THE SOURCES OF HOSPITAL INFECTION OF WOUNDS WITH *CLOSTRIDIUM WELCHII*

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(With 3 Figures in the Text)

Although gas gangrene is a rare disease in peace time, the organisms responsible for the condition are widely distributed, *Clostridium welchii* in particular being found commonly in soil, faeces, dust, air, milk and various foods (Weinberg, Nativelle & Prévot, 1937; Colebrook & Cawston, 1948; Smith, 1955); *Cl. welchii* often colonizes open wounds without causing gas gangrene (McLennan, 1943; Williams & Miles, 1945). This variety of habitat is of particular importance in relation to the much dreaded post-operative incidence of gas gangrene (e.g. Meleney, 1948; Sevitt, 1953).

In the study reported here we have used a selective medium (Lowbury & Lilly, 1955) to obtain some quantitative data on the presence of *Cl. welchii* in the air of operating theatres, of an air-conditioned dressing station and of other parts of the hospital. We have also examined the distribution of the organism in burns and other wounds, and obtained some evidence from these and other studies on the relative importance of self-infection and of infection from the environment.

METHODS

Selective medium for Clostridium welchii

The plate Nagler medium described by Hayward (1943) has been modified slightly and rendered selective by the addition of neomycin (100 μg./ml.). The details of this method are described elsewhere (Lowbury & Lilly, 1955). Cultures were incubated anaerobically in a Mackintosh and Fildes jar for 18–24 hr. at 37° C. Few organisms other than *Cl. welchii* grow on this medium. False Nagler reactions have not been encountered; more than 2000 Nagler-positive colonies on plate cultures from various sources have been fully examined and in each case the organism proved to be *Cl. welchii*. Reference strains of *Cl. bifermentans* did not grow on the medium.

Medium for the recognition of Staphylococcus aureus

In making counts of airborne staphylococci we used the phenolphthalein-diphosphate-agar medium described by Barber & Kuper (1951). After aerobic incubation at 37° C. for 24 hr., the culture plates were inverted over strong ammonia for 2 or 3 min. and pink colonies (phosphatase positive) having the appearance of micrococci or staphylococci were counted as presumptive *Staph. aureus*. Many phosphatase-positive and negative colonies were picked and tested for coagulase by a tube method, and the correlation between the results of the two tests was excellent.

Air sampling

Details of sampling by settle plates and by the large slit-sampler (Bourdillon & Lidwell, 1948) are described later. The media described above and (in some tests for 'total organisms only') Hedley Wright agar were used.

Samples from burns and other wounds

Swabs moistened with 10 % broth saline were gently rubbed over the surface of the wound and examined for aerobic bacteria by techniques described elsewhere (see Jackson, Lowbury & Topley, 1951). In addition, the swabs were inoculated on the selective medium for *Cl. welchii*, and cooked meat broth cultures were subcultured, after 48 hr. incubation, on the selective medium.

Rectal swabs

We used a swab mounted on a metal rod and surrounded by a glass pilot tube the outside of which was lubricated with liquid paraffin to facilitate insertion (Rogers, 1954).

Tests for the survival of Clostridium welchii *after drying*

Tests with cultures in cooked meat broth of five strains (C.L.O. 1, C.L.O. 2, A.A.M. 104, B.A.H. and N.C.T.C. 8327) and with suspensions of faeces were made as in previous studies on the skin (Ricketts, Squire & Topley, 1951) and on glass coverslips (Lowbury & Fox, 1953). Further details are given later with the description of these experiments.

RESULTS

Clostridium welchii *in the air of operating theatres*

Each of the two theatres in which these studies were made has a capacity of approximately 7000 cu.ft.; the suite is ventilated by two powerful extractor fans, each estimated to displace 3100 cu.ft./min. Air enters mainly through the doors from the corridor outside and as Sevitt (1953) has pointed out this kind of ventilation transforms the theatre into an 'air sewer' which drains much of the hospital air and dust.

To obtain some idea of the hazards of contamination with *Cl. welchii* in such a theatre we made a number of sampling studies with settle plates and with the slit-sampler referred to above.

(1) *Air sampling during the course of surgical operations*

Fig. 1 shows the results of air samples taken with a slit-sampler during the course of eleven individual operations. During operations nos. 1–6 all the samples were collected on to the selective medium for *Cl. welchii* and show the numbers of presumptive *Cl. welchii* per 100 cu.ft. of air. Six-minute samples (123 cu.ft.) were taken, and the count entered on the chart at the mid-point of the sample. In most cases the first sample was taken before the patient entered and the last after he left the theatre.

