PREFACE.

IN the early days of plague in India most strenuous efforts were made to stamp it out by the means adopted in European countries in dealing with epidemic disease, but these efforts failed and they too often led directly to the misfortunes which they were designed to avert. When it was recognized that it was impossible to deal effectively with the epidemic without the help of the people themselves, a policy of persuasion and assistance was substituted for the more rigorous measures, but this also failed to prevent the extension of the disease, although in many places some degree of success was achieved.

Considerable progress had been made in the study of the epidemiology of plague and valuable work had been done in laboratories in India and elsewhere, but there remained serious gaps in our knowledge which it was necessary to fill in order to give greater precision to the measures of prevention which it was possible to adopt. In the autumn of 1904 the Government of India therefore addressed the Right Hon'ble the Secretary of State for India with a view to undertaking a more complete enquiry into the etiology of the disease than had hitherto been attempted. As a result of this representation the Secretary of State replied that, on the recommendation of the Royal Society and the Lister Institute, he proposed to form a committee representing these bodies and the India Office and to grant to them £5,000 renewable annually for the purposes of the investigation, which

it was proposed should be undertaken under the direction of the committee by two experts chosen and paid by them and two skilled bacteriologists belonging to the Indian Medical Service. These proposals were accepted by the Government of India, and an Advisory Committee was appointed consisting of the following members :—

Surgeon-General Branfoot, C.I.E., I.M.S., India Office; *President.*

Sir Michael Foster, K.C.B., F.R.S. ..
Professor J. Rose Bradford, M.D., F.R.S. .. } Royal Society

Colonel David Bruce, C.B., R.A.M.C., F.R.S.
Dr. C. J. Martin, F.R.S. .. } Lister Institute.

(On the death of Sir Michael Foster in January 1907 his place on the Committee was filled by the appointment of Dr. G. H. Nuttall, F.R.S.)

The Committee decided that Dr. Martin should visit India to confer with the authorities there regarding procedure and to initiate the work.

Dr. Martin arrived in Bombay early in April 1905, and was followed in May by Drs. Petrie and Rowland, the experts chosen by the Committee. After visiting Kasauli Dr. Martin decided to commence work at Parel, near Bombay, where the Plague Research Laboratory offered special facilities.

In May the Government of India placed Captain Liston's services at the disposal of the Committee. Dr. Martin, having resolved to remain in Bombay during the summer, dispensed with the services of the second officer of the Indian Medical Service during his stay. Shortly before his departure on the 14th October 1905, the services of Major Lamb were placed at the disposal

of the Committee. Before his departure Dr. Martin represented the desirability of further assistance being given, and Captain Gloster, I.M.S., was deputed to work in the Punjab under the orders of the Committee. When Dr. Martin left India he handed over the direction of the working Commission to Major Lamb as Senior Member, when the Commission consisted of the following members :—

Major George Lamb, M.D., I.M.S., Director of the Pasteur Institute of India, Kasauli ; *Senior Member.*

Captain William Glen Liston, M.D., I.M.S., Plague Research Laboratory, Parel.

Captain Thomas Henry Gloster, M.B., B.Ch., I.M.S.

George Ford Petrie, M.D., Assistant Bacteriologist, Lister Institute.

Sydney Rowland, M.A., M.R.C.S., L.R.C.P., Assistant Bacteriologist, Lister Institute.

M. Kesava Pai, M.B., C.M., Assistant Surgeon, Assistant to the Director, Pasteur Institute, Coonoor ; lent by the Government of Madras.

V. L. Manker, L.R.C.P., L.R.C.S., D.P.H.

P. S. Ramchandrier, Hospital Assistant, Mysore ; lent by the Government of Mysore.

C. R. Avari, Hospital Assistant, Plague Research Laboratory ; lent by the Government of Bombay

The Commission thus constituted continued to work until May 1907, when it was considered that satisfactory replies to the questions which had been placed before them had been found, and the Commission was temporarily dissolved.

The head-quarters of the Commission remained at the Plague Research Laboratory, Parel, the Director of which, Lieutenant-Colonel Bannerman, I.M.S., placed every resource of his laboratory freely at their disposal.

It was arranged that reports of the work done by the Commission should be published by the Advisory Committee in the *Journal of Hygiene*, of which two numbers containing reports have already been published. It seemed to the Government of India, however, necessary that an account of the work done by the Commission should be submitted in a simple form to the public as soon as possible, and the following summary has been compiled for that purpose. It is intended that the facts ascertained shall be used by administrators in framing measures for the prevention of plague, and it is hoped that the knowledge of the facts will help the people to understand the reasons for those measures.

The summary has been compiled by Major George Lamb, I.M.S., who is alone responsible for the form in which the observations are set forth and for the way in which they are interpreted.

J. T. W. L.

SIMLA,

The 27th October 1907.

THE ETIOLOGY AND EPIDEMIOLOGY OF PLAGUE,

A SUMMARY OF THE WORK OF THE PLAGUE COMMISSION.

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CONTENTS.

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ETIOLOGY AND EPIDEMIOLOGY OF PLAGUE:

A SUMMARY OF THE WORK OF THE PLAGUE COMMISSION.

PART I.—INTRODUCTION.

The first duty of the Commission was by study of the literature and by careful enquiry from workers in India to ascertain the main conclusions which had been already formed regarding the epidemiology of plague. In the first progress report to the Advisory Committee these conclusions were set forth and may be briefly summarised as follows :—

(1) Plague, with the exception of the pneumonic form, which, however, is uncommon (2·5 per cent. of all cases), is not particularly infectious or contagious and man to man infection plays no important part in the spread of epidemics in India. The disease may, however, be introduced into a new locality and so ultimately occasion a new outbreak by the agency of man. For this to occur it is not necessary that the human agent himself should be suffering from the disease.

(2) Definite localities, huts, rooms or houses, in which plague has occurred amongst rats or man, are during an epidemic highly infectious. Further, the infection seems to cling to these localities for a long time.

(3) While plague can exist and spread under a great range of climatic conditions, it exhibits a marked seasonal prevalence, which is the most striking feature of the epidemiology of the disease.

(4) In the great majority of instances plague in man is associated with an epizootic among rats : and there seemed to be the strongest reasons for regarding the epizootic amongst rats as by far the most important cause of the epidemic spread of the disease.

It is necessary to state that, although the work of the present Commission has demonstrated the part played by the

rat and the rat-flea in the spread of plague, this demonstration did not surprise plague workers in India. On the contrary, the observations, both epidemiological and experimental, which had been made in India pointed to this conclusion. Lieutenant-Colonel W. B. Bannerman, I.M.S., has put on record the state of knowledge as regards the spread of plague prior to the commencement of work by the Commission in a paper published in the *Journal of Hygiene* of April 1906. This paper is a digest of "many very valuable reports made by officers of the Indian Medical Service who have dealt personally with plague epidemics, which reports existing in the archives of the various local Governments are not available for reference by the public." Colonel Bannerman shows that the trend of opinion amongst workers in India was, that plague is disseminated through rats and that its spread to man is occasioned by the agency of fleas. In this connection Captain W. Glen Liston, I.M.S. (*Indian Medical Gazette*, February 1905) had shown that the common rat-flea in India was *Pulex cheopis* and that this flea would bite man. In fact he had taken many specimens of this flea on human beings in a plague-infected house. He had also used guineapigs as traps for *P. cheopis* in plague-infected houses and had on several occasions observed that these animals became infected with plague when exposed in this way. He had made the further observation that numerous plague bacilli were to be found in the stomach contents of rat-fleas taken on guineapigs in plague-infected houses. Finally, so convinced were Colonel Bannerman and Captain Liston of the truth of the flea transmission theory that they had designed and built at the Plague Research Laboratory, Parel, special godowns or cabins, in which it was proposed to carry out large series of experiments to prove this theory. These godowns had just been completed when the Plague Commission began work and, as we shall see, the experiments which were made in them by the Commission went far to prove that the rat-flea is the only agent of transmission of plague infection from animal to animal.

It is not then too much to say that the work of the Commission has been a cope-stone to careful and tedious investigations already carried out in India—and of course elsewhere—rather than an original building, and that to the preliminary work and to the ready and whole-hearted assistance which the Commis-

sion received in India from all concerned the success of their labours is largely due.

The work of the Commission consisted of both epidemiological observations and experimental investigations. The epidemiological observations were made in the City of Bombay itself, in four villages in the north of the Island of Bombay within easy distance of the Parel Laboratory and in two isolated villages in the Amritsar district of the Punjab. The experimental work was carried out at the head-quarters of the Commission, namely, the Plague Research Laboratory, Parel, Bombay.

PART II.—EPIDEMIOLOGICAL OBSERVATIONS ON PLAGUE IN THE RAT AND IN MAN AND ON THE RELATION BETWEEN THE EPIZOOTIC AND THE EPIDEMIC.

A.—Methods of investigation which were adopted.
B.—Observations on the rat population.
C.—Observations on plague in the rat—the epizootic.
D.—Observations on plague in man—the epidemic.
E.—Relation of the epizootic to the epidemic :—
1. *Relation in time :—*
2. *Relation in place.*
3. *Relation in quantity.*

A.—METHODS OF INVESTIGATION WHICH WERE ADOPTED.

The methods which were adopted for studying the disease in rats and in man were practically the same in the various places where the observations were made ; they differed only in the agencies which were used.

In the first place, an endeavour was made to obtain daily as many rats, alive and dead, as possible and to examine these in as full detail as possible.

In Bombay City the collection of the rats was in the hands of the staff of the Sanitary and Cleansing Department of the Municipality, which is under the direction of the Health Officer. With this department arrangements were made for a daily supply of several hundred rats (alive and dead) from all over the City.

In the four villages around Bombay and in the two Punjab villages the collection of rats was in the hands of the Commission staff, assistance being obtained from the village officials.

Every evening many traps were set in various situations and were collected every morning. To evey trap was attached a label giving the exact locality where it had been set, *e.g.*, street, house, ground-floor, first-floor, etc., godown, stable, gully. In this way it was possible to allocate each trap containing rats to a particular part of a building. In the case of rats picked up dead a ticket was attached to each rat indicating the exact place where it

had been found. While it cannot be denied that by these methods, which were the best available, only a percentage of the dead rats were obtained, it is certain that this percentage was a fairly large one and was a good sample.

In Bombay all the rats were examined at the Parel Laboratory in the Punjab villages a small laboratory for the purpose was fitted up in a bungalow adjoining both villages. Elaborate arrangements were made for this examination, so that in Bombay it was easily possible to deal with from 1,000 to 2,000 rats daily.

A flea census of the live rats was first made, the rats being chloroformed to death for this purpose. They were then dealt with in the same way as the rats brought to the laboratory dead.

A record of all rats was kept stating their weight, species and sex ; if female, whether pregnant or not ; and if pregnant, the number of young present. Further, all rats were examined to ascertain whether they were plague infected or not, the diagnosis of such infection ultimately resting in the hands of one of the members of the Commission. A careful *post-mortem* examination of all plague-infected rats was made and the results described on a form specially drawn up for the purpose. In Bombay this detailed examination was stopped after about 5,000 *post-mortem* records had been obtained, but in the Punjab it was continued throughout the observations. As the accuracy of the statistics depends on the accuracy of the diagnosis of plague in the rats, particular attention was paid to this point. Reference will be made to diagnosis later on.

In the second place, as complete an investigation as possible was made of every plague case which came to light.

In Bombay City the Commission relied for this information on the staff of the Health Department. For purposes of administration Bombay is divided by this department into ten districts and each district into two or more sections. In charge of each district there is a qualified Health Officer, the Registrar, who has under him a staff of sub-registrars, inspectors and menials. All the senior officers have an unusually wide experience of plague on its clinical side and besides have a particularly thorough and extensive knowledge of their districts. This superior staff was trained by the Commission to fill up special plague case cards,

which contained all the necessary information. In addition to the cards outline maps of each section were distributed to the several offices and each plague case with the date of report was dotted on the map. The whole organisation was supervised on the Commission's behalf by two selected medical officers of the Health Department and was daily superintended by members of the Commission.

In the villages, both in Bombay and in the Punjab, a complete census was made, full particulars for each house being recorded on special census cards. These particulars included name, age, sex, caste and occupation of every inhabitant. In the Punjab villages, with a view to ascertaining how far plague tends to recur in particular houses, full particulars of the previous incidence of plague in each house were noted on the cards. Every plague case, and in fact every case of illness, was visited by a member of the Commission. The same system of detailing the information on cards and of spot maps was used as in Bombay. Further, in order to gain the confidence of the villagers and thus obtain early information and avoid concealment of cases a free dispensary was opened in each village and placed in charge of a competent medical man. At first an endeavour was made to confirm the diagnosis by means of a bacteriological examination. It was soon recognised, however, that any attempt to obtain material for examination as a routine measure would defeat its own object by leading to concealment of cases. The procedure was therefore abandoned and the diagnosis based on clinical features, which are usually sufficiently typical.

In the third place, the relation of the rat epizootic to the epidemic was investigated.

As regards time and quantity the relation was easily ascertained from an analysis of the daily returns of plague-infected rats and of plague cases.

As regards place relationship, we have already seen that the information concerning each plague case was recorded on a special card and that each case with its date was dotted on a map. The plague-infected rats were treated in practically the same way Special plague-rat cards were prepared, which in the case of th villages were filled up by a member of the Commission, who at th same time indicated on the map the place where the rat was found.

In Bombay a list of the rats found plague infected was sent each evening from the laboratory to the collecting agency and to the district registrar's office. Accompanying this list were sent the corresponding plague-rat cards to be filled up. The locality, where each rat had been found, was marked on the nearest wall by the collecting agency, while the cards were filled up and the locality and date dotted on the map by the senior officials of the district registrar's office. The cards were then returned to the laboratory.

B.—Observations on the rat population.

In the City of Bombay five species of rodents were found, namely, *Mus rattus* (the black rat), *Mus decumanus* (the grey rat), *Mus musculus* (the mouse), *Nesokia bengalensis* and *Nesokia bandicota* (the bandicoot). It is unnecessary here to enter into the minute differentiation of these species. It was found always possible to distinguish rats of the type of *M. rattus* from rats of the type of *M. decumanus*, but no distinction could be made between the large number of varieties of *M. rattus*, which have been described. Briefly, it may be said that from a practical point of view the important points which ought to be taken into account in differentiating between *M. rattus* and *M. decumanus* are the character of the tail and the relative size of the ears. These features, together with the shape of the head and the general colour of the fur, serve to distinguish *Nesokia bengalensis* from *M. decumanus*. The tail in *M. rattus* is always longer than the body and head together, it is dark in colour and has well marked rings. The ears in this species are larger in proportion to the size of the rat than in *M. decumanus* ; in the latter the tail is shorter than the body and head together and the ventral aspect is lighter coloured than the dorsal aspect. In *Nesokia bengalensis* the tail is shorter than the head and body together, but in appearance resembles that of *M. rattus*, *i.e.*, the rings are well marked. Further, the hairs on the tail are shorter and less numerous in *N. bengalensis* than in *M. decumanus* and there is no brush of hairs projecting beyond the tip of the tail, as there is in this latter species. The head of *N. bengalensis*, looked at from above, is broader and shorter than that of *M. decumanus* and the ears are somewhat

larger in proportion to the size of the animal. The colour of the fur of *N. bengalensis* is uniformly darker than in *M. decumanus*; it is also coarser and with well-marked spines on the back. There is no difficulty in distinguishing *M. musculus* (the mouse) and the ordinary bandicoot (*Nesokia bandicota*) from the other species.

Mus rattus and *Mus decumanus* are by far and away the commonest rodents in Bombay. *N. bengalensis* is comparatively rare, making up only about 1 per cent. of the total. The mouse appears not to be a common animal in Bombay.

Mus rattus, which is found in large numbers in every part of Bombay City, is essentially a house rat; it may almost be called a domesticated animal, living and breeding as it does in the houses where the people live. While it is typically a climbing rat, it is also able to burrow, *e.g.*, in earthen floors and walls. Its nests are as a rule to be found in little-disturbed accumulations of material, such as stacks of firewood, cotton-waste, etc., and in recesses, such as cupboards.

There is no doubt that the rat infestation of houses in Bombay is very great. There is, however, a definite relation between the rat infestation of the building and the character of the building, the features which especially favour rat infestation being earthen floors and country tiled roofs, a state of disrepair, accumulations of rubbish and food, such as stores of grain, etc.

It was found that, while *M. rattus* breeds all the year round in Bombay, breeding was most vigorous during the months June to October, so that the hottest months of the year represent the breeding season. The mean number of young per rat was found to be 5·2, while the largest number noted in a single rat was 9.

Mus decumanus, which is numerous in every quarter of Bombay and especially numerous in the native town, lives for the most part outside houses, in sewers, storm water drains, stables, etc. While it is a burrowing animal with remarkable power of gnawing through hard materials, *e.g.*, brick and concrete, it is also a good climber. Its nest is to be found in one of the burrows which it makes. The breeding season corresponds closely with that of *M. rattus*, except that there is apparently

a second breeding season in March. This species, however, like *M. rattus*, breeds all the year round. The average number of young per pregnant female is 8·1, the largest number found in a single rat being 14.

As regards the relative numbers and haunts of *Mus rattus* and *Mus decumanus*, the following statements are founded on the trapping of nearlv 12.000 rats of these two species in the native city.

M. rattus is apparently much more common in Bombay than *M. decumanus*, as, taking all traps set, seven of the former species to every three of the latter were caught. They are found in this proportion on ground floors of houses, but *M. rattus* increases relatively to *M. decumanus* as one ascends the building. *M. decumanus* has never been found above the third floor, so that on the fourth floor and upwards *M. rattus* is alone present. In gullies, compounds of houses, stables, godowns and food and tea shops the number of *M. decumanus* relatively increases, so much so in the case of compounds, that in traps set in them twice as many of this species as of *M. rattus* were taken. Further, it is evident that these two species of rats are closely associated with each other—gullies, the lower floors of the houses and godowns appearing to be their common meeting ground.

