The relationship to fungal infection of lesions of non-fungal origin is discussed, and it is concluded that, though such lesions may sometimes predispose to fungal infection, other, unknown, factors are also involved.

We are grateful to Dr. C. Bernard for his assistance with this survey. We acknowledge the kindness of the headmaster in allowing us to visit his school, and of the matron for her ready co-operation during our visits. We are indebted to Miss E. H. L. Duncan, of the Central Health Clinic, Bristol, for statistical help, and to Mr. G. A. Wills for technical assistance.

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STUDIES IN THE EPIDEMIOLOGY OF TINEA PEDIS

VII. THE CIRCULATION OF INFECTION

BY

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"In recent years there has been increasing recognition that although there may be specific and necessary causes of certain diseases, these do not provide a complete account of causation. A whole network of circumstances, inherited and environmental, determine the genesis, course, and effects of disease."—Lord Cohen of Birkenhead, *The Observer*, March 6, 1960.

Previous articles in this series (English and Gibson, 1959a, 1959b, 1960a, 1960b; English *et al.*, 1960, 1961) have shown that the incidence of tinea pedis varies in different communities situated in the limited geographical area of the City of Bristol and its immediate surroundings. Evidence has been put forward that this variation is largely due to differing opportunities for contact with an exogenous source of infection.

This is contrary to the views of Sulzberger and Baer (1955), who believe, as do many other workers who adhere to their school of thought, that "tinea pedis is not transmissible in the ordinary sense." These authors, putting forward what might be called the "flare-up" theory, state that "there is much evidence that in parts of the world where tinea pedis is prevalent, many, if not most, *grossly uninfected* subjects actually do carry fungi here or there on the feet" (p. 12, their italics), and they argue that whether or not clinical disease results depends on the personal resistance of the subject. They give no details of the evidence they mention. Yet a few lines earlier, in the same article, they have written, "One of the most instructive of the recently acquired facts is the observation that the skin of most *human beings free from clinically active tinea pedis appears to have a remarkable ability to rid itself*

of fungi, even when exposed to relatively massive, not to say overwhelming, quantities under experimental conditions" (p. 12, their italics). Their own experimental work (Baer *et al.*, 1956) and that of Strauss and Kligman (1957) support this latter statement.

Baer *et al.* soaked one foot of each of 54 subjects in a footbath containing a suspension of *Trichophyton mentagrophytes* and examined scrapings from these feet at weekly intervals for the next six weeks. They were able to re-isolate the fungus from only one subject, though they obtained microscopically positive scrapings from a further 26. This extraordinarily high rate of failure to grow the fungus from subjects who were microscopically positive (and who presumably were not using fungicides) suggests that most of the fungal elements seen were no longer viable. The sporadic nature of the microscopical evidence is also strange: of the 26 subjects whose exposed feet were microscopically positive, 18 were positive at only one of the 6 examinations; and of the 8 who were positive more than once, only 3 were positive in two successive weeks. In addition, of all the 26, only 8 were positive in the first week after exposure.

The authors do not state whether their subjects were asked to take any precautions against infecting themselves from outside sources during the follow-up period. If this was not done, such extraneous infection might well account for their isolation from the exposed feet of two of the subjects of dermatophytes other than *T. mentagrophytes*, and possibly also for some of the sporadic positive microscopical results from both exposed and control feet.

Sulzberger *et al.* (1942) found that tinea pedis and cruris very rarely spread in families, and this work is used by Sulzberger and Baer (1955) as further evidence of the lack of importance of transmission as a cause of clinical disease. The inadequacy of the methods used to obtain these results has been discussed elsewhere (English, 1957; Many *et al.*, 1960).

Strauss and Kligman (1957) placed massive inocula in the interdigital spaces of persons with clinically normal feet and subjected the feet to treatments designed to produce warm, moist conditions over long periods of time. Even with such extreme methods they state that "most infections were transient, and usually fungus elements were found on only one or two (subsequent) weekly examinations." Infections were not induced by imposing warm, moist conditions on normal uninoculated feet.

