THE PLAGUE.

A Brief Review of the History and Development of our Knowledge of the Ätiology of the Disease

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The History of Plague in the pre-Christian era. There are few diseases which can be traced back into remote antiquity with greater certainty than the plague. For example a reference is made to this disease in the fifth and sixth chapters of the first book of Samuel. This narrative was compiled probably about the year 900 B.C. It is recorded that when the Philistines brought the Ark of the Covenant, which they had captured from the Israelites, into the city of Ashdod a grievous pestilence broke out. The inhabitants of that city died in large numbers from an illness associated with swellings in their groins. The people connected the disease with deaths among rodents. Thus, nearly a thousand years before the Christian era, three cardinal features of a plague epidemic were recognised. First, the disease could be brought into a country by goods or merchandise (the Ark and its appurtenances); second, the disease is characterised by the development of emrods or buboes and is associated with a high mortality; and third, it is in some way connected with deaths among rats (the mice that marred the land).

The History of Plague in the Christian era. Confusion with other Epidemic Diseases. During the early part of the Christian era recorded outbreaks of the plague seem to have been confused with other somewhat similar epidemic diseases causing a high mortality, such as influenza, typhus fever and relapsing fever so that the cardinal features of a true plague epidemic, such as the one described above, became obscured and no longer impressed themselves on the afflicted peoples. Many and fantastic views regarding the origin and characteristics of the disease were propagated and can be read in the accounts of the plague written in the early part of this period.

Still much of interest and importance can be gleaned from a study of the history of plague and readers are advised to consult the books referred to at the end of this paper.

The Black Death. Among the recorded epidemics of plague one stands out prominently because of the effect it had upon the social and economic condition of the people of Western Europe. This epidemic began in Europe in the year 1347 and is generally known as the Black Death. An interesting and instructive account of this epidemic has been left to us by Gui de Chauliac, a physician at Avignon. He tells of the terrible mortality associated with the disease and clearly distinguishes two types—the one, pneumonic, brought prominently to notice by the spitting of blood, extreme infectivity, and death in three days; the other, recognised by the formation of carbuncles, of buboes, developing chiefly in the groins and in the armpits, characterised by slight infectivity, and fatal after a longer interval. This work of Gui de Chauliac marked an important advance in our clinical knowledge of the plague.

Social reactions to the Mortality caused by the Black Death. The Black Death swept over England in 1348, leaving behind it as it declined a great
reduction in the population. As a result many lands went out of cultivation for lack of men to till them, and many bondmen threw up their holdings and escaped into the towns, which were then increasing in size, and joined the ranks of free labourers. Various attempts were made by Parliament to overcome the difficulty of cultivating the fields because of the scarcity of labour owing to the deaths from plague. Men were compelled to work under threat of various punishments such as the stocks, branding, and imprisonment. These hardships, aggravated by the imposition of a poll tax in 1379 and 1381, were the direct causes of the Peasants' Revolt. Landlords meanwhile directed their energies towards sheep-rearing which required less labour, so that, as Peak remarks in his "English Village," "wool rather than corn became the chief item of production, and even at this date, it became clear that the future of England lay in industry rather than agriculture."

The Agrarian Revolution. During the Tudor period money came into more common use; rents were paid in cash, and labour was rewarded in wages. On the agricultural side the spirit of trading gave a fresh impulse to the system of enclosures and individual occupation of the land; the wool trade was further stimulated; and the substitution of pasture for tillage, sheep for corn, went on apace. Thus was instituted the slow and gradual change known to students of economic history as the First Agrarian Revolution (1450 to 1600).

General decline of Plague in Europe during the seventeenth century. During the first two-thirds of the seventeenth century plague was still widely prevalent in Europe, but in the last thirty years of that century plague was observed to be retreating gradually from that continent. At the beginning of the eighteenth century it became still more certain that a turning point had been reached. Only twice did plague become widely diffused in Western Europe in that century. It still lingered in the South Eastern parts of Europe and made frequent excursions northwards into this area, yet rarely did the disease extend beyond the Balkan peninsula. The epidemic excursions, when they occurred, were becoming less virulent, less prolonged and concentrated more in the larger cities.

The Disease continued, however, in other Parts of the World. During the nineteenth century plague continued to prevail in the Balkan peninsula, especially in Constantinople. The plague epidemic which occurred in Egypt during this period was carefully studied, and by the middle of the nineteenth century plague had practically disappeared from Asia Minor, Africa and Europe, while new centres came to be recognised in Arabia, Mesopotamia, Persia, India and China.

