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REPORTS ON PLAGUE INVESTIGATIONS IN INDIA.

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(Plates XIX—XLI, with seventy-six Maps and Charts.)

(*Continued from Volume VII*, p. 476.)

XXI. DIGEST OF RECENT OBSERVATIONS ON THE EPIDEMIOLOGY OF PLAGUE.

I. Introductory.

The history of the study by modern methods of the epidemiology of plague may be said to date from the discovery of *B. pestis* by Yersin and Kitasato in 1894. The severe outbreaks which since then have yearly recurred, notably in Bombay and Hongkong, have offered a wide field for investigation. That the opportunities thus afforded have not been neglected is sufficiently shown in the statement that in Bombay alone no fewer than six scientific commissions devoted their attention to various aspects of the disease within a few years. In addition, epidemics have been investigated in many places throughout the world.

Perusal of the extensive literature dealing with the epidemiology of plague makes it evident that many conflicting opinions have been held within recent years by workers in this field: especially

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is this the case with regard to the all-important question of the mode of infection in man and in rats. The reason for this confusion is not far to seek. In the first place, even at the present time there is no unanimity of opinion as to the exact rôle which ought to be attributed to the rat in epidemics of plague in man. In the second place those who champion the view that the rat is an important agent in the spread of plague are confronted with the difficulty of knowing precisely in what way the infection is conveyed from rats to man. Additional complexity has been imparted to the problem of the mode of transmission of infection from the rat to man by the suggestion, first made in 1897 and since then widely discussed, that the flea might act as an intermediary between the rat and man. In the third place, it has seemed to some that a disease which is frequently septicaemic must be contagious; the partisans of this view look upon the plague patient as the chief source of danger. Lastly, there are those who seek to explain such facts as the persistence of infection in a locality or the importation of infection into a locality from far distances, on the view that the plague bacillus is capable of living as a saprophyte in soil, in clothing, or in articles of merchandise.

It cannot be doubted, that it has often proved difficult to reconcile apparently well founded observations in the epidemiology of the disease with any one theory of infection.

We propose in the account that follows to make a survey of the conclusions arrived at by those who have worked at the subject during the last 10 or 12 years. Within the compass of this survey cognisance will be taken only of the views of these observers on what we believe to be essential points in the epidemiology of the bubonic and septicaemic varieties of the disease.

The subject matter has been arranged in sections, each having reference to a definite aspect of the problem. In each section the views held by different workers on the question under discussion are summarised; the countries in which any observations have been made being dealt with separately and in a regular order. It is hoped that in this way the reader will obtain a clear idea of the different conclusions which have been arrived at on any one point, as well as an impression of the opinions of the individual workers on the whole problem.

II. The Epizootic amongst Rats.

1. *The General Relationship between the Epizootic and the Epidemic.*

India. The importance of the epizootic in the spread of plague in Bombay was early recognised by Snow and Weir (1897), Hankin (1898) and the German Commission (1899). On the other hand the members of the Commission (1897) sent from Egypt to study the disease reported that the part played by rats was most probably a very small one, the plague patient being the chief source of danger. Simond (1898) from his observations of the disease in India assigned to the rat the essential rôle in the dissemination of plague. Hankin (1898) published his views a few months later than Simond. He pointed out that the incidence of plague bore definite relation to the accessibility of man for rats. In a later paper (1905) he appears to have modified his views, since he states his belief that rats are not a necessary cause or agent in the spread of plague. Hankin further adopts the view that there is no quantitative relation between rat and human mortality and he has cited several instances which seem to support this belief. Koch (1898) paid a brief visit to India in 1897 and as a result emphasised the "very important fact" that rats are essentially concerned in the spread of the disease (ganz wesentlich betheiligt sind). In a later contribution (1901) he defined plague as a disease of rats in which men participate.

The Indian Plague Commission (1901) summed up the evidence presented to them in words to this effect. The chief importance of rats in the epidemiology of plague seems to arise in connection with the first outbreak of the disease in an infected place. When plague is once established in a place human agency is a more important factor in spreading the disease than the agency of rats.

As plague became scattered over India opportunities were given for its study under very varying conditions and as a consequence many valuable observations bearing on the point under discussion were made by the various Sanitary Officers, notably by James (1899), and are to be found in the official reports to the Indian Government. In an excellent summary of these reports by Bannerman (1906), from which we shall frequently have occasion to quote, the statement is made that evidence derived from Indian experience incriminating the rat as an agent in the spread of plague is overwhelming. J. A. Turner (1905), from an intimate acquaintance as Medical Officer of Health with the conditions

in the native city of Bombay, stated his conviction that rats play an important part in the spread of plague. Browning-Smith (1906), who has had a large experience as a plague officer in India, has affirmed recently that in the Punjab bubonic plague in epidemic form is associated with and is dependent on an epizootic in rats.

Australia. The relationship between the epizootic and epidemic has been studied with particular care for the outbreaks which have occurred in Sydney since 1900 by Ashburton Thompson, aided on the experimental side of the work by Tidswell.

The value of the observations made by Thompson is enhanced by the continuous examination on an extensive scale of rats caught in the infected quarters of the city. On account of the comparatively small number of human cases in each epidemic a detailed investigation of each case, especially in its relation to plague-infected rats, was possible. For this reason and on account of the evident exactitude with which the work was carried out the conclusions derived by Thompson from his observations of plague in Sydney deserve careful consideration.

These conclusions may be stated thus:

(1) Plague in rats preceded the first case which occurred in man.

(2) The epizootic area was practically co-extensive with the epidemic area.

(3) The epidemic is due to communication of infection from rat to man.

Thompson has rightly drawn attention to an important point which we shall illustrate later from our own experience, namely, the danger of concluding that plague rats are absent from an infected locality because none have been found. It is obvious that this depends altogether on the extent and the thoroughness of the search for dead rats and upon the care taken in the subsequent examination of any such which may be found. There can be no doubt that a failure to recognise the importance of this matter has more than once given rise to mistaken ideas upon the subject of the relationship between plague-infected rats and man.

Baxter-Tyrie (1905) investigated outbreaks of plague in Brisbane on lines similar to those carried out at Sydney. He holds the rat responsible for conveying infection to man.