During operations nos. 7–11 all the air samples were taken on to phenolphthalein diphosphate agar; 2 min. or 4 min. samples were taken, and again the period of sampling usually extended from before the entry until after the departure of the patient. Counts of presumptive *Staph. aureus* and of total viable organisms were made on this medium, the former counts (continuous line) being expressed on the chart as organisms per 100 cu.ft. and the latter (dotted line) as organisms per cu.ft. of air.

All except no. 8 were 'clean' operations through undamaged skin; they included menisectomy, bone grafting, tendon suture, and insertion of Neufeld nail and Judet prosthesis. Operation no. 8 was for the incision and drainage of a septic lesion. The slit-sampler was standing at a distance of 6–9 ft. from the operating table. The number of people in the theatre varied from eight to sixteen, and the doors opened and closed a number of times during each operation. There was considerable activity at the beginning and again at the end of each operation, but usually little movement during the course of the operation.

The results show little variation in the numbers of *Cl. welchii* in the air during operations, or on different operating days. Every sample contained rather small numbers of *Cl. welchii* (usually between five and twenty-five per 100 cu.ft. of air). These counts were of the same order as those of *Staph. aureus*, but the staphylococci were, on the whole, less numerous and were not found on some sample plates. Contrary to expectation, there was no rise in the number of airborne staphylococci or total organisms during the periods of activity at any operation except no. 8, at which there was an increase in the number of staphylococci. There was no tendency for the accumulation of staphylococci or of total organisms in the air during operations.

These samples gave no hint as to the possible source of *Cl. welchii* or of *Staph. aureus* found in the air.

(2) *Air sampling at different times of the day*

As the exhaust ventilation plant was apparently sucking dirt-laden and contaminated air from other parts of the hospital into the theatre, we took a series of air samples for *Cl. welchii*, and for total organisms, at different times of the day, the first sample of each series being taken early in the morning before the ventilators were switched on; these samples were taken in an empty theatre or while nurses were preparing trolleys.

The results of the samplings are shown in Table 1. There was no evidence of an increase in contamination with *Cl. welchii* or other organisms after the ventilators were switched on. Samples taken during the course of operations showed a higher average total count at the beginning and at the end of the operation list than in the middle, and a slightly lower count of *Cl. welchii* in the later samples than in the earlier. From these data it appeared that the exhaust ventilators were preventing any accumulation of bacteria liberated from persons in the theatre during the course of operations.

Table 1. *Airborne bacteria* (*total and* Clostridium welchii) *in operating theatres*

Time of sampling	Organisms	Mean viable counts/cu.ft.	S.E.	No. of samples (operating days)
Early morning (before ventilators switched on)	Total	7·6	0·51	8
	Cl. welchii	0·052	0·005	8
Ventilators on, before operations	Total	5·9	0·25	12
	Cl. welchii	0·051	0·0037	12
Beginning of operating list	Total	8·1	0·37	10
	Cl. welchii	0·075	0·0046	11
Middle of operating list	Total	5·5	0·22	11
	Cl. welchii	0·073	0·0052	11
End of operating list	Total	9·2	0·6	11
	Cl. welchii	0·059	0·0037	10

(3) *Settle-plate counts in operating theatres and elsewhere*

To obtain viable counts of organisms settling from the air, we exposed on a large number of occasions plates of the special media for *Cl. welchii* and for *Staph. aureus* simultaneously during operations in both of the theatres and in the adjacent corridor. The plates in the theatre were allowed to stand on a trolley near the operating table throughout the period of operations. After overnight incubation at 37° C. under appropriate conditions, colonies of presumptive *Cl. welchii* and *Staph. aureus* and total organisms were counted. A similar daily sampling was made in the air-conditioned dressing station of the Burns Unit (Bourdillon & Colebrook, 1946) and its adjacent corridor. In addition to these samplings ('series B'), we took daily settle-plate samplings during an earlier period on to the selective Nagler medium and on to Hedley Wright agar ('series A'); from these we obtained a record of *Cl. welchii* and total organisms in both theatres and in the dressing station. Similar samples were taken weekly in various parts of the hospital, in the street and on the roof.

Table 2 summarizes the results of this survey. In the theatres, the counts of *Cl. welchii* and of *Staph. aureus* occupied a similar range, but, in contrast to the slit-sampler counts, the settle-plate counts of *Staph. aureus* were somewhat greater than those of *Cl. welchii*; this difference in ratio may have been due to difference in the size range of particles carrying these organisms. *Cl. welchii* was more abundant in the air of the adjacent corridor in both series of observations, but *Staph. aureus* (in Series B) was commonest in samples taken during 'mixed' operating days in the theatre (i.e. when 'clean' and infected cases were included in the same operating list).