The Commission have observed nothing to show that the rats of Bombay, even during the epizootic season, are in the habit of migrating from one quarter of the city to another. There may be desertion of infected buildings, but there is certainly no general migration.

Finally, it is necessary to emphasise two important facts concerning the rats of Bombay which, as we shall see, have a great significance in relation to plague. The first fact is the widespread distribution of *M. rattus* in buildings in the city. The Commission do not think it an exaggeration to state that every inhabited building in Bombay City and Island, not excepting even the better class bungalows, shelters its colony of *M. rattus*. The second important fact is that to a certain extent *M. decumanus*, as we have seen, is a house rat and even forms extensive burrows in the floors and walls of buildings.

As regards the other rodents in Bombay little need be said as they do not influence the plague epidemic.

Nesokia bengalensis is not common as it appears to be in Calcutta. It was taken in those sections of Bombay city where there are fairly large areas of waste ground and was trapped in the ground-floors of houses, in gullies, in stables and in godowns

The bandicoot is now an extremely rare animal in Bombay. It was caught only in the open country and palm groves in the northern part of the Island.

Mice were taken on all the floors of buildings, in stables and in godowns.

In none of the villages in the neighbourhood of Bombay, with the exception of Parel, was *M. decumanus* obtained during the year they were under observation. A few of this species were taken in Parel, a village, in which the buildings are very similar to those of Bombay and where there are a certain number of sewers and storm water drains.

A few specimens of *Nesokia bengalensis* were taken in these villages.

M. rattus was found to be very common in the villages. Its habits and haunts were the same as in Bombay. In two of the villages, namely, Parel and Worli, a very thorough and systematic examination of the rat infestation was made during the period they were under observation. This was done by setting daily a number of traps in the different houses and recording the number of rats caught in each trap. The traps were sent in the houses in rotation according to the census numbering.

In Parel 2,195 *M. rattus*, a number equal to two-thirds of the human population, were captured during the year. This number gives an average of 15 rats per building. From one building, which was divided into 16 tenements and sheltered 70 inhabitants, as many as 393 rats were taken. At the beginning of the operations 65 rats per 100 traps set were captured, while at the end of the year this number had been reduced to 34 rats per 100 traps set—not a very great reduction. We can conclude, then, that the rat infestation of Parel is very considerable, and that, despite the capture and removal from the village during the year's operations of a

large number of rats, equivalent to two-thirds of the human population, the number at the end of the year was apparently not very greatly diminished.

Very similar observations were made in Worli. This is an isolated village on the west coast of the Island and is chiefly inhabited by fisher folk The buildings are huts constructed of rough stones. The roofs of the huts are generally covered with palm leaves and offer excellent shelter for *M. rattus*. During the year's operations 2,603 rats of this species were taken in the village, a number larger than the human population (2,508). At the beginning of the trapping as many as 70 rats per 100 traps were caught, while at the end of the year this number had been reduced, only 17 rats per 100 traps set being taken. There is no doubt that the rat population had been considerably diminished. The inhabitants themselves recognised this fact and five months after the operations had been stopped begged that the routine setting of traps might be continued, as the rats had again become a nuisance.

It would appear, then, that the fecundity of *M. rattus* is so great that nothing but extensive and persistent efforts to destroy it can materially reduce its numbers in any village. The same conclusion was arrived at as the result of the observations in the Punjab, which we shall now consider.

From November 1905 to December 1906 continuous observations on the rat population were carried out in the Punjab villages of Dhund and Kasel. Four species of rats were found, namely, *M. rattus*, *M. decumanus*, *Nesokia bengalensis* and *Gerbillus indicus* (the Indian field rat).

Only five mice were taken. This small number may be due to the traps being unsuitable for catching them. Twenty-five *N. bengalensis* were captured, all in the fields at harvest time. Of 9 *Gerbilli* two were taken in the fields and the remaining seven in the villages, most of them in houses on the outskirts.

Mus rattus, therefore, is the common rat of the Punjab villages and is the only one which has any influence on the plague epidemic. In all 7,525 specimens were examined during the year. The type very closely resembles that found in Bombay. The colour of the dorsal fur is usually brown, while the belly is greyish, dirty yellow or

occasionally quite white. During the cold weather the fur is longer and thicker than that of the *M. rattus* found in Bombay. *Mus rattus* in the Punjab as in Bombay is essentially a house rat. The houses are closely packed together, often back to back, and at the best with only narrow lanes separating them. The walls are built of sun-dried bricks or of large clods of caked mud. The roofs are flat, made of beaten earth supported by twigs, matting or cane. The floor consists merely of beaten earth, which may or may not be plastered with cowdung. On account of this mud construction of the houses *M. rattus* adopts burrowing habits. The mud walls, floors and roofs, present no obstacle, and it is indeed the exception to find a village house in which rat burrows cannot be found. These burrows are very extensive. They have been followed extending the entire length of the wall and into the wall of an adjoining house. In short, a Punjab village may be looked upon for our present purpose as being honey-combed with rat burrows which ramify in all directions. Further, the nests of *M. rattus* are to be found in these burrows and seldom in the interior of the house as in Bombay. In the houses themselves there is kept an abundant food supply for the rats. Each house has its granary, in which is stored the grain supply for the household. In earthen vessels there are also kept such articles as flour, sugar, ghee, potatoes, etc. All these are easily accessible to rats.

From what has been said above it will not surprise the reader to find that the rat infestation of a Punjab village is very great, and that the rats live in close relation with the human population, so much so indeed, that a common complaint of the villagers is that their sleep is disturbed by rats running over them at night. As further evidence of the enormous rat infestation it is only necessary to state that during the year in Kasel the total number of *M. rattus* trapped was 4,639, an average of 1·2 rats per inhabitant, the corresponding figures for Dhund being 2,518 and 1·3. Vigorous trapping was continued during the year in both these villages. At the beginning of the operations in Kasel 148 rats per 100 traps set were taken. This proportion gradually diminished until seven months after the commencement, namely, in July, only 17 rats per 100 traps set could be obtained. From this date until the end of the operations in November the numbers caught steadily increased, until during November 69 rats per 100 traps set were taken,

or about half the number caught at the beginning. In Dhund the result was similar, so that there is no doubt that in both villages at one season of the year breeding more than compensated for the loss sustained by trapping. In this connection it was found that while breeding goes on all the year round, during the cold weather months (November-March, inclusive), it takes place to a less extent than during the hot weather and that the most favourable months are April, September and October, when the mean temperature is about 80°F. The average number of young born at one time was found to be 6 per rat.

The question of migration of the rats from village to village and from villages into the fields at harvest time was also investigated. Traps were set around Kasel for one and a half months and in one instance only, and that when the traps were placed close to a house, were a few *M. rattus* caught. During the harvesting of the spring crops in April, May and June, when the rat epizootic in Kasel was steadily progressing, no rats, except a few specimens of *N. bengalensis*, were found in the fields. In short, no evidence of migration of any kind could be obtained and the more intelligent villagers, who recognise the distinction between *M. rattus* and *N. Bengalensis*, are emphatic in denying that the former species ever leaves the villages.

Before passing on to the question of plague amongst the rats, a few words on the fleas infesting the rats in Bombay and in the Punjab are necessary.

On the rats in Bombay and in the Bombay villages practically only one species of flea was found, namely, *Pulex cheopis*. The degree of infestation of *M. decumanus* was found to be considerably greater than that of *M. rattus ;* throughout the year more than twice as many fleas being taken on the former as on the latter.

In the Punjab villages as well as *P. cheopis* another species of flea, namely, *Ceratophyllus fasciatus*, was found on the rats. This species, however, made up only about 2 per cent. of the total, and during the months May to November entirely disappeared.

Another point of interest and importance which comes out of the flea census is that *M. rattus* in the Punjab harbours considerably more fleas than it does in Bombay. In the Punjab its degree of flea infestation approximates that of *M. decumanus* in Bombay. It has also been a common observation that sick

rats habour many more fleas than healthy ones. It is not uncommon to find 100 fleas and even more on a sick, plague-infected rat.

The question of the seasonal prevalence of fleas will be dealt with later on when discussing the seasonal prevalence of plague.

The Commission examined the physiological anatomy of the mouth parts and alimentary canal of *P. cheopis*, investigated the external anatomy of this flea and its differentiation from some other common fleas and enquired into its habits and life history. Papers on these subjects have appeared in the reports,* to which we refer the reader whose interests lie in these directions. We shall note those points which are essential for our present purpose in their proper place.

C.—Observations on plague in the rat—the epizootic.

As the accuracy of the data which have reference to the rat epizootic and to its relation with the epidemic depends upon the accuracy with which plague-infected rats can be diagnosed, a few remarks on natural rat plague and its diagnosis will not be out of place. The following statements on this subject are founded on the detailed *post-mortem* examination of over 5,000 plague-infected rats, both *M. decumanus* and *M. rattus*, found dead in Bombay and in the Punjab.

Plague rats may be divided into two classes, according as to whether or not a bubo is present. The bubo if present, and it is present in 85 per cent. of the cases, is the most important sign of plague. Its most common situation is, as we shall see, the neck, the next most common being the armpit. Subcutaneous congestion is common (69 per cent.) and when combined with a purplish red appearance of the muscles affords strong suspicion of the animal being plague infected. Of other characteristic appearances those occurring in the liver are the most important; it has a waxy, mottled or finely granular appearance, in the latter case as if dusted over with grey pepper. Hæmorrhages in various parts of the body are commonly found and an abundant pleural effusion constitutes when present a noteworthy sign of plague in the rat. In putrid rats at least three of these signs may persist and when recognised are of the greatest assistance, namely, a bubo, granular liver and pleural effusion.

* *Journal of Hygiene, Vol. 6. page 486, and Vol. 7, page 446.*

If recourse be had to the microscope, the bubo is the best place to find plague bacilli in large numbers, the spleen next and then the blood.

As the result of a number of severe tests it was found that the naked eye is markedly superior to the microscopical method as an aid in diagnosis, that is to say, in the case of an experienced observer. Such an expert would be prepared to make a diagnosis of plague on the strength of the macroscopical appearances alone, even though the other tests were negative and the animal showed marked signs of putrefaction.

In short, it may be said that neither in Bombay nor in the Punjab did the Commission experience any difficulty in diagnosing plague from other diseases among rats.

The bacilli found in naturally infected rats, both during the epizootic and during the non-epizootic seasons, were fully virulent, 62 per cent. of the inoculated animals dying of acute plague in five days or less. Further, the bacilli retained their full virulence after passage through a large number of rats, no matter whether the subcutaneous or cutaneous method of inoculation was used. Finally, it was ascertained that a considerable percentage of wild Bombay rats were immune to plague infection, this insusceptibility being also observed, when fleas were used as the agent of transmission. As a point of epidemiological importance we shall have occasion later on to refer to the relative infectivity of the blood, urine and fæces of plague rats.

With these few remarks on the disease as seen in the rat and its diagnosis, we may proceed to record these facts concerning the epizootic which have a direct bearing on the epidemiology of the disease.

In Bombay City, for which a large mass of data has been accumulated and analysed, *M. decumanus* and *M. rattus* are by far the most important species in relation to the spread of plague. Both these species were found plague infected, but from the statistics it could be concluded that *M. decumanus* was twice as liable as *M. rattus* to plague infection. The explanation of this difference of plague incidence in the two species does not lie in any difference between them of susceptibility to plague infection, but in the fact, already mentioned, that the degree of flea infestation of

M. decumanus is more than double that of *M. rattus*. Before going further we would insist that in Bombay City, just as there are two common species of rats, so there are two epizootics, namely, a *M. decumanus* epizootic and a *M. rattus* epizootic, which have to be considered separately. The infection amongst the rats in Bombay must be characterised as being exceedingly severe, 4,381 *M. rattus* and 13,377 *M. decumanus* being shown to be plague infected during the year, a total of nearly 18,000 plague-rats out of a total of 117,000 rats examined. The year, however, may be roughly divided into two seasons, (*a*) the non-epizootic season, June to November inclusive, and (*b*) the epizootic season, December to May inclusive. During the epizootic season the largest number of infected *M. rattus* for one week was 432, the largest number of *M. decumanus* for a similar period being 1,334. This was in March. During the non-epizootic season never less than 20 to 30 plague-infected rats were examined during any one week. We see, therefore, that even during the off-plague season acute plague persists amongst the rats, but to a much less extent than in the plague season. The factors which govern this seasonal prevalence will be discussed later on.

A study of the section maps, the method of preparing which has been described, leads to the conclusion that *M. decumanus* is chiefly responsible for the diffusion of the infection throughout the city, as might be expected in consideration of the out-door life and wandering habits of this species. While this is so, it is to be carefully noted that the infection does not spread in any definite manner from one section to another; infection amongst the rats persists during every month of the year in most of the sections. Further, in this connection we have already mentioned that no evidence of a general migration of rats from one place to another, when plague breaks out amongst them, could be found.

As regards the relation of the *decumanus* epizootic to the *rattus* epizootic it would appear from a study of the curves which were prepared from the figures collected during the year, that the former preceded the latter by a mean interval of about ten days. Further, the evidence obtained by the Commission led them to the conclusion that the *decumanus* epizootic was directly accountable for the *rattus* epizootic. By this statement the general relation between the two epizootics is expressed, but it is not for one moment

to be supposed that in every instance *M. rattus* received its infection from *M. decumanus*. It was also considered that the persistence in the off-season was due ultimately to plague in *M. decumanus*.

These conclusions can be adequately explained, if it be granted that the conditions for epizootic prevalence are more favourable in the *decumanus* population than in the *rattus* population. Now, the only factor concerned in the severity of epizootic prevalence which does not affect the two species equally is, as far as can be ascertained, the degree of flea infestation of each, *M. decumanus* harbouring a much larger number of fleas than *M. rattus*. In this fact, therefore, is to be found the key to the elucidation of the relationship of the two epizootics. It is scarcely necessary to point out the extreme importance of this relationship in the problem of the organisation of measures for combating plague in Bombay.

As regards the four villages on the outskirts of Bombay nothing need be said with respect to the natural disease in the rat. It is necessary, however, to refer to certain points of epidemiological importance which came out of the investigations in these villages.

In the first place, it was found that the infection was not maintained in the rats (*M. rattus*) during the off-season, either in the acute or in the chronic form. It could, therefore, be concluded, as we shall see later, that the annual epizootics in these villages must be ascribed to importation of infection, generally, no doubt, from Bombay. All the evidence pointed to such importation taking place, and we shall return to this question later on.

In the second place, in one of the villages, Sion Koliwada, as soon as the mortality amongst the rats began and one or two human cases had occurred, almost the entire population evacuated the village. The human population was replaced by the Commission by a guinea-pig population. We shall have occasion later on to refer more in detail to this experiment, and in the meantime would only draw attention to a few of the facts concerning the rat epizootic.

First, in proportion to the severity of the epidemic the number of plague-rats found was very small, notwithstanding the very thorough and extensive search made. The experience both in Sion Koliwada and in the Punjab village of Dhund in this respect points to the danger of concluding that plague-rats are absent from an infected locality unless a very thorough search is carried out.

Secondly, it was found that the infection persisted among the rats in the village for two months and that in the case of two individual huts it lingered amongst the house rats, in one for at least ten days and in the other for 13 days.

Thirdly, a study of the map showed that the epizootic spread from a central focus towards the periphery and the rate of spread is indicated in the statement that the infection in the rats took six weeks to travel 300 feet.

We have already seen that in the Punjab villages *M. rattus* is the only rodent commonly present. Our remarks, therefore, refer to plague in this species.

The outstanding fact as regards rat-plague in the two Punjab villages which were under observation is, that during the non-epizootic season, when no plague cases were occurring, rats suffering from a chronic form of the disease were caught alive. These rats showed abscesses in various parts of the body, but chiefly in the abdomen and more especially in connection with the spleen. These abscesses contained plague bacilli, in small numbers certainly, but still virulent. Otherwise the rats appeared to be quite healthy and it is remarkable that no rats with this form of the disease were found dead. The two main conclusions at which the Commission arrived after a careful study of this condition were, first, that these rats had been infected by fleas in the same way as plague-rats which develop the acute disease ; and, secondly, that, from the evidence bearing on the question, no reason could be discovered for believing that chronic plague, as it occurs in the Punjab villages, possesses any significance in the seasonal recurrence amongst the rats of the infection in the acute form. It is to be carefully noted that the absence of acute rat-plague during the off-season in the two villages of Kasal and Dhund does not warrant our concluding that it is absent in all Punjab villages at this time. On the contrary, there is no question, as we shall see, that in some villages the disease persists in the rats in the acute form, as indicated by the occurrence of a certain number of human plague cases throughout the non-epidemic season.

In the village of Dhund the first acute plague-rat was found on the 27th January and the last on the 21st April : the epizootic may,

therefore, be said to have lasted about three months. In Kasel it lasted from 2nd April till 17th July, namely, about three and a half months.

In Dhund the epizootic was of very moderate severity, only 34 plague-infected rats being found. In Kasel, on the other hand, 253 rats were proved to be plague-infected and 89 more, too putrid for examination, were brought to the laboratory. The lightness of the epizootic in Dhund is probably due to the large number of rats which had been removed by trapping before it began.

The mode of spread of the epizootic in both villages was characterised by considerable irregularity. It cannot be said to have extended outwards from the original focus as a wave with a definite margin leaving the area passed over free from infection. On the contrary some plague-rats were found at a considerable distance from the original focus of infection early in the epizootic and also infected rats continued to be found in the vicinity of the original focus at a time when the epizootic had spread considerably In spite, however, of these irregularities it may be admitted that the general direction was centrifugal and that the areas furthest from the original focus were the last to become infected.