Hongkong. A large amount of research has emanated from workers in Hongkong since the discovery of the specific bacillus in 1894.

Yersin (1897) remarks "Plague which is at first a disease of the rat soon becomes a disease of man."

Clark (1901) observed that dead rats could be found in plague houses before human cases occurred. He also noted that the general rat mortality went on increasing several weeks ahead of the human mortality.

Simpson (1903) concluded that infected rats play a part in the maintenance and dissemination of plague.

Atkinson, Pearse, and Hunter (1904) remarked the general correspondence between the epizootic and epidemic and stated that rat plague begins earlier and lasts longer than plague in man. Hunter (1904) made extensive observations on the occurrence of plague in rats in Hongkong during several years: in this way he was enabled to correlate the epizootic with the epidemic. He drew up curves representing the incidence of rat and human plague for each district of the city, and came to the conclusion that the epidemic begins a fortnight later than the epizootic, the climax of the epidemic being reached a fortnight later than that of the epizootic. According to Hunter the epizootic in Hongkong maintains a low level after the disappearance of the epidemic.

Japan. Ogata (1897) from a study of an outbreak in Formosa considered that plague might be primarily a rat disease causing a subsequent spread to man. He noticed that the rats always sickened and died before men were attacked.

Kitasato, Takaki, Shiga and Moriya (1900) were entrusted with the investigation of the outbreak in Kobe and Osaka. These observers ascertained that the rats were the first to sicken and die, the rat mortality being followed at a later period by the epidemic. Kitasato (1906) makes the statement that in Japan the epidemics have been traced invariably to rats, and that the number of rats found on examination to be plague infected runs parallel with the number of plague patients. He asserts that rats were the first to become infected and that by the time the first human cases were discovered the epizootic had assumed a well advanced form.

Africa. Within recent years epidemics have been investigated in several places in Africa.

Blackmore (1902) inquired into the outbreak in Port Elizabeth in 1901. He fully recognised the importance of rats in spreading plague.

Hill (1904) from observations of the epizootic and epidemic in Natal maintained that the most important agency in the spread among men was the rat.

Pakes (1904) reported on an outbreak of plague in Johannesburg.

The great majority of the 65 cases which occurred during the first 8 days were of the pneumonic type and concentrated about one place. The author believes that the origin of the first pneumonic case was not due to rats, though he is careful to point out that a rat epizootic was known to have existed in Johannesburg in the previous year. In the next 15 weeks there was a preponderance of the bubonic type amongst 48 scattered cases; this portion of the epidemic was associated with an epizootic amongst the rats.

Mitchell (1906) reviewed the principal facts which came to light in the epidemic in Cape Colony. He argued that a close association exists between the epidemic and epizootic and pointed out that when human cases gave the first intimation of infection evidence of antecedent rat mortality had as a rule been found.

Vassal (1906) noted that the rat epizootic in Mauritius preceded the epidemic by an interval of 2 to 4 weeks, and that the latter in some localities did not cease till 6 to 8 weeks after the complete disappearance of the epizootic.

Egypt. Gotschlich (1900) in an account of the outbreak in Alexandria in 1899 stated his belief that rats are of very variable importance in the spread of plague. He thinks that human plague may exist in the absence of rat plague and *vice versâ*, but considers that rats are important means of introducing the disease from an original focus into a new locality.

Bitter (1903) drew certain conclusions from a study of plague in Egypt during four years. He stated that it could be affirmed almost with certainty that the commencement of the epidemic is always associated with infection in rats.

Odessa. The observers of the limited epidemic in Odessa in 1901—1902 (Rabinowitsch and Kempner, Skschivan, Wernitz) were unanimous in attributing to rats the principal cause of the outbreak.

South America. Agote and Medina (1901) investigated an outbreak of plague in Asuncion, Rosario and Buenos Ayres. These authors state that their researches could not be more conclusive as to the precedence of human plague by dead rats. In their view rodents are a means of propagation of the first importance

Artola, Arce and Lavoreria (1903) give a good account of an outbreak of plague in Callao and Pisco near Lima. They observed an epizootic amongst rats before the appearance of plague in man. Many rats sick or dead of plague were obtained in the mill of Santa Rosa, and following this epizootic 10 out of 70 workmen in the mill took plague.

Britain. In October 1901, 3 certain, and 5 more probable, cases of plague were discovered in Liverpool. No plague-infected rats were found in connection with any of the cases, although a good search appears to have been made. Thomson (1905) in a contribution to the subject of the relation of shipborne plague to rats based upon an analysis of records of instances of this kind arrives at the conclusion that the part played by the rat in the transmission of plague to man although real falls far short of the importance generally attributed to it.

Power (1902), in summing up similar evidence derived from records of plague outbreaks throughout the world from 1898 to 1901 compiled by Bruce Low, submits that the information thus derived goes far to confirm the belief that man and the rat are reciprocally infective, but fails to afford sufficient data for determining the degree to which man is in danger through the rat.

2. *The Mode of Infection of Rats in Nature.*

India. Simond when promulgating the theory that parasites convey the disease to man advanced the view that parasites also convey infection from rat to rat.

The German Plague Commission ascertained that rats die of plague if they eat rats dead of the infection, and put forward the suggestion that this is the method of spread amongst them in nature.

The Austrian Plague Commission (1900) acknowledged that the number (eight) of naturally infected plague rats examined by them was too small to allow of a definite opinion from the post-mortem findings, but thought that an intestinal infection was the most probable method. Neck buboes occurring in two of the rats are interpreted by them as being due to a mouth or nose infection.

The Indian Plague Commission discussed the matter at some length. They conjectured that rats might occasionally contract plague by feeding on the dead bodies of plague rats or on grain or other food contaminated by plague excretions, but influenced by certain experiments relating to feeding they believed that infection through the alimentary canal could not be a very common occurrence. Nasal infection they considered the most likely mode in cases where an epizootic is traceable to the importation of infected clothing.

