

TRANSMISSION OF HAEMOLYTIC STREPTOCOCCI

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(With 7 Figures in the Text)

INTRODUCTION

The prevention of respiratory tract infections is still a major problem in public health medicine. The solution of this problem depends, in part, on the correct evaluation of the factors which determine the successful transmission of the causative organisms in different environments in which they arise. In recent years the tendency has been to focus attention on the transmission of haemolytic streptococci, either as dust particles, or droplets and droplet-nuclei and to attach less importance to the role of direct contact infection (Cruickshank, 1949). The object of this paper is to evaluate the relative importance of these vehicles.

EXPERIMENTAL

All subjects used in these experiments were healthy individuals. The haemolytic streptococcal carriers were detected by plating throat swabs or nasal swabs on to 6% horse blood agar media containing 1 in 500,000 gentian violet and incubating at 37° C. for 48 hr. Many of the subjects carried group A haemolytic streptococci in their throats, but those carrying streptococci of other groups, e.g. B, C, and G, were included since the mechanisms by which they leave their hosts are not determined by the serological grouping or disease propensity. The few staphylococcal carriers, who took part in sneezing experiments, were identified by plating swabs on 6% sheep blood agar and incubating for 24 hr.

In the beginning a number of different methods were used to collect droplet-spray emitted during expiratory activities. These included a specially constructed cough box of 1 cu.ft. capacity, a funnel partially sealed by a Petri dish, and target plates placed 6 and 12 in. vertically below the mouth of the subject being tested. After many comparative tests it was found that the different techniques yielded similar quantitative results.

In a number of experiments a marker organism, *Chromobacterium prodigiosum*, was implanted in the upper respiratory tract. The strain was one which grew well on nutrient agar at 22° C. giving heavily pigmented colonies after 48 hr. incubation.

Air samplings were made with an electrostatic air sampler described by Luckiesh, Taylor & Holladay (1946) and a slit air sampler described by Bourdillon, Lidwell & Thomas (1941), Casella brand.

Expulsion of haemolytic streptococci by coughing

Seventeen throat carriers co-operated in experiments employing the different techniques for collection of droplet-spray. Table 1 shows results for target plates

exposed to bursts of coughing (one burst or volley=four coughs) at vertical distances of 6 and 12 in. from the subject's mouth. It will be noted that at a distance of 6 in., one-third of volleys from nine carriers produced detectable droplets carrying haemolytic streptococci and of those volleys which were positive an average of four haemolytic colonies per plate was obtained, i.e. one colony per cough. At 12 in. there was a fourfold reduction in the number of positive volleys although, when positive, the same number of streptococci per volley were recovered. When the average number of haemolytic streptococci expelled by the carriers was calculated for all positive and negative volleys the expulsion rate was still lower. In short, coughing appears to be a relatively inefficient mechanism of dispersing haemolytic streptococci in droplet-spray.

Table 1. *Expulsion of β -haemolytic streptococci (β -H.S.) during coughing by healthy throat carriers*

No. of carriers tested	Distance from target plate in inches	No. of cough volleys (av. 4 coughs)	No. of carriers yielding positive cough volleys	No. of cough volleys yielding β -H.S.	Av. no. β -H.S. per positive volley	Av. no. β -H.S. per cough for positive volleys	Av. no. β -H.S. per cough for all volleys
9	6	31	5 (55%)	10 (32%)	3.8	0.9	0.5
17	12	39	3 (18%)	3 (8%)	4.0	1.0	0.07

Expulsion of Staphylococcus pyogenes during sneezing and coughing

Many attempts were made to induce sneezing among our subjects but with variable success. However, after screening many individuals who could be induced to sneeze by irritating their nasal mucosae with powdered soap on a dried cotton-wool swab we succeeded in discovering five suitable subjects. These individuals carried in their throats coagulase positive *Staphylococcus aureus* as a marker organism in approximately the same concentration as did the heavy carriers of haemolytic streptococci. They also harboured *Staph. aureus* in the anterior nares and in the tonsillar fossae. When tested with target plates at a distance of 12 in. they were found to expel *Staph. aureus* in cough spray to the same extent as the haemolytic streptococcal carriers expelled their organisms.

The results, shown in Fig. 1, confirm the findings of others (see Discussion) that sneezing is more effective than coughing as a means of expelling oral pathogens. However, the number of *Staph. aureus* recovered was still very small, e.g. an average of four colonies per sneeze. In contrast, the number of green streptococci recovered was considerably higher, the average count for ten sneezes being 185 colonies per sneeze.

Pollution of air by haemolytic streptococcal carriers

The above experiments give little direct evidence of the degree of aerial contamination which might be expected from the activities of haemolytic streptococcal carriers in poorly ventilated rooms. In order to evaluate the importance of infected droplets, droplet-nuclei and dust particles in such situations the following experiments were performed.

