rate of 7.4%. This is interesting since his study was done in an old operating suite with insufficient ventilation. For several reasons comparison of infection rates between different investigations is of limited value. It is, however, obvious that a zoning system and a positive pressure ventilation do not in themselves diminish the infection rates.

The infection rate in clean operations was 5.5%, which is lower than in the other wound classes. The lowest infection rates in clean operations were found in operations on the thyroid and parathyroid where no infection occurred and after hernia repair where the rate was 1.5%. As could be expected the infection rates were highest in contaminated (33.1%) and dirty operations (47.6%). The classification of wounds might differ between different investigations, but the infection rates found here are about the same as those reported by other workers (Shaw *et al.* 1973; Bröte, 1976).

It is well known that several host factors such as underlying disease, e.g. malignancy and diabetes, pre-operative treatment with antibiotics, central venous catheter, etc., may increase the risk for a post-operative wound infection (Lidwell, 1961). It could be shown here that patients with one or several of these adverse factors had infection rates 2–3 times higher than patients without them. It could also be shown that the risk for infections was higher among older patients. In these respects our findings agree with those of other workers (Ad Hoc Committee, National Research Council, 1964; Bröte, 1976).

An interesting finding was the considerably higher infection frequency in patients treated in the intensive care unit. Such patients are, of course, often in a poor condition and hence infection-prone, but an analysis of the records of the infected patients gave no reason for the increased infection rate. This indicates, as has also been stated earlier (Lindbom *et al.* 1967) that the intensive care unit must be regarded as highly suspect as a source for post-operative infections and that further study should be devoted to this special problem area.

With the help of an infection-control nurse all wound infections were registered for later computer analysis. As far as possible bacteriological cultures were done from infected wounds. In spite of the efforts of a full-time nurse no samples were taken from 25% of the infected wounds. This seems to be common in investigations of this type. The disadvantage is that if surveys of hospital infection are based only on bacteriologically examined wounds the infection rates will be too low.

In a certain number of wounds no bacteria could be found in the discharge. This has also been reported in other investigations (Ad Hoc Committee, National Research Council, 1964; Bröte, 1976) and does not seem to be uncommon. The

reason for this is unclear but in this investigation an inefficient anaerobic technique may explain some of it.

The bacteria that were isolated were the same as those generally found in wound infections after general surgery of this type. Gram-negative bacilli were commonest and were found in 84 patients, alone or in combination with others. They were mainly found after clean-contaminated and contaminated operations on the bowel.

Infections caused by *Staph. aureus* were surprisingly common. They were isolated in 76 cases and in 57 of these they were found alone. They were commoner after clean operations than the other wound classes. Several workers (Finland, Marget & Bartman, 1971) think that infections caused by gram-negative bacilli are commoner now. In this investigation staphylococcal infections were about as common as those caused by gram-negative bacilli.

Forty-four staphylococcal infections were exogenous and in 23 it could be shown that the infection was probably acquired during operation. In ten cases the staphylococci that caused the infection could be found in the air during operation and the transmission route could have been airborne. In general, however, the air counts of *Staph. aureus* were low and varied between 0.02 and 0.06 c.f.u./m<sup>2</sup>/min corresponding to 0.07 and 0.20 c.f.u./m<sup>3</sup>. A comparison was made between different types of operations and there was no difference in *Staph. aureus* air counts whether post-operative wound infections occurred or not and it was not higher even if the infection was caused by *Staph. aureus*. Obviously the number of staphylococcal infections where the transmission route could have been airborne was not high compared with the total number of infections but for example in orthopaedic surgery they might be of vital importance.

The infections increased the post-operative stay in hospital, which might be about 15 days longer than that for non-infected patients. This is more than reported by Bröte (1976), who had an increase of 9 days in infected patients. This may be due to differences in the patient's disease, to the type of surgery performed and to many other circumstances. It is of interest that the increase in hospitalization time was not longer for older patients than for young ones. This favours the idea that the longer stay in hospital in infected patients is mainly due to the infection and not to adverse host factors.

If the 600 or so patients from the retrospective study are included, the increase in hospitalization because of infection was about 12400 days or, to demonstrate it in another way, 12 beds in the surgical wards were permanently unavailable since they were occupied by patients with post-operative wound infections needing prolonged treatment.

It seems obvious that an efficient ventilation in operating rooms will reduce the number of bacteria in the air and hence the number of post-operative infections caused by such bacteria. It seems equally obvious that the law of diminishing return will make it very expensive and complicated to eliminate all airborne infections by means of ventilation, and also that those in modern operating rooms are only a minority of the infections occurring after general surgery, where most infections are of endogenous origin.



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APPENDIX: LAY-OUT OF PATIENT FORM

Name: Code number:  
Birth data:  
Ward: Admission date:  
Pre-operative infection, type: Interval infection-operation:  
Pre-operative antibiotic treatment with: for  
Predisposing factors:  
(1) Diabetes (2) Steroid treatment (3) Malignancy  
(4) Immunodeficiency (5) Obesity (6) Circulatory disturbance  
(7) Pulmonary insufficiency (8) Other  
Date of operation: Theatre no.: No. on list:  
Type of operation: Type of anaesthesia: Type of drain:  
Post-operative treatment:  
(1) Intensive care for (2) Tracheostoma for  
(3) Central venous catheter (4) Urinary catheter for  
for  
Post-operative antibiotic treatment with for  
Post-operative infection type appeared after days  
Fever: Fatal outcome:  
Date of discharge:  
Infection caused an increase in stay of c. days.

[In addition a second form was filled out during the operation with the patient's identity and the names of the staff taking part in the operation.]