STUDIES OF THEATRE VENTILATION AND SURGICAL WOUND INFECTION

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The purpose of this report is to describe the measures taken to reduce the risk of air-borne infection of aseptic surgical wounds in patients treated by the Surgical Professorial Unit at St. Thomas's Hospital during the years 1955, 1956, and 1957. Particular attention was paid to the possibility of reducing the bacterial content of the theatre air, and hence the risk of wound infection, by altering the method of ventilating the theatre. The

FIG. 1.—Air currents in North Theatre 2 in 1955 before altering ventilation.

FIG. 2.—Air currents in North Theatre 2 in 1955 before altering ventilation. The doorway on the right leads to the sterilizing room. The entry doorway is shown on the left: the inward draught at floor level is referred to in the text. Numbers refer to velocities in feet per minute except 6', which indicates a distance of six feet.

System of Ventilation in Theatres and How it was Altered

About half of the operations performed by this surgical unit were done in the North Theatres of St. Thomas's Hospital, and it is this series of 982 "clean" operations that has been studied. The North Theatres are built on the twin

system. A plenum system of ventilation had been installed, and was in existence before the present investigation started. Filtered air from the roof was introduced into each theatre through three input vents placed high up on one of the walls. There were no exhaust fans in the theatre itself, so that a positive pressure of air existed in the theatre. The air emptied through two doorways—the entry doorway and the doorway into the sterilizing-room, in which there was a small exhaust fan designed to remove steam. At the outset of this study neither of the two doorways was equipped with a door.

The directions of air currents in the theatre were studied by the use of titanium chloride smoke and their velocities with a rotary multi-vane anemometer.†

Their state at the outset of the investigation is shown in Figs. 1 and 2. The air from the three inputs passed more or less horizontally across the theatre at a high level. It was deflected away from the centre of the theatre towards the side walls in the manner shown

FIG. 3.—Air currents in North Theatre 2 after altering ventilation at end of 1955.

FIG. 4.—Air currents in North Theatre 2 after altering ventilation at end of 1955. Numbers refer to velocities in feet per minute.

in Fig. 1. It will be seen that, either by design or by accident, an area of relatively still air existed in the region of the operating table.

After the initial period of study the ventilation was altered to produce a current of air passing as directly as possible from input to operating table (Figs. 3 and 4). The two side inputs were closed so that a greater flow of air could be obtained from the central one, to which a Crittall "deflecto" grille (8 by 12 in. (20 by 30 cm.) in size) was fitted (Fig. 5). This had louvres which could be adjusted to alter the direction of air-flow upwards or downwards or from side to side. The distance from the grille to the centre of the table was usually 10 to 11 feet (3 to 3.35 m.), the width of the air-stream over the table being about 4 feet (1.2 m.). The velocity of air at the mouth of the grille was 600 to 700 feet (183–213 m.) per minute at its best. The velocities over the table were usually 150 to 250 feet (46–76 m.) per minute. It was found that the velocity was much affected by alterations in the resistance of the filters through collection of dirt or variations in resistance when they were renewed. Frequent checks of the air velocity over the table were therefore necessary.

*Now holding B.M.A. Scholarship.

†Made by Short & Mason Ltd., Hale End Road, London E.17.

The twin theatres are designated theatres 1 and 2. The ventilation was altered only in theatre 2, and it was planned to use data from the unaltered theatre 1 so far as possible for comparison. The change in the ventilation in theatre 2 did not produce any detectable change in the air currents in theatre 1.

Bacterial Content of the Theatre Air

A slit sampler* (Bourdillon *et al.*, 1948) was used to estimate the bacterial content of the theatre air. The average counts, expressed as colonies per cubic foot from some

different sources, were as follows:

- (1) outside atmosphere, 3;
- (2) ventilator air, 1;
- (3) air from surgical ward, 33;
- (4) air leaving theatre through doorway to sterilizing-room, 46;
- (5) air inflow current in entry doorway to theatre (at floor level), 106.

