

## STAPH. AUREUS AIR INFECTION IN A MATERNITY HOSPITAL

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NEWBORN infants are especially susceptible to infection by *Staph. aureus*. Even the well-run maternity hospital often has a high incidence of infection among the babies during their week or so of residence. Pemphigus neonatorum, minor septic skin lesions, umbilical sepsis, nasal infection, blepharitis and conjunctivitis are common, and some cases occur of staphylococcal pneumonia, meningitis and osteomyelitis (Cass, 1940; Ludlam, 1947).

Investigations such as those of Elliot, Gilliespie and Holland (1941), Duncan and Walker (1942) and Allison and Hobbs (1947) have shown that a majority of infections may occur in outbreaks due to distinct serological types of *Staph. aureus*. During the outbreak the epidemic strain is found in a multiplicity of sources in the hospital. It occurs in the lesions of clinically infected infants, and also in the noses of healthy carriers who include a large proportion of the well infants, mothers and nurses. *Staph. aureus* contamination of the hands is likely to be present in as many as half of the nasal carriers. Commonly the milk of nursing mothers is infected, but this is not thought to be an important source of infection for the infants; it appears that the breast usually receives the infection from an already infected child (Duncan and Walker). The epidemic staphylococcus may be present and viable on the infant's garments and bedding, even after laundering, and in the floor dust and air of the hospital. In a few observations made with "settling plates," Elliot, Gilliespie and Holland (1941) and Allison and Hobbs (1947) found *Staph. aureus* to be present in the air of the hospital nurseries during outbreaks of pemphigus. Allison and Hobbs regarded the degree of air infection as low; they concluded that the main reservoir of infection was the nasal passages of healthy carriers among the nursing staff, and that the main means of spread thence to the infants was probably by contact with the carrier's hands; in addition, infection from infant to infant by the commonly shared bath, towel and laundry was thought likely to play an important part.

The present investigation of *Staph. aureus* infection in a maternity hospital unit was directed particularly to assessing the extent of infection of the air. For various reasons it was anticipated that airborne infection would prove to be of major importance. *Staph. aureus* has been one of the pathogenic bacteria most commonly found in the air of occupied premises; for instance, in surgical operating theatres (Hart, 1937, 1938; Hart and Schiebel, 1939; Devenish and Miles, 1939; MacDonald, 1940), in surgical and burns wards (Miles *et al.*, 1940; Bourdillon and Colebrook, 1946; Colebrook and Cawston,

1948), and in wards of an infants' hospital (Brooks, Wilson and Blackfan, 1942). In the case of other respiratory-tract bacteria which probably spread in the same way as *Staph. aureus*, the practice of aseptic nursing procedures for avoidance of contact spread has generally failed to prevent a high incidence of cross-infections in open multi-bed wards; on the other hand, cross-infections have been eliminated where the patients were isolated in single-bed cells designed to prevent airborne spread (Allison and Brown, 1937; Wright, Shone and Tucker, 1941; Stalker, Whatley and Wright, 1942; Chapple, 1942).

#### CIRCUMSTANCES OF THE INVESTIGATION

The investigation was carried out during sixteen weeks from 12th March to 2nd July 1947, in the maternity unit of a large general hospital in Edinburgh. The unit consisted of several rooms opening into a common corridor; it included a mothers' ward (26×16×13 ft. of nine beds), a large nursery (30×14×13 ft., of twenty-six cots), a small nursery (18×16×13 ft., of fourteen cots), a small washroom, a babies' changing room, an isolation ward and offices. The premises were clean and airy; the floors were of polished wood; the windows were large, of part-southerly exposure and usually kept open. There was no appearance of overcrowding. Most of the beds in the mothers' ward and over half of the cots in each nursery were occupied during the period of the investigation. The day and night nursing staffs together usually totalled twelve. The nurses wore masks and gowns when attending the babies. The babies were changed seven times a day or oftener, and were taken at four-hourly intervals to the mothers' ward for nursing. In the course of medical examinations, toilet, bed-making, serving meals and domestic cleaning, the ward and nurseries were entered frequently by doctors, nurses and ward maids; visitors were admitted only to the mothers' ward. Mother and child remained in hospital for about ten days.