Liston (1904) argued that, while rats could be infected by feeding on grossly infected food, yet they could without harm eat food which contained only small quantities of plague germs, such as might be

expected to occur in the excreta of plague-sick animals and man. Healthy animals could live in the same cage with infected animals without harm if fleas were excluded. While this was the case very minute quantities of plague germs introduced under the skin brought about infection. The flea to this worker appeared to be the most likely agent in nature to bring about infection in this way.

Browning-Smith has suggested that the excreta of plague patients may infect rats through the nose, and that an epizootic may be due either to rats eating infected food or to cannibalism, but he regards the flea as the principal agent in the spread of the disease amongst rats.

Australia. Tidswell (1901) stated that his experiments seemed to indicate that the disease might spread from rat to rat by inoculation through wounds from infected teeth or claws, by sharp points of bone in their food, by vermin or by feeding upon the viscera of infected animals.

Baxter-Tyrie thought it highly probable that infection from rat to rat is mainly by the agency of food infected by the excreta or saliva of plague-infected rats.

Hongkong. Yersin (1897) discovered in the soil of an infected house a bacillus like *B. pestis* but without virulence. He conceived that rats might become infected from such infected soil if circumstances were favourable.

Hunter is of opinion that the usual mode of infection of rats in nature is *per os.* This infection may be derived from the excreta of man and of rats, from infected clothing or from food contaminated by cockroaches, ants or flies. He draws the conclusion that the part played by fleas would appear to be over-estimated.

Japan. Kitasato and his colleagues (1900) regarded the mode of spread as being due to infection brought about by rats eating their infected companions. In a later contribution (1906) Kitasato notes that an infection of the submaxillary and cervical glands occurred in naturally infected rats, and infers from this that the rat becomes infected through the mucous membrane of the mouth and throat.

Africa. Mitchell makes no definite statement as to the mode of infection, but considers that it is unlikely that infection is conveyed to the rat by man.

Bitter (1903) ascribes the spread of the epizootic in rats to their habit of cannibalism.

General. Kolle (1901), Dieudonné (1903) and Kister and Schumacher (1905) favoured the view that the cannibalistic habit accounts for the

spread of infection from rat to rat. All these authors failed to find sufficient reason for the belief that insects play any part.

Finally Klein (1904) infers that the spread from rat to rat in nature by means of the flea can at best be of rare occurrence. He thinks that infected rats may convey the disease by biting their companions, and further suggests that rats become infected by plague bacilli in the faeces of infected rats gaining entrance through abrasions in the skin of other rats. Klein (1906) has recently made a further contribution to the question of the transmission of plague in the rat. He believes that certain "feeding" experiments which he carried out strongly suggest that the excreta of a plague rat, becoming dried and mixed with foodstuffs, may start an extensive infection of rats feeding on these substances. He also reviews the question of the possible transmission by the flea, and in conclusion reiterates the view already expressed by him in a former paper.

3. *On the Course taken by the Epizootic.*

Observations bearing upon this point which have been recorded are few in number.

Ashburton Thompson gives particulars of several instances where a watch was kept on the progress of the outbreak amongst rats living in certain buildings. His experience has been that although plague occasionally destroys practically the whole of a limited community of rats, *e.g.* those inhabiting a building, yet much more frequently it follows a slow course in such cases. Thompson further directs attention to the fact that in Sydney infection attached to localities and spread to others adjoining and contiguous with that in which it was first manifested. It appeared to be transported mechanically from an existent focus to a considerable distance, there initiating an independent focus. It is obvious from the context that Thompson believes this phenomenon to be due entirely to the agency of the rat.

Without offering any explanation of the fact the Indian Plague Commission noted that the most striking characteristic in the spread of plague through a place is its slow and steady advance from one group of houses to another and its long persistence in a quarter that has once become infected.

Hill described the course of the epizootic in Natal as a "continuous forward progression" with occasional branching offshoots and now and again a retrogression.

Gamaleia (1902) referring to the outbreak in Odessa remarked that

the plague infection in the sewer rats of the city was characterised by a complete localisation in the form of sharply circumscribed foci, there being no tendency to extension from these foci.

4. *The Natural History of the Rat in its Relation to the Epizootic.*

Observations relating to the natural history of rats, especially in so far as they may possess a bearing upon the course of the epizootic, are exceedingly scanty.

Species. Tiraboschi (1904 A.) has justly pointed out that most observers of the epidemiology of plague have taken no care in determining the species of rats which succumbed to the infection, since they group the affected rodents in the phrase "rats and mice." This author suggests that *Mus decumanus* and *M. rattus* are able to play a part of equal importance in the spread of plague, according as each preponderates, *e.g. M. decumanus* in large cities and *M. rattus* in ships. Some writers, *e.g.* Gamaleia, have asked if the natural resistance of *M. decumanus* to plague and its actual predominance in Europe are not sufficient to explain the present immunity of Europe to plague. Tiraboschi, however, from experiments (?) concludes that it cannot be affirmed with certainty that *M. decumanus* is less susceptible to plague than *M. rattus.*

Liston (1904) pointed out that while both *M. rattus* and *M. decumanus* were alike very susceptible to plague the importance of species in relation to the epidemic lay in the habits of the different species, *M. rattus* being essentially more domesticated than *M. decumanus.*

Hossack (1906) states that the rats most frequently found in Calcutta belong to the species *M. decumanus, Nesokia bengalensis* (a species of small bandicoot) and *M. rattus.* In the northern quarter of the city—a notorious centre of plague—where there are numerous grain godowns the *Nesokia bengalensis* accounts for 60—80 % of the total rat population. Hossack concludes that this is the rat most intimately concerned with the spread of plague in Calcutta.

Ashburton Thompson found that in Sydney during the epizootic period in 1905 0·79 % of *M. decumanus,* 0·88 % of *M. rattus* and 0·13 % of *M. musculus* were infected, the numbers being calculated as a percentage on the total number of each species examined. These numbers are in practically the same proportions as in former epidemics in Sydney.

In the Sydney report (1906) an interesting account of a small out-

break (13 plague cases) at Ulmarra is given. One hundred and six plague-infected *M. decumanus* were found and three infected mice. No plague-infected *M. rattus* was discovered. Of 1128 rats examined 1125 belonged to the species *M. decumanus* and only three were *M. rattus.*

In Thompson's experience *M. decumanus, M. rattus, M. alexandrinus rufus* and *M. musculus* are all liable to plague infection and all may be associated with plague in man. This observer believes that *M. decumanus* can by itself give rise to plague in man, and quotes in support of this view the case of the troopship "Antillean" which carried no other species.