Samples during operation were taken through a sterile rubber tube, one end of which was attached to the patient beside the incision and the other to the sampler. The samples, each of 2 cubic feet (0.028 cubic metre) of air,

FIG. 5.—The input grill with adjustable louvers

were taken at intervals throughout the operation. The first sample was taken as soon as possible after the patient had been covered with towels and just before the incision was made. Further samples were taken at intervals of 10 to 15 minutes throughout the operation. This usually meant that some eight or nine samples were taken during each operation, but during longer operations more samples were obtained. Records were kept of events and activities which might affect the bacterial content of the air in the theatre during the course of the operation.

The first series of counts was made during eight operations performed on different days in the period of time from February to December, 1955. During this time every effort was made to keep conditions unchanged. At the beginning of 1956 the ventilation was changed to project filtered air direct to the operation site in the way already described. No other alterations were made in the theatre technique. Counts were made during a further six operations on different days. The results are shown in Fig. 6. The average of the counts before the change in the ventilation was 21.7 (standard error ± 1.2); after the change it fell to 9.9 (standard error ± 0.6).

The change in the method of ventilation had been followed by a fall in the bacterial content of the theatre air to levels in line with those considered desirable by

Bourdillon and Colebrook (1946), who advised an upper safe limit of 10 colonies per cubic foot (0.028 cubic metre) for quiet periods during major operations.

Analysis of the bacterial content of the theatre air during individual operations confirmed the findings of other workers (Bourdillon and Colebrook, 1946; Blowers, 1957) that the counts were high during activity in the theatre, when people were moving about putting the patient on the operating table or making similar preparations. It fell during the operation, when there was less movement in the theatre, and rose again after the end of the operation.

The rate of fall was rapid. In a typical example the count over the operation site in one patient was 52 colonies per cubic foot just after he had been placed upon the table, but was found to have fallen to 12 six minutes later and to 8 after another six minutes. The rise in bacterial content was equally rapid when activity was renewed in the theatre at the end of the operation. In this same case the count was 11 as the last stitch was inserted, but it rose to 75 three minutes later as the patient was moved from the table. It is related of Lord Lister that it was his practice, when all was ready for an operation, to stand in meditation for a few minutes before he began. There appear to be good bacteriological as well as spiritual grounds for doing so.

Another observation of interest was made when the anaesthetist who normally sat beside the patient's head stood up in front of the table in the air upwind of the operation site. The bacterial count near the wound was found to have risen from the general level pertaining throughout operation of less than 10 colonies per cubic foot up to 35.

Other Changes to Reduce Bacterial Content of Operating Theatre Air

After the effects of changing the direction of the air current had been studied two further changes were made (Table I). The first of these was to introduce the practice by the entire surgical team of changing into clean operating-

TABLE I.—Averages of Air Counts During Operations (Total Colonies Per Cubic Foot) (All Samples Taken from Vicinity of Wound)

1. Before ventilation changed	21.7
2. After	9.9
3. After introducing use of sterile suits	7.8
4. After adding new door	7.3

suits. Before this only the surgeon and his first assistant had changed, the others merely donning a sterile gown over their ordinary clothes. Studies by Hare and Thomas (1956) had suggested that fewer bacteria might be liberated by people when they moved if they were wearing sterile or clean suits instead of their ordinary clothing under a sterile gown.

FIG. 6.—Total colonies obtained by slit sampling the air of the theatre during operations before and after altering ventilation at end of 1955.

*Manufactured by C. F. Casella & Co., Ltd., Fitzroy Square, London, W.1.

After this change of practice in 1956 another series of counts was made of bacteria over the operation site during 14 operations. The mean of the counts amounted to 7.8 compared with 9.9 before the change of practice.

The second alteration in the conditions in the operating theatre was made in 1957, when a door was hung in the entry doorway to the theatre. Before this there had always been, despite plenum system of ventilation, a current of air flowing into the theatre at floor level through the doorway. The use of a door changed the direction of this draught to an outward one. A series of samples taken over the operation site during 16 operations in 1957 following this change showed a mean of 7.3 colonies per cubic foot.

