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THE LOUSE

AN ACCOUNT OF THE LICE WHICH INFEST MAN, THEIR MEDICAL IMPORTANCE AND CONTROL

BY

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PREFACE

Lice on body and head have been nearly universal among human beings. The resources of Western civilization have recently made them rare among the more fortunate classes, but they are still abundant and widely distributed among those whose slender resources compel them to live close together, and make it difficult to wash the person or change the clothes frequently. Under those circumstances one or two lousy individuals will rapidly infest others, and it is for this reason that lice have so often been abundant among refugees, prisoners in badly administered gaols, and soldiers actually in the field. In spite of the rather full knowledge that we now possess, we are not always able to prevent their spread and multiplication.

To the medical man the louse is always important because its presence generally gives rise to irritation and scratching, which may in turn lead to impetigo and similar skin diseases not unimportant if neglected. In addition, this insect is the only vector of epidemic typhus and of trench fever: the first of these diseases is of the most grave import. In certain parts of the world, including Europe, lice are also the sole channel of transmission of relapsing fever, a serious epidemic disease.

At the present moment the control of the louse has become extremely important in civil as well as military life. It may therefore be of service to publish an account of the insect, its relations to disease and the methods that may be used for controlling it. The present book was originally written as part of a larger work on medical entomology which is in preparation. It was designed for readers with some knowledge both of entomology and medicine: I trust that it has now been made comprehensible to those who lack the one or the other.

It is generally agreed that the control of an insect must be founded on a full and precise knowledge of its normal habits and life history. It is also believed that one cannot divide the insects' biology into those parts which are of practical importance and those which are not, but that if it is to be controlled one must possess a full general knowledge of all parts of its life. It will also be found that a large part of the epidemiology of those diseases which are transmitted by insects can only be explained by a knowledge of the life of the vector. In this book attention has therefore been concentrated upon biology at the expense of anatomy. If the reader is inclined to be impatient and to think that the treatment is too detailed, he is urged to persevere and to endeavour to master the subject as a whole. The book may appear full; the author alone knows how much has been excluded, particularly on the subject of control, about which much very inconclusive work has been published.

In one respect this book includes material that is not generally considered to lie within the limits of medical entomology: I have taken the unusual step of including a brief account of spirochaetes and *Rickettsias* so long as they live in the louse, and of the epidemiology of the diseases which they produce. That appeared to be essential, for if the entomologist is to contribute to our understanding of diseases transmitted by insects, he should consider not only the vector but the history of the parasite so long as it is in the insect. To take an example from the present book: the entomologist can make little contribution to our understanding of relapsing fever unless he makes it clear that the spirochaete is in the body cavity of the louse from which it can only escape if the insect is torn or crushed.

In quoting references an attempt has been made to include major classical papers and also recent work which generally contains references to preceding work on the subject.

The book owes much to my colleague Dr. V. B. Wigglesworth, F.R.S., Dr. C. M. Wenyon, F.R.S., Dr. R. Lewthwaite and Professor R. M. Gordon, who have read and criticized parts of the text. Colonel D. T. Richardson, M.C., A.M.S., was good enough to discuss the section dealing with control, and his suggestions have led to great improvement in it. Without my colleague Dr. C. G. Johnson I could never have ventured to discuss that formidable subject, the growth of

populations. The figures have nearly all been redrawn (and many of them much improved) by my friend Mr. H. S. Leeson. The Cambridge University Press has been good enough to allow me to make use of one figure, which originally appeared in the *Journal of Hygiene*. To all of these my thanks are due.

P. A. B.

November 1939.

CHAPTER 1

THE ANOPLURA OR SUCKING LICE

1. Zoological Position. The word "louse" has been applied to a great variety of insects, and indeed of other small animals, not closely related to one another but similar in being small and wingless. Even now, though the word is used in a much restricted sense, it is applied to two different groups of insects. The first of these are called the Biting Lice or Feather Lice (Mallophaga): these insects live on the skin of birds or mammals and have mouth parts fitted for biting solid substances. They feed on pieces of feather and fragments of scurf, and some of them also nibble the skin and take blood which exudes. We are not further concerned with them in this book. It is the so-called Sucking Lice (Anoplura) which are our subject. The Anoplura are a comprehensive group, in zoological language an Order. One should perhaps explain that insects are classified first into large comprehensive categories (for example, the Coleoptera or beetles, or the Lepidoptera or butterflies and moths): these major categories are called "orders," and the sucking lice, or Anoplura, are one of these. In technical terms the Anoplura might be defined as follows:

Small, wingless insects flattened dorsiventrally. Antennae short, 3–5 jointed. Eyes reduced or absent, and ocelli absent. Mouth parts highly modified for piercing and sucking blood of host; retracted within head when not in use. Palps absent. Thoracic segments fused together, without the least rudiment of wing. Legs short, tarsi with one joint and one claw: leg adapted to clinging to hair of host. Abdomen without cerci.

Without metamorphosis, occurring on surface of host throughout life. Parasites of mammals exclusively.

The sucking lice or Anoplura stand rather by themselves, not closely related to other orders of insects, except perhaps to the Mallophaga (the biting lice, or feather lice), already mentioned. The view was once held that the sucking lice were related to the bugs (Rhynchota), but this is known to be erroneous.

The orders are in turn divided into "families," of which four are generally recognized in the Anoplura. Only one of these families, the Pediculidae, is of interest to ourselves, for it includes the lice which occur on man and monkeys: the members of this family possess eyes, a character which distinguishes them from all other Anoplura.

To carry the matter further, the lice which occur on human beings, with which alone this work is concerned, are classified into two genera (*Pediculus* and *Phthirus*); in each genus there is only one species attacking man, viz. *Pediculus humanus* and *Phthirus pubis*. The first of these exists in two forms, the body louse and head louse; these are best regarded as biological races rather than species, because the anatomical distinctions between them are somewhat indefinite, though there are more pronounced differences in behaviour and biology (page 10). *Phthirus pubis*, or the crab louse, is generally confined to the inguinal region (page 96). These lice (both *Pediculus humanus* and *Phthirus pubis*) occur only on man and not on other hosts.

It is held that the genera *Pediculus* and *Phthirus* are closely related: anatomical points which they have in common are an antenna consisting of five joints, the presence of pigmented eyes, and the fact that the tibia is provided with a process resembling a thumb, between which and the one-jointed tarsus the hair of the host is grasped.

The points of distinction between the two genera of lice occurring on man are briefly as follows:

Pediculus. All legs about equally strong (but anterior legs of male stouter than those of female). Abdomen about twice as long as it is broad. (See figure 1; pages 5 to 10.)

Phthirus. Foreleg slender with long fine claw. Middle and hind legs strong with thick claws. Abdomen broader than long, and compressed so that spiracles of 3rd, 4th and 5th segments lie almost in one transverse line. Abdominal segments with protuberances at the side. (See figure 25; pages 93 to 98.)