Baxter-Tyrie in Brisbane also noted that plague may occur in *M. decumanus, M. rattus, M. alexandrinus* and *M. musculus.*

Nime (1904) states that *M. rattus* was the species found most frequently infected by plague in the epidemic in Formosa in the year 1896.

Kitasato (1906) asserts that the *species* of rat (*M. decumanus* and *M. rattus*) has been of very little importance in relation to the spread of plague in Japan. He appears to consider that the most prevalent rat in Japan is a race which is a mixture of *M. decumanus* and *M. rattus.*

Skschivan (1903) diagnosed 32 plague rats during an extensive examination of these animals in Odessa, from 1st. Nov. 1901 to 31st March, 1902. Of these rats one was a *M. rattus,* three were *M. alexandrinus* and 28 belonged to the species *M. decumanus.* Wernitz and Skschivan (1903) found 14 *M. decumanus* dead of plague in the cellar of a house in Odessa in which a plague case occurred in October, 1901.

In Glasgow[1] during the examination of rats for plague in connection with a limited epidemic about 150 were found infected. The great majority were *M. decumanus,* but a few which were obtained near the harbour belonged to the species *M. rattus.*

Breeding. Remarkably few observations have been made on this subject. Ashburton Thompson is of opinion that in Sydney rats breed all the year round, although probably a little less freely in the four colder months.

Gotschlich (1903) in 1901—1902 carried out in Alexandria observations on a large scale to test this point. The interpretation placed by this writer upon the results of these observations will be referred to later. From the figures given there can be no doubt that a distinct

[1] Verbal communication by Dr R. M. Buchanan.

breeding season of rats occurs in Alexandria, the largest number of pregnant females having been found in May and the first half of June.

Migration. The question of the migration of rats is an important one in its relation to the epizootic. We have met with comparatively few careful records of observations bearing on the point, but it would seem that migration of communities of rats does occasionally take place. Thus Bannerman mentions that Veterinary-Colonel Brodie Mills, Principal of the Bombay Veterinary College, on one occasion observed a migration of numerous rats from his bungalow. In this case the migration appeared to have no connection with an epizootic. Colonel Weir observed a similar migration of rats through his house near Bombay.

The rat flea. In a previous volume of these reports an historical sketch of the experimental work dealing with the rat flea has been given. In the present account reference has already been made and will continue to be made as occasion arises to the epidemiological side of the question.

III. The Mode of Entrance of the Plague Bacillus into the Human Organism.

The opinions held on this subject by epidemiologists are coloured to no small extent by the views they may happen to entertain regarding the relation of the epizootic to the epidemic. It will be convenient, therefore, at this point to summarise the principal conclusions to which each observer has been led by his experience of the disease.

India. Bitter (1897) a member of the Commission sent from Egypt to Bombay to study plague reported that septicaemic cases played a very considerable part in the propagation of the disease. He believed that the most important factor in its spread was to be found in pneumonic cases, which in his view were much more frequent than was generally thought. The danger in these cases lay in the infectivity of the sputum. Bitter satisfied himself that infection through the skin was by far the most frequent occurrence in bubonic and septicaemic cases. He considered it possible that bacilli in the excreta of infected men and rats, and especially the sputum in pneumonic cases, might gain entrance through abrasions of the skin.

Wyssokowitz and Zabolotny (1897), members of the Russian Commission, carried out in Bombay some experimental work on monkeys with a view to throwing light upon the problem. They

showed that an infection by way of the skin and lymphatics with the formation of a bubo in the corresponding glands could be produced, although there was no evidence of a local lesion. They inferred, therefore, that the method of infection in man also involved the skin and lymphatics.

Simond from his observations in India in 1897 arrived at the idea that plague was transferred from rat to man by means of fleas. He considered that such a parasitic transmission of the plague bacillus explained most of the difficulties in the epidemiology of plague.

Hankin (1898) suggested that an intermediary insect was necessary to communicate the disease to man. He contended that plague was not conveyed to man directly to any appreciable extent by the dejecta of infected rats.

The German Plague Commission did not regard the bites of fleas as a probable means of transmission.

The Austrian Plague Commission devoted the time at their disposal for the study of the disease in Bombay for the most part to an exhaustive investigation of the pathology of human plague.

The conclusions at which they arrived from this work and from experimental work on animals may be given in detail, since they have a most important bearing on the point under discussion. They may be stated as follows—Undoubtedly in the overwhelming majority of cases infection occurs through the skin. A primary blood infection does not take place. The plague bacilli are always taken up in the first instance by the glands where they remain localised till their multiplication is so great that they invade the circulation. Minute injuries to the skin are sufficient to permit of the entrance of infection. Infection may also gain entrance by the mucous membranes of the mouth, nose and throat, the tonsils and the conjunctivae. In no single instance did anything point to a primary intestinal infection.

The members of this Commission suggested that violent scratching of an itching part could, under certain circumstances, lead to infection.

The Indian Plague Commission arrived at the conclusion that infection was as a rule by way of the cutaneous surface and that suctorial insects do not come under consideration as a means of infection.

Liston (1905) brought forward much new and valuable evidence in favour of the view that the rat flea is the transmitter of infection to man. He carried out investigations in plague-infected houses and premises from the point of view of the presence in them of rat fleas.

By the ingenious use of guinea-pigs as traps for rat fleas in houses Liston introduced a method[1] which has subsequently proved of great value and importance, since it affords a ready means of giving a rough estimate of the flea infestation of houses and because fleas may easily be obtained in this way for further examination in the laboratory, *e.g.* with the view of testing their capacity for infecting susceptible experimental animals. Liston further showed that the rat flea of India (*P. cheopis*) on occasion attacks man.

Australia. Ashburton Thompson (1900) inclined from purely epidemiological considerations to the view advanced by Simond, namely, the transmission of infection from the rat to man by the flea. Later (1906) from an analysis of the facts which he had collected during the outbreaks of plague at Sydney he came to the conclusion that the intermediary necessary to communicate the infection from the rat to man must be the "flea in one or more of its many species."