D.—Observations on plague in man—the epidemic.

We may dismiss this part of our subject in very few words, as the results of the observations differed in no particular from those already published by numerous observers. Thus, the figures both in Bombay and in the Punjab which have reference to the incidence of the disease in the population classified according to sex, age and caste are in harmony with what is already well known. In Bombay City during the year there were reported 12,245 cases and 11,010 deaths. Data concerning 10,880 of these cases were entered in the case cards, already mentioned, and analysed by the Commission. Deaths from plague were reported from the City during every week of the year, the smallest number, 5, being in the week ending 25th November and the largest number, 925, in the week ending 28th April.

In the village of Dhund the last case of plague before the present epidemic was attacked on 14th July 1905. During the epidemic

which was now observed there were 32 cases, the date of the first attack being 6th February 1906 and of the last 2nd May. There were 19 deaths, a case-mortality of 60 per cent.

As regards Kasel the last plague case in 1905 occurred on the 28th April. The epidemic of 1906 consisted of 75 cases with 41 deaths, a case-mortality of 55 per cent. The first case occurred on 5th April and the last on 6th July.

E.—Relation of the epizootic to the epidemic.

We now come to the most important part of the epidemiological observations, that is to say, the relationship between the epizootic and the epidemic.

In Bombay City we have seen that it was concluded that the *rattus* epizootic was dependant upon the *decumanus* epizootic. The conclusion which we shall now come to is that the epidemic is directly attributable to the *rattus* epizootic. The same conclusion holds good for the villages, both in Bombay and in the Punjab, but in these villages the problem is not complicated by the presence of the *decumanus* epizootic. This conclusion has been arrived at after a careful consideration of the relation of the epizootic to the epidemic in time, in place and in quantity.

1. *Relation of epizootic to epidemic in time.*

In Bombay City we have seen that the *decumanus* epizootic precedes the *rattus* epizootic by an average interval of ten days. Using the same methods of observation it was found that the curve of the *rattus* epizootic was separated from that of the epidemic by an average interval of 10 to 14 days. The explanation of this interval on the basis of the flea theory will be dealt with later.

In the maps for the sections the same time relations of the epizootic and the epidemic are well illustrated. It need hardly be mentioned again that during the non-epizootic season, that is, when there are only few plague-rats, there are also few plague cases.

This time relationship is also well shown in the case of the two Punjab villages. In both villages during the season when no acute plague-rats were found, there were no plague cases. When acute

plague appeared amongst the rats, human cases immediately began to appear.

In Dhund both plague-rats and cases were too few in number to allow of curves being constructed. It will be remembered, however, that the first acute plague-rat was caught on 27th January and the last on 21st April, while the first human case was attacked on 6th February and the last on 2nd May.

For Kasel curves were constructed in the same manner as for Bombay. These curves of rat-plague and human plague exihibit a very close correspondence, the variations of the curve of human plague following those of the rat-plague curve at an interval of about a week.

In both these villages, therefore, rat-plague preceded human plague and human plague ceased shortly after or just before the cessation of acute plague amongst the rats.

Observations of the same nature were made in the Bombay villages in which plague occurred.

2. *Relation of the epizootic to the epidemic in place.*

In the case of Bombay it was practically impossible to obtain direct evidence bearing upon this point. Still, in a considerable number of instances plague infected *M. rattus* were found in houses in association with plague cases. There are, however, two valuable pieces of indirect evidence which show that there cannot be the slightest doubt that the place infection of man is intimately related to that of *M. rattus*. First, we have already insisted upon the fact that *M. rattus* is essentially a house rat and that it lives in close association with man. It necessarily follows that the place infection of *M. rattus* must correspond closely with that of man—in other words, that both must be referred to inhabited buildings. This association is shown in a general way in the maps of the sections. Secondly, statistics collected and analysed for the whole of Bombay and for the different sections separately show that the incidence of plague on persons living on different floors in buildings is the same. Now, we have already seen that *M. rattus* is found on every floor of the buildings. Moreover, the construction of the buildings is such that there are abundant facilities for the

spread of infection amongst the rats living in different parts of a building. It would seem that these facts confirm the conclusion that the place infection of man and of *M. rattus* is the same.

In the case of the Punjab villages direct evidence of the place relationship of the epizootic and the epidemic was obtained.

In Dhund the 32 cases can be divided into two groups as follows—Group 1 comprises 22 cases inhabiting 18 houses, in which, or in the vicinity of which, plague-rats were found before or at the time of the occurrence of the cases; Group 2 comprises ten cases from eight houses, in which, or in the vicinity of which, no plague rats were found before or at the time the cases were attacked. Three of these eight houses (four cases) were, however, shown by guinea-pig experiments to contain infected rat-fleas. Of the other six cases two were imported, two lived in the neighbourhood of one of the houses shown to contain infected rat-fleas and the remaining two were children, whose movements before their illness could not be exactly ascertained. Plague-rats, however, were found in the vicinity of the dwellings of these two children a few days after they fell ill.

In Kasel we may summarize the data which have reference to our present point as follows:—

(*a*) Of 75 cases, four were imported.

(*b*) Of the 71 indigenous cases, 61 occurred in houses, in which, or in the vicinity of which, plague-infected rats had been found prior to the attacks.

(*c*) Plague-rats were not found in or near the residences of the remaining ten cases prior to their attacks, but six of these persons had visited houses where plague-rats had been found.

(*d*) Of the remaining four cases, one was doubtful, and plague-rats were found in the vicinity of the houses of the three other infected persons some days after they fell ill.

It would appear, then, that a more intimate association between plague cases and plague-rats was traced in Kasel than in Dhund. There is no doubt that this difference in the results obtained in the two villages can be in part explained by the fact that information of rats having died was obtained more readily in Kasel than in Dhund, as the Kasel people had ceased to look on the Commission with suspicion at the time the epizootic began in that village.

Finally, in attempting to estimate the closeness of the association between rat-plague and human plague in a Punjab village we must take into account the small size and close aggregation of the houses and the free communications by means of rat burrows between neighbouring houses. It will then be readily apparent that the association which exists between a plague case in a house and plague-rats found in an adjoining house or in a house near by, but not immediately adjoining, may have been more intimate than that which obtains between cases and plague-rats found in different rooms or even on different floors of large buildings such as exist in cities. Further, it is also certain that many plague-rats die in the burrows and do not come to view. That this is so is shown by the trapping of infected rat-fleas on guinea-pigs in houses in which no dead rat had been found.

In conclusion, it is important to point out that plague cases do not necessarily follow the finding of dead plague-rats in a house. In Dhund there were eight houses in which plague-rats were found and none of the inmates of which, 31 in number, contracted the disease. In Kasel out of 86 occupied houses, in which plague-rats were found and which were not evacuated, only 15, or 17 per cent., furnished cases.

3. *Relation of the epizootic to the epidemic in quantity.*

Little need be said on the quantitative relationship of the epizootic and epidemic. In Bombay City during the non-plague season, when there are few plague-infected rats found, there are also few plague cases. In the Bombay and Punjab villages during the non-plague season, if there are no *acute* plague-rats, there are no human cases. During the plague season in Bombay the quantitative variations of the epidemic curve followed very closely those of the *rattus* epizootic curve. The same relationship was observed in the curves of the Kasel epizootic and epidemic.

Further, in Dhund there were far fewer plague-infected rats both actually and in proportion to the size of the village than in Kasel. There were also far fewer plague cases in Dhund than in Kasel.

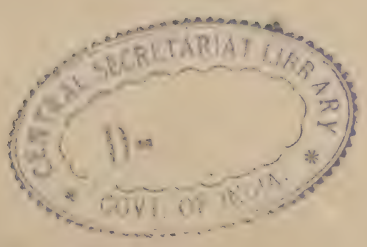
Lastly, it was soon apparent that the risk of infection of the occupants of a house increased with the number of plague-rats found.

Thus, in Kasel out of 80 houses in which single plague-rats were found only three, or four per cent. of the whole, furnished cases, whereas plague cases among the occupants followed in 16 out of 57 (28 per cent.) of the houses in which more than one plague-rat was found. It was also the experience of the Commission in Bombay that if multiple cases of plague occurred in a house more than one dead rat had been found in it, and the greater the number of dead rats, the greater the number of cases.

Before finishing this part of the subject brief reference must be made to an experiment that was made in the village of Sion Koliwada which shows well the relationship between the rat epizootic and the epidemic.

Sion is a small isolated village to the north of the Island of Bombay. The huts are well separated from one another and there is no crowding together as there is in a Punjab village.

In January 1906, plague was introduced into the village by importation from Bombay. As soon as a few dead rats had been found and one or two human cases had occurred, almost the entire population, which numbered 375, evacuated the village and occupied a temporary camp in the adjoining fields. Taking advantage of the voluntary evacuation of the village by its inhabitants the Commission substituted in as many houses as possible a guinea-pig population. These animals were confined in wire cages in the houses and were fed daily by the staff of the Commission, so that there could be no possible communication between the animals in different houses. Corresponding to the rat epizootic there was a guinea-pig "epidemic." This "epidemic," moreover, was roughly co-extensive with the rat epizootic and coincided with it in point of time. Further, in certain of the houses the number of plague-rats found corresponded to the degree of infectivity of the houses, as judged by the success of experiments carried out in them. We may, although perhaps somewhat prematurely, draw attention to the fact, that all the evidence in this experiment pointed to the rat-flea being the agent of transmission of the infection to the guinea-pigs and excluded contact as playing any part in the dissemination of the disease among the guinea-pigs.



In conclusion, before considering the means by which the infection is conveyed from animal to animal, it would be well to state the very definite conclusion which was arrived at as regards the relation of the rat epizootic to the epidemic as follows : The rat epizootic precedes and is alone accountable for the human epidemic. In Bombay City it is the *rattus* epizootic which determines the epidemic.

Part III.—METHOD OF TRANSMISSION OF THE INFECTION FROM RAT TO RAT AND FROM RAT TO MAN.

A.—Transmission of infection by direct contact.

B.—Aerial transmission of infection.

C.—Transmission of infection through the soil.

D.—Transmission of infection by means of food.

E.—Transmission of infection by means of the rat-flea :

1. *Experiments in the laboratory.*
2. *Experiments in godowns or cabins.*
3. *The rat-flea the agent of transmission of infection from rat to rat in nature.*
4. *Infection in plague houses due to infected rat-fleas.*
5. *The rat-flea the agent of transmission of infection between rat and man.*
6. *Further observations on the transmission of plague by fleas.*

   (*a*) *The fate of the plague bacillus in the body of the rat-flea and the mechanism by means of which the flea infects a healthy animal.*

   (*b*) *Can a single rat-flea transmit the infection?*

   (*c*) *Can both male and female rat-fleas transmit the infection?*

   (*d*) *Can other species of fleas transmit the infection?*

We have seen that the plague epidemic is dependent upon the epizootic amongst the rats. It is obvious, therefore, that the next problem to be solved is the method of transmission of the infection, that is to say, of the plague bacillus, from rat to rat and from rat to man. Several possibilities will at once suggest themselves to the reader, as they did to the Commission. These possibilities have been carefully examined and experiments conducted with the view either of disproving them or of proving them to be true. It is the result of this work which we would now bring forward.

A.—Transmission of infection by direct contact.

It is conceivable that a sick or dead plague-infected animal might infect a healthy animal by merely coming in contact with it. The work of the Commission, however, definitely proves that this method of conveyance may be excluded. The evidence which bears on this question may be briefly summarised as follows:—

1 A very large series of experiments was made with guinea-pigs in specially constructed godowns or cabins. As we shall have to refer constantly hereafter to these observations in the godowns, it will be well to give a brief account of their structure.

The godowns are six in number and with the exception of the roofs are of exactly the same construction. In the case of godowns 1 and 2 the roofs, being of country tiles, offer good protection and shelter to the wild rat of Bombay; the flea supply in the interior is abundant and regular. In the case of godowns 3 and 4 the roofs, being of flat Mangalore tiles, offer only poor protection to rats and in consequence the flea supply is more or less scanty and intermittent. The roofs of godowns 5 and 6 are made of reinforced concrete and are quite rat and flea proof. These godowns, therefore, could be easily kept quite free of fleas.

The experiments to which we would now refer were carried out in godowns 5 and 6. In these godowns plague-infected animals were kept in close contact with healthy animals, that is to say, running about together in a confined space and eating out of the same dishes. The plague-infected animals were allowed to die and the corpses were not removed until some time after death. In some instances the concentration of infection was very great, in one case 21 infected animals being at one time in contact with 25 healthy ones. Further, the infection was often kept up for a long period by the daily addition of freshly infected animals. It is also to be noted that, as the godowns were never cleaned out, close contact includes contact with urine and fæces of infected animals and contact with, and eating of, food contaminated with fæces and urine of infected animals.

In all these experiments, done under various conditions, the result was always the same, namely, if fleas were rigorously excluded not one of the healthy animals contracted plague. As these observations are of great importance a typical example

will be given, which will help their being understood. On 8th January, 1907, in godown No. 5 there were placed 25 healthy guinea-pigs and five guinea-pigs which had been inoculated with a virulent culture of the plague bacillus. By 11th January, 1907, all the inoculated guinea-pigs had died of plague. After this date more infected guinea-pigs were added daily, 25 in all being put in between 15th January, 1907, and 24th January, 1907. All these guinea-pigs died of plague, the last death taking place on 31st January, 1907. It is to be noted that on 18th January, 1907, there were 21 plague-infected animals in contact with the 25 uninoculated guinea-pigs. The latter, however, remained healthy until the experiment was ended on 21st February, 1907. No fleas were observed on the guinea-pigs throughout the course of the experiment.

2. Young guinea-pigs in the absence of fleas may be suckled by plague-infected mothers up till the death of the latter and still not contract the disease. This observation has been made on several occasions.

3. Contact of healthy animals with plague-infected animals is not necessary to start an epizootic among the former. Thus, in godowns Nos. 1 and 2, in which abundant rat-fleas were present, the following experiment has often been made. A few plague-infected animals have been put into the godown. A day or two after the last of these guinea-pigs had died and been removed, a number of healthy animals have been placed in the godown. An epizootic at once breaks out amongst these animals. In these experiments the healthy animals, it is evident, were never in contact with the plague-infected animals.

4. In plague-infected houses animals, placed in cages so constructed as to prevent contact with plague-infected animals which might be present in the house, have in many instances contracted the disease. Similar observations have been made with monkeys in the godowns which contained fleas and in which plague-infected animals had been present a short time previously.

We shall deal with the infectivity by contact of human plague cases later.

B.—Aerial transmission of infection.

The same experiments which have been noted above as evidence against contact infection may with equal force be brought forward as evidence against ærial infection. In addition to these experiments we can, however, cite the following observations, which all point to the same conclusion :—

1. In godown No. 1 or 2, in which many fleas were present and which had recently contained plague-infected animals, guinea-pigs were suspended in cages two feet above the ground. Not one of these animals contracted plague, while animals exposed in the same godown at the same time, but suspended in cages two inches above the floor or running about on the ground readily sickened and died of the disease. It is to be noted that a flea cannot jump more than 4 inches. All these groups of animals were equally exposed to ærial infection.

2. Animals placed in infected godowns or in plague-infected houses in cages protected by a curtain of fine wire gauze or surrounded by a strip of "tanglefoot" never contracted plague. Their neighbours in similar cages, but not protected as described, often succumbed to the disease. The animals of both these groups were equally exposed to ærial infection.

We shall have occasion to refer more in detail to all these experiments when we come to speak of the conveyance of infection by means of fleas. In the meantime we may note that we may exclude ærial infection as playing any part in the conveyance of the infection from animal to animal in nature.

C.—Transmission of infection through the soil.

The conception which can be formed of this method of infection is as follows :—Rats or human beings may contaminate the soil or floors of houses with their infected excreta. Healthy animals or man may become infected by the rubbing into skin abrasions of soil or dust contaminated in this way.

This has been in recent years generally accepted as the most probable way in which man becomes infected. As it was recognised that the infection was inside the houses it was only natural to suppose that it was in the soil. This deduction seemed to receive support from the fact that in the great majority

of human cases the position of the primary bubo is in the groin, indicating that the bacilli had gained entrance through the skin of the legs or lower part of the body. Such a mode of entrance seemed to be in harmony with the well-known customs of the native of India, namely, that he is practically always bare-footed in the house and as a rule takes his food squatting on the floor and also sleeps thereon. The theory of soil infection, moreover, offered an explanation of the problem of recrudescence, inasmuch as it was supposed that the bacillus had an existence during the non-plague season in the soil. We shall return to the question of the position of the primary bubo in man; but, in the meantime, we have to draw attention to the fact that up to date no competent worker has ever recovered the plague bacillus from the soil of infected houses, and now the work of the present Commission definitely proves that this method of infection can be excluded. The evidence which justifies this conclusion is briefly summarised as follows:—

1. The urine of both infected rats and human beings may contain plague bacilli in large numbers, but they are never present in them in such large numbers as in the blood. The urine can in some cases infect guinea-pigs when injected in considerable amount under the skin, but in no instance, out of a large number of experiments, did it infect an animal when tested by natural methods, *e.g.*, rubbed into abrasions and scarifications. It is of course evident that in nature injection of infected urine under the skin could not occur, the only probable way of infection being through abrasions. A large number of experiments on the infectivity of the fæces of both rats and man were made. These tests were carried out by rubbing the fæces into scarified surfaces on the skin of susceptible animals. Only on one or two occasions out of several hundred experiments did infection result, even when the blood of the animal, of which the fæces were used contained abundant plague bacilli.