Plague in Mesopotamia recognised as a House Disease and "miseria morbis". An illuminating account of plague in Mesopotamia in 1876-77 is given by Dr. Dickson in the "British Medical Journal," March, 1879. He points out that while Mohammedans, discarding all sanitary precautions, lived with and handled plague patients, the Jews and Christians, on the contrary, firmly believing in its contagious properties, very seldom touched them; yet all of them equally caught the disease if they lived in the same house with the plague patient but were safe if they quitted the house the moment the case of plague occurred in it. Plague thus came to be recognised as a "house" disease. He described the disease as "miseria morbis" because he found the poor were seldom spared, the wealthy hardly ever attacked. In Hilla he describes houses of the poor encumbered with a horse, with poultry and with two or three buffaloes.

Further Social and Economic Changes in England which led to the Abolition of the Plague. Meanwhile let us return to England and see what was happening.
there to lead to the decrease in the prevalence of plague. We have already noticed the effect of the Black Death in initiating the First Agrarian Revolution. Other powerful forces were at work on the social revolution of the country. The extension of the Italian Renaissance—the new learning, the discovery of printing and the widespread distribution of books, led to a vast increase in the number of schools and the advancement of education. Meanwhile the commercial policy developed during the comparatively tranquil times of Elizabeth's reign led to the formation of companies for trading and an increase in the wealth of the people. In this reign more oak was used for building than had been used in the preceding hundred years. Manor houses were built not of timber but of brick and stone, and the mud and wattle and daub huts of the country people were being replaced by dwellings constructed of brick and stone. The abandonment of salted meat and fish and the greater consumption of fresh meat pointed to an increase of refinement in the country people, as did also the improvement in the construction and furnishing of their homes and in their manners and habits. This general prosperity was held in check during the civil war in England (1642-1652) and during the Thirty Years War on the Continent (1618-1648), but when these came to an end a fresh impetus was given to social progress.

Social and Economic Defects still remained in some Towns and in Remote Areas. In the towns, however, many hovels and much social degradation still remained, and a few remote areas in the country were unaffected by these impulses. Plague therefore continued to visit certain parts of Europe after the close of the seventeenth century. Many years were still required to complete the social reformation now well established. Nevertheless the sting of the disease had been removed by this time and such epidemics of plague as did occur subsequently were generally shorter and more circumscribed.

Summary.

This very brief outline of the history of plague has shown us that plague was already a recognised disease some three thousand years ago, that subsequently the disease was confused with other epidemic diseases causing a high mortality and the ætiology of the disease became less plain. The Black Death, a mixed epidemic of bubonic and pneumonic plague, caused so great a mortality, especially in England, that the cultivation of the land became difficult owing to the scarcity of labour, and so the first Agrarian Revolution began. England slowly passed from an agricultural to an industrial country. Similar changes were developing in other parts of Western Europe. Plague epidemics in this part of the world were simultaneously becoming less virulent, less prolonged and more concentrated on the larger cities where many hovels and much social degradation still remained. Many years were required to complete the social and economic revolution which was initiated by the terrible mortality caused by the disease. By the middle of the eighteenth century plague had disappeared from Western Europe and a century later from the rest of Europe. The disease was now almost forgotten, but new centres of the disease were recognised in Arabia, Persia and China. From this last centre about the year 1894 the disease spread to various parts of the world and a new chapter was opened in the history of plague.

A new pandemic of plague and the discovery of the plague bacillus.

For some years little had been heard of the plague. The disease had receded to the remoter parts of the world. Suddenly in 1894 it appeared in Canton and,
almost immediately thereafter, in Hong-Kong. Scientists from a number of countries visited Hong-Kong to investigate the disease, taking with them the comparatively new knowledge of bacteriology. It was not long before Kitasato, a Japanese, and Yersin, a Frenchman, almost simultaneously, in June, 1894, discovered that the disease is caused by a bacillus—the bacillus pestis. This was fulfilled the prediction of Eggeredes made in 1720, one and three-quarter centuries earlier, when he wrote, "If my history of plague and those of others is to be credited, this transference of infection has taken place either through goods, in which there has been concealed a certain material poisonous entity that could infect man when he came in contact with it, or it had been handed on to others by men who were themselves already infected with it. If then the plague arises from such a material poison-entity, which can be carried per fomitem, as by a tinder, from one place to another, it follows necessarily that such poison must be organized, and that it can likewise multiply to infinity." Obviously an important advance had been made in the study of the disease, but the problem of the dissemination of plague had not yet been solved.