Both of these changes in bacterial content, although small and perhaps of doubtful statistical significance, were in the direction desired.*

Records of Wound Sepsis

A record was kept in a "wound book" of the particulars of all surgical operations on the surgical unit from 1955 onwards and the way in which the wounds healed. Cases in which infection existed before operation were excluded.

We were particularly interested in studying exogenous infections in clean surgical wounds. We therefore excluded from the sepsis figures cases of endogenous infection—for example, cases where the bowel was opened during operation and infection with coliform organisms ensued. The sepsis figures were found in the event to consist almost entirely of staphylococcal infections.

Sepsis was divided into two grades. It was classed as grade 1, or minor sepsis, if merely low-grade inflammation in the surface of the wound or the skin around it existed or if stitch infection occurred. Grade 2, or major sepsis, comprised those cases in which definite suppuration, delay in wound healing, and fever occurred. Swabs were taken from all infected wounds and records kept of the organisms grown and of their sensitivity to antibiotics.

Several things suggested that many of the cases of grade 2 sepsis were due to infection acquired during operation. Frequently the sepsis manifested itself first by pyrexia and perhaps deep pain or induration below the wound, during which time the surface of the wound appeared to be healing normally and showed no signs of inflammation. Later the inflammatory process reached the surface and pus was evacuated. It seemed likely that inflammation which arose deeply in this way was more probably caused by an infection introduced into the wound during the operation rather than to infection working its way down from the surface afterwards. On the other hand, many of the minor or grade 1 inflammations may have been post-operative ones. Support for this was suggested by the finding in a number of cases that swabs taken from the wound at the end of the operation were sterile but that later superficial grade 1 sepsis with positive swabs of the hospital staphylococcus developed.

Relation of Sepsis Rate to Bacterial Content of Theatre Air

The sepsis rates for clean surgical cases for the years 1955, 1956, and 1957 are shown in Table II. It is evident at once that the reduction in the bacterial content of

*The bacterial counts were also statistically analysed in another way. For each operation a bacterial count was done a number of times. The average of these was the average for the operation. To assess the count over a series of operations the average of the averages was taken. In this way the statistics for the four groups shown in Table I worked out as 22.0, 10.1, 8.1, and 8.2.

TABLE II.—Sepsis Rates in 681 "Clean" Operations in Theatre 2 During 1955-7 (Ventilation System was Changed at the End of 1955)

	1955	1956	1957
All sepsis	9.2% (22/237)	9.7% (29/237)	10.8% (16/147)
Grade 1 sepsis	6.3%	5.7%	7.4%
" 2 "	2.9%	4%	3.4%

the theatre air effected by the changed method of ventilation introduced at the beginning of 1956 and already described was not followed by a comparable fall in the sepsis rate for patients operated upon in theatre 2 where the change was made. This was so both for major (grade 2) sepsis rate and for the overall rate.

The figures for theatre 1, the twin theatre with unchanged ventilation, have not been included in Table II because less than half as many operations (301) were done in it and when broken down into subgroups the numbers were too small to be significant. The total sepsis rates for both theatres are, however, shown in Fig. 7.

Analysis of the monthly sepsis rate in Fig. 7 shows it to be unaffected by the change in ventilation in theatre 2 in 1956. Nor did the introduction in 1956 of the use by the entire surgical team of clean operating-suits for each operation list, or of the addition of a door to the theatre in 1957, affect the sepsis rate despite the downward trends in the bacterial content of the air. It appears that there is a rough correspondence between the sepsis rates in the two theatres, suggesting that they might have been influenced by some factors common to both.

The rate of grade 2 (major) sepsis might be considered to be more truly representative of infection acquired during operation than the total sepsis rate. However, analysis of this on a month-by-month basis showed that it followed in general the total sepsis rate and did not appear to be influenced by the measures taken to reduce the risk of air-borne infection in the theatre.