2. We have already seen that in godowns 5 and 6, from which fleas were excluded, healthy animals ran about and lived on the floors which were continually being contaminated with the urine and fæces of plague-infected animals and still did not contract the disease. A large number of such experiments were carried out and always yielded the same result.

3. Several series of experiments were made to ascertain the duration of infectivity of floors which had been grossly contaminated with virulent cultures of the plague bacillus. In these experiments the contamination was made artificially and was extremely gross, the floors being flooded with thick cultures of the bacillus. Such gross contamination could never possibly occur in nature. When the test of infectivity employed was to allow healthy susceptible animals to run about on the floors, it was found that cowdung floors remained infective for 12 but not for 24 hours after contamination, while *chunam* floors kept their infectivity for 6 but not for 12 hours. In these experiments only a very small percentage of the animals exposed to infection contracted the disease and those only when the floors were still wet when the animals were put on. It is again to be noted that the contamination in these experiments was very gross, much more so than could ever possibly occur in nature.

Further, when we come to analyse the data which refer to the distribution of the primary bubo in the few animals which did become infected through soil contamination and compare this distribution with the distribution in the same species of animals, namely, guinea-pigs, infected in nature, *e.g*, by running about in plague houses, we find a marked contrast, which points to a different method of infection. Thus, in the case of the soil infected animals the position of the bubo was in the great majority of instances in the groin, or in the axilla, the neck glands being involved in only 22 per cent. of the animals, while in the animals infected in nature the bubo was situated in the neck in over 90 per cent. of the cases.

4 That animals may become infected with plague, although they are carefully protected from soil infection, is definitely shown by experiments which were made both in infected godowns in the presence of fleas and in plague-infected houses. These animals were placed in cages of such a description that they were protected from soil infection, and still, in the instances in which the accessof fleas was permitted, some of the animals contracted the disease. Again, in the experiments in infected-flea godowns, in which the animals were suspended two inches from the floor and were never

allowed to come in contact with the ground, they readily contracted the disease. Two inches is an easy jump for a flea.

5. The last argument which we shall bring forward against soil infection playing any part in the epidemiology of plague is afforded by two series of experiments made in plague-infected houses. In one series the houses had not been disinfected, while in the other series disinfection had been thoroughly carried out with an acid solution of perchloride of mercury of strength 1 : 750, a solution which, as has been abundantly proved, kills the plague bacillus even in organic mixtures. The same proportion of disinfected as of non-disinfected houses, namely, 30 per cent., was found to be infective to guinea-pigs allowed to run free over the floors. If the infection had resided in the soil it is only reasonable to suppose that the disinfection would have rendered the houses non-infective. It will be observed that the disinfection had no effect on the fleas in the rooms.

D.—Transmission of infection by means of food.

It has been frequently asserted lately, especially in respect of rats, that infection is introduced by means of food. Thus, it has been supposed that rats might become infected by eating the excreta either of plague rats or of human plague cases or perhaps by eating food contaminated with such dejecta. It has also been stated that a common way of infection of rats might be the eating of the carcases of their dead infected comrades. In the case of man it is held by several observers that infection takes place through eating food contaminated either with the excreta of infected rats or by flies, etc., coming from infected material.

These hypotheses receive a certain amount of support from successful feeding experiments carried out by various workers in the laboratory. But the evidence which has been accumulated by the present Commission goes far to prove that infection does not thus occur in nature. Let us briefly consider this evidence ; first as regards rats—

1. We have already seen that the fæces and urine of plague infected rats and of human plague cases are not at all or only slightly

infective when rubbed into abrasions of the skin. It is surely justifiable to suppose that these excreta would be still less infective when diluted with food and brought in contact with a healthy mucous membrane. This supposition is borne out by a series of experiments which was made on rats. A large number (194) of rats were given the urine of human plague cases, in many of which bacilli were present in the blood at the time the urine was drawn off, but not one of these animals contracted plague.

2. We have already drawn attention to the contact experiments which were carried out in godowns 5 and 6 in the absence of fleas. In these experiments the food of the healthy animals was being continually contaminated with the urine and fæces of their plague-infected comrades and still not one of the former developed the disease.

3. We have also mentioned the observations made with young guinea-pigs, which were suckled by their plague-infected mothers until the death of the latter. Not one of these sucklings contracted plague, although it is reasonable to suppose that the milk of some at least of the mothers contained plague bacilli.

4. Many observers have shown that it is possible to infect rats in the laboratory by feeding them with grossly contaminated material, such as the organs or carcases of animals dead of plague. On these grounds and on these grounds only it has been held that in a state of nature rats generally become infected in this way, the bacilli gaining access through the mucous membrane of the mouth, throat or intestine. On account of those observations the Commission devoted particular attention to this question with the following result—

It was found possible to infect rats with plague by feeding them with grossly contaminated material of a soft nature, 21·4 per cent. of wild Bombay rats being susceptible to this method of infection. In a series of similar experiments made with *M. rattus* in the Punjab 67·8 per cent. of the rats were susceptible, but in this series a much larger dose of infected material was given. Further, a large number of wild Bombay rats were infected by feeding them on the carcases of their plague-infected comrades. No difference as regards the *post-mortem* appearances or the distribution of the primary bubo was found between rats infected in this latter way and rats infected by feeding on soft contaminated material. But, while

the general pathological lesions found in all rats infected by feeding were in the main the same as those found in rats naturally infected, there were observed two most important differences. First, in naturally infected rats, while the primary bubo was as a rule in the neck (74 per cent.), the axillary and inguinal glands being also often affected (25 per cent.), in not one single instance, out of 6,000 *post-mortem* examinations, was a bubo found in connection with the mesenteric glands in the abdomen. On the other hand, in the rats infected by feeding, the neck glands were involved in only 29 per cent. of the cases, the inguinal and axillary glands were practically never affected, while the mesenteric glands were the site of the primary bubo in no less than 72 per cent. of the infected animals. Secondly, in the case of naturally infected rats the stomach and intestines showed, as a rule no marked pathological change, while in the case of rats infected by feeding, well-marked lesions were found in the intestines. It would appear justifiable to conclude, then, that in nature, infection of rats by feeding rarely or never takes place and that rats do not become infected by eating the carcases of their comrades. At least this method of infection can play no part in the epizootic spread of plague.

As regards man becoming infected through eating plague-infected food all competent observers are agreed that the evidence is against such a method of infection. The first Indian Plague Commission were not able to discover any fact which would support the suggestion that plague may effect an entrance into the human organism through the stomach or intestinal canal. They concluded that, if infection takes place at all through this channel, it can be only in the very rarest instances. There is on record no *post-mortem* examination which points to the bacilli having gained entrance through the intestine and there is no description of primary mesenteric buboes having been observed.

Further, it is evident that man could never receive with his food anything like the number of bacilli which were ingested by the experimental rats mentioned above. In this connection it is also to be remembered that in the experiments in the flea-free godowns none of the guinea-pigs that ate food contaminated with the urine and fæces of their infected comrades

contracted the disease, and none of the rats which were fed on food contaminated with the urine of human plague cases developed the disease.

We are, therefore, now in the position to conclude that the transmission of infection by food plays no part in the spread of plague in nature either from rat to rat or from rat to man.

E.—Transmission of infection by means of the rat-flea.

We have now to consider the possibility of the plague bacillus being conveyed from rat to rat and from rat to man by means of some biting insect, such as the flea. A number of observers had already suggested and had brought forward a certain amount of evidence in support of their suggestion, that the rat-flea was the insect responsible. With the exception of two Frenchmen, Gauthier and Raybaud, no worker had, however, succeeded in an unequivocal manner in conveying the disease from animal to animal in the laboratory by means of fleas.

It was soon apparent to the Commission that, if any biting insect was the agent of the transmission of the bacillus from rat to rat and from rat to man, fleas, and those species of flea which infested rats, were practically the only insects which need be considered.

Investigation then showed that practically the only species of flea to be found on Bombay rats was *Pulex cheopis*, a flea first described by Rothschild, who has expressed the opinion that this species, except in Northern and Central Europe, is the commonest rat flea—in some localities almost the only species, found upon rats. All the experiments which are now to be summarised were made with this flea and when we refer to the rat-flea it is this species which is meant.

1. *Experiments in the laboratory.*

After several failures a command of the conditions necessary was attained and it soon became a simple matter to transmit plague from animal to animal by means of rat-fleas.

In the first series of successful experiments a glass case containing two wire cages side by side, each standing in a tin tray which collected the urine, was used. Both trays were filled with sand, in order to provide dryness and shelter for the fleas. Each cage was furnished with a lid through which the rats were introduced and food and water given to them. The whole apparatus was covered in with fine muslin to prevent the escape of the fleas. From this description it is seen that a rat placed in one of these wire cages could not come in contact with a rat in the other cage or with its urine and fæces.

The method of experiment was as follows. A plague-infected rat and a number of rat-fleas were placed in one of the wire cages. After the rat died, a fresh healthy rat was put into the other cage, the corpse of the infected rat being left in for 24 hours longer.

Sixty-six experiments with English white rats and with Bombay wild rats were done in this way, with the result that 30 healthy rats contracted plague ; that is to say, there were 45 per cent. of successful transmissions. In all cases a fairly abundant supply of fleas was present ; these could pass freely between the cages and, except for the air, formed the only apparent means of transmission of the bacilli from rat to rat.

In order to exclude aerial infection a second series of experiments was carried out, in which fleas were taken from a rat which had died of plague and were placed on a fresh rat in a clean flea proof cage of similar construction to that already described, but containing only one wire cage. Twenty-one (55 per cent.) successful transmissions out of 38 experiments were obtained in this way, both English white rats and Bombay wild rats being again used. The possibility of the rat-flea carrying plague from one rat to another was therefore demonstrated directly.

Following on these successes a comprehensive scheme of flea transmission experiments was at once started with the object of investigating several important questions which suggested themselves. The teaching of these experiments will be referred to later in their proper place. It is sufficient to state here, that many hundred successful flea transmission experiments were carried out with guinea-pigs, an animal which is an excellent host for *P. cheopis*. Finally, a considerable number of successful transmissions were obtained by confining fleas, taken from plague-infected rats, in test

tubes and allowing them to feed on definite areas of skin of healthy animals through a layer of muslin covering the mouth of the tube.

It is thus demonstrated, that, when the proper conditions are obtained, it is an easy matter to infect susceptible animals by means of rat-fleas taken from plague animals, all other means of infection being rigorously excluded.

2. *Experiments in godowns or cabins.*

We have already made passing reference to the experiments which were carried out in godowns or cabins especially constructed for the purpose. Attention has been drawn to the fact that these godowns differed from one another only in the structure of their roofs, which were so constructed, that in the interior of godowns Nos. 1 and 2 the supply of rat-fleas was abundant and regular, in Nos. 3and 4 it was more or less scanty, and in Nos. 5 and 6 there were no fleas. We have already seen that if fleas are rigorously excluded, as they were in godowns 5 and 6, close contact of plague-infected animals with healthy animals does not give rise to an epizootic among the latter. We have now to see what happens under similar circumstances if fleas are present. With this object in view a large number of observations were carried out in godowns 1 and 2 at all seasons of the year. When the experiments were carried out during the plague epidemic season, the disease at once started amongst the healthy animals and rapidly spread from animal to animal until not one was left alive. When, on the other hand, the experiments were made during the non-epidemic season, *e.g.*, in June or July, either none of the healthy animals became infected or only two or three contracted the disease and died. These experiments have been many times repeated and always with the same results. It will perhaps render the subject more easily understood if one experiment of each type is detailed as an example.

(*a*) *Godown No* 2, *January*, 1907.—This experiment was made at the same time as the one already described as having been carried out in godown 5, that is to say, at the beginning of the plague epizootic season in Bombay.

On 8th January, 1907, there were placed in the godown five guinea-pigs which had been inoculated with a virulent culture of

the plague bacillus. By 11th January, 1907, these five animals had succumbed to acute plague.

On 11th January, 1907, after the last inoculated guinea-pig had died and been removed from the godown, there were put in 25 healthy guinea-pigs, which were allowed to run free. An epizootic of plague of the most rapid description at once broke out amongst these healthy animals, the first dying on 15th January, 1907, and in a fortnight from their being placed in the godown the last one had succumbed to the disease.

Fleas were present in great numbers in the godown throughout this experiment.

(*b*) *Godown No. 2, June*, 1905.—On June 13th, 1905, that is during the non-epidemic season, 50 healthy and 10 inoculated guinea-pigs were placed in godown No. 2. The inoculated animals had all succumbed to plague by June 29th. Of the uninoculated guinea-pigs four died of plague, the first on the 2nd July and the last on 12th July. All the other animals remained healthy.

Experiments done in June and July, 1906, gave similar results, although in some instances not a single uninoculated guinea-pig became infected.

Again, by making contemporaneous experiments during the epidemic season in a godown with many fleas and in another godown with few fleas it was shown that the rate of progress of the epizootic is in direct proportion to the number of fleas present. Thus in an experiment carried out in godowns 2 and 4 during the rise of the plague epizootic of 1907 the following result was obtained. In godown 2, in which fleas were very abundant, the epizootic spread through 25 guinea-pigs in nine days, while in godown 4, in which few fleas were present, it lasted 68 days, the same number of guinea-pigs being present.

If further proof were necessary to prove that the fleas present in the godowns were the agents of transmission of infection, this proof is afforded by the following observations :—

(1) Fleas taken from infected godowns, placed in test-tubes and fed through muslin on healthy guinea-pigs, infected the latter.

(2) We have already referred in passing to some experiments which were carried out in godowns 1 and 2, in which three

groups of guinea-pigs were exposed to infection in different ways, one group being allowed to run about on the floor, the second group being placed in wire cages two inches from the floor and the third being suspended two feet from the ground, also in open wire cages. It was already known that a flea could not jump more than from four to six inches. This experiment has been repeated on several occasions and a'ways with the same result. The following may be taken as a typical example :—

On 28th January, 1907, into godown 2, in which a plague epizootic had just come to an end by killing all the animals, three groups of four guinea-pigs each were distributed as follows :—

(*a*) four guinea-pigs running free on the floor;
(*b*) four guinea-pigs in wire cages two inches above the ground;
(*c*) four guinea-pigs in wire cages suspended two feet above the ground.

On 30th January, 1907, these guinea-pigs were removed from the godown, freed from fleas under chloroform and segregated. One hundred and twenty-five fleas were taken on the guinea-pigs of Group A, 27 on those of Group B and none on those of Group C. The eight animals of Groups A and B were observed to be ill and to have buboes in the neck. The four guinea-pigs of Group C appeared to be quite well.

The fate of the animals of these three groups was as follows :—

Group A.—One died under the chloroform ; it was proved bacteriologically to be plague-infected. The other three all died of plague.

Group B.—All four animals died of plague.

Group C.—All four animals remained healthy.

In short, the animals which were within the limit of a flea's jump all died of plague, while none of those which were outside this limit contracted the disease.

(3) On several occasions monkeys were placed in pairs in cages in an infected godown. Both animals were protected from soil infection and were equally exposed to aerial infection. One animal was, however, protected from fleas, either by a broad (six inches) strip of sticky material, namely, "tanglefoot," or by a fine metallic gauze curtain, while the other was not so protected. They were left in the godowns for 48 hours.

The result of these experiments was that not one of 11 animals protected from fleas contracted plague, while six out of 13 unprotected developed the disease.

It will be seen that these godown experiments were of the most exhaustive nature and yielded most convincing proof of the part played by the rat-flea in plague epizootics. As the references made to these observations have of necessity been somewhat scattered, it will be well to summarize the conclusions which may be drawn from them. These conclusions are—

(*a*) Close and continuous contact of plague-infected animals with healthy animals, if fleas are excluded, does not give rise to an epizootic among the healthy animals. As the godowns were never cleaned out, close contact includes contact with fæces and urine, and eating of food contaminated with fæces and urine of infected animals. Close contact, even the suckling of young by plague-infected mothers, does not give rise to the disease.

(*b*) When fleas are present, the epizootic, if it does start, varies in severity and rate of progress according to the season of the year and the number of fleas present. The season, in which epizootics are readily produced experimentally and spread rapidly, corresponds with that of the plague epidemic.

(*c*) An epizootic of plague can occur in a godown containing infected fleas without direct contact of healthy animals and infected animals.

(*d*) In an infected godown the infection is effective in proportion as the test animals are accessible to fleas.

(*e*) Infection can take place without any contact with contaminated soil.

(*f*) Aerial infection is excluded.

(*g*) The experiments lead to the conclusion that fleas and fleas alone were the transmitting agents of infection.

3. *The rat-flea the agent of transmission of infection from rat to rat in nature.*

We have already seen from experiments in the laboratory and in the godowns, that the only means of transmitting plague from

animal to animal at all comparable to what would occur in nature, are—

(*a*) by feeding on grossly contaminated material, and
(*b*) by rat-fleas.

Further, we have excluded the possibility of the first of these methods ever happening in nature.

We propose now to bring forward more evidence in support of the second of these methods, namely, flea transmission. This evidence is obtained from a comparison of the distribution of the primary bubo in animals, rats and guinea-pigs, infected in nature with its distribution in the same animals infected in the laboratory by means of fleas. Let us first consider the case of rats.

In Bombay, during both the plague season and the non-plague season, it was found that the great majority of rats that died of plague in nature had the primary bubo in the neck, the next most common sites being the armpit and the groin. This statement holds good both for *M. decumanus* and for *M. rattus*. The same distribution of the primary bubo was found to be present in plague-infected rats in the Punjab villages.

When we compare this distribution with the distribution in rats infected in the laboratory by means of fleas, we find a remarkable similarity, the neck glands being again most commonly involved, those in the axilla and groin next. The following table shows at a glance this comparative distribution :—

	Naturally infected.	Infected by fleas.
Rats examined	5,188	117
	per cent.	per cent.
Rats without buboes . . .	16	18
Cervical bubo	72	61
Axillary bubo	23	22
Inguinal bubo	18	35
Mesenteric bubo	0	0

Material evidence is here adduced that the rats in nature are infected by means of fleas.