Two groups of thirty schoolboys, aged 12-16 years, were selected for the experiments, and fifteen boys (50%) in each group were carriers of haemolytic streptococci. Both groups were retested on 4 successive days, the following procedure being strictly observed. A classroom 28 ft. by 17.5 ft. by 12 ft. high (5880 cu.ft.) was sealed by closing doors, windows and air vents and a 5 min. air sample was collected before the boys entered. There were three operators present. The boys were admitted and seated, in random fashion, on chairs previously arranged in a circle 15 ft. in diameter, so that each boy faced the centre of this

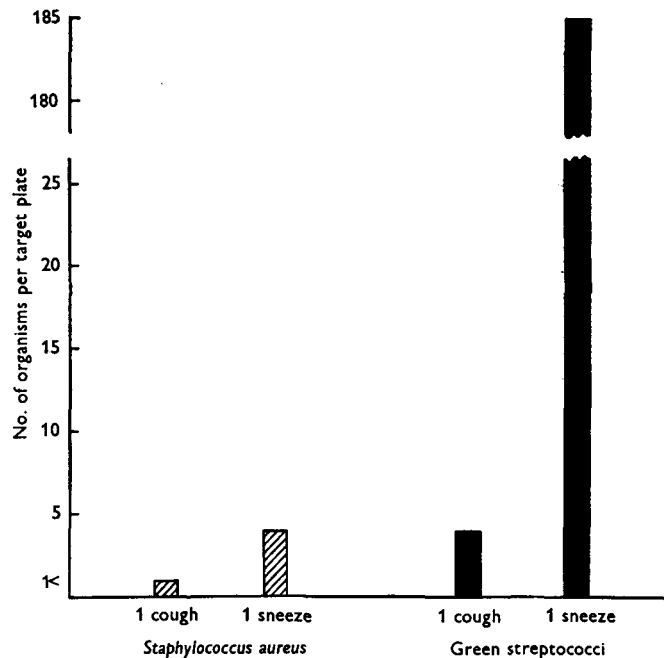


Fig. 1. Expulsion of *Staphylococcus aureus* and green streptococci during sneezing and coughing. Average counts from ten sneezes by five carriers or from sixty coughs by five carriers.

circle. A 3 min. air sample was taken while the boys were entering the room and finding their seats. The time and sequence of the subsequent exercises and samplings are clearly indicated in Figs. 2, 4 and 5. In the first group all air samplings made were done with an electrostatic air sampler only (Fig. 2) but in the second group this and a slit sampler were run simultaneously (Figs. 4 and 5). The air was collected in each instrument at the rate of 1 cu.ft. per minute at a height of 3.5 ft. from the floor. During each sampling the machines were slowly moved on a trolley around the circumference of a 12 ft. circle so that the samples taken when the boys were present were made at a distance of 3 ft. from their mouths. Six settle plates were distributed around the circle of boys at equidistant points and each was placed on the floor 1.5 ft. in a horizontal and 4 ft. in a vertical direction from the mouth of the boy directly in front of it. These plates were

exposed for times indicated by the width of the columns in Fig. 3. With this positioning of air samplers and settle plates it was hoped to collect droplet-nuclei in the former and droplets on the latter.

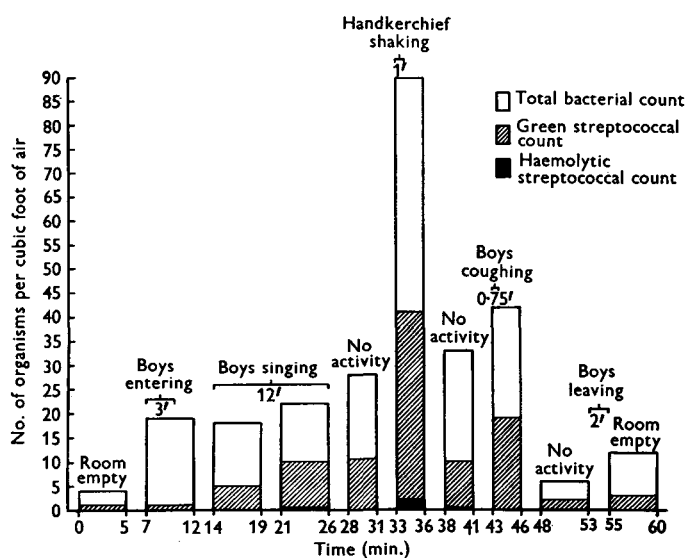


Fig. 2. Changes in bacterial air content with various activities (electrostatic air sampling). Average of four air samplings with first group of thirty boys (see text).