2. General Biology. All sucking lice (Anoplura) are obligate parasites, spending their whole life on the skin of a mammal and living exclusively on blood. Some 200 to 220 species of sucking lice are known. Though all the hosts are Mammalia there are certain important groups which have no parasites of this type; for instance, the Carnivora (exclusive of the dog family) and the Marsupials. A general account of the order is given by Ferris (1934).

The Anoplura have, so far as is known, no insects which are parasitic upon them and probably very few enemies, except their hosts. They harbour certain parasitic micro-organisms, some at least of which (*Spirochaeta* and *Rickettsia*) are pathogenic to the mammalian hosts. For this reason human lice (*Pediculus*) have great importance as vectors of relapsing fever (page 70) and typhus (page 56).

The relation of sucking louse to host is often very close, one species of louse living on one host, or on a few which are closely related to one another. In general it seems probable that this specificity is maintained by the parasite's reaction, which prevents it biting hosts other than the normal.

Those who have studied the Anoplura, or lice, have found that those mammals which are closely related to one another tend to have closely related or identical lice. It seems that in the course of evolution the mammals have come to differ from one another more than the lice, so that occasionally the insect parasite points to relationships between species of mammal which have become rather dissimilar. To take a very simple case, the Ground Squirrels (*Citellus*) of North America and Siberia are related but different, though the lice on them appear to be identical. A more complicated case is presented by the lice found on man and other Primates. The lice on these hosts all belong to one of the families (Pediculidae) into which the Anoplura are divided, and no member of that family occurs on any other host. On a conservative view, the family may be said to consist of three genera, *Pedicinus*, *Pediculus* and *Phthirus*. Of these, the first is found only on the monkeys of the Old World (Cynomorpha). Both *Pediculus* and *Phthirus*

CHAPTER 4

THE MEDICAL IMPORTANCE OF *PEDICULUS HUMANUS*

MAN'S REACTIONS

The piercing of skin and taking of blood is described on page 17. The insect's saliva is no doubt introduced through the tubular hypopharynx so that it enters the tissues at the level of the most superficial capillaries. Inasmuch as the salivary ducts are united one must suppose that the secretion of the different glands (figure 13) is mixed. It has been shown by dissecting the glands out and injecting them separately that it is the secretion of the reniform gland which produces the irritation and other reactions (page 20).

Many people are insensitive to the bite of the louse and neither feel nor show any reaction; as they are not aware of being infested they may be a danger to others. It appears also that some individuals, though not all, can acquire immunity. But in most people the biting is followed after several hours by the production of a very small red papule, which continues to be irritable for several days. In very sensitive individuals a few bites produce urticaria and itching, and the loss of sleep which may result may be a serious matter. The irritation may also cause severe scratching and resultant dermatitis, impetigo, etc. These relatively minor troubles caused much loss of man-power during the war of 1914–1918, particularly in units whose military duties prevented their being effectively and frequently washed and disinfested. It is, for instance, recorded that in 1917 in the "Second Army" of the British Forces the casualty clearing stations admitted more than 10,000 men for inflammatory conditions of the skin, mostly due to lice; this figure is about 10% of the total admissions.

A great variety of types of skin infection have been attributed to infestation with lice among the destitute and neglectful. Most of these conditions (impetigo, furunculosis, eczema) are clearly due to secondary infections with *Staphylococci* and other organisms which normally occur on the skin. There is apparently some evidence suggesting that these organisms may be transmitted by lice, though perhaps only for short periods of time: experiments are quoted by Herms (1939) in which lice from a child suffering from impetigo (or even lice which had been fed for only 20 minutes on such a child) were transferred to a clean child which subsequently developed the disease. A condition is occasionally observed in which the hair becomes matted with exudate from the infested and eczematous scalp, lice multiplying to an extraordinary extent in and under the crusts. Cervical adenitis frequently accompanies the other conditions; general pyaemic infection and death have been described. Thickening and pigmentation of the skin, the so-called "vagabond's disease," may apparently follow from very long-continued infestation.

It appears to be established that if large numbers of lice feed on a person, general but rather indefinite symptoms will occur, such as dull headache, drowsiness, pains in joints, a rash resembling that of German measles, and a slight but persistent rise of temperature: Moore and Hirschfelder (1919) observed these symptoms repeatedly, in volunteers on whom they were feeding from 4,000 to 200 lice daily. They were satisfied that the condition was not due to any ordinary infectious disease, nor to an infection transmitted by their strain of lice, and they attributed it to some toxic substance inoculated by the lice when sucking blood.

There are a number of negative records, showing that various micro-organisms which occur in human blood do not develop in *Pediculus*. The most interesting is perhaps the work on plague. Several records show that *Pasteurella pestis* may be recovered from lice removed from those suffering from plague, but there is no evidence that they remain infected for long; it is stated that in the Andes people crush lice with the teeth and may acquire a plague infection of the tonsils.

Japlin claiming he has demonstra this He does not reference Burton or Herms

The Entomology of Typhus and Trench Fever

1. Introductory. It is now generally accepted that the objects known as *Rickettsia* form a well-defined group of living organisms, the position of which relative to the bacteria and filter-passers is still uncertain. We may probably accept the view that all *Rickettsiae* occur at some time in their life-cycle inside the alimentary canal of insects or Acarina, though this definition excludes certain organisms which resemble *Rickettsia* in most respects. Many but not all of the insects and Acarina which harbour *Rickettsia* are blood-suckers (for example, lice, bugs, fleas and mosquitoes: also ticks, larvae of *Trombicula*). In certain cases *Rickettsia* occurs not only in a blood-sucking insect, tick or mite, but also in a mammal, to which the micro-organism may be pathogenic: when this occurs the *Rickettsia* is generally more numerous and more easily demonstrated in the insect than in the mammal. So far as one may judge from morphology, these organisms do not go through a regular cycle of development in their two hosts: nor is it known whether *Bacillus proteus* is a stage in the life-cycle, or an independent organism.

There are particular difficulties in studying *Rickettsia.* Some are due to their minuteness and to their resemblance to debris of dead cells, or to the granules which are common in the tissues of insects and mammals. Another source of difficulty is that, according to most authors, these organisms cannot apparently be cultivated except in the presence of living cells (see, however, Anigstein and Lawkowicz, 1939, who hold the contrary opinion), so that one must cause them to multiply in the insect or tick, and study them there. If this is done one must assure oneself that these hosts are not already infected with some similar organism, and remember that in ticks *Rickettsia* may be hereditary. In general it seems that *Rickettsia* has a tendency to alter some of its most important characteristics: for instance, though they are naturally specific to certain hosts they can establish themselves in others under laboratory conditions.

For these reasons the study of *Rickettsia* is extremely difficult. Though the accumulation of knowledge has made it easier to understand that part of the life history which

occurs in the mammal, it is still difficult to give an account of what happens in the insect or tick. We may regard it as proved that certain species of *Rickettsia* are the causative organisms of certain diseases: for instance, *R. prowazeki* is the cause of epidemic typhus.