Of greater interest were the results of sampling in the burns dressing station which was ventilated with filtered air (twenty changes per hour). Here *Cl. welchii* was rarely isolated, but *Staph. aureus* was present in much greater numbers than in the air of operating theatres. By contrast, the settle plates exposed in the corridor adjacent to the burns dressing station showed a rather high count of *Cl. welchii*, and a count of *Staph. aureus* much lower than that in the dressing room, but comparable with counts obtained in the operating theatres and their adjacent corridor.

Table 2. Clostridium welchii, Staphylococcus aureus *and total organisms on settle plates exposed in operating theatres and elsewhere*

Place	*Cl. welchii*			*Staph. aureus*			Total organisms		
	Mean colonies/ sq.ft./hr.	Samples (days)	S.E.	Mean colonies/ sq.ft./hr.	Samples (days)	S.E.	Mean colonies/ sq.ft./hr.	Samples (days)	S.E.
Theatre I									
Clean operations only, series B	2·3	32	0·06	3·6	32	0·16	234	32	3·5
Mixed operations, series A	4·5	65	0·15	—	—	—	267	65	2·7
Mixed operations, series B	3·0	15	0·3	9·7	15	0·65	220	15	0·7
Theatre II									
Clean operations only, series B	2·5	47	0·06	2·8	47	0·1	185	47	1·8
Mixed operations, series A	3·7	62	0·09	—	—	—	230	62	0·5
Corridor outside theatres									
Series A	7·8	57	0·16	—	—	—	327	57	2·6
Series B	7·9	50	0·17	5·6	50	0·2	315	50	2·3
Burns dressing station (air conditioned)									
Series A	0·49	19	0·05	—	—	—	231	19	10·2
Series B	0·84	24	0·09	29·3	24	0·9	259	24	3·8
Corridor outside burns dressing station									
Series B	10·3	26	0·42	6·4	26	0·25	270	26	4·3
Caualty reception hall	26·4	9	1·7	23·5	1	—	1003	9	43
Outpatient dressing room (casualty)	16·3	9	0·65	2·1	1	—	940	9	36
Ward A	16·0	9	1·8	2·1	1	—	707	9	44
B	52·8	9	10·0	25·5	1	—	646	9	27
E, F } Burns	2·8	9	0·48	21·0	1	—	835	9	49
E, F } Burns	4·1	9	0·36	17·1	1	—	674	9	17
Burns shock room (empty)	1·3	5	0·52	—	—	—	75	5	19
Burns saline bathroom	2·9	8	0·49	—	—	—	267	8	13
Street	44·7	8	5·6	0	1	—	255	8	25
Roof	20·9	9	2·7	0	1	—	148	9	12

Of the samples taken in various parts of the hospital, those showing the highest counts of *Cl. welchii* came from the casualty reception hall and dressing room, and from two wards on the ground floor; the lowest counts were found in the burns wards and in the empty shock room, the latter showing also the lowest count of total organisms. Both street and roof air showed high counts of *Cl. welchii*.

Total counts bore no relationship to counts of *Cl. welchii*. The highest total counts were found in the casualty department and in one of the burns wards; those from the roof and the street were among the lowest.

From the data presented in Table 2 it would appear that airborne *Cl. welchii* is introduced from outside the hospital, while *Staph. aureus* is added to the air inside from sources within the hospital. The counts of *Cl. welchii* varied little during the course of any single day, but there were obvious variations with weather; the highest counts were found in dry weather, the lowest during continuous rain or snow.

(4) *Slit-sampler counts in burns dressing station*

Fig. 2 shows the results of sampling during comparable dressing for *Cl. welchii* (left) and for *Staph. aureus* (right). The very small numbers of *Cl. welchii* found here are in contrast to the moderate numbers found in the operating theatre (Fig. 1). Large numbers of staphylococci were dispersed into the air during the removal of dressings from the burns, which were heavily colonized with *Staph. aureus*. *Cl. welchii* was not found on any of these burns.

Fig. 2 gives further evidence of the exclusion of *Cl. welchii* from the air by filtration, and of the absence of air contamination with *Cl. welchii* by persons in the dressing station.

(5) *The source of airborne* Clostridium welchii *and* Staphylococcus aureus

In order to obtain further evidence as to the source of these airborne bacteria the following experiment was made: three persons who were known to carry *Staph. aureus* in their noses and *Cl. welchii* in their stools entered the dressing station of the burns unit after the air-conditioning plant had been running for 15 min. The plant was then switched off, and the air was sampled for *Cl. welchii* before and during the performance of a series of fairly vigorous arm and leg exercises. This performance was repeated after another 15 min. ventilation, and samples were collected on phenolphthalein diphosphate agar for counts of *Staph. aureus* and total organisms. A series of samples with both media were then taken in a laboratory (representing hospital air) and in the street.