A feature of Fig. 7 which may be of significance is the very similar rise in the sepsis rates which occurred in June, 1956, when the plenum ventilation system of both theatres went out of action. This resulted in the failure of the positive-pressure ventilation in both theatres and may have allowed the ingress of bacteria containing air from elsewhere in the hospital.

Relation of Sepsis Rate to Presence of Staph. aureus in Air of Theatre

In the preceding experiments only total colonies were considered when counting the plates exposed in the slit sampler. All the plates used contained phenolphthalein diphosphate

FIG. 7.—Total sepsis rates in the two theatres on a monthly basis. Ventilation altered in Theatre 2. The numbers developing sepsis expressed as percentage of the "clean" operations at risk. ---, Theatre 1. —, Theatre 2.

(Barber and Kuper, 1951), which enabled *Staphylococcus aureus* to be readily detected. It is of interest that this organism was recovered from the air of the theatre during clean operations in 1955-7 on only six occasions out of the 42 "clean" operations which were studied and that none of the patients involved developed sepsis.

On the other hand, staphylococcal infection did occur in patients during whose operations frequent air samples were taken and no staphylococci were detected. This certainly occurred with two out of the remaining 36 patients studied in 1955-7.

Thus there seems to be little relationship between the development of post-operative sepsis and the presence or absence of *Staph. aureus* in the theatre air. There are two possible explanations for this: first, that the sampling has in some way been unrepresentative of the risk of air-borne infection (particularly when it is remembered that all the air in the theatre is changed some 10 to 12 times an hour); or, secondly, that infection when it did occur was not air-borne but arose by some other means.

Possible Sources of *Staph. aureus* Other than Air of Theatre

There are many possible sources of infection of clean surgical wounds other than air-borne infection in the operating theatre, and some of them are discussed further below.

One source for which we discovered some evidence in our study was the patient himself. It is possible for the patient to become a carrier of the hospital staphylococcus during his stay in the hospital ward before operation and to bring the organism with him to the theatre. Swabs were taken from 50 "clean" surgical patients at operation: 30% were found to be nasal carriers and 10% skin carriers of the hospital staphylococcus.

An unfortunate example of the possible danger of such carriage was provided by a male patient who showed strongly positive cultures from his nose and bedclothes of a hospital staphylococcus resistant to antibiotics other than chloramphenicol and erythromycin. He developed a superficial infection with this organism in his femoral arteriogram wound. It cleared, and an arterial homograft was inserted three weeks later. This second wound healed *per primam*, but a false aneurysm developed three weeks afterwards at the arterial anastomosis, and from it the organism was grown. It was also isolated by blood culture. Ablation of the graft and amputation were necessary.

Discussion

Analysis of data from this investigation has shown that a substantial fall occurred in the bacterial content of the theatre air after altering the ventilation in it. The physical basis of this requires explanation. It is unlikely that a continuous emanation of contaminants from sources near the table would be effectively eliminated by a draught such as this because of mixing. Indeed, some experiments which were kindly performed for us by Dr. D. M. Lidwell showed that vapour emitted continuously by sources alongside the table was not prevented by the draught from reaching a detector placed upon it. Under natural conditions it is likely that much contamination of the air is of an intermittent nature due to the movements of people near the operating table. Bacteria or bacteria-carrying particles emitted in an intermittent fashion might be carried away before they had time to settle upon the wound or its surroundings.

No decline occurred in the incidence of post-operative wound sepsis amongst the patients operated upon in the theatre comparable to the fall in the bacterial content of the air. It is interesting to compare these results with those of Shooter *et al.* (1956), who in reducing the bacterial content of the air in their theatre achieved a marked reduction in the incidence of post-operative wound infection. They concluded that the infections in their series were chiefly due to

contaminated air being sucked into the theatre from the surgical wards and that the reduction in the incidence was due to the inception of positive-pressure ventilation and possibly also to a cross-draught of fresh filtered air which they directed across the operating table. It may be that the introduction of positive pressure was more important than the cross-draught in their series, because in ours positive pressure was in operation from the beginning and no fall in sepsis followed the use of a somewhat similar cross-draught.