The Extension of the Disease to other Countries. The plague epidemic in Hong-Kong exhibited its familiar and well marked seasonal prevalence, increasing steadily to a maximum in a few months, then rapidly declining as it had done throughout the centuries in other parts of the world. A respite from the disease lasted for about six months, when it again became epidemic; this second outbreak break of 1895 was, however, mild. In the spring of 1896 the disease appeared for the third time and caused a considerable mortality. Meanwhile, during the three years the plague had prevailed in Canton and Hong-Kong, infection had been carried into many neighbouring towns and villages, as well as into Formosa.

Extension of the Disease to India. But the most important extension was to Bombay. The disease seems to have been brought there, in all probability, by a ship, about March, 1896, for at that time an unusual mortality among the rats in the docks was noticed, and the existence, among the inhabitants of this neighbourhood of a strange disease, associated with a high mortality and the development of buboes, was commented upon. Its nature was not suspected till Dr. Viegas suggested that it was in fact the plague. His diagnosis was confirmed bacteriologically by Mr. Haffkine in October, 1896. The mortality steadily increased during the remainder of the year and a panic seized the inhabitants so that the great city, of nearly a million inhabitants, became almost deserted. The disease was carried into at least nine districts of the Bombay Presidency before the close of the year in spite of the most stringent precautions to prevent its spread by the inspection and quarantining of the fleeing citizens. Infection was disseminated along the main lines of communication by rail and ship. The new centres of infection, in their turn, distributed the disease to other centres, till at the close of the nineteenth century almost all the provinces of India reported deaths from plague. In the last year of the century alone 150,000 deaths were caused by the disease in India.

Extension of the Disease to other parts of the World. Meanwhile plague appeared in other parts of the world, carried thither chiefly by ships to seaport towns, so that places so far distant from one another as Manila and San Francisco, Sydney and Cape Town, Buenos Aires and Oporto, Honolulu and Glasgow, Mauritius and Auckland became infected. Ships carrying grain and forage played a very important part in the spread of the disease, and it became evident that
rats participated in its diffusion. In the majority of the places affected the source of infection of the first cases was seldom traced. The plague patients generally lived in the neighbourhood of the docks, some of them were dock labourers, and not infrequently an unusual mortality was noticed among the rats in the infected area.

**Dead Rats in the Plague-Infected Areas.** In Hong-Kong, for example, as in the land of the Philistines almost three thousand years earlier; the mortality among rats attracted attention. Twenty thousand dead rats were collected in a short time and as many as 1,500 were obtained from a single street. In Bombay, too, the mortality among rats in the Mandevie district was commented upon; cart-loads of dead rats were removed daily from this area.

Divergent views held on the rôle of the rat in disseminating the plague.

**The Soil as the Source of Infection.** Some authorities held the view that the plague bacillus had its home in the soil and that men acquired infection from the soil. It was for this reason that buboes were more frequently found in the groin, infection having entered the body through the feet. The bare-footed coolie thus suffered more often from the disease than the more wealthy inhabitants who could afford shoes. It was natural, in these circumstances, to find infection, they said, earlier and of greater intensity among rats than men, for these animals came in closer contact with the soil. Similar views had been held by many who had experience of the plague in the middle ages.

**Rats the Source of Infection.** Other authorities were of the opinion that rats were the primary source of infection and that in some way men contracted the disease from them. The work of Ashburton Thompson in Sydney and of Blackmore in Port Elizabeth shed much light on this vexed question. Thompson pointed out that in Sydney, at least, the disease was not communicated from the sick to the healthy; that infection was attached to localities, and spread to others adjoining that in which it was first manifested; that a plague epizootic among rats preceded the first case which occurred in man, and that the area of the epizootic was practically coextensive with that in which cases of plague were observed. The epidemic was, in fact, caused by communication of the infection from rats to man. An insect vector between rats and men seemed to him to fit the facts he had collected.

Blackmore showed that in Port Elizabeth plague cases followed in places where infected rats were found, and that in places where there were no infected rats only four cases occurred, and in these the source of infection could not be traced. In no case was there direct evidence of man-to-man infection, and in most the possibility of it was definitely excluded.