Clearly a subject with an inherent resistance to tinea pedis will not contract the disease *despite* the fact that he has been in contact with it: that he will continue to carry the fungus on lesion-free feet over long periods seem most unlikely, on the available evidence, in more than a very small percentage of cases. For a subject with temporarily or permanently lowered resistance tinea pedis is transmissible: he may contract the disease if, *and only if*, he has recently been exposed to it. This is the only reasonable explanation for differing infection rates in communities of similar types.

Factors Determining the Incidence of Tinea Pedis

The ideas put forward in the present article, based on findings in Bristol, serve only to underline the results of Gentles and Holmes (1957) in their careful investigation

of tinea pedis in coal-miners, and to support their closely argued conclusions that tinea pedis is a transmissible disease.

The most important factors determining the incidence of tinea pedis are: (1) the presence of inoculum in places in which the bare foot may come into contact with it; (2) the frequency and duration of exposure of the foot to the inoculum; (3) the susceptibility of the foot once inoculation has taken place, depending on personal resistance to infection, the condition of the foot, the type of footwear, etc. (susceptibility in any one person may vary from time to time); and (4) the species of dermatophyte and any variation in virulence.

The interaction of these four factors determines whether or not an individual, at any given time, will contract tinea pedis, and will therefore also determine the level of infection in the community to which that individual belongs. The existence of a very small number of true carriers does not affect the general picture.

The relative importance of the factors varies in different communities according to their customs and conditions of life, whether these are voluntary or imposed by circumstances or authority. It is this varying interaction that explains differences in incidence in the various communities, and also in the same community at different times.

The present lack of knowledge concerning host resistance and fungal virulence largely precludes the study of the epidemiology of tinea pedis from these points of view. But this does not prevent the elucidation of those aspects of the problem which depend on exposure to infection. This is what has been attempted in this series of studies, although a few indications of the factors affecting host resistance—for example, sex and footwear—have also been obtained.

With some exceptions (Gentles and Holmes, 1957; Lesun, 1958; Cremer, 1958, 1959) mycologically controlled surveys of tinea pedis consist of single visits to specific residential or working groups, or of reports on incidence from hospital clinics; seldom have a number of surveys been made in the same locality at close time-intervals. The resulting epidemiological picture is incomplete and gives little idea of the continuity of circulation of this infection. By studying different groups of people in a limited geographical area, and by visiting some of them more than once, it has been possible to discover, for Bristol, the ways in which tinea pedis is most usually spread, and so to deduce the risk of infection run by individuals at different times in their lives.

Circulation of Infection in the Bristol District

The marked difference in the incidence and distribution of the two species of *Trichophyton* principally involved is sufficient evidence of differences in their epidemiology to warrant their separate treatment. *Epidermophyton floccosum* occurred so infrequently that useful comment is not possible.

In all that follows, statements for which no specific reference is given have been discussed in previous articles in this series. Numerical relationships used in the diagrams are either those obtained during the surveys or are reasonable deductions from them.

Obviously the conclusions reached can only be general ones, and the diagrams do not represent the *only* routes

of cross-infection in the given circumstances, but merely the *most usual* ones. For instance, cross-infection with *T. rubrum*, both in the armed Forces and at swimming-baths, undoubtedly occurs (Gentles (1956) has isolated this fungus from the floor of a pit-head bath), so does cross-infection with *T. mentagrophytes* among girls, but, compared with other routes, they are not of sufficient importance to be included in the relevant diagrams.

T. mentagrophytes (interdigitale Type)

This fungus is by far the most common cause of tinea pedis in Bristol. In boys aged 11–14 years in local authority day-schools the incidence of infection is about 6.5%, and cross-infection usually takes place at the local swimming-bath. In a boarding-school, on

FIG. 1.—Probable route and extent of dissemination of tinea pedis due to *T. mentagrophytes* in males of families whose children attend local authority day-schools (mainly social classes III, IV, and V, some of class II).

FIG. 2.—Probable route and extent of dissemination of tinea pedis due to *T. mentagrophytes* in males of families whose sons attend boarding-schools (mainly social classes I and II).

the other hand, the incidence in boys of the same age was about 12%, a level which can be attributed mainly to communal life and an emphasis on sport.