Among guinea-pigs the distribution of the primary bubo in three groups was as follows :—

(*a*) A group of 87 animals, naturally infected in plague houses.

(*b*) A group of 253 animals, infected in the course of the godown experiments already referred to. (It will be remembered that the conclusion was come to that these animals, were infected by rat-fleas, all other means of infection being excluded.)

(*c*) A group of 108 animals, experimentally infected in the laboratory by means of fleas.

The following table summarizes very shortly the distribution of the primary bubo in these three groups of guinea-pigs.

	Naturally infected.	Infected in godowns.	Infected by fleas.
Guinea-pigs examined .	87	253	108
	per cent.	per cent.	per cent.
Without buboes . . .	1	1	1
Cervical bubo . . .	92	92	91
Axillary bubo . . .	1	3	6
Inguinal bubo . . .	14	13	22
Mesenteric bubo . . .	0	0	0

The close correspondence between the distribution of the buboes in these three groups of animals points to the conclusion that the mode of infection was the same in all cases. It would follow that both in the experimental godowns and in plague-infected houses the infection was conveyed to the guinea-pigs by fleas.

4. *Infection in plague houses due to infected rat-fleas.*

We have now to consider certain observations which prove both indirectly and directly that in a plague-infected house the infection is due to the presence therein of rat-fleas which are capable of transmitting the disease to animals. These

observations, which were carried out in Bombay and in the Punjab, fall naturally into four groups.

Group I.—In this group, which is divided into two series, guinea-pigs were allowed to run free for about 18 to 40 hours in houses in which one or more plague cases had occurred or in which dead rats had been found. They were then removed, cleared of fleas and segregated in the laboratory. In the first series the houses had not been disinfected, while in the second series disinfection had been carried out.

Series 1.—In this series we have to record observations made in Bombay during the plague season of 1906 and again during that of 1907, and also observations made in the Punjab villages of Dhund and Kasel in 1906. The results were as follow :—

(*a*) Bombay 1906 : 42 houses tested ; 12 houses infected the guinea-pigs, namely, 29 per cent.

(*b*) Bombay 1907 : 100 houses tested ; 19 houses infected the guinea-pigs, namely, 19 per cent.

(*c*) Punjab villages 1906 : 49 houses tested ; 9 houses infected the guinea-pigs, namely, 18·4 per cent.

Of a total of 189 houses tested in this way 40, or 21 per cent., proved " infective " to guinea-pigs.

Series 2.—The observations in this series were made in Bombay in 1906 in houses which had been disinfected before the guinea-pigs were put in. In most cases the process of disinfection carried out by the Health Department of the Municipality of Bombay, consisted in washing thoroughly the walls and floors with an acid solution of perchloride of mercury of a strength of 1 in 750, a solution which, as has been abundantly proved, readily kills the plague bacillus even in organic mixtures. In a few instances gaseous disinfection with the fumes of burning sulphur was used, while in still a few other cases a combination of these two methods was carried out. The results were as follow :—

Thirty-one houses were tested and in nine instances (29 per cent.) the animals became infected. It is noteworthy that in many instances the number of fleas trapped by the guinea-pigs was very large, as many as 263 being taken from one house, while the average of the 31 observations was 40 fleas per house.

The significance of this group of experiments may be stated

as follows :— We have already seen that guinea pigs may live in contact with plague-infected animals, may run about on floors contaminated with the urine and fæces of these animals and may eat food similarly contaminated, and still not contract the disease, if fleas are excluded. In the above experiments, therefore, we are led to conclude that the guinea-pigs which became infected contracted plague, not from contact with plague-infected animals nor from contaminated floors nor from contaminated food, but possibly from fleas infected by plague rats. This conclusion receives support from the fact that rat-fleas, as we shall see, were caught in considerable numbers on the animals. It receives further support from the fact, which we have already mentioned, that disinfection with perchloride of mercury kills all plague germs present in the walls and floors, even when the latter are covered with cowdung, but does not affect the fleas.

Group II.—In this group of observations, which also is made up of two series, fleas taken in plague houses were fed on rats or guinea-pigs in flea proof cages in the laboratory. The two series only differ from one another in the manner in which the fleas were obtained.

Series 3.—In this series the fleas were taken on rats, which were proved at the laboratory to be plague-infected. They were transferred in each instance to healthy guinea-pigs. The results were as follow :—

(*a*) Bombay, 1906 : 3 experiments ; 3 successes.
(*b*) Bombay, 1907 : 3 experiments ; 3 successes.
(*c*) Punjab villages, 1906 : 6 experiments ; 3 successes.

A total of 12 experiments with 9 successes (75 per cent.).

Series 4.—In this series the fleas were taken on guinea-pigs, which had been left for some time in plague houses. They were brought to the laboratory in test-tubes and were then transferred to fresh animals, guinea-pigs or rats, in flea proof cages.

The results of these observations were as follows :—

(*a*) Bombay, 1906 : 40 experiments ; 8 animals died of plague (20 per cent.).
(*b*) Bombay, 1907 : 31 experiments ; 11 animals died of plague (35 per cent.).
(*c*) Punjab villages, 1906 : 25 experiments ; 7 animals died of plague (28 per cent.).

A total of 96 experiments with 26 successful transmissions, namely, 27 per cent.

It is important to note that the great majority of the fleas caught on the guinea-pigs placed in the houses were rat-fleas (*P. cheopis*).

Group III.—In this group of experiments, which is also made up of two series, the conditions were so arranged that, while all the animals were protected from soil infection and from infection by contact with any plague-infected rats which might be in the room and were equally subject to aerial infection, half of them were protected from fleas and the other half were not so protected. For each experiment a pair of animals, one protected and the other not protected, was used.

Series 5.—In this series the protection from fleas was obtained by means of a curtain of fine metallic gauze, the mesh of which was slightly larger than of that used for filtering petrol. In the other cage a layer of ordinary wire netting took the place of the gauze. The cages were left in the room for 48 hours: they were then removed and the fleas taken off the animals which were segregated. The following were the results:—

(*a*) Bombay, 1906: 42 experiments.

(1) Protected animals—all remained healthy.
(2) Unprotected animals—4 developed plague.

(*b*) Punjab, 1906: 21 experiments.

(1) Protected animals—all remained healthy.
(2) Unprotected animals—4 developed plague.

(*c*) Total; 63 experiments.

(1) Protected animals—all remained healthy.
(2) Unprotected animals—8 developed plague (13 per cent.)

Series 6.—The experiments of this series differ from those of the last series in that one of the animals instead of being protected from fleas by means of a metallic gauze curtain was surrounded by an area spread with "tanglefoot," a sticky, resinous preparation used for catching flies. The minimum width of this area was six inches, a distance which no flea can jump. In the case of the control animal the "tanglefoot" was replaced by a layer of sand.

The following were the results of these experiments:—

(*a*) *Bombay*, 1906 : 29 experiments.

(1) "Tanglefoot" animals—all remained healthy.
(2) "Sand" animals—7 developed plague.

Out of 247 fleas caught on the "tanglefoot" 60 per cent. were human-fleas, 34 per cent. were rat-fleas, and 6 per cent. were cat-fleas.

Plague bacilli were demonstrated in the stomach contents of 1 out of 85 of the human-fleas dissected and of 23 out of 77 rat-fleas (30 per cent.).

(*b*) *Punjab villages*, 1907 : 30 experiments.

(1) "Tanglefoot" animals—all remained healthy.
(2) "Sand" animals—2 developed plague.

The species of 156 of the fleas caught on the "tanglefoot" was determined ; 138 were rat-fleas, and only 18 were cat-fleas. There were no human-fleas. Fifty-five rat-fleas were dissected, and the stomach contents of three were found full of plague bacilli.

The small number of successes in the experiments of Group III in comparison with those of Group I, in which the guinea-pigs were allowed to run free, is due to the fact that fleas did not reach the caged animals in anything like the same number as they did the free animals. Thus, in Series 1 the average number of fleas per house was 20 and in Series 2, 40 ; while in Series 5 an average of only three fleas per house were taken on the unprotected animals.

Before passing on to the last group of observations we have to draw attention to the fact that by far the most common site of the primary bubo in the animals which became plague-infected in all the above experiments was the cervical region. We have already pointed out the significance of this distribution and have shown that it points strongly to an infection by means of fleas.

Group IV.—This group consists of a series of observations, having as its object a comparison of the number of rat-fleas caught n plague houses with the number taken in non-plague houses.

In the course of the observations of Group I with free guinea-pigs carried out in 1906 in Bombay and in the Punjab a careful census was made of the fleas caught in the houses. At the end of the observations the houses were divided into two classes : (A), a class in which the houses were definitely shown to be plague infected, either because plague-infected rats had been found in

the house or because one or both of the guinea-pigs developed the disease ; and (B), a class made up of the remainder, in which the houses were only presumably plague-infected, inasmuch as one or more plague cases had occurred in them. The data concerning the flea census in these two classes of houses are summarised in the accompanying table :—

	Class A.			Class B.		
	Houses definitely proved plague-infected.			Houses only presumably plague-infected.		
	Bombay.		Punjab.	Bombay.		Punjab.
	Houses not disinfected.	Houses disinfected.		Houses not disinfected.	Houses disinfected.	
No. of houses examined	13	10	18	29	21	31
Total No. of fleas caught	445	731	467	388	488	246
Average No. of fleas per house	34	73	26	13	23	8

From this table it is seen that the average number of fleas in the houses which were definitely proved to be plague-infected was in each instance about three times as great as in the houses which were only presumably plague-infected.

During the plague epidemic in Bombay of 1907 further observations of a similar nature to those mentioned above were made. In this instance, however, a third class of houses was added, namely, houses which were definitely known not to be plague-infected. The three classes of houses, therefore, in which the fleas were enumerated were as follows :—

A. Houses deemed plague-infected for one or more of the following reasons : (1) a dead plague-infected rat or

rats had been found in the house; (2) the guinea-pig—in this series only one animal was put into each house—which was allowed to run free in the house developed plague and died; (3) one or more of the fleas taken in the house were found on dissection to be plague infected; (4) fleas taken in the house gave plague to a healthy guinea-pig, on which they had been placed.

B. Houses presumably plague infected, either, (1) because a plague case or cases had occurred in the house; or, (2) because dead rats, which had not been sent for examination, were found in the house.

C. Control houses of the same type and situated in the same neighbourhood as above, but which were definitely known not to be plague infected.

The results of the flea census made in these three classes of houses are set forth in the accompanying table, from which it is seen that houses which were definitely proved to be plague infected contained on an average nearly three times the number of rat-fleas-contained in houses which were only presumably plague infected and 12 times the number contained in houses which were free from suspicion.

	Class A.	Class B.	Class C.
Total No. of houses	27	73	68
Total No. of fleas taken	784	755	169
Average No. of fleas per house	29	10·3	2·5

A further point of interest which came out of these observations is, that out of 130 fleas which were dissected and examined the stomach contents of 41 (32 per cent.) contained abundant plague bacilli.

From a consideration of all these observations, both in Bombay and in the Punjab, the only conclusion which can be come to is that in a plague-infected house the infection is due to infected rat-fleas and not to any infection of the soil or of the air.

5. *The rat-flea the agent of transmission of infection between the rat and man.*

We may now state the evidence which can be adduced in favour of the theory that the rat-flea is the agent and the only agent of transmission of the infection from the rat to man.

In the first place, we have to consider the question of the path by which the plague bacillus effects an entrance into the human organism.

In the case of primary pneumonic plague there is no question that the infection is contracted by inhalation. Pneumonic cases are, however, rare (2·5 per cent.) and play little or no part in the spread of epidemic plague. While this is true of pneumonic plague, almost all observers are agreed that, as far as the common forms of the disease are concerned, man becomes infected through the skin, the primary bubo developing in the glands in connection with the lymphatics which drain the area of skin through which the plague bacilli gain entrance. A large series of experiments in guinea-pigs, in which infected fleas were fed on definite areas of skin, supported this opinion, inasmuch as they showed that in this case at any rate the bubo always developed in the glands in connection with that area of skin on which the fleas were fed. This being admitted, at one time it was thought that Indians, going about as they do bare-footed, usually became infected by bacilli in the soil getting rubbed into abrasions on the feet. This hypothesis was founded chiefly on the observation that a large proportion of plague cases have the bubo in the groin. The Indian Plague Commission, however (Vol. V, p. 70), pointed out that in proportion to the area of skin which drained into them the glands of the groin were not more commonly affected that the glands of the axilla or of the neck. Thus, they pointed out that the areas of skin surface, which drain respectively into the glands of the neck, the axilla and the groin, stand to each other approximately as the figures

1 : 1·8 : 5, while the numbers of cervical, axillary and inguinal buboes stand to each other severally in the relations expressed by the figures 1 : 1·3 : 5·8. Further, it has also been shown that in communities wearing shoes the percentage of groin buboes is no less than in those who go about bare-footed.

It would appear, then, from these considerations that in the case of man there is no seat of election, as it were, of the skin area through which the plague bacillus enters.

In considering other possible modes of entrance of the plague bacillus, the Indian Plague Commission came to the conclusion that man never or only in the very rarest instances became infected through the digestive tract. Within recent years, however, certain workers in Hong-Kong, as a result of clinical experience, *post-mortem* examination and feeding experiments, have favoured this method of infection. The evidence brought forward by them is by no means convincing, and the results of the *post-mortem* examinations and of the animal feeding experiments have not been confirmed by other observers.

In conclusion, we may take it, therefore, that all the evidence which is available points to man becoming infected through the skin and is in favour of the agent of infection being of such a nature as the flea.

In the second place, we have already seen that both in Bombay and in the Punjab there is a definite time relationship between the rat epizootic and the epidemic.

In the case of Bombay City the average interval, as deduced from the curves showing the relation in time of the *rattus* epizootic and the epidemic, was 10—14 days, while in the case of the village of Kasel in the Punjab the same interval was about a week. The Bombay epidemic curve, however, was calculated on plague deaths, while the Kasel curve was on plague attacks. The interval in the latter case would, therefore, be shorter by a few days than the Bombay interval. Further, in the village of Kasel an opportunity was obtained of estimating the average interval between the finding of dead plague rats in the houses and the occurrence of the first plague case in them. In five houses, in which plague rats were found on only one occasion prior to the human case, the average

interval between the two was ten days. In 14 houses, in which plague rats were found on more than one occasion prior to the human attack, the average interval between the finding of the first plague rat and the first case was 12 days, while the average interval between the last plague rat and the first case was seven days. These intervals correspond closely with those deduced from the curves representing the *rattus* epizootic and the epidemic both in Bombay and in Kasel itself. This interval is best explained on the supposition that there is an intermediate agent between rat and man. Assuming the truth of the flea theory it is divisible into three periods as follows :—

(*a*) A period elapsing before the rat-flea, coming from the dead rat, bites man, namely, three days.

This period of three days is deduced from a large number of observations made with rat-fleas in the laboratory. In these experiments it was found that rat-fleas deprived of food for from 72 to 96 hours attack and feed on man most readily. In this connection it is also to be noted, as will be shown later, that the percentage of infected fleas taken from plague rats is greatest for the first four days and after that rapidly diminishes.

(*b*) Incubation period of human plague, namely, average of three days.

(*c*) Duration of illness of fatal human plague cases, namely, average of 5½ days.

The periods (*a*), (*b*), and (*c*) make up the interval between the *rattus* epizootic and the epidemic in Bombay, and the periods (*a*) and (*b*) the interval in the village of Kasel.

In the third place, we have already seen that in experiments in plague-infected houses the only possible explanation of the results obtained with animals, *i.e.*, guinea-pigs, was that the rat-flea and the rat-flea alone was the agent by means of which the animals became infected, and that the infection in the houses was solely due to the presence therein of infected rat-fleas. Further, in several of these experiments and in some experiments in the godowns, which have been referred to already, monkeys were infected under the same conditions, that is to say, under conditions which excluded all other means of infection but infected rat fleas. It has, of course,

been impossible to make direct experiments with man of a similar nature to those described and one is always reluctant inferentially to transfer the results of experiments made on animals to man. In the present instance this reluctance, it appears to us, would be completely overcome, if it could be shown that rat-fleas will at all readily use man as a host. With this end in view a large number of observations have been made by the Commission which confirm those already made by Liston in Bombay. These observations are summarized as follows—

(*a*) Observations made in the laboratory.

In the course of the large number of flea experiments made in the laboratory it was often noticed that, when a man's hand is put into a cage containing rat-fleas, the fleas will jump on the hand and if given time will feed on it. When the fleas are starved they will more readily bite man and most readily when the starvation process has lasted for from 72 to 96 hours. While this is so, it was also noticed that unless the fleas were very numerous they would not attack man in the presence of their natural host, the rat.

Further, it was found that rat-fleas may be attracted to man, jump on him but take some time to feed on him. This last observation is of importance in connection with the question of importation of infected fleas from place to place. Fleas might be carried by man from one place to another without infecting him, but would, when brought near a rat, attack and infect it in preference to man.

Finally, it was ascertained that rat-fleas could be kept alive for some considerable time, namely, 3—4 weeks, by feeding them on human blood alone. Rat-fleas when starved never survive longer than a week.

(*b*) Observations in the course of the godown experiments.

In the course of the godown experiments, to which reference has been already made, fleas in considerable numbers have often been taken on the legs of men who entered the godowns only for a short time. As many as 44 fleas have been captured on the legs of a man who went inside four times in quick succession and remained in the godown each time no longer than was required to pick up and remove a cage

(*c*) Observations made in houses in Bombay.