Baxter-Tyrie states that his experience points to the conclusion that the relation of fleas to the transmission of the disease has been overestimated. He makes the conjecture that the source of infection in man, when glandular symptoms are absent or are secondary to an infection of the blood, is to be found in food which has been contaminated by the excreta or saliva of infected rats. He indeed suspects that this may hold good in many cases where apparently there is only glandular infection.

Hongkong. Yersin (1897) expressed the view that man becomes infected either by wounds on the skin or by the intestinal canal.

Wilm (1897) strongly urged that infection by way of the alimentary canal was a very common mode of infection.

Hunter concludes that plague-infected fleas are of no practical importance in the spread of plague, and that indeed the importance attached to skin infection in plague has been exaggerated. The principal part played by insects is the infection caused by them of food; cockroaches, flies and other non-suctorial insects are important in this respect. Hunter, further, declares that plague rats scatter plague bacilli broadcast in their excreta, thereby rendering possible a great infection of food and water. This author believes that the intestine is the principal avenue of infection in man, and that buboes are usually secondary to the blood infection which supervenes.

Hunter's views generally are supported by Simpson, who remarks: "The facility with which the lower animals contract plague by feeding

[1] See Historical Introduction in previous volume of these reports (vol. VI. p. 430).

is in favour of man contracting it often in the same way." Simpson makes the further statement that septicaemic cases are dangerously infective on account of the presence of plague bacilli in the excreta.

Japan. Ogata (1897) suggested from epidemiological considerations that plague was mostly conveyed by suctorial insects such as mosquitoes and fleas.

Yamagiwa (1897) from evidence derived from a research into the pathology of human plague concluded that a skin infection occurred almost exclusively.

Kitasato (1906) appears to believe that direct contagion from man to man plays a considerable part in the spread of plague. He suggests that the soil becomes infected by the excreta of plague rats and that soil thus infected constitutes a danger in certain instances, *e.g.* in children.

Africa. Blackmore regards the rat flea as the usual transmitting agent and suggests that the human flea may occasionally act as the intermediary.

Hill came to no definite conclusion with regard to the rôle of fleas. He contends that no grounds exist for assuming the agency of fleas in the cases without buboes, and invokes as an explanation of such cases an infection through either the mouth or nose or by particulate matter in air or in food.

Bitter (1903) does not consider that blood-sucking insects play in themselves an important part in the transmission of plague.

In a report on an outbreak of plague in Mauritius (1899) it is stated that inoculation by the flea certainly did not hold good in the majority of cases.

General. Klein entertains the idea that man may contract plague through skin abrasions by the faeces of plague-infected rats. By comparison of cultural and animal tests of several strains of *B. pestis* obtained from different sources he professes to distinguish between two types of the bacillus, (1) a "rat" type, a weakly virulent bacillus regarded by him provisionally as that proper to the rat, and (2) a virulent "human" type which may occur in the rat, but by assumption occurs less commonly than the "rat" type.

Dieudonné (1903) makes the surmise that the bacilli in the excreta of septicaemic cases enter through very small abrasions of the skin. He considers that fleas, flies and bugs may have a certain importance, because in the puncture or "finger scratch" plague bacilli adhering to their bodies may be rubbed in. He thinks, however, that the danger from fleas is inconsiderable.

IV. The Mode of Spread of the Infection.

Having epitomised the views held by epidemiologists upon the question as to how the plague bacillus gains an entrance into the human organism, we may proceed to chronicle the various points of view on the wider issue which concerns the means by which the infection of plague is spread. It will be convenient to arrange the subject under four headings:—(1) the possibility of infection by direct contact with the patient suffering from plague; (2) the question of the infectivity of houses; (3) the spread of infection by indirect means, *e.g.* through the medium of infected clothes or articles of merchandise; and (4) the importation of infection into a hitherto uninfected locality.

1. *Infection by Direct Contact with a Patient suffering from Plague.*

India. Bitter (1897) from his experience in Bombay reported that intimate contact with the sick was the cause of the majority of the cases.

Simond, on the other hand, arrived at the opinion that infection from man to man plays only a secondary rôle in the propagation of plague.

The Indian Plague Commission reviewed the bacteriological evidence bearing on the infectivity of patients suffering from bubonic or septicaemic plague as follows. The ordinary bubonic case may be considered as non-infective until the septicaemic symptoms supervene; from that time onwards the plague patient will become infective by the fact that the plague bacilli escape from the body in the discharges; on the one hand from the nose, lungs and intestinal tract, and on the other hand from the kidneys. In cases which recover a further possibility of infection will be afforded by the fact that the pus from the suppurating bubo, as well as the sputum and saliva, may contain the infective agent.

Bannerman refers to the well recognised experience in India that attendants in hospitals remain singularly free from danger of infection.

The experience of Captain Thomson, I.M.S. (1907), who had charge of a large plague hospital in Bombay, is worth quoting in this connection. Although 533 cases of plague were treated in his hospital, there were no instances of the spread of plague from the patients to the nurses or attendants. "In upwards of 240 instances the friends of the patients attended their sick and in 20 instances scarcely ever left their bedside, and in not a single case did the disease spread to the friends."

Dr Dallas, who also had a large hospital experience in Bombay, has stated that though there were "about 400 people—men, women and children—who either visited their sick friends or remained constantly at their bedsides, together with the cases under observation, in not a single instance did any of these persons contract plague."

Bannerman further cites instances reported by Sanitary Officers in India where in a village people of different castes, and having no intercourse with each other for this reason, were affected, the incidence of cases amongst them giving no support to a theory of direct contagion, and being explicable only on the view of a common source of infection.

Evidence of a similar character has been brought forward by Browning-Smith. This observer states that in the Punjab villages infection often spreads from one house to a contiguous one placed back to back, although the entrance doors are widely separated by actual walking distance and although the families living in each house are absolutely prevented by caste rules from having any relations with each other. In such an instance, however, the rats in each house may freely communicate by means of rat holes and burrows.