The *Rickettsiae* of interest in human medicine may be divided into four groups on their purely entomological characteristics: fortunately, these groups coincide with those based on other characters such as their clinical, pathological and immunological effects. The groups are as follows:

(*i*) *The typhus group.* Examples: *R. prowazeki* da Rocha Lima, the cause of exanthematous or epidemic typhus; *R. muricola* Monteiro and Fonseca (*R. mooseri*), the cause of murine typhus. Characteristics: developing in insects (fleas and lice) and becoming intracellular in the epithelium of the midgut.

(*ii*) *The extracellular group.* Example: *R. pediculi* Munk and da Rocha Lima, harmless to louse and man. One should probably place here *R. quintana* Munk and da Rocha Lima, cause of trench fever, and one or two others (page 68). Characteristics: developing only in lumen of gut of louse, and not becoming intracellular. When pathogenic to man, the fever is recurrent.

(*iii*) *The spotted fever group.* Examples: the organisms producing Rocky Mountain spotted fever, the exanthematous fever of the Mediterranean and other lands, São Paulo typhus. Characteristics: developing only in ticks, in which they are hereditarily transmitted: invading many tissues in ticks and becoming intranuclear.

(*iv*) *The tsutsugamushi group.* Examples: the causative organisms of tsutsugamushi or Japanese River fever which has very recently been shown to be identical with Malayan scrub typhus, etc. Characteristic: developing in mites (*Trombicula*) in which they become hereditary.

The members of the third and fourth groups will not be considered in this book.

For a general account of *Rickettsia*, see Burnet (1937); Cowdry (1926); Pinkerton (1936); Zinsser (1937); Donatien and Lestoquard (1937); or any large textbook on bacteriology.

2. Cycle of *Rickettsia prowazeki* in louse. It was shown by Nicolle (1909) that the infection of typhus could be transferred by injecting blood from a patient into a chimpanzee, an important experiment which showed where the cause of the disease existed in the human body. If one feeds a louse on such a patient, it is easy to demonstrate a great multiplication of *Rickettsia* in the midgut, both in the lumen and also inside the epithelial cells. These become so distended with the growth of the micro-organisms that they may be distinguished from the normal cells even at a magnification of 22 diameters. After some days these cells rupture and the *Rickettsia* then appears in enormous numbers in the insect's excrement. The effect of this on the louse is to delay its digestive processes: death also occurs within a week or 10 days, though da Rocha Lima has recorded an exceptional survival to the 24th day.

It appears that the typhus patient is infectious towards the louse from early in the disease to about the 10th day, and occasionally later. Indeed, it has been recorded that the louse may occasionally be infected a week after the temperature has fallen (Baruikin, Zakharov, Kompaneetz and Baruikina, 1927); later than that there is no evidence that the patient can infect the insect. It has also been shown that if lice are infected by injection and kept at 32° C. (90° F.) a few *Rickettsia* may be found in the cells on the 3rd day: after that almost every louse is heavily infected (Bacot and Ségal, 1922); one might perhaps assume that at lower temperatures a week or more would elapse before the lice began to pass *Rickettsia* in large numbers. From this it seems to follow that the danger of acquiring the disease is greater when the patient is convalescent, or dead, than when he is at the height of the illness. Under natural circumstances not every louse which feeds on a typhus patient becomes infected; indeed, Wolbach, Todd and Palfrey (1922) record 52 experiments in most of which groups of lice were fed repeatedly, but *R. prowazeki* were subsequently found only in 27 of the groups.

It is by the insects' faeces, in which the micro-organism has become so abundant, that the infection is transmitted to man. The normal channel is probably through scratches or abrasions, but there is some evidence that infection may be acquired through the conjunctiva and it is at least possible

that minute particles of excrement, which must frequently be inhaled, might produce the infection through the respiratory passages. The recent work of Sparrow (1936), with animals and human volunteers, shows that transmission by inhalation is at least a possibility.

It has been shown that if the infected faeces are kept dry at room temperature the *Rickettsia* may remain alive and virulent for at least 66 days (Starzyk, 1936). Whether the organism would live longer in faeces, or in louse intestines, dried and kept *in vacuo*, is not yet known. The organism of murine typhus has similar powers of survival in dried faeces of fleas (below, page 61). This long survival in dried faeces under natural conditions may be of great epidemiological importance, for it might explain the sudden appearance of the disease after an interval in which it had not been observed. It is also of great technical importance for it allows one to preserve strains, or to send them to other workers.

At one time it was supposed, by analogy with other diseases conveyed by blood-suckers, that the infection of typhus was acquired from the bite of the louse. The work of Atkin and Bacot (1922) brought this view into discredit: they fed infected lice repeatedly on a monkey, taking great care to avoid the possibility of transmission by the insects' faeces: the monkey did not acquire the disease, but was shown at a later date to be susceptible. Moreover, examination of the salivary glands, mouth-parts and oesophagus of infected lice failed to reveal any *Rickettsia* (Atkin and Bacot, 1922; Arkwright and Bacot, 1923). It is now accepted not only that the disease may be transmitted by the faeces of the insect, but that this is the only source of infection. In the earlier experimental work precautions were taken to avoid being bitten by infected lice: ignorance of the real source of infection led to many workers acquiring typhus, of whom some of the best, including Bacot, Ricketts and von Prowazek, died.

It seems that there is no hereditary infection and that the eggs are free of *R. prowazeki*, though they may be contaminated by infected faeces on the surface. It appears to be unknown whether one can acquire typhus by crushing the infected louse with the teeth, though it would appear probable that one might do so.

The whole cycle described above, including the subsequent appearance of the micro-organism in great numbers in the insects' excrement, may be demonstrated by injecting lice by the rectum (for method, see page 102). This may be done with material derived from the gut of an infected louse, or from a mammal (such as brain tissue or platelets from a guinea-pig). The injection technique leads to almost every louse acquiring the infection. By this method *R. prowazeki* originally derived from a case of typhus may be passed from louse to louse indefinitely: the infection may then be given to a guinea-pig or monkey, which develops the reactions and immunity characteristic of the disease; the infection may then be returned to the louse. This work furnishes a material part of the proof that *R. prowazeki* is the causative organism of epidemic typhus.

Under natural circumstances *Pediculus humanus* acquires *R. prowazeki* by feeding on a human being suffering from typhus fever. It is also possible that the insect may be infected from the faeces of other lice, particularly if the contact is very close as it may be in a breeding-box. This type of infection is known to occur with certain other *Rickettsia* (see below): it may not be common under natural conditions, but it might lead to a louse which had never bitten a patient becoming infected with *R. prowazeki* and capable of transmitting typhus.

Most of the experimental work has been carried out with body lice which are generally associated with epidemic typhus fever, but it is known that head lice are capable of acquiring the infection and transmitting it (Goldberger and Anderson, 1912). If monkeys (*Macacus*) are experimentally infected, *R. prowazeki* appears in the gut and faeces of their lice (species of *Pedicinus*).