The results are shown in Table 3. The 'mock operation' in the dressing station resulted in some contamination of the air with *Staph. aureus* but apparently none with *Cl. welchii*. Laboratory air contained fewer *Staph. aureus* and more *Cl. welchii*. Street air contained considerably more *Cl. welchii* and virtually no *Staph. aureus*.

Clostridium welchii *in burns*

For a period of 15 months all the swabs taken from burns of in-patients on admission, at operations and at changes of dressing (or daily from exposed burns)

were inoculated directly on neomycin Nagler plates and also into cooked meat broth. Subcultures from the latter were subsequently plated on to neomycin Nagler agar.

Out of 454 patients, 158 (34·8 %) were found to have *Cl. welchii* in their burns at some time during their stay in hospital. Fig. 3 shows the incidence of colonization by *Cl. welchii* in patients with burns of different sizes; as in the case of *Pseudomonas pyocyanea* (Lowbury & Fox, 1954), colonization by *Cl. welchii* was found more

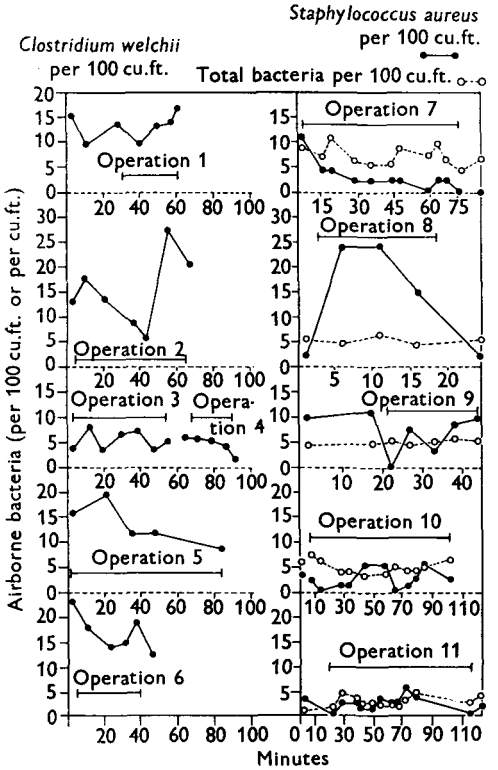

Fig. 1

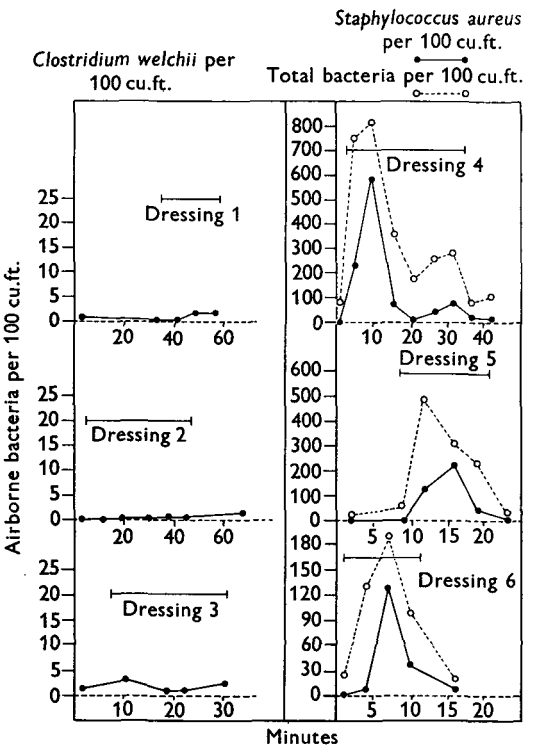

Fig. 2

Fig. 1. Slit-sampler counts of *Cl. welchii* (on left) and *Staph. aureus* (on right) per 100 cu.ft. and of total viable organisms (on right, dotted line) per cu.ft. of air during the course of eleven operations in theatre ventilated by extractor fans.