**Some Difficulties in Accepting the view that Rats are the Source of the Disease.** The early experience of plague in Glasgow differed remarkably from that recorded above. In August and September, 1900, thirty-six cases of plague were recognised in that city. The origin of the disease could not be discovered, but the first cases had occurred in a house occupied by a dock labourer. All the subsequent cases were more or less associated with one another, and arose chiefly from three houses in which "wakes" were held over the bodies of individuals who died of plague in the houses. Two of the cases were of special interest, for direct contact with infected rats could be definitely excluded in them. One was that of a ward maid who contracted the disease while following her duties at the hospital where the plague cases were isolated; the other was the wife of a man
employed by the Corporation to collect clothes from infected houses for disinfection. Presumably, while escaping himself, he carried home the infection to his wife. Moreover, although some 265 rats were caught in the infected area, many of them in and about the infected houses, and were examined bacteriologically, none was found infected. In the following year a group of five cases of plague, mainly associated with a rag store, situated in the area infected in the previous year, came under notice. On this occasion a single plague infected rat was discovered. However, five weeks later, a new group of five cases of plague occurred in quite another part of the city. Here dead rats were found in association with, and antecedent to, each of the cases; some of these rats were proved bacteriologically to be infected with plague. Further investigations showed that plague infected rats existed in a number of adjoining premises—for example, in the basement of certain tea-rooms. A rat warren was also discovered in another situation which gave a bag of sixty-five rats; thirteen of these were dead, the remainder were killed, and among them no less than forty were found infected with plague. In the end the epizootic was thus shown to be fairly widely distributed throughout the city. Plague infected rats continued to be found in Glasgow during the next two years at irregular intervals, though no cases of human plague were observed or notified in connection with this epizootic.

Difficulties in Accepting the Rat Origin of the Plague explained by a knowledge of the Habits of the Species of Rodent infected. For some years I had been engaged in the study of plague, first as an Assistant to The Indian Plague Commission 1898-99, later, from 1902-1905, as a worker in the Plague Research Laboratory in Bombay under Mr. Haffkine and Colonel Bannerman. As the result of numerous experiments carried out in the earlier part of this period, I abandoned the view that the plague bacillus found a suitable nidus in the soil and that men and rats acquired infection from this source. My experiments compelled me to adopt the alternative view, that rats were the reservoir of infection.

Remarks on the Habits of Rats. Before following up this line of research I studied the habits of rats in Bombay. There I found two species in the houses, the one, *Rattus rattus*, popularly known as the house rat, the other, *Rattus norvegicus*, the sewer rat. I soon realised that the habits of the two species differed in certain important respects so far as the spread of plague is concerned. The house rat is a relatively tame confiding creature which lives and breeds in the houses among the lumber and litter which is accumulated in almost every Indian dwelling. It finds shelter and food among the sacks of grain, the firewood, the animals (goats, hens, cattle) which frequently share the human habitation. They may even burrow into the mud walls and floors of the buildings. The sewer rat, on the other hand, is a shy rat. It lives chiefly in burrows, occasionally constructed beneath the floors of the dwelling, but more often it lives in out-houses or even outside dwellings in the open where it constructs its runs and at nights seeks food in the houses. Drains and sewers are places in which it lives and breeds. The sewer rat thus comes into less intimate contact with man than the house rat. In a paper which I read before the Bombay Natural History Society in 1903 I inferred from this study of the habits of rats that the remarkable difference in the rôle of the rat in distributing plague infection among men, as illustrated on the one hand in the East, in a city like Bombay, and, on the other hand, in Europe, in such a city as Glasgow, might be explained on the ground of the differences in the habits of the two species. The house rat when infected with plague would be more liable to convey the disease to man because it lives in closer relation to him than the sewer rat does. The epizootic in Glasgow
occurred among sewer rats; the disease among this species of rat is not so easily discovered until it is looked for in the haunts of this rat. The history of plague in Glasgow clearly showed that the epizootic existed in the city for years, although men were rarely infected.