It will be seen that the life-cycle of *R. prowazeki* includes two hosts, the louse and the man. No other animal is involved for the louse is a highly specific parasite of human beings (page 32): moreover, it is known from inoculation experiments that the infection will not develop in most of the common animals. The normal transmission from louse to man and man to louse is well established, and explains much of the spread of the disease (page 64) so long as it exists in

its epidemic form. But it fails to explain what occurs at the conclusion of an epidemic when it seems impossible to discover any succession of human cases. We cannot suppose that the infection remains in the louse community, for it is not hereditary, and the individual insect lives only about 40 days. The work of the last few years on murine typhus helps to solve this difficulty.

3. The Cycle of *Rickettsia muricola*. A disease of the typhus group occurs in many parts of the world. It has passed under many names, but we may now think of it as a single condition and call it murine typhus. The causative organism is *R. muricola* (*mooseri*). Much of our present knowledge of the subject comes from the work of Dyer and others published in the United States from 1931 onwards, confirmed and extended in many other countries.

R. muricola is normally transmitted from rat to rat by a rat-louse (*Polyplax*) and by several different sorts of flea. In these insects the cycle is similar to that already described, the organism multiplying in the cells of the midgut and being passed in great numbers in the excrement of the insect. The flea most commonly concerned appears to be *Xenopsylla cheopis*, the tropical rat-flea: this flea has been distributed by commerce to nearly all the warm parts of the world and is also found in docks and grain stores in many temperate countries. It is a parasite of domestic rats, and readily bites man. Infection with *R. muricola* appears to cause no harm to the flea, which may live for many weeks. In the rat, though the organism lives for long periods in the brain, it does not cause serious sickness. What appears to be the same organism has been recovered from wild rodents of many sorts from several parts of the world. In the Mediterranean region the infection has been found not only in rats, shrews and squirrels, but also in cats and dogs. It may easily be maintained in the laboratory by passage through rats or mice.

In faeces of *X. cheopis*, the causative organism of murine typhus remains alive and virulent for long periods: survival for 40 days in the dark in a laboratory cupboard, and for 100 days *in vacuo* has been reported. There is no reason to think that these periods were maxima (Blanc and Baltazard, 1937).

It occasionally happens that the organism causing murine typhus reaches a human being, presumably by way of the faeces of an infected flea. In the human being the infection produces a mild form of typhus and then generally dies out so that cases are single and sporadic. But one may take infected blood from such a man and infect *Pediculus* with it by rectal injection, and one may also, under certain circumstances, infect human lice by allowing them to feed on a monkey suffering from murine typhus (Lépine and Bilfinger, 1934).

In *Pediculus*, *R. muricola* becomes intracellular and causes the death of the louse, perhaps even more rapidly than *R. prowazeki* does.

In general, a man suffering from murine typhus does not produce natural infection of the louse. But he may occasionally do so, particularly in Mexico, where a type of murine typhus known as tabardillo is quite common among human beings. It appears that this particular type of the disease produces natural infection in *Pediculus*, and then in other human beings. The disease is therefore to some extent intermediate between murine typhus, which is generally sporadic in man, and the epidemic louse-carried disease.

It is possible to infect bed-bugs (*Cimex*) and also certain ticks with the organism causing murine typhus. There is nothing to suggest that this occurs in nature and attempts to recover the organism from bugs in infected areas have so far been unsuccessful.

4. Epidemiology of Murine and Epidemic Typhus. Several authorities, among them Nicolle in Tunis and Zinsser in the U.S.A., take the view that murine typhus is the more primitive disease. They hold that the infection may overflow to man, generally producing a single case without further issue, but that occasionally human lice have become infected and have in turn produced typhus in other men. According to this evolutionary view the infection has gone through two mutations, changing both its vertebrate and its invertebrate host. Whether this occurred in the remote past or continues to happen from time to time, and whether it is reversible, is unknown.

This view can neither be proved nor disproved, but certain

facts are in its favour. It will be remembered that in Mexico and perhaps elsewhere a disease exists in rodents and man which might be regarded as intermediate between the murine and the epidemic types. It is also undoubted that many of the biological characters of "species" of *Rickettsia* are not stable. There is, for instance, a record that guinea-pigs were infected with a strain of epidemic typhus derived from Europe: fleas fed on these guinea-pigs became infected, as was shown by grinding them up and injecting them into susceptible animals, and (in one case) by keeping such fleas in close contact with rats (Mooser, 1932). In this instance a strain of epidemic typhus took on certain murine characteristics in the laboratory. The view that the murine is the more primitive and ancient infection, and that the epidemic disease carried by lice is more recent, is consistent with the facts that *R. muricola* is harmless to the flea, whereas *R. prowazeki* causes the death of the louse, to which it is therefore regarded as less completely adapted. The fact that epidemic typhus often occurs in areas in which the murine infection has been found might point to the one arising from the other, but it is more probably due to the concentration of study in those parts of the world where one disease has already been detected.

Whatever theory one adopts about the origins of these diseases, they are very distinct in their effect on the human community. Many of the points of distinction were defined by Maxcy (1926), who was arguing solely from observation and not from experiment. He put forward the view that the sporadic cases of typhus which he had observed in the south-eastern part of the United States were in no way connected with the louse: he held that they were derived in some way from rats and mice with which many of his patients had been in close contact. It was only later that the soundness of the reasoning became apparent, when the cycle of *R. muricola*, described above, was worked out: the essential points in the epidemiology of the disease remain as Maxcy defined them.

As murine typhus is sporadic in man it is seldom a serious menace, unless one takes the view that it might give rise to louse-carried epidemic typhus. But even in its sporadic form