In the course of the observations in Bombay the members of the Commission had very often occasion to enter plague-infected houses. On many instances they caught rat-fleas on their own persons as well as on those of the attendants. In one house in particular, which the inhabitants had evacuated after a very severe rat mortality, many rat-fleas were caught on successive days on a man who went inside only for a short time; thus, on April 18th, 51; on April 19th, 34, and on April 20th, 60 rat-fleas were taken in this way.

From these various observations it is evident that the rat-flea, *P. cheopis*, under certain circumstances, especially in the absence of its true host, the rat, is attracted by man and will readily bite and feed on him.

Additional evidence of a more indirect nature might be brought forward in support of our present thesis, but it would appear to be unnecessary.

We can, therefore, now safely conclude that the rat-flea and the rat-flea alone is the agent of transmission of the plague bacillus from rat to man.

(6) *Further observations on the transmission of plague by fleas.*

We have now reached a stage when we may profitably pause and consider some subsidiary problems which naturally follow on the demonstration of the part played by the rat-flea in the transmission of plague from animal to animal in nature. These problems are —

(*a*) The fate of the plague bacillus in the body of the rat-flea and the mechanism by means of which the flea infects a healthy animal.

(*b*) Whether a single rat-flea can transmit the infection.

(*c*) Whether both male and female rat-fleas can transmit the infection.

(*d*) Whether other species of fleas, as well as *P. cheopis*, can transmit the infection.

(*a*) *The fate of the plague bacillus in the body of the rat-flea and the mechanism by means of which the flea infects a healthy animal.*

A study of the anatomy of the mouth parts and of the alimentary canal of the rat-flea shows that the blood is sucked up from the wound made by the pricker and is then passed down the gullet by successive waves of contraction of the muscles from before backwards into the stomach, which is guarded anteriorly by a valvular arrangement.

The stomach is a pear-shaped organ occupying a considerable part of the abdomen of the insect. That the stomach is capable of containing a considerable amount of blood is apparent from the observation that after a flea has fed nearly the whole of the abdomen is seen to be filled with a bright red mass.

In order to arrive at some conception of the chance of a flea taking plague bacilli into its stomach and of the number likely to be imbibed from the blood of a rat dying of plague, the Commission made both approximate measurements of the average capacity of the flea's stomach and accurate estimations of the average number of live plague bacilli contained in the blood of rats dying or recently dead of plague. The technique of these operations is too complicated to describe here ; it is sufficient to state the following conclusions :—

The average capacity of a rat-flea's stomach has been approximately estimated to be 0·5 c. mm. The blood of a plague-infected rat before death may contain as many as 100,000,000 bacilli per c. c. If, therefore, a rat-flea imbibed the blood of such a rat it would receive into its stomach 5,000 germs. Further, it is evident that a flea that imbibed the blood of a rat containing 10,000 or more germs per c.c. would take some bacilli into its stomach. Now, it was found that the blood of about two-thirds of plague-infected rats contains more than this number of germs, so that rat-fleas in sucking the blood of plague rats in nature must have ample opportunity of taking bacilli into their stomachs.

Evidence was next obtained on the question of the multiplication of plague bacilli in the stomach of the flea. Fleas were fed on plague-infected rats until the death of the latter animals. They were afterwards fed on healthy animals, a fresh animal being supplied each day, so that it was impossible for them to imbibe any

more bacilli. Each day a number of the fleas was dissected and the stomach contents examined as to the presence or absence of plague bacilli. In a certain proportion abundant germs were found up to the 12th day and in one instance on the 20th day. We have good evidence in this observation that multiplication of plague bacilli may take place in the flea's stomach, for, if there had been no multiplication, the bacilli-laden blood imbibed originally would soon have been diluted to a marked degree and the bacilli washed out by the blood taken in at each feed on the healthy animals.

The next point to determine was the approximate proportion of fleas in the stomachs of which multiplication of plague bacilli takes place. This proportion was found to vary with the season of the year, being six times greater in the epidemic season than in the non-epidemic season. In the epidemic season the percentage of infected fleas was greatest for the first four days (43 per cent.) after removal from the plague rat, but a certain number were found with bacilli in their stomachs up to the 12th day; thus, on the 6th day there were 15 per cent., on the 8th day 16 per cent. and on the 12th day 9 per cent. On one occasion the stomach contents of a 20th day flea were found full of plague bacilli. In the non-epidemic season no flea was found with plague bacilli in its stomach after the 7th day and of those examined during the first six days only 5·2 per cent. were infected.

It was important now to determine the duration of infectivity of rat-fleas taken from plague rats when tested on susceptible animals. This was done by feeding fleas, which had imbibed blood containing plague bacilli, on healthy guinea-pigs, a fresh animal being supplied each day, until all the fleas had died. After being in contact with the fleas for 24 hours each guinea-pig was carefully cleared of fleas and segregated. In this way several series of experiments were done with the following results:—One series done during the epidemic plague season and in which a limited number of fleas were used showed that, in these circumstances, fleas could remain infective for at least 10 days. A second series, also carried out during the epidemic season, but in the presence of a very large number of fleas, gave the time that fleas might remain infective as 15 days. In a third series of experiments, conducted under the same conditions as the second series but during the non-plague season, the fleas remained infective for only seven days and,

further, far fewer (one-third instead of two-thirds) animals than in the second series contracted the disease. It is to be remembered that in these experiments the fleas were fed throughout. Starved fleas, even when placed under the most favourable conditions, never survive longer than a week.

The next questions which suggested themselves were, (1) are the bacilli to be found anywhere in the body of the flea outside the stomach? and (2), how do the bacilli leave the flea's body? The blood after the end of the digestive process in the stomach passes into the rectum of the flea as a thick, slimy, dark-red mass and appears at the anus as minute, dark-red or black, tarry droplets. It is easy to demonstrate by dissection and examination that the rectal contents are often crowded with plague bacilli, and it has been repeatedly shown, both by microscopical examination and by animal tests, that the fæces may contain abundant and virulent plague bacilli.

On the other hand, a very large number of fleas, which had come off plague rats at intervals varying from a few hours to several days, have been dissected and the various parts of the body examined for the presence of bacilli. On rare occasions a few bacilli have been seen in the gullet but only in these cases in which the flea has been killed immediately after feeding. As regards the other regions of the body, in not a single instance have any plague bacilli been observed outside of the organs already mentioned. No infection of the body cavity has been seen and, although particular attention was paid to the salivary glands, nothing at all resembling a plague bacillus has ever been detected in them. It would appear, then, that nowhere outside the stomach and the alimentary canal posterior to the stomach are plague bacilli to be found in any numbers and that they leave the body chiefly, if not entirely, along with the fæces.

These observations have a distinct and important bearing on the next question which we have to consider, namely, the question of how the flea transmits its infection to the healthy animal. It is evident that several methods of transmission are possible, such as (*a*) the animal eating the infected fleas; (*b*) the mechanical conveyance of the bacilli by the pricker; (*c*) the injection of the bacilli along with the saliva as the result of an infection of the salivary glands; (*d*) the regurgitation of the stomach contents or the retention

of the infected blood about the mouth parts or in the pharynx, the bacilli being then injected with the saliva or carried down on the pricker or rubbed into the wounds made by the pricker; (*e*) the deposition of the infected fæces on the skin, the bacilli being then injected by the pricker or rubbed into the wounds made by the pricker.

After careful consideration of all the available evidence bearing on the subject the Commission were of opinion that it pointed to the conclusion that the bacilli after multiplying in the stomach leave the body of the flea with the fæces and then become injected into the healthy animal either by being carried in by the pricker or by being rubbed into the pricker wounds. In addition to the evidence already mentioned pointing to this conclusion we may mention the fact, that the flea while sucking has a habit of squirting blood *per anum*. Further, experiments have shown that the wounds made by the pricker afford a sufficient avenue for the entrance of the bacilli, even when no rubbing is resorted to. While all the evidence points to the inoculation of the fleas' fæces being the method of infection, the possibility of infection by contaminated mouth parts or by regurgitation from the stomach cannot be altogether excluded, although no evidence could be obtained in favour of either of these methods. Infection by the eating of infected fleas and by infected saliva can be almost certainly excluded.

(*b*) *Whether a single rat-flea can transmit the infection.*

Rat-fleas were taken off plague-infected rats after the death of the latter. They were then transferred to healthy guinea-pigs in clean flea-proof cages, one flea being added to each cage. Sixty-seven experiments were made in this manner, but only in one instance was there a successful transference of the disease. As we can estimate that about half of these 67 fleas contained plague bacilli in their stomachs, it would appear that the chances of an animal contracting plague after being bitten by a single infected flea are remote.

(*c*) *Whether both male and female rat-fleas can transmit the infection.*

Observations were made to ascertain if both the male and female *P. cheopis* could transmit plague from animal to animal.

Six experiments were carried out with each sex, with the result that one animal in each series became plague infected.

(*d*) *Whether any other species of flea, as well as P. cheopis, can transmit the infection.*

Three other species of flea were available for these observations, namely, *Ceratophyllus fasciatus*, *Pulex felis and Pulex irritans*.

1. Experiments with *Ceratophyllus fasciatus*.

This is the common rat-flea of Northern Europe. It is not found at all in Bombay, but in the cold weather was taken on rats in the Punjab to the extent of 2 per cent. On account of its scarcity and because the experiments were made towards the end of the observations at Dhand and Kasel, only two experiments were completed with this flea. Both these experiments were successful, showing definitely that *Ceratophyllus fasciatus* can convey plague from infected to healthy animals.

2. Experiments with *Pulex felis*.

This is the common flea found on cats and dogs. It was found not to live well on guinea-pigs and rats. Transmission experiments with it were carried out by feeding the fleas first on Bombay rats infected with plague and on the death of the latter transferring them to fresh guinea-pigs in clean flea-proof cages. Although 27 experiments were made in this way, not a single successful transmission was obtained. It should be added that these experiments were made during the height of the plague epidemic in Bombay.

3. Experiments with *Pulex irritans*.

Experiments with this flea, the common species found on man, were carried out in the same manner as those with cat fleas. Out of 38 experiments three of the guinea-pigs became plague infected. This small number of successes may be explained by the fact that this flea does not live well either on rats or on guinea pigs. It was found that, if kept on rats, only 1·2 per cent. of the number originally put on could be recovered after 24 hours and that after 72 hours this was further reduced to 1 per cent.

Part IV.—RELATION OF THE HUMAN PLAGUE CASE TO THE SPREAD OF THE EPIDEMIC.

A.—Introduction.
B.—Experience in hospitals.
C.—Influence of imported cases on the spread of the epidemic.
D.—Previous history of plague cases as regards contact with other plague cases.
E.—Relative frequency of the occurrence of single and multiple cases of plague in houses and buildings.

A.—Introduction.

Considering that we have already arrived at the conclusion that the plague epidemic is solely attributable to the rat epizootic, it may seem superfluous further to examine the question as to the part played by a human plague case in the spread of the epidemic. This question is, however, of so much importance to the sanitarian, who is called upon to devise prophylactic measures, that we propose now to gather together all the evidence on the subject which is available, in order that such a definite conclusion may be arrived at as to enable the administrator to act upon it with confidence.

In the following remarks it is to be understood that pneumonic plague cases are excluded. The contagiousness of this class of case and the mode of transmission of the infection have never been disputed; but on account of their rarity pneumonic cases can play only a minor part in the spread of the epidemic.

A little consideration will make it evident that an ordinary plague case can only be infectious, in so far as the excreta are infectious or in so far as the infection is carried by means of a suctorial insect such as the human flea. We have already brought forward experimental evidence to show that the excreta of plague cases, as well as of plague rats, are not infective when the methods of inoculation practised are such as would occur in nature. As regards the human flea being an agent in the conveyance of the disease, it cannot be denied that this flea can transmit the infection

from animal to animal in the laboratory. Other experimental data, however, such as, the comparatively small number of plague bacilli present in the blood of plague cases, are against this hypothesis, so that to conclude off-hand from the transmission experiments done in the laboratory that such a method of transmission from case to case takes place in nature would be extremely dangerous and, as we shall see later, would lead us into grievous error. We do not now intend to enter again into the experimental evidence, valuable as it is, which is opposed to the belief that a plague case is infectious. We propose, however, to take up the question from the epidemiological aspect, drawing our evidence from various sources and only referring to experimental data when necessary.

B.—Experience in Hospitals.

It has long been observed in India that the attendants in a plague hospital remain singularly free from infection, although they are brought frequently into intimate contact with patients in the acute stage of the disease. So well is this fact recognised that it has become a saying "that the safest place in a plague epidemic is a hospital." The Commission's experience in the plague hospitals of Bombay, as well as in the homes where cases were treated, forced the members to the same conclusion.

In order, however, further to investigate the point, experiments of three different kinds were made—

(1) Two guinea-pigs were allowed to run free in the acute plague ward of the Maratha hospital, Bombay. Although kept in the hospital for one week these animals remained healthy.

(2) Bedding recently soiled by the excreta of acute cases just before death was obtained daily from the hospital and put into a confined space, namely, godown No. 5, along with 15 guinea-pigs. Each lot of bedding was kept in the godown for 24 hours, but the same guinea-pigs were exposed throughout. Although the experiment was continued for several weeks and in the intimate contact of a confined space, a contact, which was closer and more prolonged than any that could possibly happen in the case of man, none of the guinea-pigs contracted the disease.

(3) We have already stated that neither the urine nor fæces of acute plague cases infect guinea-pigs when rubbed into abrasions on the skin.

C.—Influence of imported cases on the spread of the epidemic.

When we come to deal with the subject of importation of plague into localities hitherto uninfected, we shall see that imported plague cases are in many instances seemingly the starting point of the epidemic. Now, we have already arrived at the conclusion that the epidemic is wholly dependent on the rat epizootic, so that it follows that there must be a connection between the imported case and the start of the epizootic. What this connection is we shall see later on. At present, however, we wish to bring forward some observations of the Commission in regard to the fate of the contacts of plague cases imported into the villages in Bombay and in the Punjab, when there was no evidence of a rat epizootic resulting.

(1) Out of 28 cases which occurred in Parel village 17 were undoubtedly imported, having acquired their infection in Bombay. In the houses in which these cases were treated a large number of individuals were living in the same rooms as the sick, but in no instance did any of the healthy become infected.

(2) In the case of Wadhala village early in the year two separate cases were imported from Bombay City. None of the inhabitants of the houses in which these cases lived contracted the disease and there was no extension of the infection in the village.

(3) During the year that Worli village was under observation three cases of plague occurred. There is no doubt that all these cases were infected outside the village. Again the contacts remained healthy and there was no extension of the disease.

Without entering into details we may say that similar observations were made in the Punjab.

Before leaving this question we would like to make it clearly understood that while these observations appear to show that an imported plague case is of no danger *per se* to those with whom it comes in contact, it by no means follows that a plague case may not import with it something, *e.g.*, infected rat-fleas

which may infect the indigenous rats and thus be the starting point of the rat epizootic and, in consequence, indirectly, of the epidemic.

D.—Previous history of plague cases as regards contact with other plague cases.

In Bombay City it was absolutely impossible to obtain any trustworthy information on this point. In the Punjab villages, however, in the great majority of cases accurate information was obtained. In Dhund there were 32 cases: 25 of these (80 per cent.), it was definitely ascertained, did not prior to attack come in contact with other plague cases. The remaining 7 cases had come in contact with plague cases, so the possibility of their having been directly infected from the latter cannot be excluded. In Kasel out of a total of 75 cases it was ascertained that 53 (70 per cent.) did not prior to attack come in contact with other plague cases; that 11 cases (15 per cent.) had been in contact with cases prior to becoming ill and that with regard to the remaining 11 cases (15 per cent.) it could not be determined whether or not such contact had taken place.

In these two villages, therefore, the great majority of cases did not receive their infection from other plague cases.

Finally, it will be remembered that in the village of Sion Koliwada on the evacuation of the inhabitants a guinea-pig population was put into the empty houses. A severe epizootic spread through these animals, although there was no chance of contact in any instance with a sick animal.

E.—Relative frequency of the occurrence of single and of multiple plague cases in houses and buildings.

If plague were an infectious disease, it would certainly happen that multiple cases in a house would be the rule and not the exception. The observations of the Commission throw much light on this point.

(1) In Dhund the 32 cases inhabited 26 houses: of these houses one furnished three cases, four furnished two cases each and the remaining 21 houses a single case each. That is to say, 70 per

cent. of the cases were single cases. All the cases were treated in their own houses throughout their illness. In the 21 houses which furnished single cases the number of contacts was 86, all of whom came into intimate relation with the patients. None of these contacts contracted the disease.

(2) In Kasel the 75 cases inhabited 67 houses. One house furnished three cases, six houses furnished two cases each and 60 houses a single case each. That is to say, 80 per cent. of the cases were single cases. In the houses which furnished single cases the number of contacts was 273, of whom 18 had been inoculated against plague. In other words, out of 255 presumably susceptible persons who came into contact with plague cases not one was attacked.

Further, both in Dhund and Kasel it was observed that when multiple cases did occur in a house they were attacked practically simultaneously, as if from a common source of infection.

(3) In Parel village there were 28 cases, 17 of which were imported. Of these cases 20 (71 per cent.) were single cases, the remaining eight being divided amongst four houses, two in each. In all the houses where cases occurred a number of inhabitants were living in the same room as the sick. In no instance was there any evidence to show that the sick communicated the disease to their healthy attendants or friends.

(4) In Bombay City the experience of the Commission showed that it is comparatively rare to find two or more cases in a house. Attention was specially directed to this point, because throughout the epidemics of 1906 and 1907 a continual endeavour was made to find instances of this kind with the purpose of using such houses for guinea-pig experiments. The number of houses suitable for this purpose was very small when compared with the total number of plague houses.