Australia. Ashburton Thompson sums up his experience in Sydney in this manner:—The disease was not directly communicated from the sick to the well. Cases in an infected locality occurred irregularly, and the infection showed no special tendency to attack adjoining houses. Secondary cases rarely happened in a building. Plague in short owes nothing of its epidemic form to communication with the sick.

Hongkong. Lowson (1895) reported that no attendant in the plague hospital contracted the disease.

Japan. Kitasato (1906) appears to suggest that direct contagion from man to man frequently takes place.

Africa. Blackmore stated that in the outbreak in Port Elizabeth in no case was there direct evidence of man to man infection and in most cases the possibility of this was definitely excluded.

Hill considered that in Natal the disease had but a very slight tendency to spread from man to man even when the lungs were affected, except in the case of acute primary pneumonia.

It seemed to Mitchell that the bubonic form of plague in Cape Colony was only slightly infectious.

Bitter (1903) remarked that the transmission of plague from man to man had not played an appreciable part in Egypt, but he adhered to the view that such a method of transmission was really the cause of the epidemics in India.

South America. Artola (1903) could find no proof of direct transmission of plague from man to man in the outbreak at Callao already referred to.

Europe. Lastly, Rabinowitsch and Kempner asserted that not a single case at Odessa could be traced to the transference of infection from man to man.

2. *The Infectivity of Houses.*

India. The German Plague Commission were persuaded that with relatively few exceptions infection takes place within the house.

The Indian Plague Commission called attention to the general experience of observers in India with regard to this question, namely, that plague is essentially a disease of locality. The commissioners gave credence to the view, that this circumstance was best explained by a contamination of clothes and other effects by excreta of plague-infected men and rats.

Hankin (1905) considered that in a town threatened with plague the grain dépôts and all industries attracting rats ought to be regarded as dangerous, and pointed out that in India it has been found that the infected locality is a far greater source of danger than the plague patient. He criticised the view that plague infection in a house is due to bacilli from the dejecta of the patients, on the ground that it was inadequate to explain cases of infection of contacts 20 days to four months after the arrival of the first patient.

The belief that the infection of plague resides in the soil has been entertained and advocated by Creighton (1905) who adopted it in his *History of Epidemics in Britain* (1891) and reaffirmed it in 1905 after having paid a visit of investigation to India. He thought the infection rose to the interior of dwellings with the ground air and was commonly taken in by man with the breath.

Bannerman points out that in India voluntary evacuation of infected localities is widely practised, for no other apparent reason than that the people believe the infection to reside within the houses. He further cites instances showing that a premature return to an infected house has proved dangerous.

Australia. Ashburton Thompson gives it as the experience in Sydney that the infection of man is always contingent on his presence in buildings of some sort, and that, moreover, the incidence of infection on the houses is erratic. Out of 221 plague houses in 1900 as many as 215 escaped in 1902. The source of infection in a considerable

proportion of the cases was traced to produce stores and other similar buildings, which offered great attraction for rats.

In Brisbane, Baxter-Tyrie also found that a heavy incidence of plague rats and cases was associated with produce stores.

Africa. Hill in Natal states that 22 °/₀ out of a total of 221 cases were employed in produce stores or stables.

Hongkong. Reference has already been made to the bacillus which Yersin found in an infected house in Hongkong and which he evidently believed to be a modified *B. pestis.* So far as we are aware this observation has never been repeated.

Simpson (1904) came to the conclusion that to infected houses was principally due the maintenance of plague in an infected locality, and he believed that the infection adheres to those houses which are old, dark, damp and rat ridden.

Discussion of a vague character has occasionally been made as to the recurrence of plague cases within the same house year after year. The point seems to us to require further investigation since no instance of this kind has been put forward which will bear strict scrutiny.

3. *The Spread of Infection by Indirect Means, e.g. by infected Clothing, Food, or Articles of Merchandise.*

India. Bitter (1897) entertained the idea that articles which may have been infected by the sick person—clothing, linen, carpets, etc.—were likely to convey infection.

Hankin (1898) remarked on the circumstance that the infection can remain for a long time in clothes.

The Indian Plague Commission concluded that clothes and other effects soiled by excretions of plague-infected men and rats are infective, and may remain infective for very considerable periods.

Australia. Ashburton Thompson believed that the infection in the Sydney epidemics was not communicated in any important degree from the sick to the well by indirect means.

Hongkong. Wilm held the belief strongly that contaminated food was chiefly responsible for spreading infection. This view is also advocated by Hunter.

Africa. Hill attributed the source of infection in eight cases out of 221 in the Natal outbreak to "fomites." He thought there was no evidence for the view that infection may be conveyed through food.

Mitchell imputed the infection of six out of 337 cases in Port Elizabeth to infected clothing and other articles.

Gotschlich (1900) believed that an indirect infection through the medium of houses or clothes and other articles contaminated, *e.g.* by sputum, was an important means of spread. This opinion has also been expressed by Dieudonné.

4. *The Importation of Infection into a hitherto uninfected Locality.*

India. Simond stated that the introduction of plague rats into a hitherto healthy place was generally followed after a brief interval by epidemic cases in man.

Hankin (1905) thinks there can be no doubt that plague is not infrequently carried from place to place by persons who themselves escape or are not the first attacked in the places to which they have carried the infection.

In the summary by Bannerman, from which we have already quoted, several instances are given in which clothes removed from a plague house to a hitherto uninfected house infected either the inhabitants in this house or the rats. Bannerman sums up the evidence bearing on the question of the transportation of infection and its introduction into a fresh locality as follows:—

It seems certain that human beings are the carriers of infection when it is introduced into a new area. The man who introduces the infection may not be the first victim and may not develop the disease. It seems to be more common for infection to spread amongst rats in the house where the introducer lodges so that in this way an epizootic breaks out and is followed by the epidemic.

With regard to the possibility of transportation of infection by means of grain or merchandise Bannerman, from a *résumé* of opinions held by authorities in India, concludes that grain cannot be incriminated.

Liston (1905) believed that infection could be conveyed from one place to another, either by infected rats and fleas transported by ships and trains conveying merchandise or by infected fleas carried on the clothing of man. He was unable to communicate the disease to animals by means of soiled clothing and contaminated food.