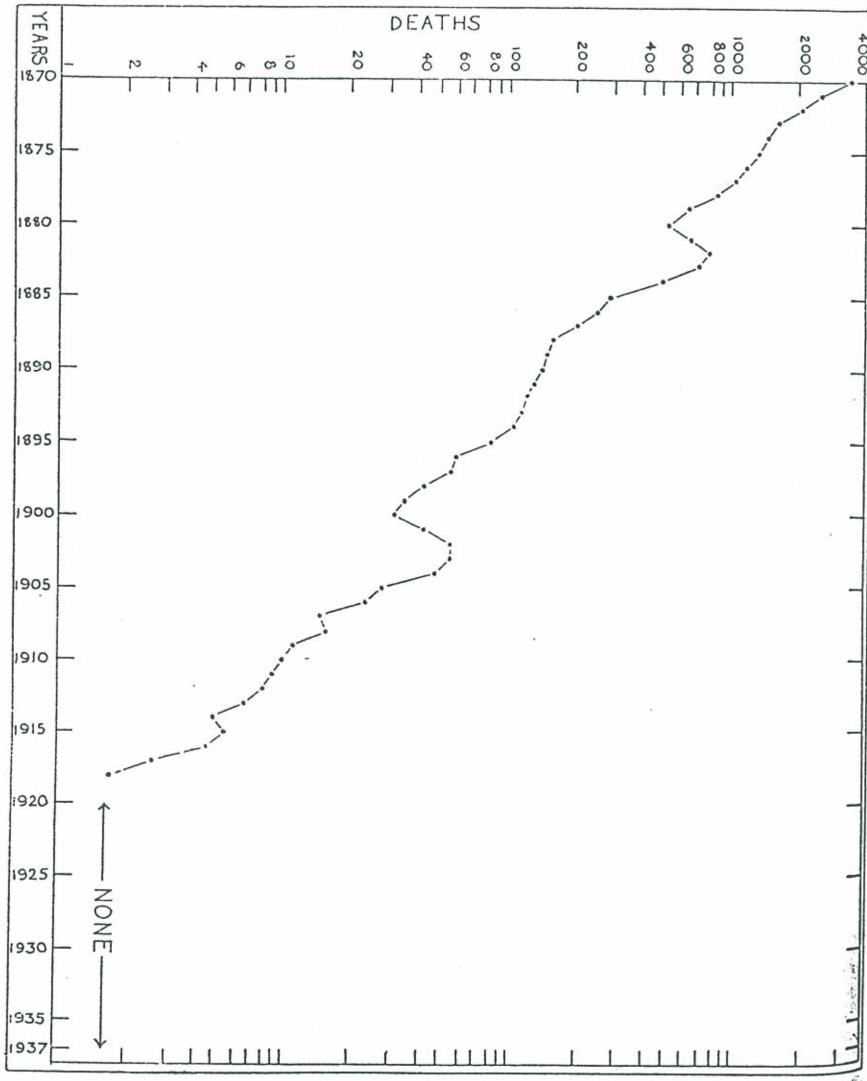

FIG. 23.—Showing deaths from typhus fever of males and females together, for England and Wales, from 1870.

The graph is a "smoothed curve" on which each point is the mean value for three successive years. (*Data from Ann. Reports Registrar-General.*)

rare. It is remarkable that on the Western Front from 1914 to 1918, in which vast numbers of infested men lived crowded together for years, epidemic typhus did not break out: this becomes the more remarkable when one remembers how many races coming from many different parts of the world took part in that struggle.

Epidemic typhus is also absent from most tropical countries, for instance, India. This is unexpected, for the body louse is very abundant, and infection must frequently come down into India from Persia, Afghanistan and Turkestan. Indeed, it seems that epidemic typhus transmitted by lice exists in the foothills of the Himalayas but is absent from the plains. The absence of the disease from India and from most other hot countries is remarkable and quite unexplained. There are, however, some records of the disease occurring in the tropics, for instance in the Philippines, the northern part of the Gold Coast, and Indo-China (Zinsser, 1937).

There are many very close parallels between epidemic typhus and epidemic relapsing fever, depending on the fact that they are both spread by the body louse. These diseases also resemble one another in that each is related to (and perhaps derived from) a disease, which is spread by rodents and sporadic in man.

see page 73 ? term confuses issue

5. **Extracellular *Rickettsia* in *Pediculus*.** In several parts of the world an organism to which the name *Rickettsia pediculi* is given has been found in "normal lice." It may be shown by sections that it lives and multiplies in the lumen of the midgut but that it does not invade the epithelium. In taking up this extracellular position it differs strikingly from *R. prowazeki*, etc.; this point of distinction seems to be sharp, not subject to variation, and important.

R. pediculi is sometimes common. There is, for instance, a record of it being identified in 53 out of 72 lice examined in France, but at other times and places it appears to be absent. Transmission seems to be direct from louse to louse, the infected faeces being swallowed when the insect pierces the human skin. The eggs may be contaminated externally so that the young larvae readily pick up the infection, but by sterilizing eggs one may rear uninfected stock. One would suppose that the infected material might be air-carried, so that a person might bring it from his home to the laboratory, and there introduce it into a culture of lice. This would explain the apparently spontaneous appearance of this organism in lice which have been bred and observed to be uninfected for generations.

R. pediculi is common in lice on normally healthy people and is harmless both to louse and man. It has of itself no medical importance. For recent information Herzig (1939*b*), Sparrow (1939).

There are certain other species of *Rickettsia*, extracellular in the louse and harmless to it, but pathogenic to man. Of these the most important is *R. quintana*, believed to be the cause of trench fever.

A man suffering from trench fever is not infectious to the lice for the first three days of his illness; after that he infects them throughout the period of fever and of convalescence, and indeed, sometimes, for months. In the louse the life history of the parasite is much like that of *R. pediculi*; living only in the lumen of the gut, it multiplies for from 6 to 10 days, by which time it appears in the faeces in great numbers. The disease has been transmitted to man by scratching the skin of volunteers and rubbing in the faeces of infected lice. Some of those who studied the disease about 1918 held that they had demonstrated transmission by the bite, but it is possible that they had failed to exclude the possibility of contamination by faeces. The infection is not hereditary in the louse. Owing to the apparent disappearance of trench fever it has not been possible to study *R. quintana* by modern methods.

The essential points in the epidemiology of trench fever are simple. The disease itself gave rise to at least two acute febrile attacks and it was not difficult to diagnose nor likely to be confused with other fevers. It was extremely prevalent in the war of 1914–1918 among troops actually engaged in fighting, also among those who treated them, handled blankets or engaged in disinfestation. In other words, it occurred among those exposed to infestation by the louse or brought into close contact with the faeces of the insect. Some hold that trench fever is identical with a disease previously described in Wolhynia, others that it arose suddenly and that nothing like

it was previously known. It disappeared completely from Western Europe soon after the end of the war, a curious fact when one remembers that lice continued to exist in that part of the world. (See Strong and others, 1918.)

There are at least two other records of an extracellular *Rickettsia* appearing, causing fever in man, and then disappearing. On the first occasion an organism to which the name *R. weigli* was given appeared in a laboratory strain of lice in Poland soon after the Great War and caused an outbreak of illness which was confined to the staff of the institution. The disease is known as Weigl's disease. It was shown that the micro-organism developed in lice fed on the patients and that it was extracellular in the insect and harmless to it. Something very similar has occurred in recent years, again in Poland (Herzig, 1939*a*). On both occasions this *Rickettsia*, pathogenic to man, appeared in a stock of lice which were maintained for experimental work on typhus; they were therefore continually tested and examined, and it was known that *Rickettsia* had previously been absent.

There are two views which might be maintained. It is possible that the laboratory stock of lice, however carefully they were kept and tested, became contaminated from outside by *R. weigli* which existed in the human population and was presumably causing disease. Against this view is the fact that at least on the first occasion a careful search was made for Weigl's disease outside the institution and no cases were discovered. The alternative possibility that under conditions which are still obscure to us *R. pediculi*, which is normally harmless to man, may be transformed into something which causes trench fever or Weigl's disease. One cannot at present decide between these views. Whichever of them is correct the close resemblance between Weigl's disease and trench fever is important. Both are caused by an extracellular *Rickettsia*. It is much to be regretted that owing to the disappearance of these organisms they cannot be compared or studied by modern technique. At least we may say that there is no evident difference between them, that they give rise to diseases in which more than one period of fever is characteristic, and that they appear to originate and disappear in a mysterious manner.

The Entomology of Relapsing Fever

1. Introductory. The relapsing fevers are a group of closely related diseases in which periods of pyrexia recur at rather regular intervals. In warm countries these diseases are not always clearly distinguished from malaria (in which also the fever tends to recur). For this reason the relapsing fevers are frequently overlooked: but they are of great importance, for they occur in many parts of the world and occasion much illness and many deaths in some: one type of relapsing fever, that carried by lice, gives rise to great epidemics.