During the spring of 1947 the maternity unit reported a high incidence of *Staph. aureus* infections; this prevalence continued throughout the period of the investigation. Among the infants, septic skin lesions and conjunctivitis were especially common, and there was one fatal case of staphylococcal pneumonia. Among the mothers, there were cases of breast abscess, boils, conjunctivitis and Cæsarian wound infection due to *Staph. aureus*. The taking of nasal swabs on one occasion revealed a high incidence of healthy carriers; 2 out of 7 nurses and 11 out of 26 babies carried *Staph. aureus* in the nostrils.

#### EXPERIMENTAL METHODS

Two methods were used for examining the bacterial content of the air; namely, exposure of culture plates to direct sedimentation of infected particles ("settling plates"), and use of the slit sampler of Bourdillon, Lidwell and Thomas (1941). The "settling plates"

presented 10 sq. in. of culture medium surface ; they were left open on a table in the centre of the room. The slit sampler was run at 1 cu. ft. per minute, with a slit-plate distance of 2 mm. ; it was placed centrally in the room at about 3 ft. above the floor. No person was allowed to approach closely to the slit sampler, except the observer at the time of changing plates.

Four different culture media were used : (1) nutrient agar (1 per cent. meat extract, 1 per cent. peptone,  $\frac{1}{2}$  per cent. sodium chloride and 2 per cent. agar), (2) blood agar (nutrient agar with 5 per cent. horse blood), (3) MacConkey agar (2 per cent. peptone,  $\frac{1}{2}$  per cent. sodium taurocholate, 1 per cent. lactose, 2 per cent. agar and neutral red to tint), and (4) salt-milk agar (nutrient agar with 20 per cent. milk and 7 per cent. sodium chloride). The batch of MacConkey agar used gave good growth of *Staph. aureus* with enhancement of pigmentation, and inhibited growth of many other airborne species. Similarly, the salt-milk agar was partially selective for *Staph. aureus* because of its 7 per cent. salt content (Chapman, 1945) and enhanced pigmentation because of its milk content (Christie and Keogh, 1940). Plates were incubated aerobically at 37° C. for twenty-four hours and then left at room temperature for a further twenty-four hours. The colonies were counted with the aid of a plate microscope. All golden-coloured colonies which resembled *Staph. aureus* were subcultured and tested for coagulase production ; only the coagulase positive strains were recorded as *Staph. aureus*.

#### TWENTY-FOUR HOURS SETTLING PLATE OBSERVATIONS

Observations with settling plates exposed for a continuous twenty-four-hour period were made on each of forty days chosen at intervals between 12th March and 2nd July ; a MacConkey plate and a salt-milk agar plate were exposed in each room. *Staph. aureus* was thereby recovered from the air of the maternity unit on thirty-six of the forty days : on twenty-six of forty days in the large nursery, on twenty-six of forty days in the small nursery, on eleven of fourteen days in the mothers' ward and on fourteen of twenty-three days in the washroom. The number of *Staph. aureus* colonies obtained was small, seldom more than two or three per plate ; the number did not vary much between the different rooms, nor between different weeks throughout the investigation.

#### SLIT SAMPLER AND SETTLING PLATE OBSERVATIONS DURING MORNINGS

On seven days during the investigation period, parallel observations with slit sampler and settling plates were made during the morning. In one of the nurseries, or in the mothers' ward, air sampling was carried out continuously from 7.30 a.m. till 2 p.m., the period of the day when the wards were busiest and the air infection presumably

highest. MacConkey plates were used in the slit sampler on six occasions, and nutrient agar plates on the seventh; 25 cu. ft. of air was taken on to each plate in the slit sampler during the first twenty-five minutes of each successive half-hour throughout the morning. Concurrently, a blood-agar settling plate was exposed during each twenty-five-minute period. As a rough measure of the amount of activity in the ward during the taking of each sample, a record was made of the number of "entrances," that is the number of occasions on which a doctor, nurse or maid entered the ward.