Fig. 2. Slit-sampler counts of *Cl. welchii* (on left) and of *Staph. aureus* and total viable organisms (on right, the latter dotted line) per 100 cu.ft. of air during dressing of six burns in dressing station ventilated by plenum system with filters.

commonly in the more extensive burns. When compared with *Ps. pyocyanea* or *Staph. aureus*, however, *Cl. welchii* was found to be a transient inhabitant of burns and usually present only in small numbers. These features are illustrated by Table 4, in which the persistence of *Staph. aureus* and of *Cl. welchii* in burns are compared, and by Table 5, which shows the proportions of heavy and scanty growth of the two organisms. A heavy growth of *Cl. welchii* was sometimes obtained from the

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Table 3. *Airborne* Clostridium welchii *and* Staphylococcus aureus *in unventilated dressing room, laboratory and street*

	Unventilated dressing station during 'mock' operation													
	Serial samples						Laboratory Serial samples				Street Serial samples			
	Quiet		Action											
	1	2	3	4	5	6	1	2	3	4	1	2	3	4
Cl. welchii per 100/cu.ft. (6 min. samples)	0·7	—	1·5	1·5	—	—	1·5	4·5	—	—	19	23	—	—
Staph. aureus per 100 cu.ft. (2 or 4 min. samples)	2·2	0	11	56	37	56	4·4	2·2	2·2	—	0	1·1	0	—
Total viable organisms per 100 cu.ft. (2 or 4 min. samples)	83	37	287	1191	1489	2289	176	169	159	—	143	152	181	—

slough over extensive burns, and it seemed possible that the organism might be contributing something towards the symptoms of 'toxaemia' which are usually found in such patients. Clinical gas gangrene, however, was not found in any of them.

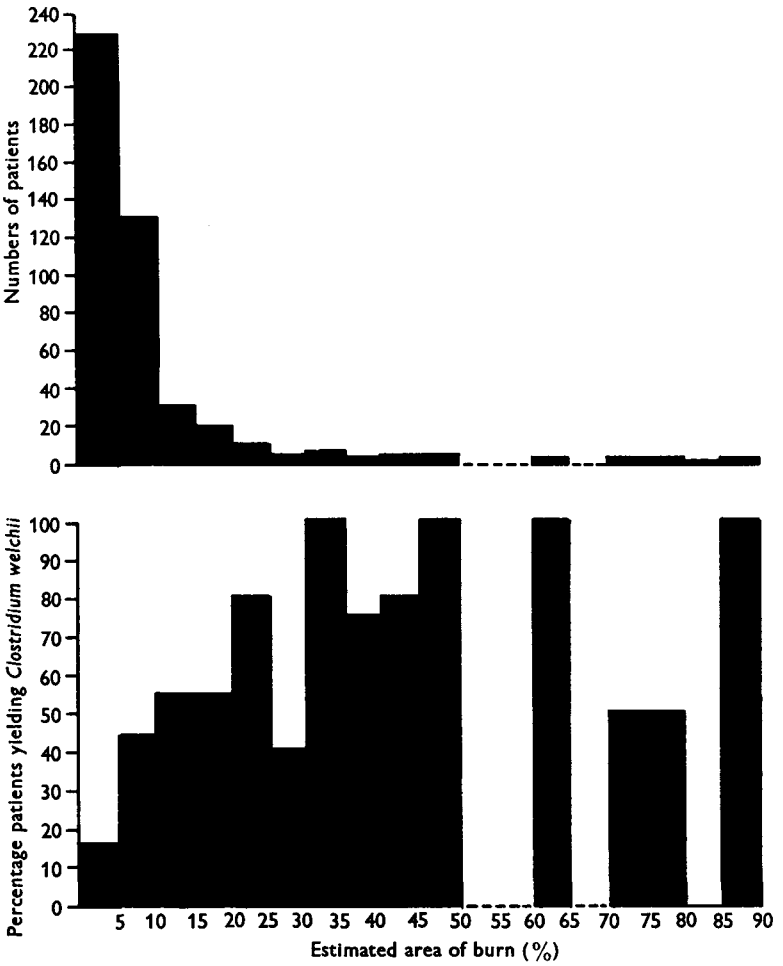

Fig. 3. The lower chart shows the proportion of burns of different percentage total body area yielding *Cl. welchii* at some time during treatment in hospital; the distribution of patients with burns of different percentage area is presented in the upper chart.

Table 4. *Persistence of* Clostridium welchii *and* Staphylococcus aureus *in burns of in-patients*

	No. of burns in which time between first and last positive swab was								
Organism	0 days (1 positive)	1–4 days	5–9 days	10–14 days	15–19 days	20–24 days	25–29 days	>29 days	Total
*Cl. welchii**	150	30	25	12	2	3	3	13	238
Staph. aureus†	40	16	23	18	14	11	9	48	179

* All strains isolated from 158 patients between September 1955 and December 1956.

† All strains isolated from the burns which also yielded *Cl. welchii* in this period.