Day-school boys seldom contract an infection from their families. No figures are available for boarding-school boys, but the high cross-infection rate in families of high social class, from which boarding-school pupils are drawn, suggests that these run more risk in their families than do day-school boys. From his childhood, therefore, the average boy of social class III, IV, and V (Registrar-General's social classification) is likely to run less risk of infection with *T. mentagrophytes* than a boy from class I or than many from class II.

Proportionately more boys from the higher social classes than from the lower attend universities. Marples and di Menna (1949) and other workers have shown that the incidence of tinea pedis among students is high, especially in those living in hostels. Here again, therefore, boys from the higher social classes run a greater risk of infection.

Grammar schools have not been investigated, but the incidence in them could reasonably be supposed to approximate to that in other day-schools, though it might be raised somewhat owing to the higher social class of the pupils.

Tinea pedis in girls attending day-schools averages 1.6% and is therefore far less common than among boys. No direct information about girls' boarding-schools is available, but the ratio of 2:1 infected males to females in families suggests that girls are indeed less liable to be infected with *T. mentagrophytes* than boys and that the incidence in girls' boarding-schools might also be low. Girls of all social classes, therefore, seem less likely to be infected than boys.

After leaving school, many more boys than girls join sports and swimming clubs, and, up to the time of writing, all boys have been subject to national service with the armed Forces. These are all situations in which cross-infection with tinea pedis is likely to take place (Hopkins *et al.*, 1947; Tritsmans and Vanbreuseghem, 1955). As young adults too, therefore, males run more risk of infection than females.

The foregoing discussion can be summarized in two diagrams (Figs. 1 and 2) which illustrate the probable way in which tinea pedis due to *T. mentagrophytes* circulates in Bristol.

Trichophyton rubrum

The low incidence of this fungus in all schools and in a sample of the adult population (Warin, unpublished evidence) indicates that there is still too small a reservoir of infection in Bristol for it to cause a major outbreak of tinea pedis in communities. This is not true of other countries (Scheffler, 1958) or of all communities in Britain (Gentles and Holmes, 1957).

There are two main sources of new cases in Bristol. The first, and probably the most important, is cross-infection within the family. Though apparently not highly infectious, the disease caused by this fungus is usually far more resistant to treatment than that due to *T. mentagrophytes*, so that members of a family in which there is an infected person are exposed to constant risk over a long period.

Secondly, a considerable number of cases are not attributable to indigenous cross-infection at all, but,

as is made clear by patients' histories, to infections contracted during residence abroad and imported *de novo* into Britain.

Evidence from all sources in Bristol and from Scheffler (1958) in Germany supports the idea that, unlike *T. mentagrophytes*, *T. rubrum* can attack females almost as readily as males.

Information regarding the effect of social class on the incidence of *T. rubrum* is scanty. That it occurred no more often in the boarding-school than in the day-schools suggests that it is not particularly associated with any social group, and this may well be true at present, after a war in which large numbers of all classes have served abroad. But a very much higher proportion of members of the professional classes than of the working classes are employed abroad in peacetime, and this, coupled with the possibility suggested by the family survey of a higher cross-infection rate in professional families, should ensure that *T. rubrum*, as well as *T. mentagrophytes*, will eventually have a higher incidence in the upper classes.

The surveys on which this reconstruction was based were carried out before the introduction of oral therapy with griseofulvin. The success of this drug offers some hope of breaking the chain of infection (see Fig. 3).

FIG. 3.—Probable route of dissemination of tinea pedis due to *T. rubrum* in both sexes and in all social classes.

The incidence of *T. rubrum* as a cause of tinea pedis in this country has been increasing steadily for many years. If, despite griseofulvin, this trend continues, residential communities, swimming-baths, and communal washing facilities will become relatively more important foci of cross-infection as the total number of cases rises. Circulation diagrams for this species will then increasingly resemble those for *T. mentagrophytes*, except that a larger proportion of females are likely to be affected.