The results of the seven experiments are summarised in Table I,

TABLE I

*Air Contamination with Staph. aureus and other Bacteria in a Maternity Hospital. (Shows for each day the average number of bacteria-carrying particles per cu. ft. of air taken by the slit sampler, and the average number recovered per 10 sq. in. settling plate per hour)*

Date of experiment :—	18/6	25/6	14/5	21/5	28/5	4/6	2/7	Overall Average
Room :—	Large Nursery	Large Nursery	Small Nursery	Small Nursery	Mothers' Ward	Mothers' Ward	Mothers' Ward	...
Number of "entrances"	136	55	...	51	100	80	114	...
Amount of ventilation :—	Medium	Medium	Medium	Great	Very Great	Great	Medium	...
Slit sampler * :—								
Cubic ft. of air sampled	325	300	300	300	325	275	300	...
"All bacteria" per cu. ft.	5.9	5.2	5.1	1.5	9.2	10.6	14.2	7.4
<i>Staph. aureus</i> per cu. ft.	0.040	0.037	0.027	0.010	0.100	0.040	0.020	0.04
Settling plates † :—								
Plate-hours exposure .	5½	4½	...	5	5	4½	5	...
"All bacteria" per plate-hour	43	30	...	21	110	87	132	71
<i>Staph. aureus</i> per plate-hour	0.9	0.2	...	0.2	1.0	0.24	0.2	0.46

\* MacConkey agar plates except in experiment 2/7, when nutrient agar was used.

† 10 sq. in. blood agar plates.

and the detailed observations for one experiment in the large nursery are shown in Table II. In the seven days a total of 2125 cu. ft. of air was examined with the slit sampler; this was found to contain eighty-five particles carrying *Staph. aureus*, an average of 0.04 per cu. ft. Some *Staph. aureus* were found present in the air in each room and on each day; the average numbers for the different days varied from 0.01 to 0.10 per cu. ft. The results of the examinations with the settling plates were in general agreement with the slit sampler results; *Staph. aureus* was recovered from the air on all of the seven days, the overall average recovery rate being 0.46 infected particles per 10 sq. in. plate per hour.

The amount of *Staph. aureus* air contamination did not show obvious correlation either with the concurrent amount of activity as measured by the number of "entrances," or with the amount of ventilation as judged by the extent of window opening and the sensation of draught. The heaviest *Staph. aureus* air contamination occurred on

the occasion when the ventilation was greatest: namely, in the mothers' ward on 28th May, a breezy and sunny day when all windows were fully open and a strong draught was felt almost continuously.

The *Staph. aureus* colonies comprised 0.70 per cent. of all colonies on the MacConkey plates exposed in the slit sampler (six experiments) and 0.68 per cent. of all colonies on the blood-agar settling plates (six experiments).

## DISCUSSION

Throughout sixteen weeks when infections were prevalent, *Staph. aureus* was found to be present almost constantly in the air of the maternity ward and nurseries. The number of infected particles found

TABLE II

*Air Contamination with Staph. aureus and other Bacteria in Large Nursery during Morning of 18th June*

Time	"Entrances."	Colonies per 25 cu. ft. of Air by Slit Sampler.*		Colonies per 25 Minutes per 10 sq. in. Settling Plate.†	
		All Bacteria.	<i>Staph. aureus.</i>	All Bacteria.	<i>Staph. aureus.</i>
07.30-25	15	180	0	18	0
08.00-25	20	160	0	26	0
08.30-55	17	140	0	23	0
09.00-25	7	196	0	33	1
09.30-55	6	120	0	6	0
10.00-25	12	200	0	26	1
10.30-55	5	132	1	22	1
11.00-25	11	216	0	19	0
11.30-55	13	204	1	18	0
12.00-25	14	154	4	23	1
12.30-55	7	53	0	14	0
1.00-25	7	48	1	5	1
1.30-55	2	104	6	6	0

\* MacConkey agar plates.

† Blood agar plates.

in the air was small. Nevertheless, because of the large volume of air respired, the amount of air infection observed was sufficient to ensure that each adult and baby would inhale *Staph. aureus* on many occasions while in the hospital. The average morning air contamination was 0.04 *Staph. aureus*-carrying particles per cu. ft. If in each day the air contamination continued at this level for the fourteen daytime hours and at zero for the ten quiet night hours, then, on average, about twelve *Staph. aureus*-carrying particles would have been inhaled per day by an adult respiring 500 cu. ft. of air, and one *Staph. aureus*-carrying particle by a newborn child respiring 44 cu. ft. (Nelson, 1946).