There are two possible explanations for the failure to reduce the sepsis rate in our patients. The first is that the reduction in bacterial content of the air, although marked, was insufficient for the purpose. This seems unlikely, because the reduction from 20 to under 10 colonies per cubic foot was about the same in Shooter's series as in ours, but it was sufficient to reduce the sepsis in his series. A second possible explanation is that the method of contamination of the wounds in our series was not air-borne, but by some other means.

There are many possible ways in which this might occur, many of them well-recognized hazards. Glove punctures constitute one (Devenish and Miles, 1939). McDonald and Timbury (1957) have shown that a suppurating area on the arm of the surgeon may provide the organisms. A somewhat similar occurrence was reported by Colebrook and Ross (1947). These are, of course, well-recognized hazards, against which strict precautions were taken. The second is an obvious and highly preventable one, and is unlikely to have occurred during this study, as it was particularly guarded against. Another which has already been mentioned, and for which some evidence was found in our studies, is the presence of hospital staphylococci on the skin of many patients when they reach the theatre. Still another hazard is contamination of the wound, or of suture or similar materials, by some member of the surgical team who has become a carrier of a particularly virulent type of staphylococcus. Examples of such happenings have been described by Penikett *et al.* (1958) and by Sompolinsky *et al.* (1957).

At the present time there appear to be no certain or simple means of distinguishing the particularly dangerous staphylococci from those found in routine swabbing in a high proportion of hospital personnel and patients until they make their presence known by causing sepsis. Until some simple test for distinguishing them is evolved, defence against wound infection must lie in a general effort to reduce cross-infection in both theatre and wards.

Conclusions

The bacterial content of the air of an operating theatre declined following the introduction of a cross-draught of fresh filtered air over the operating table.

This reduction in bacterial content occurred in a theatre in which a plenum positive-pressure ventilation system was already in operation.

No corresponding reduction occurred in the rate of post-operative wound sepsis in patients operated upon in this theatre.

The presence of wound infections can be attributed to several possible causes. One which was considered to be important in this study was the acquisition of hospital staphylococci by patients in the wards before operation. Many patients were found at operation to be carriers of the organism in the nose, on the bedclothes, or on the skin.

Reduction of the bacterial content of the air in operating theatres is desirable as a general principle, but is unlikely by itself to eliminate infection.

There is a need for a simple and practical test to detect the more dangerous carriers of organisms in hospitals.

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ATTEMPTED SUICIDES ARRIVING AT A GENERAL HOSPITAL

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Patients who have tried, with varying degrees of determination, to take their own lives present special medical and administrative problems in a general hospital. Their admission may be regarded with disfavour, treatment may be narrowly confined to their physical condition, provision for aftercare or psychiatric investigation haphazard or ignored. They may even be notified to the police, and taken from hospital to court, where a prison sentence may follow. If the hospital has a psychiatric department, the reception and disposal of these patients is more likely to be conducted in accordance with the needs of their mental state.

Over the past 20 years, and markedly since the war, there has been a continued rise in the incidence of suicidal behaviour—deaths by suicide in England and Wales in 1956 were 5,262, the highest ever recorded (Registrar-General, 1956) and there were known attempted suicides 5,387 (*Criminal Statistics*, 1956), thus bringing to the doors of the general hospital an increasing number of patients requiring resuscitation and rehabilitation. Some of these patients came to Guy's in 1957. What they were like, and how they were dealt with, is the subject of the present inquiry.