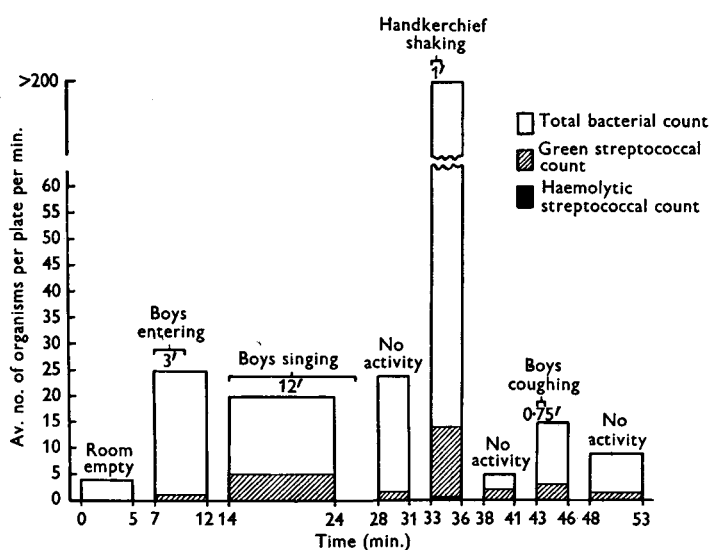


Fig. 3. Changes in bacterial air content with various activities (settle plate sampling). Average of four counts with first group of thirty boys (see text).

In all experiments gentian violet horse-blood agar medium was used and incubated at 37° C. for 48 hr. before inspection. The results, given in Figs. 2-5, represent the averages of four separate experiments. As the colony counts were

remarkably constant with each instrument on the different days no useful purpose is served by recording figures for each of the daily samplings.

A brief perusal of the histograms immediately shows that the only effective mechanism of polluting the air with haemolytic streptococci was that resulting

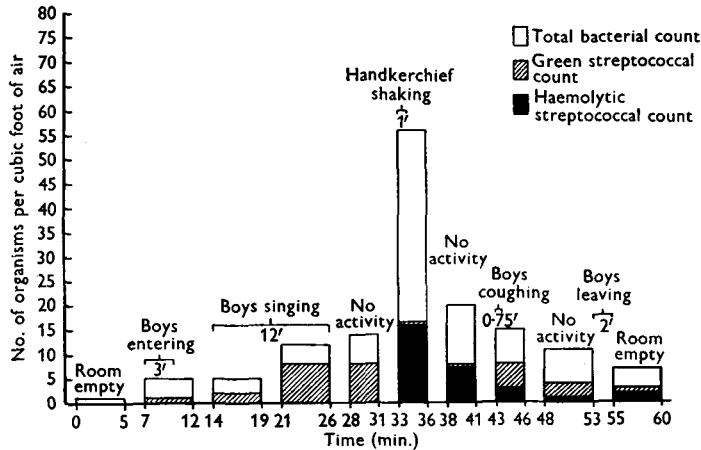


Fig. 4. Changes in bacterial air content with various activities (slit air sampling). Average of four air samplings with second group of thirty boys (see text).

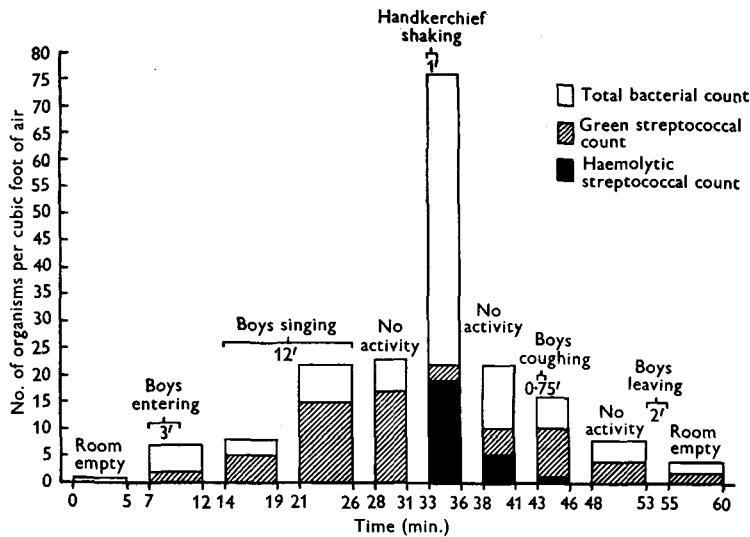


Fig. 5. Changes in bacterial air content with various activities (electrostatic air sampling). Average of four air samplings performed at the same time as those shown in Fig. 4 with second group of thirty boys (see text).

from the shaking of handkerchiefs. It will be noted that vigorous singing for 12 min. failed to contaminate the atmosphere with detectable droplets (see settle plate results, Fig. 3) or droplet-nuclei (Figs. 4 and 5) carrying haemolytic streptococci, although one colony was obtained in sampling 40 cu.ft. of air during singing (Fig. 2). Coughing, which consisted of ten vigorous coughs over 45 sec. (i.e. a total

of 300 coughs for the group or 150 from the streptococcal carriers) did not yield any haemolytic streptococcal droplets or droplet-nuclei, although the green streptococcal count varied from 0 to 8 per cu.ft. of air during this activity. This calculation was based on the difference between counts for period of no activity prior to coughing and the counts obtained during coughing.