The relapsing fevers are a most interesting group of diseases, much like one another in some respects, distinct in others. In their clinical and pathological effects they are very similar: they also resemble one another in parasitology, for they are all caused by spirochaetes which live in the blood. It is impossible to distinguish the organisms which cause different types of relapsing fever on any point of anatomy: immunological distinctions exist, but most of them are not very sharp. One would therefore be justified in saying that these spirochaetes form a closely related group; many different scientific names have been given to different forms, but their relationship to one another is obscure. None of the spirochaetes which cause relapsing fever can be directly transmitted from man to man, but all of them must pass through an alternative host, which may be either a louse or a tick. This difference in the alternative host is of great practical interest, for it means that the types of relapsing fever which occur in different parts of the world differ very greatly in epidemiology and in the measures that must be used for controlling them. The distinction which is sometimes made between "epidemic relapsing fever" (carried by lice) and "sporadic relapsing fever" (carried by ticks) expresses an important difference.

2. Transmission by the Louse. The epidemic type of relapsing fever, which is transmitted by the louse (*Pediculus humanus*), is much more important than the other and will be considered first: it is caused by *Spirochaeta recurrentis*.

In the blood of a human being during a period of fever the spirochaetes may be abundant or sparse; but in either case the louse, which takes about 1 mg. of blood, will swallow large

numbers. These may be discovered in the blood in the insect's midgut for short periods up to a day (28° C., 82° F.); in sections one can see some spirochaetes fixed to the surface of the epithelial cells lining the midgut and others inside the cells, but many appear to die in the gut. By the end of the first day, and often earlier, the spirochaetes have disappeared and there follows a period in which they can seldom or never be found in any part of the insect's body. It is possible that they may persist as spirochaetes which have become rare and difficult to find. It is also possible that they have changed into some other form, perhaps a minute granule: if such a granule stage occurs it would be difficult to recognize, for the insect's tissues normally contain many granules. Most modern workers seem to incline to the first view.

From about the 6th day at 28° C. (82° F.) (or even after a few hours according to Chung and Feng, 1936) spirochaetes begin to appear in the blood of the insect, which circulates through its body cavity.[1] They increase rapidly and may be found in all parts of its body and limbs: but they cannot be found inside the lumen of any part of the gut or inside the salivary glands or ducts: it has been stated that parasites may be found inside the eggs, but that is not now generally accepted. Spirochaetes are not transmitted from louse to louse in copulation. In the louse's body they persist throughout its life; and as they have been seen 25 days after the infecting meal we may perhaps think that they are not harmful to the insect, a point on which fuller information is required. A considerable proportion of the lice on a patient may be found to be infected: Riding and Macdowell (1927) say that half the lice can be shown to be infected on patients who have been ill for 10 days: lower but considerable proportions are recorded by other authors.

[1] It is to be understood that the body cavity of an insect is completely different from the apparently similar structure in a mammal. In insects the cavity is not lined with any epithelium (such as would correspond to the peritoneum), but is an indefinite space existing among the organs to all parts of the body and limbs: the insect's blood circulates throughout this space, which may be referred to as a body cavity, or a haemocoel if a more precise term is desired. It is inaccurate to refer to it as a coelome, a term which is correctly used for the structure that exists in mammals.

It must be understood that when the spirochaete has reached the body cavity of the louse it has no natural means of egress or of infecting man, for it can neither be transmitted by the bite nor voided in the excrement. It is therefore safe to allow such a louse to bite a human being. Indeed, Nicolle records feeding infected lice many thousands of times without securing transmission, though he subsequently showed that the subject of the experiment was susceptible to the disease; several other authors have recorded many thousands of bites without transmission. But if one ruptures the body of such a louse, even by pulling off an antenna or part of a leg, some of the insect's blood and some parasites will escape on to the skin; it is probable that the parasites present in the blood cannot penetrate the unbroken skin but they will enter any small abrasion. We suppose that transmission normally occurs by the man rupturing a louse and inoculating himself by scratching. It is clear that the practice of popping lice between the thumb-nails, which is how a European instinctively destroys them, may be dangerous. The custom of crushing them with the teeth, which may be observed among the indigenous races of Australia and North and South America, and in certain other primates, is reprehensible on hygienic grounds if for no other reason, for we suppose that the parasite can pass through any mucous membrane, as it certainly can through the conjunctiva. It should however be stated that Chung and Feng (1936) report several failures to infect man by placing crushed infected lice in the mouth.

There is no doubt that the transmission of louse-carried relapsing fever normally occurs in the manner described above, the parasite going through a cycle of development in the insect and then returning to man owing to some accident. But transmission might also occur directly, the louse feeding on a patient and then passing at once to feed on a second human being: in this case it might inoculate spirochaetes which had continued to live on its mouth parts. It is improbable that this type of transmission, if it occurs at all, is as important as that first described. It is also unlikely that transmission by the faeces of the louse occurs: spirochaetes are occasionally passed, but only for a few hours after the infecting meal, and most or all of them dead.

It seems that the head louse and the body louse are both capable of transmitting the infection, but probably the body louse is the more important transmitter, for it is generally the one which is abundant in the presence of epidemics. The crab louse (*Phthirus pubis*) appears to be incapable of allowing the parasite to develop in its body cavity, if one may rely on a very few observations (Chapcheff, 1925). It seems that if lice (*Pediculus*) feed on a human being during the periods between bouts of fever, they do not become infected.

For a general account of the subject, see Wenyon (1926) or Hindle (1931); recent references are Chapcheff (1925), Riding and Macdowell (1927), Robertson (1932), Chung and Feng (1936), Chung and Wei (1938).

3. Bed Bug as Vector. The status of the two species of bed bug (*Cimex lectularius* and *rotundatus*) as transmitters of relapsing fever is obscure. Many observers have fed bed bugs on animals or men in whose blood the parasites were circulating, using spirochaetes transmitted by lice or by ticks. In all these experiments the spirochaetes have been seen to die in the midgut after a short interval, but they soon appear in great numbers in the insect's body cavity and remain active there for many days. They cannot be found in the salivary glands or in the excretory tubes, but if the bug is crushed the spirochaetes in its body cavity readily produce infection if introduced through the skin of a mammal. (See Chung and Feng, 1938.)

To what extent the bug is responsible for transmission under natural conditions is not known, but there is no evidence from any part of the world to suggest that it is an important carrier. It seems, however, that it might maintain the infection for long periods which the louse could not do, for its life is short. It would therefore be possible for bed bugs to keep a strain of spirochaetes alive at a season when lice were rare and when no infections were occurring in man.