A large mass of data relating to this question was obtained from the municipal records for four epidemics, 1903-1906. The records relating to the incidence of plague for these years in all the buildings in 10 typical sections of the city were analysed and statistics under the following headings compiled :—

(*a*) Mean number of inhabitants per building.
(*b*) Mean number of tenements per building.

(*c*) Mean number of plague cases per building in each epidemic.

(*d*) Percentage of buildings which yielded one case, two cases, three cases, etc., in each epidemic.

The results of a study of these statistics are very striking.

Thus, it was found that although the mean number of inhabitants per building is as high as from 27 to 61 in the different sections and the mean number of tenements per building is between 4·5 and 9·1, that is to say, the buildings are of considerable size, the mean number of plague cases per building in the epidemic season is very low, never, indeed, rising to 3 per building, and in the different sections varying between 1·5 and 2·9. In the non-plague season the mean number of cases per building was never in any section higher than 2 and was generally between 1 and 1·5.

This low mean number of cases per building, when considered in the light of the fact that the buildings on the whole have a large population distributed as separate families in houses or tenements within the building, is without doubt evidence that the mean number of cases *per house* must be a very low figure.

This conclusion is supported by the figures which relate to the percentage of infected buildings which yield single and multiple cases. Thus, for example, in the epidemic of 1906 in Dongri section 49·7 per cent. and in Kumbharwada section 71 per cent. of the buildings infected had single cases. The figures for the other sections come in between these. In order to make the statistics clear to our readers, the figures for the year 1906 for Dongri section are given below.

Dongri section, 1906.

Number of occupied buildings.	Population.	Mean number of inhabitants per building.	Mean number of tenements per building.	Total number of plague cases.		Total number of buildings which yielded plague cases.		Mean number of plague cases per infected building.	
				Jan. to June.	July to Dec.	Jan. to June.	July to Dec.	Jan. to June.	July to Dec.
535	32,663	61	9·1	435	32	197	24	2·2	1·3

Jan.—June = Plague season.

July—Dec. = Non-plague season.

Number and percentage of buildings which yielded cases.

	1 case.		2 cases.		3 cases.		4 cases.		5—10 cases.		11cases and over.	
	Jan. to June	July to Dec.	Jan. to June.	July to Dec.	Jan. to June.	July to Dec.	Jan. to June.	July to Dec.	Jan. to June.	July to Dec.	Jan. to June.	July to Dec.
Number	98	20	31	2	35	1	14	..	16	1	3	..
Percentage of totalinfected buildings.	49·7	83·3	15·7		17·8	4·2	7·1	..	8·1	4·2	1·5	..

All the evidence, then, points to the conclusion that in the great majority of instances a house during a plague epidemic yields only a single case. Moreover, it was also found that, when two or more cases do occur in a house, they are attacked practically simultaneously as if from a common source of infection, and that in houses with multiple cases the evidence regarding the rat mortality is much stronger than in those instances in which only a single case occurred in a house.

This phase in the natural history of plague is adequately explained when we consider certain facts in connection with the transmission of the infection from rat to man by rat-fleas, which have been already mentioned. Thus, we have seen that the percentage of infected fleas rapidly diminishes from the 3rd or 4th day after the flea has imbibed the blood of the plague rat. In this connection it is to be noted that only 21 per cent. of plague houses were infective for guinea-pigs, although in these experiments the houses were chosen as being apparently badly infected and the tests were made as early as possible. We have also seen that the chances of infection being given by a single flea are remote, an important fact when taken in conjunction with the observation that rat-fleas will not attack man unless forced to do so.

It would appear from all these considerations that the chances of man being infected in the course of the disease amongst the rats are not very great, that, in other words, he only participates, as it were, by an off chance in the rat epizootic.

It is unnecessary here to draw attention to the bearing of these facts on the prophylaxis of the disease. Their teaching with reference to such measures as disinfection, segregation of plague cases, etc., is too obvious to require comment.

Part V.—RELATION OF INSANITARY CONDITIONS TO THE SPREAD OF PLAGUE.

A.—Influence of insanitary conditions considered without reference to rat plague upon the spread of the epidemic.

B.—Influence of insanitary conditions upon the spread of rat plague and upon the transference of infection from rats to man—

(1) *The conditions which favour the spread of rat plague over a city, or through a village.*

(2) *The conditions which favour the spread of rat plague into and throughout inhabited buildings.*

C.—Incidence of plague on different classes of the community.

When we consider in what manner insanitary conditions might influence a plague epidemic, it is evident that, accepting as true the conclusion that the epidemic is wholly dependent upon the rat epizootic, the problem divides itself into two parts, namely, (1) the influence of insanitary conditions considered without reference to rat plague upon the spread of the epidemic, and (2) the influence of insanitary conditions upon the spread of rat plague and upon the transference of infection from rats to man. These two problems have to be kept entirely separate.

A.—Influence of insanitary conditions considered without reference to rat plague upon the spread of the epidemic.

When we consider the manner in which insanitary conditions, such as defective ventilation, bad lighting, etc., may affect a plague epidemic, it is evident, in the light of what has gone before, that we have to consider only the possible effect of such conditions in lowering the resistance to infection of persons who are exposed to them. It cannot be denied that insanitary conditions may exert such an influence. On the other hand, there can be no doubt that plague is a disease which most frequently attacks men and women in full vigour of the prime of life. Leaving, however, *à priori* reasoning behind, the Commission examined, as far as was possible, the question during the epidemic of 1906 in Bombay. They used chiefly the statistical method and the results were as follow :—

(1) Personal experience of native houses in Bombay leads to the belief that the ventilation of these houses is not on the whole

defective. Moreover, from experience of the ventilation of houses in which plague cases occurred and from statistical data based on observations of the state of ventilation of a large number of plague houses, the Commission were led to form the conclusion that no relation exists between the incidence of plague in these houses and their ventilation.

(2) Similar evidence relating to the conditions as regards lighting, which are found to obtain in plague houses, led also to the conclusion that no relation exists between such conditions and the incidence of plague in these houses.

(3) It is certain that in many of the sections of Bombay dense overcrowding of the population exists. The evidence obtained bearing upon the relation of this overcrowding to the incidence of plague was of two kinds—

First, statistical data relating to three criteria of overcrowding were compiled, namely—

(*a*) the number of inhabitants per acre ;
(*b*) the number of inhabited buildings per acre ;
(*c*) the average number of inhabitants per occupied building.

These data were compared graphically with the incidence of plague per mille of the population for each section.

Secondly, an analysis was made of data relating to the amount of space available for each occupant in over 4,000 houses in which plague cases occurred.

Consideration of the whole of the evidence led the Commission to the conclusion that, although the incidence of plague was highest in the most crowded tenements, it was apparently unaffected, so far as the City of Bombay is concerned, by the density of population in the different sections of the City, the smallest areas regarding which figures could be obtained.

(4) It cannot be denied that the system of the disposal of night soil and sullage water, that is to say, the system of open drains or gullies between the buildings, which prevails in the native city of Bombay, is a highly insanitary one. Nevertheless, *if the rat epizootics are excluded*, the Commission were unable to discover any definite relation connecting this state of affairs with the spread of epidemic plague. In confirmation of this view

the case of the outlying villages in the island, which possess no such system and which nevertheless are liable to severe epidemic outbreaks, may be cited. Again, in Bombay itself severe attacks may occur in buildings provided with an excellent water carriage system.

In short, the Commission felt justified in coming to the conclusion that the insanitary conditions which exist in Bombay have no influence which acts directly on the spread of epidemic plague.

In support of this conclusion attention can be drawn to a severe epidemic which occurred in a number of new *chawls* recently built by the Improvement Trust, buildings which in respect of their sanitary arrangements could not be improved upon. Reference will be made to this outbreak later on. It is, of course, also true that during the epidemic many buildings in the City in a highly insanitary state escaped infection altogether.

B.—Influence of insanitary conditions upon the spread of rat plague and upon the transference of infection from rats to man.

It will be convenient to consider this part of our subject under two heads, namely, (1) the conditions which favour the spread of rat plague through a city such as Bombay and through a village, *e.g.*, in the Punjab; and (2) the conditions which favour the spread of rat plague into and throughout inhabited buildings.

1. *The conditions which favour the spread of rat plague through a city* e.g., *Bombay, or through a village,* e.g., *in the Punjab.*

In Bombay we have seen that the spread of epidemic plague through the City is directly due to plague in *Mus decumanus*. It follows, therefore, that the conditions which favour this species of rat will be the conditions which favour the spread of the epidemic through the city. We have already drawn attention to the habits of *M. decumanus*, so that all that is now necessary is to mention briefly those conditions obtaining in an oriental city like Bombay which are favourable to its existence.

In the first place, the structure of the buildings is for the most part of the flimsiest description. The foundations are not by any

means rat proof and as a rule there are no solid masonry plinths. The buildings in consequence are easily infested by *Mus decumanus*.

In the second place, separating the buildings from one another, there is a system of gullies, which are simply open drains. These gullies communicate freely, on the one hand, with the ground floors of the buildings and, on the other hand, with the sewers and storm-water drains. The latter come into complete function only in the rainy season and, therefore, during the greater part of the year are practically dry, and must then offer excellent shelter for rats with habits like *M. decumanus*.

In the third place, scattered throughout the City there are innumerable stables and store houses or godowns of all descriptions, situated either in detached buildings or more often on the ground floors of inhabited buildings. These afford excellent shelter for rats.

Finally, the food supply for rats is abundant. The stables and godowns themselves contain a good food supply, and into the gullies, court-yards and lanes the inhabitants throw all the remains of their food, the sweepings of the rooms and other garbage. It is, moreover, a common custom to tether goats, sheep and cattle in the court-yards, lanes and entrances to the houses. A special corps of municipal servants, the sweepers, is entertained to keep the streets and gullies clean, but even with their best endeavours this is an almost impossible task.

To sum up then, the flimsy structure of the houses and the lack of solid plinths, the system of gullies and drains in general, the stables and godowns so common throughout the city in close connection with the human habitations, the abundant food supply, all play their parts in attracting and fostering *M. decumanus*. These conditions, therefore, have an indirect influence on the diffusion of plague throughout the city.

As regards the Punjab villages we have already seen that the case is simplified on account of the absence of *M. decumanus*. We have seen also that the chief factors which favour *M. rattus* are, the configuration of the villages, the close aggregation of the houses, the mud walls and floors easily permeable by rats and the abun-

dant food supply present in the court-yards and the houses themselves. These are the conditions, therefore, which favour the diffusion of plague throughout the villages.

2. *The conditions which favour the spread of rat plague into and throughout inhabited buildings.*

We have already come to the conclusion that the *rattus* epizootic in Bombay is directly attributable to the *decumanus* epizootic. Now *M. rattus* is, as we have seen, essentially a house rat and to plague in this species the whole or by far the greater part of the house infection is due. It follows, therefore, that those conditions which favour the coming together and meeting of *M. decumanus* and *M. rattus* will be the conditions which are responsible for the spread of plague into buildings, while those conditions which favour the existence of *M. rattus* in the buildings will be responsible for the diffusion of the disease throughout the buildings.

As regards the first point, namely, the conditions which favour the coming together and meeting of the two species, we have already pointed out that *M. rattus* and *M. decumanus* in Bombay are closely associated with each other in gullies, on the lower floors of houses and in godowns, which localities appear to be their common meeting ground. It is evident, therefore, that the gully system of drainage, the unsubstantial character of the foundations and plinths of buildings, which render the latter easy of access by rats, the presence of godowns, stables, etc., on the ground floors of buildings, are the conditions which are mainly responsible for the spread of plague into the buildings.

In the case of the Punjab villages the same conditions, which we have seen favour the diffusion of the epizootic through the village, namely, the close aggregation of the houses, their mud walls and floors, etc., favour its entrance into the houses.

Passing on to the second question, namely, the diffusion of the epizootic throughout the buildings, we find present in all Indian houses conditions which are eminently favourable for the existence of *Mus rattus*.

The structure of the houses does much to favour this species. The flimsy walls and floors, the mud walls of the Punjab village house, the country-tiled roof, the general condition of disrepair, all offer attraction and afford good shelter to *Mus rattus*. But

as important, if not more so, are the conditions which depend upon the habits and customs of the people themselves.

In the first place, the natives of India are universally indifferent to the presence of rats in their houses and in some instances go so far as to protect them from molestation.

In the second place, the people are in the habit of filling their houses with all kinds of useless articles and accumulations of rubbish. Small lofts are improvised with planks or bamboos, and in these lofts are stored all kinds of odds and ends, such as, earthenware and brass jars, pieces of matting, firewood, old clothes, etc. In the interior of the houses, therefore, there are splendid shelters and breeding places for the house rat.

In the third place, the food supply is abundant. The supplies of raw material, grain, seeds, ghee, etc., are stored in wooden chests, earthenware pots, etc. (in the case of the Punjab houses there are special grain receptacles), all of which are easily accessible to rats. The food is cooked and eaten in the room off plantain leaves or brass platters placed on the floor, neither tables nor chairs being used.

As an illustration of the influence of the habits of the people and the conditions resulting therefrom on the spread of plague inside buildings, we may with advantage instance the case of the Improvement Trust *chawls*, to which passing reference has already been made. These *chawls*, 16 in number, were built recently by the Bombay City Improvement Trust and, in fact, some of them had only just been occupied before the plague epidemic of 1906 began. The walls are solidly built of brick and are supported on high, solid, masonry plinths. The floors are of concrete or patent stone and the roofs of flat Mangalore tiles. The verandahs and corridors are also paved with concrete and are wide and airy, the lighting and ventilation of the whole building leaving nothing to be desired. There are no gullies, and excellent water closets are provided. In short, the buildings in themselves offer no shelter to rats. In spite of this *M. rattus* is common in the houses. It is further certain that the rat infestation of the buildings is entirely due to the habits of the people in the matter of the disposal of their household belongings and food stores as described above. In the plague season of 1906 these *chawls* were so badly infected, that the people had to evacuate and live in huts made of

bamboos and matting built on an adjoining piece of vacant ground. They have a population of about 4,000 and no fewer than 57 cases of plague occurred amongst the inhabitants. It may be added that at the time of the epidemic in the *chawls* there was a considerable mortality amongst the rats, several of which on examination were proved to be plague infected.

C.—Incidence of plague on different classes of the community.

It has been the general experience in India of all plague workers that the incidence of the disease is not so great amongst the well-to-do classes as amongst the poorer population. Europeans are practically exempt. The Commission's experience bears this out, and certain statistical data which they collected are in harmony with it. The explanation is not far to seek. The description of the houses and habits of the people which we have given above apply only to the poorer classes. As the people rise in the social scale, their houses are of better structure and, more important still, their mode of living becomes more like that of Europeans. The compounds of the houses are kept clean and the household rubbish which accumulates is relegated to a godown. There is, therefore, little or no shelter or attraction for rats. Further, the people themselves, like Europeans, show much aversion to live in association with rats. It can, therefore, be readily understood that the houses of the well-to-do Indians in a city such as Bombay, as well as the houses of the Europeans, do not harbour anything like the number of rats which are to be found in the houses of the poor population. It would appear, in consequence, that the explanation of the fact that the incidence of plague is much greater on the poor population than on the well-to-do Indian and European is ultimately to be found in the different conditions in which they live and in their different habits.

PART VI.—THE RECURRENCE OF PLAGUE IN HOUSES IN SUCCESSIVE EPIDEMICS.

It has often been alleged that infection may persist in a house or in a locality apart from rats and that plague tends to recur in certain houses in successive epidemics. It has generally been assumed that the plague bacillus is able to live for long periods in soil, and that infection may lie latent there until the next plague season, when it breaks out afresh in a virulent form. Associated with this assumption is the idea that the conditions in certain houses are especially favourable for the persistence of infection, so that the inhabitants of these houses are attacked by plague year after year.

The evidence obtained by the Commission is quite against this view.

In the first place, all experiments show that the plague bacillus very soon dies in soil; it seems to have no existence in nature outside an animal body.

In the second place, a number of houses in Bombay which were plague infected during the epidemic of 1906 were experimentally investigated at regular intervals during the period of one year, but no evidence of the persistence of infection in any of them was obtained nor did plague occur in them during the subsequent season.

In the third place, the question was investigated by the statistical method, both in the Punjab villages and in Bombay City. The results obtained in the former are worth detailing.

An attempt was made to determine whether houses in Dhund and Kasel which were infected in one epidemic were especially liable to be again infected in any subsequent epidemic. All particulars of the incidence of plague in houses during previous epidemics were ascertained and lists of the houses in which plague cases had occurred were prepared for each epidemic. Table 1 shows the total number of occupied houses and the number of houses infected in each epidemic, for both Dhund and Kasel. Table 2 shows the actual number of houses which were infected in one epidemic only, in any two, in any three and in all four epidemics; while Table 3 gives the figures, which have been calculated from the data in

Table 1, showing the probable number of houses which would have been infected in 1, 2, 3 and 4 epidemics, on the assumption that the houses were equally liable to infection throughout all four epidemics.

The close correspondence between the actual and calculated figures suggests that the assumption on which the latter figures were worked out is a legitimate assumption or, in other words, that plague showed no tendency to recur in houses during successive epidemics.

Similar results were obtained in Bombay, so the epidemiological evidence supports the experimental in showing that infection does not persist in a house apart from rats and that there is no such thing as a " plague house," in which the disease is liable to recur in successive epidemics.

TABLE I

Showing the total number of occupied houses and the number of houses infected in each epidemic in Dhund and Kasel.