In contrast, gentle handkerchief shaking for 1 min., which involved some movement of clothing, markedly increased the counts for all types of organisms. With the second group of boys the haemolytic streptococcal count rose from 0 to 16 and 20 colonies per cu.ft. of air with the slit and electrostatic samplers respectively (Figs. 4 and 5), and 20% of the particles remained air-borne for at least 30 min. (Fig. 4). It is interesting to note that the counts obtained with the electrostatic air sampler were generally higher than those obtained with the slit sampler. The boys were not encouraged to use their handkerchiefs before attending a session but were merely told to bring a handkerchief, some of which may have been unused.

The obvious importance of these secondary reservoirs in pollution of air raises the question as to how fabrics become contaminated. There is no difficulty in explaining handkerchief contamination by nose-blowing, but it is more difficult to accept the assumption that blankets and clothing are contaminated by droplet secretions when the output of haemolytic streptococci in droplet-spray is so low. Duguid (1946*b*) suggested that the number of pathogenic organisms present in the saliva was an important factor in determining their expulsion in droplet-spray while Hamburger, Green & Hamburger (1945) pointed out the close connexion between the presence of nasal carriers and contamination of the environment. In an attempt to analyse the contribution of each of these factors towards the contamination of fabrics, other than handkerchiefs, the following experiments were undertaken.

Dealing first with the question of salivary concentration. An examination of the saliva of nine haemolytic streptococcal carriers by surface plate counts showed a considerable variation in salivary concentration ranging from 0 to 1 million per ml. of saliva (Table 2). It appeared that if a high salivary count, e.g. greater than 10^4 per ml., was obtained on any single examination, a similarly high count could be expected on re-examination on the same or other days. However, when the count was low, e.g. less than 10^3 per ml., the daily concentration in the saliva was unpredictable. It is also interesting to note that the heaviness of growth from a tonsillar swab was not a good indication of the salivary concentration.

When we compared the droplet output of carriers having approximately the same salivary concentration of haemolytic streptococci marked individual variations were noted. This suggested that the salivary concentration was not the only critical factor determining expulsion in droplet-spray. It was then observed that the degree of salivary secretion was as important as the concentration of the organism in forecasting whether a carrier would be a good or poor expeller. The following experiments clearly show this.

Two persons were repeatedly tested for their ability to expel *Chrom. prodigiosum* in a standard reading test which involved reading page 99 of *Aerobiology* (1942) for

Table 2. Concentration of β -haemolytic streptococci in the saliva of healthy carriers

Subject	Tonsillar swab		No. β -haemolytic streptococci per ml. of saliva								Av. no. β -H.S. per ml.
	Growth*	Group	Breakfast		Lunch			Tea			
			7 a.m.	9 a.m.	11 a.m.	1 p.m.	3 p.m.	5 p.m.	7 p.m.		
G.H.	+++	A	0	0	0	0	0	0	0	0	
J.B.	+++	G	0	0	0	0	0	0	0	0	
P.S.	+++	G	0	0	0	0	0	0	0	0	
J.L.	+++	G	0	20	700	0	600	0	N.D.	220	
J.C.	+++	A	10	10	1000	0	1000	4000	N.D.	1030	
M.B.	++	A	1×10^6	3×10^5	7×10^5	8×10^5	1×10^6	4×10^4	1×10^6	7×10^5	
J.S.	+	A	5×10^5	2×10^5	4×10^4	1×10^5	4×10^5	1×10^5	2×10^5	2×10^5	
P.R.	+++	A	6×10^5	4×10^4	3×10^5	4×10^4	4×10^4	2×10^5	2×10^5	2×10^5	
B.McK.	+++	A	2×10^5	8×10^4	$< 4 \times 10^4$	$< 4 \times 10^4$	2×10^5	9×10^5	4×10^4	2×10^5	

* +++ heavy growth > 50 colonies per plate. + light growth < 25 colonies per plate.

N.D. signifies 'not done'.