The Disappearance of Plague from Europe coincided in time with the appearance of a new Species of Rat. I also drew attention to the fact that the disappearance of plague from Europe in the seventeenth and eighteenth centuries coincided in the main, in point of time, with the appearance of the sewer rat and the disappearance of the house rat. I attributed this substitution of the one species by the other to the social and economic changes which occurred at this time to which I have drawn attention in the earlier part of this paper. These changes,—the improvement in the habits of the people, the construction of more substantial houses, the development of drains and sewers,—produced conditions which were more favourable for the sewer rat than the house rat, so the house rat gradually disappeared and the sewer rat took its place. It was not due to a war waged by the sewer rat on the house rat, as is held by many naturalists, which caused the preponderance of the one species over the other, but the changes in the environment which led to the substitution of the one species by the other. We found this substitution actually in progress in Bombay; the sewer rat is displacing the house rat in the more Europeanised parts of the city, while the house rat still remains supreme in the un-Europeanised suburbs. In those places where the two species exist side by side the Plague Research Commission found that the house rat lives in the upper stories of the houses while the sewer rat thrives in the compounds, drains and basement.

The Importance of a Knowledge of the Species of Rodent affected by the Disease. The view I enunciated in 1903 that the species of rodent affected by the disease has an important bearing on the spread of plague, not so much from any inherent difference in susceptibility of the different species to plague infection, but because of the habits of the species, has been abundantly verified by a study of epidemics in different parts of the world. The adoption of this view enabled the authorities in England to regard with comparative equanimity the fairly widespread epizootic of plague which was discovered in 1910 among rats, rabbits and hares in East Anglia; the epizootic had existed for at least two or three years before it was discovered. In spite of this only a few cases of plague were associated with it, for the animals involved did not live in human dwellings.

Epizootics among other Species of Rodent. It is convenient here to refer to some of the known epizootics among other rodents, for example the epizootic among ground squirrels in California, *Citellus beecheyi*, described by Blue & Wherry, which McCoy showed had been associated with twelve cases of human plague in 1910. Then there is the existence of plague among gerbilles in some parts of Africa, for example the epizootic recorded by Dr. Mitchell in the Journal of Hygiene, December 1921, in the Free State. The gerbelle, he believes, is the main factor in the persistence of plague. The multimammate mouse acquires infection from the gerbelle and conveys it to the houses in which men dwell. Perhaps the best known endemic centre of plague is among the tarbagans *Arctomys lobac* which live in Eastern Siberia and Northern Mongolia. It was from this centre that a terrible epidemic of pneumonic plague swept over Manchuria in the winter of 1910-11 "with a death roll of 50,000 persons and a track, including ramifications, for at least 3,000 miles."
Pneumonic Plague not spread by Rats. I may mention here that the epidemiology of pneumonic plague is altogether different from that of bubonic plague; the two forms of the disease have little in common except that both are caused by the same micro-organism. The pneumonic form of the disease, as was recognised by Gui de Chauliac more than five centuries ago, is highly infectious and is spread by direct contact from man to man and rats play no part in its general dissemination, although there is abundant evidence that pneumonic epidemics may have their origin among domestic rats or among the shyer or wilder species of rodents. The Manchurian epidemic above referred to had such an origin and the cases of plague which occurred in connection with the epizootic in East Anglia were of this nature, as were also some of the cases of plague associated with the epizootics among gerbelles and multimammate mice in South Africa. The prevention of pneumonic plague, in as much as infection is conveyed from man to man, is a simpler problem than that presented by bubonic plague.

The Transfer of Infection from Rats to Men. We have still to consider how infection is conveyed from rats to men. In 1897 Ogata observed a number of fleas on two infected rats which were sent to him for examination when he was investigating an outbreak of the disease in Formosa. He proved that the fleas caught on the infected rats contained virulent plague bacilli in their bodies and suggested that blood sucking insects, such as fleas and mosquitos, might extract bacilli from an infected animal. In 1898 Simond confirmed Ogata's observation to the effect that fleas taken on plague infected rats contained plague bacilli and reported that he had transmitted infection to uninfected animals by means of fleas in two out of four experiments. He found also that the fleas captured on rats fed either upon a man or a dog.