Village.	Total No. of occupied houses.	No. of houses infected.			
		In first epidemic.	In second epidemic.	In third epidemic.	In fourth epidemic.
Dhund . .	418	101	198	40	26
Kasel . .	806	308	252	230	67

TABLE II

Showing the actual number of houses in Dhund and Kasel, which were infected in 1, 2, 3 *and* 4 *epidemics.*

Village.	No. of houses infected.			
	In one epidemic only.	In any two epidemics.	In any three epidemics.	In all four epidemics.
Dhund	208	65	9	0
Kasel . . .	383	169	43	2

Table III

Showing the probable number of houses which would have been infected in 1, 2, 3 *and* 4 *epidemics, if all houses were equally liable to infection throughout; all epidemics calculated from Table I.*

Village.	No. of houses infected.			
	In one epidemic only.	In any two epidemics.	In any three epidemics.	In all four epidemics.
Dhund	201	73	8	0·3
Kasel	393	162	40	2

Part VII.—THE IMPORTATION OF INFECTION FROM AN INFECTED TO AN UNINFECTED LOCALITY.

A.—Conveyance of infection by rats.

B.—Conveyance of infection by infected rat fleas.

Having excluded all probable modes of spread of infection of plague other than the rat and the rat-flea, we are led to the conclusion that the importation of the disease into an uninfected locality must be attributable solely to the conveyance of the infection in the rat or in the rat-flea.

A.—Conveyance of infection by rats.

As regards this method of importation from place to place we have already dealt with the subject of migration of rats in general and have seen that all the evidence pointed to there being no such thing as a general migration of rats even as a result of a severe mortality amongst them. While this is so, it cannot be denied that a plague-infected rat may be conveyed into an uninfected locality in merchandise, *e.g.* in hay, bales of cotton, grain, etc. The Commission, however, obtained no direct evidence on this point.

B.—Conveyance of infection by rat-fleas.

Consideration of what has gone before will suffice to convince the reader, that transportation of the plague bacillus in the body of the rat-flea is not only conceivable, but under certain circumstances a very likely contingency. Thus, it is conceivable that infected rat-fleas might be imported from an infected to an uninfected locality by one or other of the following means :—

(1) On the host, namely, rats, carried in merchandise, etc.

(2) In merchandise, grain, etc., the host not being transferred with the fleas.

(3) On the person or clothing of a man, who has been in a plague-infected house, the man himself being either plague stricken or healthy.

(4) In bundles of clothing, bedding, etc., removed from a plague-infected house.

As there is no direct evidence bearing on the first two possibilities, nothing further need be said about them.

As regards the importation of infected rat-fleas by the direct agency of man, on his person, amongst his clothing, etc., or by bedding and such like articles coming from a plague-infected house, the following observations have a direct bearing—

(*a*) We have seen that rat-fleas will under certain circumstances come on to a man and in some instances will be attracted by him, but not feed on him for some time.

(*b*) We have seen that rat-fleas fed on man may remain alive for two or three weeks; also, that infected rat-fleas if fed may remain infective for 15 days. In this connection it is important to remember that experiments have demonstrated that an animal, *e.g.*, a guinea-pig, may pick up fleas in a plague house and still not contract plague, while a second animal to which the fleas are transferred may develop the disease.

(*c*) Rat-fleas if starved may remain alive for several days.

(*d*) During the visits of the Commission to plague houses in Bombay the members and their assistants often carried away fleas on their persons and clothing, some of which proved to be rat-fleas.

(*e*) Experiments were made with bundles of bedding, clothing, etc., got from houses in Bombay in which plague cases had occurred. Rat-fleas were taken on guinea-pigs brought in close contact with these articles; one of the guinea-pigs died of plague with a bubo in the neck, and a rat-flea which was dissected had abundant plague bacilli in its stomach contents.

In this connection it is to be remembered that a plague-infected house may contain a very large number of infected rat-fleas.

(*f*) Histories of the probable importation of plague into an uninfected village in the Punjab by human agency are common. Thus, in a district in the Punjab in which this question was carefully investigated in 80 per cent. of the infected villages there was a clear history of probable importation by men coming from infected localities.

(*g*) Some observations made by the Commission in the outlying villages of Bombay are worthy of reference in this connection—

(1) In the case of Sion Koliwada village, enquiries showed that the origin, of the rat epizootic was probably due to the

importation of infection from an infected quarter of Bombay on the person of an old woman who herself did not contract the disease.

(2) In Wadhala village the first plague-infected rat was found outside a house in which the coolies who worked for the Commission lived. All these men worked amongst plague-infected rats and fleas at the laboratory and two of them likewise assisted in the work in Sion, which at that time was badly infected.

(3) An old woman contracted plague in a badly infected house in Bombay City. When ill she returned to her home in Worli village, which at that time was not infected. Guinea-pigs placed in her house in Worli immediately after her return yielded rat fleas and one of the guinea-pigs died of plague.

(4) A woman was brought when moribund from a badly infected house in Bombay to a house in Parel village. She died a few hours after her arrival. Her friends at once removed the body, but left behind a certain amount of clothing and bedding. Next day two guinea-pigs were placed in the room. They yielded rat-fleas and one of them died of plague. There was no plague at this time in the neighbourhood of the house.

We have already pointed out that an imported plague case may seem to be the start of the epidemic in an uninfected locality. The connection is now clear. The sufferer from plague imports on his person, in clothing or in bedding, etc., infected rat-fleas from the house where he was infected. These fleas at once take to their natural host, the rat, and thus start the disease amongst these rodents. As the mortality amongst the rats begins in the vicinity of the house occupied by the imported case, the human cases will also begin in that neighbourhood. It is of course apparent that a healthy man may act in the same way as a plague case and may bring infected fleas from an infected locality, and also that bedding, clothing, etc., may do so.

In conclusion, then, we may state that all evidence points to the usual method of the importation of plague from an infected to an uninfected locality being by means of infected rat-fleas and to the fleas being brought in by human agency, namely, by healthy men, by plague cases or in their belongings.

Part VIII.—THE RECRUDESCENCE AND SEASONAL PREVALENCE OF PLAGUE.

A.—The existence of the plague bacillus in nature during the non-epidemic season.

1. *A saprophytic existence of the bacillus in the soil.*
2. *The existence of the bacillus in man.*
3. *The existence of the the bacillus in the rat.*

B.—The factors which influence the rise and fall of the epidemic.

1. *Temperature.*
2. *The number and susceptibility of the rats.*
3. *Variation in the number of fleas.*

C.—Conclusion.

The most striking feature of plague epidemics is their seasonal prevalence. In places where plague has once become established the epidemic period, lasting as a rule about three months, tends to recur always at the same season of the year. Now, we have already seen that, as far as epidemics are concerned, plague depends solely upon the transmission of the bacillus from rat to rat and from rat to man in both cases by the rat-flea. In the light of this well-established fact we must seek for an explanation of the phenomena of recrudescence and seasonal prevalence. A little consideration will show that two distinct and separate problems are involved, namely:—(A) how the plague bacillus continues to exist in nature during the non-epidemic season, and (B) the factors which govern the rise and fall of the epidemic.

A.—The existence of the plague bacillus in nature during the non-epidemic season.

With reference to this problem we have to consider three possibilities, namely—

(1) A saprophytic existence of the bacillus in the soil.
(2) The existence of the bacillus in man.
(3) The existence of the bacillus in the rat.

1. *A saprophytic existence of the bacillus in the soil.*

We have already seen that the work of the Commission definitely shows that the plague bacillus does not survive in soil or on

floors for any length of time. It was found that the longest period that floors remained infective after gross contamination was 24 hours.

In short, all experimental evidence, which need not be again detailed, proves that there can be no question of a continued existence of the bacillus in the soil.

All the epidemiological facts accumulated by the Commission point to there being no such thing as soil infection.

2. *The existence of the bacillus in man.*

We have already pointed out that human plague is dependent upon plague in the rat, and that the only way man becomes infected is by the bacilli being conveyed to him from the rat by the rat-flea. There is no evidence that infection is ever carried from man to rat, although the possibility of this occurring cannot be denied. Cases of human plague which occur in the off-season must, therefore, be dependent upon acute plague in rats. This correlation was shown to be present in Bombay City during the off-plague season.

Again, there is no evidence that man harbours the bacilli after he has recovered from the disease or while he is not a sufferer. All the evidence, in fact, is against such a contingency.

These considerations, therefore, would negative the view, that man was in any way responsible for the bridging over of plague epidemics.

3. *The existence of the bacillus in the rat.*

In Bombay City it was found that the period between the epidemics was bridged over by cases of acute plague amongst the rats, accompanied by a few cases in man. There was never a week in which acute rat plague was not present.

In the case of the two Punjab villages no rats were found in the non-epidemic season suffering from acute plague nor did any human plague cases occur. While this is so, a considerable number of rats were caught alive, which, although apparently in good health, harboured living and virulent plague bacilli in chronic abscesses. It is to be carefully noted that these chronic plague-rats inasmuch as the bacilli are shut up in abcesses, where fleas

cannot possibly get at them, are *per se* of no importance in spreading the infection. After a careful study of this condition the Commission came to the opinion that there was no reason for believing that chronic plague in the rats, as it occurs in the Punjab villages, possesses any significance in the seasonal recurrence amongst the rats of the infection in an acute form.

While this is so, in the off-plague season in the Punjab there are always plague cases occurring every week in some district or other. In the year 1905 the smallest number was 129 in one month, namely, September. It is certain also that the number of these cases is greater and their distribution more widespread than comes to the knowledge of the officials. Now, we have already come to the conclusion that, if human plague cases are occurring, acute plague amongst the rats must also be present. It is also probable that acute rat plague might be present and still no plague cases appear among human beings. That acute rat-plague does not exist in all the villages in the off-season is shown from the observations in Dhund and Kasel. That it does exist in some villages, that it is widespread over the Province and that the districts where it is present vary in different off-seasons, are facts graphically shown by a series of weekly maps depicting the distribution of human plague cases in the Punjab from July to October (the non-epidemic season) in various years.

We can conclude, therefore, that the plague bacillus exists during the non-epidemic season in the rat, giving rise to acute rat-plague and being carried from rat to rat by the rat-flea, the epizootic, meanwhile, being kept in check by the factors which we are now about to consider. This conclusion holds good both for large cities such as Bombay and for provinces such as the Punjab.

We may now consider the second problem namely—

B.—The factors which influence the rise and fall of the epidemic.

Granted the presence of acute rat-plague during the non-epidemic season and the dependence of human plague on rat plague, it is evident that we have now to enquire into the factors which influence the rise of the diseasee among rats and its fall after it

has reached a climax. If we can find an adequate explanation o these phenomena, it is clear that in the case of a city like Bombay we shall have answered satisfactorily the questions we set ourselves, but that in the case of a province like the Punjab, where the villages are scattered and where acute rat plague is present during the off-season in only a comparatively small number of them, simultaneously, we shall require in addition to explain the diffusion of the infection during the rise of the epizootic from the foci where acute rat plague exists at the beginning of the epidemic season.

Let us then consider the factors which influence the rise and fall of the epizootic, when the disease is present amongst the rats. These factors have been shown to be as follows.

1. *Temperature.*

(*a*) A high mean temperature, *i.e.*, 85°F. and over, affects the fate of the plague bacillus in the stomach of the flea. At this temperature fewer successful transmissions from animal to animal are obtained and, besides, the flea does not retain its power of infecting nearly so long as it does at a lower temperature, *i.e.*, 70°F. At the higher temperature the plague bacilli disappear from the stomach much more quickly than at the lower temperature.

(*b*) While a mean temperature, high in comparison with 70°F., has no effect on the number of plague infected rats which contain bacilli in the blood at death, at a low mean temperature, such as 50°F., the number of infected rats that die before bacilli appear in the blood is much greater than at the higher temperature, *i.e.*, 70°F.

(*c*) Temperature may have an influence on the prevalence of fleas in nature. It has been shown that a high temperature affects the breeding of fleas to a considerable extent. It appears not only to restrain the adult from depositing eggs, but also to deter the development of the eggs into larvae.

(*d*) Finally, from a study of the climatic conditions and epidemic plague in six places in India it appears that plague cannot exist in epidemic form in any place when the daily mean temperature is high, *i.e.*, 85°F. and over. In some places the rise of the mean temperature to this degree and the fall of the epidemic coincide, while in other places, *e.g.*, Belgaum and Poona,

the epidemic subsides when the mean temperature is most suitable, namely, about 70°F. Another factor or factors must, in these instances, be in operation in causing the decline of the epidemic.

In the Punjab during the winter months a low mean temperature, such as 50°F., inasmuch as it diminishes the number of infected rats which contain plague bacilli in their blood at death, may be a factor in limiting plague outbreaks.

We find, therefore, that the epidemiological facts are in harmony with the experimental data, as far as temperature is concerned.

2. *The number and susceptibility of rats.*

There is evidence to show, that a plague epizootic diminishes for the time being the total rat population of a place. There is also evidence to show, that the effect of a plague epizootic is to increase the proportion of immune to susceptible rats. It is evident that these two factors would have an influence in limiting and in bringing to an end plague amongst the rats.

Again, it was found both in Bombay and in the Punjab that breeding of rats goes on all the year round, but that it is especially vigorous during the season between the end of one epizootic and the beginning of the next. During this interval there would, therefore, be added to the rat population a large number of young susceptible individuals, a factor which would evidently influence the rise of the epizootic.

3. *Variation in the number of fleas.*

It is not only *à priori* certain, but it has also been experimentally proved by the Commission, that the rate of progress of a plague epizootic is in direct proportion to the number of fleas present. The questions, therefore, to be answered are ; (*a*) Is there in nature a seasonal variation in the number of rat-fleas ? and (*b*) if so, does it correspond to the rise and fall of the plague epidemic ?

The Commission have obtained answers to these questions In Bombay and in the Punjab it was found that there is a very definite seasonal prevalence of rat-fleas. And it was further found that the plague epidemic season corresponds with the greatest prevalence of these fleas, while in the months when plague

is at its minimum the fleas are fewest in number. No direct evidence was obtained to show what factors are concerned in this variation in the flea prevalence, except the few temperature experiments already mentioned.

Other factors which might possibly influence the seasonal prevalence of plague have been considered, but no evidence could be obtained that they came at all into play. These factors were; (*a*) other climatic conditions, such as rainfall and humidity; (*b*) variation in the virulence of the plague bacillus; (*c*) influence of climatic conditions on the life history and habits of the rat or on the life history and habits of the flea or on the habits of man.

We may in conclusion of this part of our subject sum up as follows:—

The rise of a plague epizootic depends upon;

(*a*) a suitable mean temperature, something below 85° F.; (*b*) a sufficient number of susceptible rats; and (*c*) a sufficient number of rat-fleas.

The fall of a plague epizootic is determined by some one or all of the following factors:—

(*a*) a high mean temperature, 85° F. and above; (*b*) a diminution in the total number of rats and an increase in the proportion of immune to susceptible animals; and (*c*) a diminution in the number of rat-fleas.

C.—Conclusion.

As we have throughout insisted on the fact that the epidemic is wholly dependent upon the rat epizootic, it is now evident that our conception of the seasonal prevalence of human plague in a city such as Bombay is complete.

In the case of a large Province with scattered towns and villages, in only a few of which the disease persists simultaneously in the off-season as acute rat plague, we have still to explain the outward diffusion from these centres during the rise of the epidemic. Granted that the factors, which, as we have seen, govern the seasonal prevalence of the disease, are favourable, we have only to seek for some easy and ready method of importation of the infection from village to village, in order to arrive at an explanation of this diffusion. We have already considered this question of importation and have

come to a very definite conclusion on the subject, which need not now be repeated. The conception that importation from village to village—villages which had been infected in previous epidemics and villages which had never been infected before—is the determining factor, in addition to the factors already considered, in the rise of the epidemic in a province such as the Punjab receives further support from the following considerations :—

(1) First, importation is the only way in which a village first becomes infected. If a village becomes infected in this way to begin with, why not a second and a third time ?

(2) Secondly, the work of the Commission shows definitely that importation is not only possible but extremely probable. It shows that it is the only possible way by means of which the villages in the neighbourhood of Bombay become infected year after year.

(3) Thirdly, a careful study of a Punjab district has shown that a history of possible importation could be obtained in 80 per cent. of the villages which became infected.

The question of how importation is brought about has already been considered and need not now be entered into, except to remind the reader of the conclusion that it is dependent solely upon the conveyance in different ways of infected rat-fleas from place to place.

Our conception of the causes of the recrudescence and of the seasonal prevalence of plague in a large area like the Punjab may, therefore, be stated as follows : The non-epidemic season is bridged over by acute rat plague accompanied by a few human plague cases in the towns and villages, the disease being kept in check by one or other of the factors which, as we have already shown, act in this manner. When the conditions which are suitable for the rise of the epizootic become established, the disease rapidly increases in the places where at that time it was present as acute rat plague and then spreads outwards from these foci by the conveyance of infected rat-fleas from village to village, these fleas being the starting point of the rat epizootic in the uninfected villages. The decline of the epidemic is determined by one or more of the three factors we have already mentioned.

PART IX.—GENERAL CONCLUSIONS.

1. Pneumonic plague is highly contagious. It is, however, rare (less than 3 per cent. of all cases) and plays a very small part in the general spread of the disease.
2. Bubonic plague in man is entirely dependent on the disease in the rat.
3. The infection is conveyed from rat to rat and from rat to man solely by means of the rat-flea.
4. A case of bubonic plague in man is not in itself infectious.
5. A large majority of plague cases occur singly in houses. When more than one case occurs in a house, the attacks are generally nearly simultaneous.
6. Plague is usually conveyed from place to place by imported rat-fleas, which are carried by people on their persons or in their baggage. The human agent not infrequently himself escapes infection.
7. Insanitary conditions have no relation to the occurrence of plague, except in so far as they favour infestation by rats.
8. The non-epidemic season is bridged over by acute plague in the rat, accompanied by a few cases amongst human beings.

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