3 min. at a constant pace and pitch, and directing the droplet-spray on to target plates placed 12 in. vertically below the mouth. The marker organism was implanted by swabbing the anterior mouth (upper and lower labial sulci, the hard palate and lingual sulcus as far back as the first premolar) and the nose (midway between vestibule and the roof) immediately before each test. The results are shown in Table 3.

Table 3. *Expulsion of Chromobacterium prodigiosum in a standard reading test*

Site of contamination	Subject	Concn. of the organism per ml. of saliva	No. of tests	No. of colonies per target plate at 12 in.
Anterior mouth	M.B.	10 ⁶	1	9
		10 ⁷	1	31
		10 ⁸	1	20
	J.C.	10 ⁶	2	1
		10 ⁷	1	5
		10 ⁸	5	4
Anterior mouth and nose	M.B.	10 ⁶	4	9
		10 ⁷	2	44
		10 ⁸	5	33
	J.C.	10 ⁶	7	< 1
		10 ⁷	5	2
		10 ⁸	14	3

The most notable feature in Table 3 is the marked difference in expulsion capacity between the two subjects who consistently produced high and low counts of *Chrom. prodigiosum* on target plates at the same salivary concentration. It will also be noted that the salivary concentration was important in determining the degree of expulsion in each subject but that nasal contamination did not significantly alter the number of droplets expelled.

In order to correlate these individual differences with differences in the amount of salivary secretion available for atomization the tests were repeated 15 min. after each subject had been given a subcutaneous injection of 1 mg. of atropine sulphate. Salivary counts by the surface plate technique were made as before and control reading tests without atropine were repeated. The results are recorded in Fig. 6. The dramatic effect of atropine on the normally good expeller M.B. clearly illustrates the importance of salivary flow, as distinct from concentration, in determining expulsion of oral flora in droplet-spray. A less elegant, but equally convincing, demonstration of this point was obtained by measuring the volume of saliva produced by each subject in a given time. M.B. usually produced 3 ml. of saliva in 1 min., whereas J.C.'s yield was 0.8 ml. From these experiments we conclude that the emission of infected droplets and droplet-nuclei is determined by two factors, the concentration of the organism in the saliva and the amount of saliva available for atomization. A potential expeller of droplets or droplet-nuclei is one who can produce approximately 2-3 ml. of saliva in 1 min. containing at

least 10^5 organisms per ml. Healthy throat carriers of haemolytic streptococci seldom satisfy these requirements.

Turning to the question of environmental contamination by nasal carriers, Hamburger & Green (1946) strongly emphasized the importance of the hands in transferring haemolytic streptococci from the nose to the environment. In an effort to analyse more closely this suggestion we carried out the following experiments.

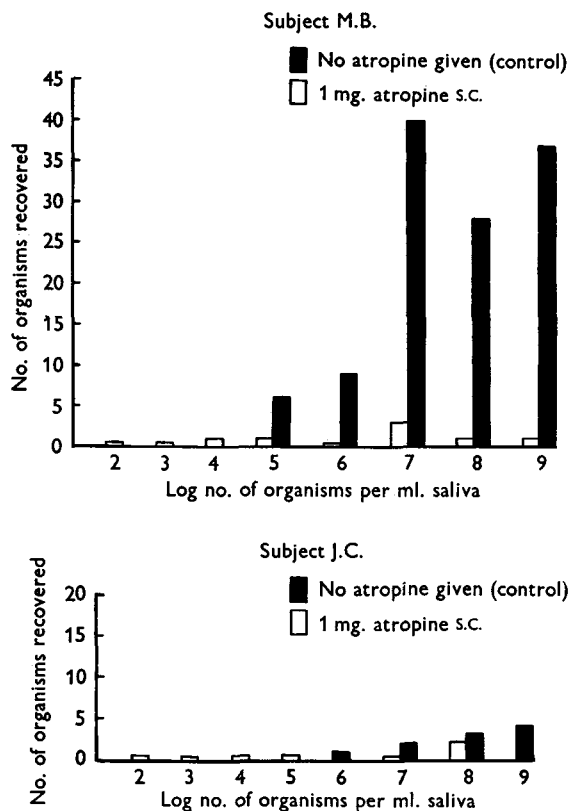


Fig. 6. Influence of atropine on the number of organisms expelled during a standard reading test.

Two subjects, M.B. and J.C., were heavily contaminated with *Chrom. prodigiosum* by swabbing the tonsillar fossae, oro-pharyngeal wall, anterior mouth and nose, after which they proceeded with their laboratory work in clean white coats. They avoided contact with one another and refrained from smoking, sneezing or coughing during the hour following contamination. In this period various sites of the body and clothing (see Table 4) were sampled with swabs moistened in broth and salivary concentrations were determined. The diffusion of the organism at different salivary concentrations and from the different primary sites of contamination was then determined. In one series a conscious effort was made not to touch the face with the hands during the experimental period. The results are shown in Table 4. Although the technique of swabbing was such that only a small percentage of organisms was likely to be recovered, the findings probably reflect

a fairly accurate picture of the diffusion of organisms from heavily infected primary sites.