4. Epidemiology of Relapsing Fever carried by Louse. It is essential to remember that *Pediculus humanus* is a highly specific parasite of man and of no other host. *Spirochaeta recurrentis* is also specific in the sense that it is transmitted by the louse (and perhaps the bug) but not by ticks (*Ornithodorus*). Moreover, as transmission to man depends upon the insect being crushed and inoculated through a mucous membrane or through broken skin, we may suppose that many lice become infected, but that few of them actually cause transmission to man. As crushing entails the insect's death, one infected louse can never infect more than one man, at the most. It is perhaps for these reasons that the spread of the disease only occurs when the insects are abundant, not merely where they are present.

From what has been said it follows that this type of relapsing fever, often in epidemic form, is frequently associated with overcrowding, destitution, insanitary conditions and famines, all of which may lead to abundance of lice. Relapsing fever is therefore associated, as typhus is, with calamities, wars, movements of armies or bodies of refugees, etc. The great epidemics of the disease which occurred in the Balkans from 1914 onwards are a familiar example of this, though they were to some extent obscured by outbreaks of typhus. It should be borne in mind that great abundance of lice is not invariably associated with outbreaks of relapsing fever; for instance, on the Western Front in the war of 1914–1918 these insects were most abundant and men were living uncleansed and crowded together, but the disease did not occur, perhaps only because the infection was not introduced.

Not every outbreak of louse-carried relapsing fever is associated with calamities or unusually insanitary conditions. There was, for instance, a great epidemic starting in 1921 in northern equatorial Africa. This region is one in which louse-carried relapsing fever is always widely spread. The epidemic occurred in the rather arid zone which extends across Africa south of the Sahara in about 15° N. It continued for 7 or 8 years from 1921 and reached the Atlantic in Senegal and the Gold Coast, etc.; it was extended through Upper Guinea, the French district of the Niger, the northern parts of the Gold Coast and Nigeria, the region about Lake Chad, Wadai, and the western parts of the Anglo-Egyptian Sudan. It was clearly established that transmission was by lice; indeed, no tick of the genus *Ornithodorus* is known to occur in the greater part of the territory effected. We have only the most imperfect idea of the number of cases or deaths produced, but it is certain that millions of people were affected by it and that according to the estimates of many observers the death-rate was probably about 5% of the population; in some areas it reached 25% of the population. (See Atkey, 1929; Mathis, 1931; McCulloch, 1925; Selwyn-Clarke, Le Fanu and Ingram, 1923.)

It has been observed in many parts of the world that relapsing fever is seasonal, and that its incidence coincides with the season when lice are most abundant. A clear case in Northern India has been described by Cragg (1922*a* and 1922*b*). In that part of the world the climate is exceedingly hot and dry in April and May; in June the monsoon rains fall and the air becomes moister and cooler. From then onwards through autumn, winter and early spring lice may multiply, and through a great part of that period they can move freely about away from their host; in April and May, when the hot weather again occurs, it is known that their numbers are greatly reduced (page 52). Cragg uses these facts to explain the seasonal incidence of relapsing fever in Northern India, an area in which it is known to be a disease of the cold weather and to come to an end before the monsoon. He goes further than that, and says that in 1917 April and May were unusually cool and therefore not unfavourable to *Pediculus*, and that the epidemic of relapsing fever did not come to an end at that season.

It seems probable that events are similar throughout the Mediterranean area and the Arab and Persian lands, a region in which the summer is very hot, passing gradually to a cool autumn and cold winter. In this area lice tend to be rare in the summer, and relapsing fever is a disease of winter and spring, disappearing at or soon after midsummer. In many other parts of the world, for instance China (Robertson, 1932; Shrimpton, 1936), the seasonal incidence of relapsing fever may to some extent be related to seasonal changes in the numbers of the insect. One should, however, remember that though climate has a direct effect on the insect, the matter is complicated by such human factors as seasonal changes in the amount of clothes worn and movements of agricultural labourers, shepherds and pilgrims.

The relation between abundance of the insect and liability to relapsing fever is sometimes shown in the incidence of the disease among different parts of the human community; in Central Africa, for instance, naked pagans and naked children may tend to escape. The disease may also be almost limited to particular communities; in rural epidemics in South India it is recorded by Russell and others that it was almost confined to two castes of poverty-stricken labourers. But the entomologist must be cautious and not try to explain the whole epidemiology in terms of the vector; doubtless there are important human factors, such as different degrees of susceptibility at different ages.

The fact that epidemics of this disease may be brought to an end by active measures directed against the louse is a further example of the close relation between the spread of the disease and the abundance of its vector. Even a very imperfect control of lice leads to the gradual disappearance of the disease, as one sees in North and West Europe at the present moment; relapsing fever is extinct, apparently because head and body lice are less prevalent than they were.

It is not easy to tabulate the geographical distribution of epidemic relapsing fever carried by lice, for until recent years it was not realized that the types carried by ticks are widely distributed: there was therefore a tendency to assume that all relapsing fever other than that of Central Africa was transmitted by the louse. It is now known that as the two types of infection are distinct they may occur, independently, in the same area, as they are known to do in French North Africa, Palestine, Iran, Senegal and perhaps other areas. As to the louse-carried disease, its occurrence at the present day or recently is established in the following parts of the world (Hindle, 1931; Joyeux and Sicé, 1937):

EUROPE: at present believed absent from Western Europe (Scandinavia, British Isles, France, Germany, etc.); widely distributed in Eastern Europe (Poland, Russia, countries bordering Black Sea, Balkans). In the war of 1914–1918 and in subsequent years great epidemics occurred in this region.

ASIA: probably very widely distributed, though positive records not available from some important areas; present and important in nearly all parts of India and China; Indo-China, Annam, etc.; Western Asia (Turkey, Arab lands, Iran).

AFRICA: present in two great belts, running east and west, and separated by the Sahara; the northern belt extends from Morocco, through Algeria, Tunisia and Tripolitania to Egypt; the southern from Senegal to the Anglo-Egyptian Sudan (see page 74, epidemic of 1921), and Abyssinia (Kirk, 1939).

AMERICA: in North America may well have occurred, but at present appears absent, all cases recently studied being of the sporadic type carried by species of *Ornithodorus*; in Mexico, Central and South America it seems that the louse-carried disease occurs, perhaps commonly; it is not generally distinguished from the sporadic disease.

ABSENCES. There are considerable areas from which louse-borne relapsing fever has never been recorded. It seems to be absent from tropical Africa (except the belt south of the Sahara from Senegal to the Anglo-Egyptian Sudan), perhaps because so many people are very scantily clad. It also seems absent from the Malay Peninsula and Archipelago; this may be due in part to the cleanliness of Malays, who seem to be free of body lice. There are no records of its occurrence in the continent of Australia, which is rather remote from sources of infection, and in which crowding and destitution are rare.