Other Studies

The literature on suicide and attempted suicide is extensive, contributed mainly by psychiatrists and sociologists. A number of investigations on clinical series have been undertaken: of these, the most recent and most relevant for comparative purposes are those of Batchelor and Napier (1953, 1954), Batchelor (1954a, 1954b), Schmidt, O'Neal, and Robins (1954), Ettlinger and Flordh (1955), Robins, Schmidt, and O'Neal (1957), and Stengel and Cook (1958). Ecological factors affecting suicide rates in different London boroughs are examined by Sainsbury (1955). Epps (1957) analyses the social and psychiatric status of a series of 100 women committed to prison following a suicidal attempt. The preventive effect of hospital admission is discussed by Parnell and Skottowe (1957) in a study of 100 consecutive suicides.

By virtue of their setting—that is, in institutions or public general hospitals—the clinical studies have largely been limited to patients from lower-income groups. Stengel and Cook (1958) have pointed out the lack of information on

the incidence and motivation of attempted suicide among better-off patients, whose action may never come to public notice. The present inquiry, covering both N.H.S. and private patients admitted to the York Clinic of Guy's Hospital, throws some light on social class differences.

Material Available

During the 12-months period January 1 to December 31, 1957, 44 attempted suicides arrived at Guy's, 34 coming to the casualty department and 10 being admitted direct to the York Clinic. Ten of the casualty arrivals were transferred elsewhere; 24 were admitted to the general wards. As the York Clinic group was so small, the previous year's direct admissions (11) were also included, giving an overall total of 55. Full psychiatric histories had been taken on all York Clinic patients: information available on ward patients was much less detailed and occasionally incomplete. No interviews were undertaken with any patient, nor were they followed up after discharge, but information was available for the 1956 York Clinic patients through the clinic's follow-up scheme.

Transfers from Casualty Department (Group 1)

This group comprised 10 patients (7 women and 3 men) who were sent elsewhere after emergency treatment, their transfer being arranged by the psychiatric out-patient department in co-operation with a duly authorized officer. Most were seen by the duty psychiatric registrar. Seven went to observation wards, three to mental hospital as voluntary patients. The patients had mostly been brought in by ambulance from the neighbouring district, either living locally or having been picked up in the street. Two had no fixed address; three came from other Central London areas. Involvement of the police was recorded in only one case. Six arrived before midday, three in the afternoon, and one at 7 p.m. Eight were conscious on arrival, one semi-conscious, one not recorded. Four required no special treatment, three had stomach wash-out, two sutures, and one an emetic. The method of the suicidal attempt was barbiturate overdose (4), slashing (2), coal gas, hanging, jumping, and other poison (1 each). Ages ranged from 19 to 66, six being between 20 and 49 years. Three were married, three single, one was separated, and three were not recorded. Occupation, where recorded, was mainly unskilled. One patient was a vagrant, two were unemployed, and one was a foreigner (Polish).

The precipitating stress of the suicidal attempt, so far as could be judged from the scanty information available, was depression (2 cases), marital trouble (2), unemployment, desertion by girl friend, physical illness, alcohol (1 each), not known (2). Six patients had a history of previous psychiatric illness; of these, four had two or more mental hospital admissions. Three were known to have made previous suicidal attempts (one more than once). Other psychiatric abnormality included two known epileptics (one with borderline mental deficiency), a leucotomized schizophrenic, and a drug-taker. There was evidence of hysterical traits (two patients had made frequent suicidal threats) and general instability. Only one patient, a man of 66, appeared to have had a good previous personality. (Unemployed man living alone, in poor health, suffering pain and sleepless for weeks, put his head in the gas oven.)

It was obvious that this was a sick and socially submerged group.

Admissions to the General Wards (Group 2)

Twenty-four patients (14 women and 10 men) were admitted from the casualty department during the year (one woman was admitted twice). Sixteen lived in the neighbourhood (S.E.1), four in other S.E. London districts, and two in S.W. districts. One, from Yorkshire, was found unconscious in a local public lavatory. The source of referral to hospital was the patients' G.P. (9 cases), the police (9 cases), uncertain or not stated (6). Seven patients were brought in before midday, three in the afternoon, and 14