In analysing these results we might first discuss those obtained with M. B. When the anterior mouth was heavily contaminated (10^4 – 10^8 per ml. of saliva) the organisms were recovered from approximately 25 % of the swabs (range 22–29 %) from only two sites, lower face and hands—the chest and arms being mostly negative, 1 positive in 45. When the anterior mouth and nose were contaminated the organisms were recovered from every area sampled, the heaviest contamination (70–100 % positive swabs) being found again on the hands, chin and cheeks. In the ‘no touch’ experiments the dispersal markedly decreased and only the skin immediately adjacent to the nose showed consistent contamination. These findings clearly indicate that the hands are contaminated by direct contact with the nose and mouth, and that clothing is soiled by contact with the hands and not through the expulsion of droplets.

With J. C diffusion was evident only when the nose was the primary site of contamination in which case the hands served as vehicles for this diffusion. These findings confirm the views of Hamburger, and strongly suggest that organisms harboured in the upper respiratory tract most easily gain access to the environment by carriage on the hands, particularly if the site of colonization is in the nasal cavity. The significance of these findings in the transmission of haemolytic streptococci will now be discussed.

DISCUSSION

Importance of droplets and droplet-nuclei

Although these vehicles have been accepted as important in the transmission of haemolytic streptococcal infections and are still given prominence in such authoritative texts as Topley & Wilson (1946), Harries, Mitman & Taylor (1951), etc., an impressive body of evidence has now accumulated showing that these forms of transmission are probably of minor importance in the genesis of streptococcal infections. For example, Bloomfield & Felty (1924), Colebrook (1933), Hare (1940), Hamburger & Green (1946), Duguid (1946*a*) and Hamburger & Robertson (1948) have shown that extremely poor yields of haemolytic streptococci are obtained in droplet-spray during forced expiratory exercises. Our findings are in agreement with these observations. In one series of experiments it was found that only 18–55 % of the carriers could expel detectable haemolytic streptococci during violent coughing at target plates held at 12 and 6 in. from the mouth respectively, the average count being one colony per cough per target plate (Table 1).

Apart from the violence and nature of the expiratory activity two factors are important in determining whether or not infective droplets or droplet-nuclei will be ejected into the surrounding atmosphere. These are the concentration of the organism in the saliva (anterior mouth), as pointed out by Duguid (1946*b*), and the amount of salivary secretion as indicated in the present study. The concentration of β -haemolytic streptococci seldom exceeds 1 million per ml. and of nineteen healthy throat carriers, nine of them studied in detail (Table 2), thirteen (70 %)

Table 4. *Distribution of Chromobacterium prodigiosum on clothing and skin after contamination of the upper respiratory tract*
 Culture of swabs taken during 1 hr. following contamination

Subject	Primary site of contamination	Concn. of organisms per ml. of saliva	Culture of swabs taken during 1 hr. following contamination											
			Upper face (forehead)		Lower face (chin and cheeks)				Chest		Arms		Hands	
			-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve	-ve	+ve
M.B.	Anterior mouth	10 ⁴ -10 ⁶	7	0 (0%)	10	4 (29%)	7	0 (0%)	14	0 (0%)	5	2 (28%)		
		10 ⁷ -10 ⁸	8	0 (0%)	13	5 (28%)	8	0 (0%)	15	1 (6%)	7	2 (22%)		
	Anterior mouth and nose	10 ⁴ -10 ⁶	7	3 (30%)	4	16 (80%)	5	5 (50%)	12	8 (4%)	3	7 (70%)		
		10 ⁷ -10 ⁸	1	3 (75%)	0	8 (100%)	0	4 (100%)	2	6 (75%)	0	4 (100%)		
	Anterior mouth and nose 'no touch'	10 ⁴ -10 ⁶	6	1 (14%)	5	9 (64%)	7	0 (0%)	14	0 (0%)	3	4 (57%)		
		10 ⁷ -10 ⁸	5	0 (0%)	6	6 (50%)	4	2 (33%)	12	0 (0%)	6	0 (0%)		
J.C.	Anterior mouth	10 ⁶	3	0 (0%)	6	0 (0%)	3	0 (0%)	6	0 (0%)	3	0 (0%)		
		10 ⁷ -10 ⁸	7	0 (0%)	12	2 (14%)	7	0 (0%)	14	0 (0%)	7	0 (0%)		
	Anterior mouth and nose	10 ⁶	5	0 (0%)	3	7 (70%)	4	1 (20%)	9	1 (1%)	2	3 (60%)		
		10 ⁷ -10 ⁸	6	0 (0%)	2	4 (67%)	4	2 (33%)	9	3 (25%)	4	2 (33%)		
	Anterior mouth and nose 'no touch'	10 ⁶	2	0 (0%)	1	3 (75%)	2	0 (0%)	4	0 (0%)	2	0 (0%)		
		10 ⁷ -10 ⁸	12	0 (0%)	15	9 (37%)	10	1 (9%)	24	0 (0%)	12	0 (0%)		