The settling plate results give a measure of the danger from sedimentation of airborne infected particles on to the face and other exposed parts of the baby. A *Staph. aureus*-carrying particle would be received

per 10 sq. in. of exposed surface in each two or three hours during a morning in the nursery.

If a single infected particle, containing perhaps from 1 to 100 *Staph. aureus* cells, be sufficient to initiate infection, then the amount of *Staph. aureus* air contamination discovered in the hospital was clearly enough to account for a very high incidence of infection among the inmates, even for universal infection of the babies within a day or two of birth. On the other hand, it is sometimes argued that initiation of infection normally requires contamination by a large number of bacteria, and can seldom follow receipt of the small numbers which are transmitted by the air; then, it is suggested that the large number of bacteria which constitute an adequate infective dose will be transmitted most commonly by contact and handling. However, there are reasons why one should not too readily assume that especially large numbers of pathogenic bacteria are likely to be transmitted by contact. The experiments of Ostermann (1908) have shown that only a very small proportion, usually less than 1 in 10,000 of the bacteria on a contaminated hand are transferred to a clean hand by the act of hand-shaking. In the present investigation a series of "handling" tests were made with two profuse nasal carriers of *Staph. aureus*, each test on a different day. The surface of a culture plate was heavily handled by the carrier with the fingers, knuckles and palmar eminences of both hands. *Staph. aureus* was obtained on the plate in most tests: in thirteen of fifteen tests with one carrier and in five of six tests with the other. However, the number of *Staph. aureus* colonies obtained was small; it varied from 1 to 112 per plate and averaged only 13 per plate. These observations suggest that as a rule only small numbers of *Staph. aureus* will be transmitted by contact with the contaminated hands of nasal carriers. Heavier infection by handling may well be caused by "deep" skin carriers, persons whose hands are colonised and not merely contaminated by the staphylococci (Gilliespie, Devenish and Cowan, 1939); however, such skin carriers are relatively uncommon.

The anterior nares constitute the main natural habitat of *Staph. aureus*; presumably this is the site most favourable to the initial establishment of colonisation. It is thus suggested that the spread of *Staph. aureus* is in the first place mainly airborne, a small number of staphylococci being inhaled, caught in the anterior nares and there greatly multiplied. From the infected nose of an infant, large numbers of staphylococci may then be spread during bathing and toilet to skin abrasions, the conjunctiva and other susceptible parts of the body where they give rise to clinical infections.

The main source of the staphylococcal contamination of the hospital air was probably dust from bedding (Bourdillon and Colebrook, 1946), from personal clothing (Duguid and Wallace, 1948) and from handkerchiefs (Dumbell, Lovelock and Lowbury, 1948). In view of our previous finding that very little *Staph. aureus* contamination of air was

produced by the sneezing of nasal carriers (Duguid and Wallace, 1948), we conclude that the air infection was not due in any important degree to the secretion droplet-nuclei described by Chaussé (1913) and Wells (1934).

#### SUMMARY

(1) THROUGHOUT sixteen weeks during an outbreak of *Staph. aureus* infections in a maternity hospital, the bacterial content of the air in two nurseries, a mothers' ward and a washroom was repeatedly observed by use of a slit sampler and of settling plates.

(2) Air contamination with small numbers of *Staph. aureus* was present almost constantly, being found in at least one room on forty-three out of forty-seven days on which examinations were made.

(3) During seven mornings a total of 2125 cu. ft. of air was taken by the slit sampler from the nurseries and ward. On average this contained 0.04 *Staph. aureus*-carrying particles per cu. ft., these comprising about 0.7 per cent. of all bacteria-carrying particles collected. On this basis it was calculated that while residing in the hospital an infant would inhale about one *Staph. aureus*-carrying particle per day, and an adult about a dozen.

(4) Observations made with settling plates showed that during the mornings *Staph. aureus* particles were falling from the air at the average rate of 0.46 particles per 10 sq. in. per hour.

(5) Experiments were made in which culture plates were heavily handled by nasal carriers. Only small numbers of *Staph. aureus* colonies were obtained on each plate. It was concluded that *Staph. aureus* would not be transmitted in much larger numbers by contact and handling than by the air.

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