5. Central African Relapsing Fever. We shall deal briefly with the cycle of spirochaetes in ticks and the epidemiology of the corresponding disease, mainly in order to point out the contrasts between it and the relapsing fever transmitted by the louse. The most important species of tick is *Ornithodorus moubata*, which transmits *Spirochaeta duttoni*, the cause of the tick fever of Central Africa. The female of this tick lays very numerous eggs in batches over a period of months. From these eggs hatch larvae which do not feed but moult into nymphs. These go through a succession of stages in each of which they grow and moult; finally they become adult males or females. The nymphs and adults feed on nothing but blood and it is believed that man is much the most frequent natural host, though they will occasionally take blood from a number of animals. In general, ticks of this species are found where man lives, for instance in cracks in walls, round well-heads, and in the bases of floors and camp sites. The ticks spend nearly their whole time in these positions and only come to man when they require to take blood, which occupies only half an hour or so. If they have an opportunity of feeding whenever they require to do so, the life occupies some months, but if they are starved it may be greatly extended to cover several years.

O. moubata is distributed over the whole east side of Africa from Egypt to Natal. It extends to the west coast close to the mouth of the Congo, but not elsewhere. The Central African type of relapsing fever of which this tick is probably the only vector has a less wide distribution, but is found from Kenya and Uganda southwards.

If *O. moubata* is fed on a man or animal whose blood contains *S. duttoni*, the early part of the cycle resembles what occurs in the louse (page 71): the spirochaetes disappear rapidly from the gut and after a period in which they are difficult or impossible to find they appear in great numbers in the body cavity or haemocoel, where they may continue to live for many months. The cycle differs from that observed in the louse in that some of the spirochaetes enter the solid organs of the tick; if it is a female some can be found in the ovaries and a proportion of the eggs which are laid are infected. This infection persists in the next generation and indeed for several generations, and ticks which have received an infection from their mothers are capable of transmitting it to man.

In order to understand the transmission of the spirochaete from the tick to the mammal, one must understand exactly what occurs when the tick feeds. The mouth parts make a relatively large hole in the skin, and the saliva is delivered at the base of the mouth parts so that some of it presumably enters the wound. Towards the end of feeding the tick evacuates the contents of the hind-gut which consists partly of faeces and partly of nitrogenous waste derived from the excretory (Malpighian) tubes. Ticks also excrete fluid from the coxal glands through an aperture at the base of the front legs; in *O. moubata* this occurs while the tick is still feeding, and the coxal fluid may be seen to mix with the blood which is oozing from the wound made by the mouth parts. It will therefore be realized that there are three possible channels by which infection might be transmitted:

the saliva, the excrement, and the coxal fluid. Several authors have established that spirochaetes can be found in the coxal fluid and that infection can be produced by injecting it (Bone, 1938); under natural circumstances the parasites are presumed to enter the vertebrate host through the rather large hole made in the skin by the mouth parts. Attempts to demonstrate transmission by the saliva and the excreta have not been successful. It seems improbable that infection would occur naturally through the tick, which is very tough, being ruptured on an abraded surface.

In the epidemiology of Central African relapsing fever the most characteristic thing is the localization of the infection. A community of infected ticks inhabit a particular building, courtyard, etc. The people who become infected are therefore those who spend the night in a certain resthouse or live in one part of a particular village. Moreover, as the tick is long-lived and as infection may be hereditary, these spots continue to be centres of infection for years. It follows that the disease is not epidemic and that it is typically a "house disease." It is also important to remember that so far as we know animals other than man have nothing to do with the spread of this disease; they appear not to act as reservoirs for the spirochaete and they are not common hosts of the ticks.

6. Other Tick-carried Relapsing Fevers. Relapsing fever transmitted by ticks occurs in two other large areas. The first we may call Mediterranean, using that word in an extended sense. The area is perhaps not quite continuous, but it extends from Spain and French North Africa south-westwards as far as Dakar in Senegal; eastwards it stretches along the Mediterranean at least on its northern side and includes most of the Arab, Persian and Turkish lands, including Transcaucasia. The eastward limit appears to be in Russian Central Asia (Bokhara, etc.). This type of disease does not extend into China or India. The second area covers the warmer parts of America. Relapsing fever of this type has recently been shown to be widely spread in many of the states of the U.S.A.; it also occurs in Mexico and Central America (not apparently the West Indies); in South America it is widely distributed as far southwards as the northern Argentine.

In each of these areas, the Mediterranean and the American, several different species of *Ornithodorus* are involved in the transmission of relapsing fever to man: *O. moubata* is completely absent. In each area there are also apparently several different varieties or species of *Spirochaeta*. The general life-cycle is like that of *S. duttoni* in *O. moubata*, but there are certain important differences, for these spirochaetes may be found in rodents, both wild and domestic (rats, squirrels, etc.), and occasionally in other animals (dogs, shrews and American monkeys). The ticks also normally feed on rodents, most of them inhabiting caves or rat-holes, but some of them entering buildings, particularly if rats are present. None of these ticks feed normally on man, though they will bite man readily enough if an opportunity occurs.

It follows that both in the Mediterranean and in America, relapsing fever only occurs in man sporadically and that it attacks special groups of people who are brought into close contact with the ticks on rats and other animals. There are, for instance, records of human beings becoming infected in particular rat-infested houses and pigsties; relapsing fever has also attacked scientists and archaeologists working in caves. It would probably be correct to say that each human case is a separate accidental event and that the transmission from man to man is very rare, if indeed it occurs.

It will be realized that the control of any species of *Ornithodorus* is difficult. In Central Africa one may under certain circumstances be able to control *O. moubata*, for it lives in human dwellings. If relapsing fever is occurring in a particular spot it is probably best to destroy badly infested buildings by fire. It is also desirable to construct cement floors and bases of walls even if the upper parts of walls must be made of mud or other material which contains cavities and cracks. If it is impossible to put in cement floors one can at least fill cracks with cement or tar or treat them with creosote or with kerosene emulsion (page 90). In schools, etc., it would be well to supply bedsteads rather than to allow pupils to sleep on the floor.

In the Mediterranean and American areas the ticks are not generally in human dwellings but spread about the country-

side in caves, holes of rodents, etc. Under these circumstances control appears to be impossible.

As the types of relapsing fever are somewhat confusing, it may perhaps be convenient to present the most important points of difference in a compact form (Table 5).

TABLE 5

SHOWING THE PRINCIPAL POINTS OF DIFFERENCE BETWEEN THE TYPES OF RELAPSING FEVER

	Louse Fever	African Tick Fever	Other Tick Fevers
Vector	*Pediculus humanus*	*Ornithodorus moubata*	Other species of *Ornithodorus*
Parasite	*Spirochaeta recurrentis*	*S. duttoni*	Various
Vector's haunts	Human body and clothes	Floors, cracks, courtyards	Rodents' burrows
Transmission	Crushed louse. Not hereditary.	Coxal fluid. Hereditary	Channel doubtful. Hereditary
Reservoir	Man	Probably man only	Rodents and a few other animals
Vector's biology	Only on man short-lived	Feeding mainly on man. Living months or years	Feeding on animals, occasionally man. Living months or years
Disease type	Epidemic	House disease	Sporadic on man
Disease range	Eastern Europe, India and China, North Africa, and belt south of Sahara. Some parts tropical America	Tropical East and Central Africa	"Mediterranean" from Atlantic to Russian Central Asia. Warm parts of America
Control	See pages 82 to 92.	Destruction of infested building. Concrete. Kerosene emulsion	None