carried β -haemolytic streptococci in their saliva at an average concentration of 346,000 per ml. (range from 200 to 4 million). Hamburger & Robertson (1948) reported a salivary carrier rate of 95 % for convalescent and healthy carriers at an average concentration of 780,000 per ml., whilst Duguid (1946*a*) found only 15 % carriers with detectable haemolytic streptococci in the saliva. It can be assumed that the poor yields of haemolytic streptococci obtained during various expiratory activities (see Figs. 2–5) is, in part, due to their comparatively low concentration in the saliva and not to their absence from this fluid. The concentration of *viridans* streptococci in saliva is high, and in contrast to haemolytic streptococci, they are recoverable from the air as droplet-nuclei largely because of this high concentration (20 to 30 million per ml. of saliva).

These facts seem to indicate that in normal habitations, where other factors such as dilution and ventilation operate, streptococcal infection resulting from inhalation of droplets or droplet-nuclei is most improbable unless the effective dosage is very small.

The other factor which will also determine the expulsion of a pathogen in the mouth spray is the amount of saliva available for atomization. That this factor, which may vary with individuals and in the same individual, exercises an important influence on droplet expulsion is shown in Fig. 6. We were able to show that suppression of salivary flow by subcutaneous injection of atropine caused a 30- to 40-fold decrease in the number of droplets emitted. This physiological masking was not so marked in another subject (J. C.) whose natural salivary flow, and hence droplet output, was slight. These subjects represent two distinct types comparable to those described by Bourdillon, Lidwell & Lovelock (1948), one of whom produced a colony count of 280 and the other, under the same conditions, a count of 18.

Unless a haemolytic streptococcal carrier has a good flow of saliva (2–3 ml. per min.) containing a high concentration of organisms (greater than 10^5 ml.) he is unlikely to be an effective expeller of infective droplets or droplet-nuclei. In our experience few carriers measure up to these requirements.

Importance of infected dust particles

A good deal of attention has been given to the role of dust in the spread of haemolytic streptococci. In spite of this the importance of dust-borne spread still remains obscure, particularly among healthy individuals. We do not propose to analyse this topic in great detail as it falls outside the scope of the present study. However, a brief comment is appropriate.

It has been shown repeatedly that carriers of haemolytic streptococci may contaminate their bedclothing and personal clothing which, on agitation, pollute the air with infected particles (e.g. Cruickshank & Godber, 1939; Duguid & Wallace, 1948; Dumbell, Lovelock & Lowbury, 1948; Figs. 2, 4 and 5 in this study). There is also general agreement that oiling of bedclothes and floors in hospital wards and military barracks effects a 75–90 % reduction in the number of air-borne dust particles carrying bacteria. However, there is little direct evidence that such measures effectively reduce the incidence of streptococcal disease. For example, Loosli, Lemon, Robertson & Hamburger (1952) showed, in a 10-week

study of 3224 recruits, that the total hospital admission rate for haemolytic streptococcal nasopharyngitis was 2.9 and 4.4 cases per 1000 per week for oiled and unoiled barracks respectively, i.e. a 34% reduction in attack rate of cases requiring hospital treatment. These findings show that at least two-thirds of the cases were due to infections transmitted by mechanisms other than air-borne dust. That these other mechanisms are most probably due to direct or indirect contact with dangerous carriers is well illustrated in an earlier paper by Lemon, Loosli & Hamburger (1948) who described an outbreak of Type 46 and Type 30 haemolytic streptococcal infections. These outbreaks only occurred when the population at risk was exposed to a particular carrier. This carrier, and probably others infected by him, succeeded in heavily contaminating the barracks—84% of the beds being positive for the organism—but clinical infections immediately ceased on his removal to hospital in spite of the fact that the environment remained heavily loaded with Type 46 organisms. While such findings are open to several interpretations the most acceptable one seems to be that personal contact with the carrier provides a greater hazard than exposure of infected dust particles. In this regard we may note that Laurell (1949, 1952) showed that the incidence of cross-infections due to haemolytic streptococci was almost identical in the oiled and unoiled wards, but that the incidence of acquired infections among personnel (nurses and physicians) was five to six times more frequent than that occurring among the infants they attended, irrespective of whether the wards were oiled or unoiled. Although this author speaks of air-borne dust infections all the evidence in his findings, such as high incidence of infection among the staff, one case infecting two nurses and two doctors, etc., points to the fact that the main channel of spread was by contact and not through infected dust. Krugman & Ward (1951), in a study of respiratory cross-infection rate in infants' wards, concluded that contact infection was responsible for most of the cross-infections and that air-borne transmission through dust played a very small part.