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Table 5. *Numbers of* Clostridium welchii *and* Staphylococcus aureus *in burns*

Organism	'Positive' swabs showing: Moderate or* heavy growth	Scanty* growth	Total	Burns†
Cl. welchii	135	265	400	238
Staph. aureus	860	33	893	179

* 'Moderate or heavy growth' = growth on culture plates on to which swabs were inoculated; 'scanty growth' = growth only on subculture from fluid medium.

† The same series as in Table 4; see footnotes to that Table.

Clostridium welchii *in other wounds*

We are indebted to Dr S. Sevitt for permission to use his record of swabs from lesions other than burns which were examined in the clinical pathology laboratory during 1956. These were not taken as a routine from all wounds, and so are not statistically comparable with the data from burns.

Out of 141 wounds in this record, ten were found to be colonized by *Cl. welchii*. Twenty-seven of these were operation wounds, from none of which *Cl. welchii* was isolated. The proportion of *Cl. welchii* in traumatic wounds was therefore ten out of 114 (8·8 %).

The source of contamination of burns and other wounds with Clostridium welchii

From the data presented above, unfiltered air must be regarded as a potential source of contamination of wounds with these organisms, but so also must the patient's alimentary tract. Wilson & Miles (1955) state that *Cl. welchii* is uniformly present in human faeces. We have found the organism in 89 out of a series of 112 stools (79 %), often in large numbers.

To obtain some information on the possible importance of self-infection from this source, we examined rectal swabs taken on admission from sixty-two patients, and also swabs taken from burns of these patients on admission and later. The results of this study are summarized in Table 6. Out of thirty patients whose rectal swabs yielded *Cl. welchii* on admission, twenty (66 %) with burns originally free from *Cl. welchii* were subsequently found to be harbouring the organism

Table 6. Clostridium welchii *in rectal swabs on admission to hospital and in burns later*

	Patients with *Cl. welchii*: Present in rectal swab	Absent from rectal swab
Cl. welchii present in burns later	20	8
Cl. welchii absent from burns later	10	24
Total	30	32

$\chi^2 = 9{\cdot}4$, $P < 0{\cdot}01$.

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in burns; by contrast, only eight out of thirty-two (25 %) patients whose rectal swab did not yield *Cl. welchii* were found to acquire *Cl. welchii* in their burns. ($\chi^2 = 9{\cdot}4$, $P < 0{\cdot}01$.) The two series were comparable in range of area burned. This result supported a view that burns are at least as frequently contaminated with *Cl. welchii* by self-infection from the alimentary canal as from other sources (e.g. air).

In view of the special liability of burns to receive contaminants from the air, it seems probable that other kinds of wound also stand a risk of self-infection with *Cl. welchii* which may perhaps be greater than that of contamination by airborne vectors of the organism.

Viability of Clostridium welchii *on drying*

One of the principal factors in the successful transfer of bacteria is their ability to survive the evaporation of the fluid menstruum in which they have grown. Gram-positive cocci are, in general, more resistant to the lethal effects of drying than Gram-negative bacilli, but in each group of organisms there is considerable strain variation (Lowbury & Fox, 1953). The elimination of Gram-negative bacilli from the skin is apparently due to their sensitivity to the effects of atmospheric drying (Ricketts *et al.* 1951).

Using the methods described in the above papers, we studied the effects of drying on suspensions of *Cl. welchii* culture and of faeces containng *Cl. welchii*. Five strains of *Cl. welchii* from different sources and specimens of faeces from three carriers of the organism were used. Overnight cultures in cooked meat broth were washed three times in physiological saline and resuspended in horse serum and in distilled water. Each suspension was spread in 0·02 ml. amounts on six cover-slips which were extracted in pairs immediately (wet), after 2 hr. (dry) and again after 48 hr. by shaking with glass beads in 10 ml. broth saline. Viable counts of the extracts were made by the method of Miles and Misra on neomycin Nagler plates. Dense suspensions of faeces in saline were tested in the same way on cover-slips and also on the skin, the latter receiving inocula from a wire loop and being covered with a nylon dressing; samples were taken by rubbing the area in a standard fashion with a moistened swab and then rubbing the swab over the whole area of a neomycin Nagler plate. Cultures and faecal suspensions were also tested for survival of *Cl. welchii* after heating at 65° C. for 1 hr.