Some Difficulties in accepting the Transmission of Plague by Fleas explained. But it was well known, and I had observed, that in ordinary circumstances fleas of particular species were confined to particular hosts. Rat fleas were generally captured on rats, human fleas on men, dog and cat fleas on dogs and cats respectively. For example, of 246 fleas caught on men, only one was a rat flea. If this rule held in all circumstances, the transfer of infection from rat to man seemed to be a remote possibility. But I found that in certain circumstances when a particular species of flea was deprived of its natural host for some time this species would attack and feed upon another species of host. In a house, for example, in which a cat had been kept but which had been removed and the house closed for some time, a man on entering it again after a period was attacked by large numbers of cat fleas. Other similar opportunities occurred of verifying the fact that fleas which normally feed upon a particular host may attack another host in exceptional circumstances. One of the most interesting of these experiences was the following. On April 6th and 7th, 1903, rats began to die in a certain block of tenement houses in Bombay. The cause of the death of the rats was not verified but it was probably plague. After a few days no more dead rats were found but, by April 11th, the people living in the house were troubled by fleas which were so numerous and annoying that the people abandoned their rooms and slept on the veranda. While thus living on the veranda on April 17th one of the residents was attacked by plague; other cases followed. A missionary friend persuaded some of the people in the infected house to collect the fleas which bit them. He sent the collection to me for examination on April 20th. There were thirty fleas in all and no less than fourteen of them were rat fleas. Here again, apparently, rat fleas, deprived of their usual host by the death of the rats from plague, had attacked men.
In March 1903 some guinea-pigs which had died in the Victoria Gardens in Bombay were sent to me for examination; I found that they had died of plague. I visited the gardens and examined the surviving guinea-pigs for fleas; many rat fleas were found upon them, one sick animal harbouring as many as eighteen rat fleas.

Guinea-pigs used as Traps for Rat Fleas. This experience suggested the use of guinea-pigs to trap fleas in possibly infected houses. Having learned that a plague case had occurred in a particular house, I placed a couple of guinea-pigs in the room which was adjudged to be infected and left them to run about the room until the following morning when they were examined for fleas. This method of proving that houses were infected with plague was repeated on ten occasions, and in every instance rat fleas were captured on the guinea-pigs. Some of the fleas were dissected and some of them were found to contain plague bacilli in their bodies. In a few instances the guinea-pigs which had been used as traps for the fleas became infected and died of plague.

Difficulties in carrying out Flea Transmission Experiments in a Laboratory. In attempting to carry out transmission experiments by means of infected fleas using rats, I found it difficult to obtain invariable success. The rats had to be suspended in cages over a disinfectant solution in order to prevent the escape of the fleas and the infection of the laboratory. Fleas were frequently found drowned in the antiseptic solution; they had deserted the rats in the un congenial surroundings which they experienced, and this I thought accounted for many failures.

These Difficulties overcome by the Construction of Godowns or Cubicles. I sought the sanction of the director of the laboratory to erect six small cubicles, rooms, or godowns. They were to be constructed very much after the manner of Indian houses but were to be made rat and flea proof. I proposed to use these rooms to ascertain whether plague could be transmitted from animal to animal where fleas were present, and whether infection failed to be propagated in their absence. These cubicles were not completed when I was invited to join the Plague Research Commission.

The Appointment of the Plague Research Commission. This Commission consisted of Major Lamb, Drs. Petrie, Rowland, Gloster and myself. It worked under the auspices of an Advisory Committee appointed in 1905 by the Secretary of State for India, who also supplied the funds for the operations of the Commission. Sir Charles Martin, then Dr. Martin, Director of the Lister Institute, one of the members of the Advisory Committee, visited India in March 1905. He inaugurated the work and established active co-operation between the Commission and certain public bodies which greatly facilitated the subsequent operations. When he left India the direction of the work of the Commission devolved on Major Lamb.

An Outline of the Contemplated Work of the Commission and Arrangements for Publication. At a conference of the members of the Commission, we decided to carry on the scheme of work which I had commenced and in which I was engaged when the Commission was appointed, but in order to secure more ample opportunities for studying the disease an epidemiological inquiry on a large scale was arranged to be conducted in Bombay city with the co-operation of the Medical Officer of Health, Dr. Turner. In addition a more detailed investigation throughout a whole year was instituted in three small villages on the outskirts of the city, as well as in two villages in the Punjab. Obviously work on so large a scale called for many assistants and the complete co-operation of all the members of the
Commission. It was in these circumstances considered desirable to publish our findings as from the Plague Research Commission and not in the name of the individual members of the Commission. It would be impossible to review, in the space available, all the work of the Commission. I can here refer only to the completion and confirmation of the work which I started and to which I have referred above.

The Godown Experiments. A number of experiments were carried out by the Commission in the small cubicles or godowns. Some of the godowns contained but others were free from, rat fleas. Many experiments were made at all seasons of the year. In the godowns in which fleas were present infection was carried by them from the inoculated to the uninoculated animals, while in those which contained no fleas infection was confined to the inoculated animals alone. The following experiment may be given as an example. It was carried through at the height of the plague season. One godown contained many fleas, the other had none at all.