Importance of contact

Contact infection by direct inhalation of droplets has already been discussed and the improbability of this route noted. At this stage we are concerned with the importance of physical contact, direct or indirect, through fomites, in the transfer of organisms from donors to receivers. As in the case of dust-borne transmission, it is peculiarly difficult to evaluate the importance of contact infection except on circumstantial evidence. Bloomfield & Felty (1924) concluded that haemolytic streptococci were transmitted by direct contact because of the failure of carriers to expel these organisms in droplet spray. Colebrook (1933) suggested that hand contact was important in the origin of puerperal infection but without support by direct experimental evidence. Hamburger & Green (1946) showed that the hands of nasal carriers become heavily contaminated after blowing the nose, an average of 790,000 haemolytic streptococci being recovered from the hands of 54 carriers, and later Hamburger (1947) demonstrated that large numbers of these organisms are readily transferred by hand-shaking. Our studies (Table 4) support the hypothesis of Hamburger and his associates that the hands constitute the principal

mechanism by which haemolytic streptococci harboured in the upper respiratory tract leave their hosts. In so far as dust suppressive measures do not block the majority of streptococcal infections occurring in ambulatory individuals (Personnel of United States Naval Medical Research Unit, 1952) and in hospital patients (Laurell, 1952), and as droplets and droplet-nuclei cannot be considered as dangerous vehicles (see above), one can only assume that the most common pathway of infection is by contact between infectors and infectees (see also Krugman & Ward, 1951). These views are set out in the diagram below, Fig. 7.

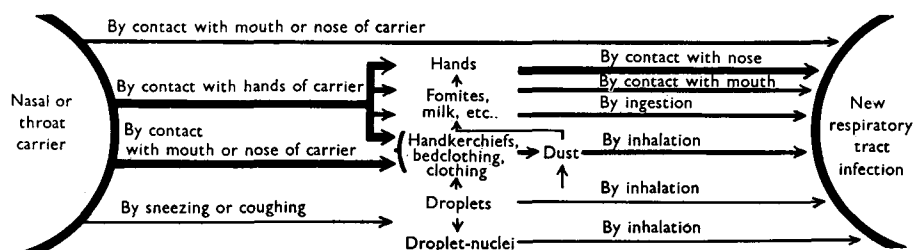


Fig. 7. Possible pathways of transmission of haemolytic streptococci. Heavy lines indicate the most common pathways; moderately heavy lines indicate less common pathways; light lines indicate least common pathways.

In regard to the seasonal periodicity and global distribution of streptococcal infections, it might be suggested that these factors could be profitably considered in terms of survival of haemolytic streptococci on the skin and nasal mucosae under different conditions of temperature, humidity and sunlight. The social distribution of streptococcal infections in children (Holmes & Rubbo, 1952) appears to be linked with the incidence of tonsillectomy and personal hygiene in different levels of society.

Although this discussion has dealt with the spread of haemolytic streptococci it is not unlikely that the pathways of transmission of other respiratory pathogens, such as diphtheria, influenza and the common cold are similar. In this connexion we may note that Lovelock, Porterfield, Roden, Somerville & Andrewes (1952) came to the conclusion that the transfer of the common cold occurred most readily under conditions of close contact, but the route or routes of spread were obscure.

SUMMARY

1. A study of factors involved in the transmission of haemolytic streptococci has been made by experiments with healthy carriers and individuals whose upper respiratory passages were contaminated with *Chromobacterium prodigiosum*.

2. The following conclusions were reached:

(a) Expulsion of haemolytic streptococci in droplet spray is determined by the nature of the expiratory activity (Fig. 1), the concentration of the organism in the saliva (Table 3) and the volume of salivary flow (Fig. 6).

(b) Droplets and droplet-nuclei are less important vehicles of transmission because of the extremely low content of haemolytic streptococci in them (Figs. 2-5).

(c) Dust particles carrying haemolytic streptococci and liberated by agitation of handkerchiefs more effectively pollute the air than violent expiratory activities (Figs. 4 and 5).

(d) Hands and clothing readily become contaminated by heavy nasal carriers (Table 4) and the former serve as the principal means of contaminating the environment and other individuals.

3. A diagram showing probable mechanisms of transmission is given (Fig. 7) in which hand contact is represented as a more important pathway of spread than air-borne dust which, in turn, is more important than either droplets or droplet-nuclei.

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