The results are shown in Table 7. All cultures of *Cl. welchii* were completely killed by drying suspensions of them on cover-slips and by heating at 65° C. *Cl. welchii* in faecal suspensions, on the other hand, survived both heating and exposure to drying, the latter both on cover-slips and on the skin. Apparently *Cl. welchii* will survive drying only in the spore form, the vegetative clostridia being even more sensitive to drying than the Gram-negative bacilli. Many sporing *Cl. welchii* are present in stools and can survive on the skin. It is understandable, therefore, that self-infection of wounds commonly occurs; on the other hand, it is surprising that *Cl. welchii* is not commoner on the skin (we found it in sixteen out of 114 swabs from the hands of in-patients, in fluid culture only), and that *Cl. welchii* is apparently not dispersed by faecal carriers into the atmosphere. Our failure to

detect this may be due to inadequate sensitivity of the tests; this view is supported by the fact that we isolated *Cl. welchii*, sometimes in considerable numbers, from the trousers turn-ups of 14/14 male laboratory workers tested.

Table 7. *Effect of atmospheric drying and of heat on survival of* Clostridium welchii

Strains and sources of *Cl. welchii*	Percentage of initial count after: Drying on coverslips 2 hr.	Drying on coverslips 48 hr.	Drying on skin 2 hr.	Drying on skin 24 hr.	Heating at 65° C. for 1 hr.
Cultures of five strains in cooked meat broth	0	0	—	—	0
Faeces A	100	71	37	69	110
Faeces B	73	64	55	11	69
Faeces C	130	100	—	—	—

DISCUSSION

It is now generally recognized that the ventilation of operating theatres by extractor fans is undesirable, and the advantages of the 'plenum' type of ventilation have been reported by a number of workers (Girdlestone & Bourdillon, 1951; Lowbury, 1954; Blowers, Mason, Wallace & Walton, 1955; Shooter, Taylor, Ellis & Ross, 1956). From the data presented in this paper it would appear that the 'plenum' system protects the open wound from airborne staphylococci liberated in the theatre by blowing them away, and from *Cl. welchii* and (if the air comes from indoors) from more staphylococci by filtering them off. The numbers of *Staph. aureus* and *Cl. welchii* in the air of an operating theatre ventilated by extractor fans are of the same order, but their sources are quite different, the former being derived apparently from persons in the hospital (see also Hare & Thomas, 1956), while the latter, unless contaminated material is directly introduced into the hospital, come in with 'fresh air' through windows and doors. A powerful extractor fan can be expected to prevent the accumulation of airborne staphylococci liberated in the theatre, but it will not reduce the level of *Cl. welchii* or prevent the ingress of *Staph. aureus* already present in the hospital air. Plenum ventilation without filters blowing in air from outside the hospital might well increase the level of *Cl. welchii* in the theatre.

While it is obviously desirable to reduce the level of airborne *Cl. welchii* in operating theatres, the importance of this source of contamination is possibly smaller than that of the faecal reservoir. In burns, at least, we found evidence which suggests that self-infection with *Cl. welchii* is at least as common as infection from external sources. *Cl. welchii* in the faeces are mostly in the form of spores which survive the lethal effects of drying and are more resistant to disinfectants than staphylococci and other vegetative bacteria. They are, therefore, well adapted to survive on the skin even after pre-operative cleansing. Skin carriage of *Cl. welchii* is fairly common, but the organisms are fortunately sparse, and the healthy tissues provide a poor medium for their growth; they are often present on burns,

especially if the burns are extensive, but, unlike *Staph. aureus* or *Pseudomonas pyocyanea*, they usually appear in small numbers and for a short time only.

A point of biological and perhaps also of hygienic interest is the extreme sensitivity to drying of vegetative forms of *Cl. welchii*. It would seem that mechanisms which render the non-sporing Gram-positive cocci and, in smaller measure, Gram-negative bacilli capable of surviving the evaporation of their suspending menstruum are not present in the vegetative forms of this organism, but it can achieve better protection for itself by forming spores.

SUMMARY

The air of operating theatres ventilated by powerful extractor fans was sampled during operations with special media for *Cl. welchii* and *Staph. aureus*, and also for total organisms. Counts made with the slit-sampler showed the presence of *Cl. welchii* in all samples in a range slightly higher than that of *Staph. aureus* (mostly between five and twenty-five colonies per 100 cu.ft.). There was no evidence of a build-up of either *Cl. welchii* or *Staph. aureus* during the course of operations, nor were there any consistent peaks of contamination during operations.

Settle plates exposed on numerous days in the operating theatres showed similar counts of *Cl. welchii* and *Staph. aureus*—the latter slightly more abundant in this series. Settle-plate counts from many parts of the hospital and from the road outside provided evidence that airborne *Cl. welchii* comes into the hospital from outside, while *Staph. aureus* is contributed to the air inside the hospital. This view was supported by study with the slit-sampler and with settle plates in a dressing station ventilated with filtered air, where *Cl. welchii* was rarely found and *Staph. aureus* momentarily abundant during dressings; staphylococci but not *Cl. welchii* were dispersed by the operators in a mock operation. The numbers of airborne *Cl. welchii* inside and outside the hospital were higher in dry than in rainy weather.