On January 8th five guinea-pigs which had been inoculated with plague were placed in the flea infested godown. All the animals were dead by January 11th and they had all been removed when twenty-five healthy guinea-pigs were allowed to run free in the godown. An epizootic of plague of the most virulent description at once broke out among the animals. The first guinea-pig died on January 15th and in a fortnight from that date all were dead. Contrast with this the course of events in the godown which contained no fleas. On January 8th five inoculated guinea-pigs together with twenty-five healthy guinea-pigs were placed in this flea free godown. By the 11th January all the inoculated animals had died and from this date other inoculated animals were added daily, twenty-five inoculated guinea-pigs in all being put in between January 15th and 24th. All these inoculated guinea-pigs died of plague, the last on January 31st. At one time as many as twenty-one infected animals were living in contact with the twenty-five uninoculated guinea-pigs originally placed in the godown and yet not one of these latter contracted infection.

In the flea infected godowns the rate at which the uninoculated animals died in the various experiments depended on the number of fleas present in the godown and on the season of the year at which the experiment was carried out. In the non-epidemic season infection sometimes failed to spread from the inoculated to the uninoculated animals in spite of the presence of fleas.

These experiments, and others with monkeys, justified us in assuming that close and continuous contact with plague infected animals, if fleas are excluded, does not give rise to an epizootic among healthy animals, and that when fleas are present, an epizootic may develop which varies in severity and rate of progress according to the season of the year and the number of fleas present; that an epizootic may be started without contact with infected animals if infected fleas are available.

An Explanation why the Flea and not other Blood Sucking Insects conveys Plague from Animal to Animal. A last word has to be said to explain why fleas and not other blood sucking insects can convey the plague.

Early in my work in Bombay I had made serial sections of fleas and found that some of them which had fed on plague infected rats showed numerous plague-like bacilli in the oesophagus and in a valvular organ which is sometimes called "the gizzard" or proventriculus. The organ is situated immediately in front of the stomach and is a circular muscular organ furnished with a lining covered by
long finger-like cells which project into the lumen of the organ in a slightly antero-posterior direction. They allow fluid to pass into the stomach but the finger-like cells, if pressure is exerted upon them by fluid from within the stomach, coming together effectively close the opening into the stomach and regurgitation from the stomach in these circumstances cannot occur.

Martin and Bacot, by observing through a magnifying lens fleas feeding upon a healthy animal, succeeded in showing that infection could be brought about by bites alone, without the deposition of infected material on the punctured surface. During the course of these experiments they noted that whereas certain fleas sucked energetically and persistently yet no blood entered their stomachs, but the cesophagus became unusually distinct. On dissecting these fleas a curious condition was discovered. Their gizzards were blocked with what proved to be a solid culture of plague. They explain that "although with the proventriculus obstructed in this manner blood cannot find its way into the stomach, this does not prevent the insect sucking, but it only succeeds in distending the cesophagus. The blood in the distended cesophagus may flow out again on the cessation of the sucking act." They have seen drops of blood escape from the mouth parts of "blocked" fleas when the insect withdrew its proboscis.

The Anatomical Structure of the Flea, the make up of its Proventriculus, explains why Fleas especially can convey the Plague. It is important therefore to note that it is the anatomical construction of the proventriculus of the flea which allows the pathological development of the "blocked" condition which distinguishes these insects from other common blood sucking insects such as bugs, lice or mosquitos, and is one of the reasons why fleas are the instruments by which plague infection is transferred from animal to animal.

Summary.

The modern study of bubonic plague, then, has shown that the disease is essentially one of rodents; that men become infected from these animals by living in propinquity to them; that the plague bacilli, which are the cause of the disease, are transmitted from rodents to men by the instrumentality of fleas, which, on account of their anatomical structure, are liable to develop a peculiar pathological condition which allows the injection of the bacillus under the skin when certain species of rodent fleas feed upon men in exceptional circumstances.

Books and Papers which may be consulted.


The Great Plague in London in 1665, by Walter G. Bell—John Lane, the Bodley Head, Ltd. London (1924).


Reports on Plague Investigations in India, published as supplements to the Journal of Hygiene from 1906 to 1915. Also, in part, separately in three volumes—Cambridge University Press (1911).