Relevance to Other Localities

The foregoing discussion, and the diagrams evolved from it, apply specifically to Bristol. What is their relevance elsewhere? Fig. 1 could be expected to apply to most British cities and towns with public swimming-baths. But since the baths are one of the main foci of cross-infection it would not be a true picture for country districts (Amrein, 1953) too far from the baths for children to use them frequently. A very low infection rate would be expected in such conditions, though the disease would be kept in existence by returning national service men. With the ending of national service it is probable that the incidence of tinea pedis due to all fungi will gradually decline over the whole country.

Fig. 2 shows the boarding-school and the family as the main sources of cross-infection; Fig. 3 the family and residence abroad. These sources are not primarily dependent on local amenities, so the diagrams could be expected to apply to the appropriate sections of the population in any part of the country.

None of the diagrams would be true for towns or districts of Britain where a high proportion of the population is engaged in a single employment involving particular risks; for instance, mining communities. Here the main source of infection is the pit-head bath, and the high incidence in the miners themselves (Gentles and Holmes, 1957) would be expected to lead to an abnormally high incidence in their families and in the schools.

Finally, it must be stressed that many of the ideas put forward in this article are only deductions from the observed facts, and further surveys of specific sections of the population would be necessary to verify them.

Summary

The relative importance in attacks of tinea pedis, of flare-ups of latent endogenous infections, and of recent contact with exogenous sources of infection is discussed. It is concluded that the great majority of such attacks can be attributed to contact with infection from an outside source. If this is true, it should be possible to determine the routes by which tinea pedis is most usually circulated in any given locality. Such routes are suggested for the *interdigitale* type of *Trichophyton mentagrophytes* and for *T. rubrum* infections in Bristol and its immediate surroundings, and their applicability to other localities is discussed.

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Medical Memoranda

Meningitis due to a Soil Organism after Penetrating Injury of Pharyngeal Wall

The remarkable nature of the following case seems to be sufficient reason for putting it on record.

CASE REPORT

On March 23, 1959, a boy of 12 years was engaged in throwing a bayonet, dating from the 1914-18 war, and weighing 15 oz. (425 g.), against a tree-trunk, when the bayonet glanced off and entered the open mouth of his younger brother, aged 10. The point pierced the posterior pharyngeal wall and embedded itself in the cervical spine, whence it had to be pulled out with some force.

When admitted to hospital the boy was somewhat shocked and complained of dysphagia. There was a small superficial cut of the dorsum of the tongue, and a minute chip off the margin of the second upper right incisor tooth. A vertical laceration about $\frac{1}{4}$ in. (2 cm.) long in the posterior pharyngeal wall was gaping slightly, but no attempt was made to suture it. A.T.S. and prophylactic penicillin were given.

During the next 24 hours the boy became progressively more and more drowsy, and complained of severe frontal headache. Neck rigidity was marked and Kernig's sign strongly positive. Lumbar puncture yielded turbid blood-stained fluid. A combined regime of parenteral streptomycin and penicillin and oral sulphadiazine was instituted, and after a further 24 hours his condition rapidly improved. A week after onset, all signs of meningeal irritation had disappeared, and the pharyngeal wound had healed. The boy was discharged fit two weeks later.

The cerebrospinal fluid was found to contain numerous pus cells and occasional Gram-negative bacilli. These proved sensitive to all the antibiotics given. The final laboratory report stated that the organism grown was none of the known pathogens, but had the characteristics of one of the nitrifying soil bacteria. These organisms run into many thousands, and have never been fully classified, so it is not surprising that the one isolated could not be identified with any of the known types.

X-ray films of the cervical spine showed no bony injury. From a study of the films and from examination of an articulated skeleton it was evident that the bayonet tip must have pierced the meninges in one of two places—either beside the odontoid process of the axis vertebra or through the articulation of the atlas vertebra with the skull.

COMMENT

The possibility of such an occurrence must indeed be very remote. A slightly greater degree of force would have resulted in sudden death. To complete an unusual combination of circumstances, the tip of the bayonet must have carried into the meninges a soil organism which then became pathogenic. A search in the literature has so far revealed no comparable case.

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The 1961 edition of the International Planned Parenthood directory, *World List of Family Planning Agencies*, is now available from the IPPF, 69 Eccleston Square, London S.W.1, price 2s. 6d. a copy. The directory contains the latest population figures and information on family planning services in fifty-seven countries.