Browning-Smith thinks that the spread of plague from one locality to another is generally due directly to human agency, and that plague infection may be transported for long distances by any articles

contaminated with infective material or harbouring infected fleas or concealing the dead bodies of plague rats.

Australia. Ashburton Thompson believes the successive epidemics at Sydney to have been due to repeated infection from importation by sea of infected produce. He regards "produce of all sorts, returned empties with packing still in them, and bundles of empty bags" as the most dangerous class of goods concerned in the transportation of plague infection.

Hongkong. Wilm considered that the contagion of plague might be imported into a fresh locality by men suffering from the disease, by fomites or by animals. Simpson thought it possible that infected food might be imported into the colony.

Japan. Kitasato (1906) recognises two modes of importation into a new locality: (1) contagion from imported plague patients; (2) contact with disease germs mingled with the freight brought in from some infected region. Rats are the first infected by such an imported infection, and by the time the first human victims are discovered the epizootic has assumed a well advanced form.

Africa. Lastly, Mitchell believed that rats had been the means of introducing plague into the ports of Cape Colony, and that they also spread infection from infected centres to other places.

V. Certain alleged Contributory Causes of the Spread of Infection.

Having summarised the views held as to the methods by which plague infection is considered to be spread, we may now draw attention to certain factors which have been represented as favouring the dissemination of infection in a locality. These are (1) insanitary conditions generally, and (2) the occurrence of plague in domestic and other animals.

1. *The Influence of Insanitary Conditions on the Spread of Plague.*

India. Bitter while serving on the Egyptian Plague Commission came to the conclusion that insanitary conditions aided in spreading plague, for the reason that under such conditions the danger of intimate contact with the sick is increased.

Hankin (1898) took quite the opposite view. He thought that the evidence available at the time reduced to the rank of an unnecessary hypothesis the influence of those insanitary conditions which were pre-

sumed to favour the spread of plague. Badly constructed houses, according to his view, were more exposed to contagion not for this reason but because they offered shelter to rats.

The German Plague Commission appeared to consider that insanitary conditions, such as dark, badly ventilated and overcrowded dwellings, were favouring circumstances for the spread of infection, and that when such conditions are present an epizootic amongst rats is not a necessary concomitant of the epidemic.

A majority of the members of the Indian Plague Commission stated that they were unable to find any evidence which went to prove that the ordinary sanitary defects exercised any marked favouring influence on the spread of plague. They considered overcrowding to be the principal defect.

The President of the Commission, Sir T. Fraser, dissented from this view. He gave as his opinion that after plague has been introduced into a place its extension and virulence are chiefly fostered by the pollution of the atmosphere and other conditions which result from the inadequacy of ventilation and sunlight and from the uncleanness within and near dwellings, which characterise the great majority of native houses.

Recent opinion in India appears to be divided on the subject, judging from the account given in Bannerman's article.

Hongkong. The majority of the observers in Hongkong (Lowson, Atkinson, Pearse and Simpson) agree in regarding general insanitary conditions as important contributory causes of the spread of the epidemic. Simpson considered that the insufficient latrine accommodation and the insanitary condition of many of the existing latrines probably favoured the endemicity of plague in Hongkong.

Africa. Mitchell believed that sanitary defects undoubtedly had their effect in fostering plague in Cape Colony.

General. Hope (1902) remarks on the circumstance that the cases in the limited outbreak at Liverpool were entirely dissociated from the squalor and filth with which plague is commonly found. Dieudonné looks upon plague principally as a disease of filth and poverty, and remarks that where light and air are plentiful and cleanness reigns plague finds no settlement.

2. *On the occurrence of plague in domestic and other animals.*

Undoubtedly the rat is not the only animal apart from man which is subject to plague in an epizootic form, but it is not our intention to collect instances of epizootics of this kind. No one will, we imagine, seek to controvert the statement that no animal approaches the rat in importance from an epidemiological standpoint. It is, however, beyond question that outbreaks in mice are not infrequently to be found concurrently with the rat epizootic. Several examples of this have already been given. Mitchell signalises the fact, but remarks that although plague-infected mice were frequently found they did not appear to play any important part in the spread of the disease in Cape Colony.

The statement has been made that certain domestic animals are liable to plague infection during an epidemic and that they constitute a grave danger to man when thus infected.

Wilm (1896) asserted that fowls contracted plague by eating infected material. He made the further assertion that in 1896 a shipload of pigs imported from an infected locality into Hongkong were proved by bacteriological evidence to have died of plague. Atkinson, Pearse and Hunter (1903) stated that poultry from the markets in Hongkong were proved to have died of plague.

Hunter (1904) notes the following animals as having been found affected with spontaneous epizootic plague:—rat, mouse, cat, guinea-pig, monkey, hen, pigeon, turkey, goose and duck. He also makes the statement that plague has been experimentally given to the following animals:—pigs, calves, sheep, monkeys, hens, pigeons, turkeys, geese, and ducks.

Experiments on a large scale were carried out in Hongkong in 1902 by Simpson assisted chiefly by Hunter. Simpson (1905) has summarised the results of these experiments thus:—

"From the experiments it is shown:—

(i) That pigs, poultry, and cattle are susceptible to plague whether derived from the infection of a human being infected with plague, or from their own species, or from some other animal.

Sheep are also susceptible.

(ii) That plague among animals may be acute and rapid in its termination, or chronic and slow in its course. In neither case may the symptoms be very marked.

(iii) That the animals take the infection of plague as easily by feeding with plague material as by inoculation.

(iv) That plague material from man, pigs, poultry, cattle and monkeys, will give plague to rats, and that plague material from rats will give plague to monkeys by feeding, by inoculation, by contact and without contact; and if to monkeys probably to man by the same channels."

Pearse in his report (1904) has criticised Simpson's experiments in detail, and throws some doubt upon the significance of his observations.

Bannerman repeated these experiments in Bombay but with negative results. Hill also attempted to repeat them in Natal with fowls, pigs and calves, but his experiments were uniformly unsuccessful.

Simpson (1905) makes the following observations on the results of the Natal experiments :—

(i) The experiments were not carried out in the epidemic season.