Of the patients in the Burns Unit 35 % had at some stage *Cl. welchii* in their burns; contamination was commoner in the more extensive burns. In contrast to *Staph. aureus*, *Cl. welchii* was usually present in small numbers and for a short period.

Cl. welchii was found in the burns of twenty out of thirty (66 %) patients whose rectal swab taken on admission showed the presence of *Cl. welchii*; a significantly smaller proportion of patients whose rectal swabs were free from *Cl. welchii* picked up the organism while in hospital (eight out of thirty-two, 25 %; $\chi^2 = 9{\cdot}4$, $P < 0{\cdot}01$). This observation supports the view that burns and possibly other wounds acquire *Cl. welchii* by self-infection at least as often as from the environment. While it is obvious that plenum ventilation of operating theatres with filtered air is desirable, it is uncertain to what extent this will reduce the small hazard of post-operative gas gangrene.

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REFERENCES

BARBER, M. & KUPER, S. W. A. (1951). Identification of *Staph. pyogenes* by the phosphatase reaction. *J. Path. Bact.* **63**, 65.

BLOWERS, R., MASON, G. A., WALLACE, K. R. & WALTON, M. (1955). Control of wound infection in a thoracic surgery unit. *Lancet*, ii, 786.

BOURDILLON, R. B. & COLEBROOK, L. (1946). Air hygiene in dressing rooms for burns or major wounds. *Lancet*, i, 561, 601.

BOURDILLON, R. B. & LIDWELL, O. M. (1948). Studies in air hygiene. *Spec. Rep. Ser. med. Res. Coun., Lond.*, No. 262, p. 19.

COLEBROOK, L. & CAWSTON, W. C. (1948). Studies in air hygiene. *Spec. Rep. Ser. med. Res. Coun., Lond.*, No. 262, p. 233.

GIRDLESTONE, G. R. & BOURDILLON, R. B. (1951). Infection of clean surgical wounds. *Lancet*, i, 597.

HARE, R. & THOMAS, C. G. A. (1956). The transmission of *Staphylococcus aureus*. *Brit. med. J.* ii, 840.

HAYWARD, N. J. (1943). The rapid identification of *Cl. welchii* by Nagler tests in plate cultures. *J. Path. Bact.* **55**, 285.

JACKSON, D. M., LOWBURY, E. J. L. & TOPLEY, E. (1951). *Pseudomonas pyocyanea* in burns. *Lancet*, ii, 137.

LOWBURY, E. J. L. (1954). Air conditioning with filtered air for dressing burns. *Lancet*, i, 292.

LOWBURY, E. J. L. & FOX, J. E. (1953). Influence of atmospheric drying on the survival of wound flora. *J. Hyg., Camb.*, **51**, 203.

LOWBURY, E. J. L. & FOX, J. E. (1954). Epidemiology of infection with *Ps. pyocyanea* in a burns unit. *J. Hyg., Camb.*, **52**, 404.

LOWBURY, E. J. L. & LILLY, H. A. (1955). A selective plate medium for *Cl. welchii* . *J. Path. Bact.* **70**, 105.

MACLENNAN, J. D. (1943). Anaerobic infection of war wounds. *Lancet*, ii, 63.

MELENEY, F. L. (1948). *Treatise on Surgical Infections*, p. 664. New York: O.U.P.

RICKETTS, C. R., SQUIRE, J. R. & TOPLEY, E., with LILLY, H. A. (1951). Human skin lipids, with particular reference to the self-sterilising power of the skin. *Clin. Sci.* **10**, 89.

ROGERS, K. B. (1954). Examination of faeces for infection and infestation. *Brit. med. J.* i, 147.

SEVITT, S. (1953). Gas-gangrene infection in an operating theatre. *Lancet*, ii, 1121.

SHOOTER, R. A., TAYLOR, G. W., ELLIS, G. & ROSS, J. P. (1956). Post-operative wound infection. *Surg. Gynaec. Obstet.* **103**, 257.

SMITH, L. D. S. (1955). *Introduction to the Pathogenic Anaerobes*, Chicago.

WEINBERG, M., NATIVELLE, R. & PRÉVOT, A. R. (1937). *Les Microbes Anaerobes*. Paris.

WILLIAMS, R. E. O. & MILES, A. A. (1945). Bacterial flora of wounds and septic lesions of the hand. *J. Path. Bact.* **57**, 27.

WILSON, G. S. & MILES, A. A. (1955). *Topley and Wilson's Principles of Bacteriology and Immunity*, 4th edition. London: Arnold.

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