(ii) The strain of bacillus in the Natal epidemic may not have possessed that degree of virulence which belongs to the bacillus in China.

(iii) There may be a more or less comparative racial immunity among animals in one country as compared to another.

VI. The Seasonal Prevalence of Plague.

The last problem with which we have to deal in this account relates to the peculiarity which has long been recognised of the marked prevalence of plague in a particular place at a certain definite season of the year. At or about the same date plague yearly reappears, rises, declines and disappears.

This prevalence varies sometimes in a striking manner in different places, and even in places not far distant from each other. As an example Bombay and Poona may be cited. These places are situated only about 80 miles apart, and yet the plague season of one may be said roughly to correspond to the off plague season of the other.

The reason for this seasonal prevalence has been much speculated upon by epidemiologists, but it is apparent from a review of the literature that very few facts have been brought forward which will serve even partially to explain the phenomenon. It may be of interest, however, to summarise the observations which have been made upon the subject.

India. Simond suggested that retention of infection by fleas may be the cause of the recrudescence which usually occurs a year after the first appearance of the outbreak. He, further, believed that variations in the rat population is an essential cause, although not the only one,

of the yearly recrudescences. Thus, he ascribed the decline and disappearance of the infection to the death of a large part of the rat population, to a migration of large numbers of rats, and to an immunity of a certain proportion of those remaining. Simond thought that the recrudescence coincided with a repopulation of the rat community by new generations of susceptible rats.

Hankin (1905) drew attention to the disappearance of dog fleas in hot weather in Agra, and suggests that if rat fleas similarly disappear this may be a possible explanation of the seasonal decline of the epidemic.

The German Plague Commission concluded that an unusually high temperature by itself could not be a determining factor in seasonal prevalence.

The Indian Plague Commission came to no definite conclusion upon the matter. They remark "If the rise and fall of plague mortality is in reality dependent upon the meteorological variations (temperature and humidity) it seems quite clear that the inter-dependence must be a very indirect one."

Browning-Smith in a recent article expressed his belief that not one but many factors must enter into the problem. Amongst these he regards a prevalence of fleas as essential. Certain subsidiary factors have an influence, *e.g.* the breeding of fresh generations of rats, temperature, humidity, and the habits and occupations of man.

Australia. Ashburton Thompson remarked that the epizootic and epidemic period in Sydney is the season of fleas, at least of the dog flea. Moreover, Tidswell observed that rat fleas were more abundant in the epizootic period than at the end of the epizootic.

Baxter-Tyrie states that rainfall during an epidemic was invariably followed by an increase of cases, a circumstance which he attributed to rats being driven from sewers into buildings.

Hongkong. Clark noted that in Hongkong the disease declined rapidly as soon as the mean weekly temperature exceeded 80° F.

Pearse thinks that in Hongkong the worst epidemic period is that in which the temperature varies from about 70°—80° F., and that with a rise to 81° F. and over the epidemic declines.

Simpson makes the statement that in this city any continuous temperature above 83° F. is followed by a fall in the number of cases and ultimately causes a cessation of the epidemic.

Africa. Hill in Natal thought there was no evidence to show that the outbreak bore any relation to the temperature of the air or to

rainfall. He noted that fleas on rats were scarce in Maritzburg when plague was absent.

Mitchell remarks that no definite general correlation between temperature or rainfall and the epidemic prevalence has been observed in Cape Colony.

Gotschlich (1903) carried out some interesting observations to test the statement that the recrudescence is due to a large addition of susceptible rats to the rat population, consequent on a definite breeding season. An examination was made in Alexandria of 6500 rats caught alive from the 15th August, 1901, to the same date next year. A note was made of those found pregnant and a percentage of these was calculated on the total rats during each fortnight. The results were briefly as follows. During the plague-free winter months—November to February—less than 2% of the rats were found pregnant. In March and the first half of April there was a slow rise, till in the second half of April 6% of pregnant females were found. The percentage rose to 12% in May and the first fortnight of June and then quickly fell, keeping an average of 5% till a minimum in December of under 1% was reached. The maximum period corresponded well with the summer epidemic of bubonic plague.

General. It is stated in a report of the outbreak in Mauritius that temperature and other climatic changes did not seem to have had any influence on the progress or otherwise of the epidemic.

Agote and Medina (1901) in South America conclude that the climatic conditions favourable to plague are a moderate temperature and a relatively low humidity of air and soil.

Finally Dieudonné remarks that meteorological conditions play no great rôle in the origin and spread of the disease, and have perhaps only an indirect influence.

Chronic Plague in Rats.

Before bringing this section to a close we may refer briefly to the suggestion that the infection may continue throughout the off plague season in the bodies of rats suffering from a chronic form of plague.

Simond (1898), for example, believed that after the epizootic ceased to be acute plague continued to linger amongst the rats in a benign form, and that sporadic cases in man occurring during the off season might be thus explained.

Kolle and Martini (1902) described a chronic form of plague in rats which had been experimentally infected by various methods months

previously. These rats showed cheesy submaxillary and bronchial glands and induration of the lungs; the bacilli in the lesions were virulent. They considered that these results had an important bearing upon the problem of the seasonal prevalence of plague.

Gotschlich (1903) agreed with these writers as to the significance of their observations and explained the recrudescence of the epizootic by supposing that when the rat population receives an accession to its ranks of highly susceptible young individuals infection from such a latent case might start a fresh epizootic.

Ashburton Thompson could find no evidence that plague persisted in a chronic form in the rats in Sydney after the epizootic had ceased.

We have elsewhere given an account of chronic plague in rats caught in several villages in the Punjab (vol. VI. p. 530; vol. VII. p. 457). The condition of these rats seems to be clearly different from that described by Hunter (1904), who in Hongkong found a large number of rats suffering from chronic plague. These animals were much emaciated and suffered from chronic diarrhoea; on section necrosed areas of cheesy material were found in the lymphatic glands and viscera, containing few plague bacilli but capable of giving rise to acute plague when administered to healthy rats. He found that such animals were caught more frequently in the interval between, than during, the epizootics of acute plague. Our rats on the other hand showed no signs of general illness and in only one instance was emaciation noticed.

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