

POTENTIAL FORCE OF INFECTION OF HUMAN RABIES TRANSMITTED BY VAMPIRE BATS IN THE AMAZONIAN REGION OF BRAZIL

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Abstract. Human rabies transmitted by bats has acquired greater epidemiologic relevance in various Latin American countries, just when cases transmitted by dogs have decreased. Concern has been heightened by reports of increased rates of bats biting humans in villages in the Amazonian region of Brazil. The aim of the present work was to estimate the potential force of infection (per capita rate at which susceptible individuals acquire infection) of human rabies transmitted by the common vampire bat if the rabies virus were to be introduced to a colony of bats close to a village with a high rate of human bites. The potential force of infection could be then used to anticipate the size of a rabies outbreak in control programs. We present an estimator of potential incidence, adapted from models for malaria. To obtain some of the parameters for the equation, a cross-sectional survey was conducted in Mina Nova, a village of gold prospectors in the Amazonian region of Brazil with high rates of bats biting humans. Bats were captured near dwellings and sent to The Rabies Diagnostic Laboratory at the Center for Control of Zoonoses (Sao Paulo, Brazil) to be examined. To estimate the force of infection, a hypothetical rabies outbreak among bats was simulated using the actual data obtained in the study area. Of 129 people interviewed, 23.33% had been attacked by a vampire bat during the year prior to the study, with an average of 2.8 bites per attacked person. Males (29.41%) were attacked more often than females (11.36%); also, adults (29.35%) were attacked more often than children (8.33%). None of the 12 bats captured in Mina Nova tested positive for rabies, but the force of infection for a hypothetical outbreak was estimated to be 0.0096 per person per year. This risk represents 0.96 cases per 100 area residents, giving an incidence of 1.54 cases of bat-transmitted human rabies per year in the village of Mina Nova (160 inhabitants). The estimated risk is comparable with what has been observed in similar Brazilian villages.

Just as the incidence of human rabies transmitted by dogs is decreasing in Brazil, the number of cases due to rabies transmitted by bats is increasing. In the last 10 years, 15% of the human cases reported in Brazil were transmitted by bats (Fundacao Nacional de Saude, unpublished data). Other Latin American countries, such as Peru, have also reported important human rabies outbreaks transmitted by bats (Instituto Nacional de Salud, unpublished data).¹ There have also been other reports of outbreaks of attacks by bats on people; even without the occurrence of rabies, these represent a potential risk for the disease.^{2,3}

Accurate records of this kind of information are very scarce, mainly because outbreaks of vampire bat attacks on people normally occur in remote regions, where little or no health assistance is available. Most of the reported outbreaks occurred in the Amazonian region.⁴ Control efforts are often implemented only after the occurrence of cases of human rabies. The most highly recommended control strategies are preventive treatment against rabies prior to or after exposure and control of the bat population (Fundacao Nacional de Saude, unpublished data).

The potential force of the infection (per capita rate at which susceptible individuals acquire infection), which is essentially a hypothetical incidence rate, could be a useful estimator to quantify the problem. The aim of this work was to estimate the potential force of human rabies infection transmitted by common vampire bats in possible outbreaks in the Brazilian Amazon region. The number of cases of human rabies transmitted by bats in Brazil is small, but even those can be avoided. Knowing the potential magnitude of

the disease in certain areas at risk could contribute to control efforts.

MATERIALS AND METHODS

An equation used in models for malaria transmission was adapted to estimate the force of infection for human rabies transmitted by hematophagous bats in the Amazonian region of Brazil.^{5,6} The force of the infection was represented by the following equation: $\lambda = mayb$, where λ = the force of the infection per person per year; m = the ratio of the bat population to the human population; a = the rate of bites on humans per bat per year; y = the proportion of infectious bats; and b = the proportion of bites on humans by infectious bats that actually transmit rabies. In practice, m and a are measured only as their product, ma , the rate of bat bites per person per year.

To obtain the values of the parameters to be used in the equation, a cross-sectional study was carried out in a Brazilian village considered to be at risk for human rabies transmitted by the common vampire bat, *Desmodus rotundus* (Figure 1). Because bat bites are less common and more memorable than mosquito bites, information on biting can be collected by interviewing the community directly instead of using selected individuals as human bait. The cross-sectional study was used to obtain the relevant information pertaining to people and bats to be used as parameters to estimate a potential force of infection for the disease in the region.

Human population. One hundred twenty-nine people



FIGURE 1. The hematophagous bat species *Desmodus rotundus* involved in the cases of attacks of humans.

were interviewed in a village called Mina Nova (Figure 2) on the island of Aurizona, in the municipality of Godofredo Viana, State of Maranhao in the part of the Amazonian region belonging to Brazil (Figure 3). The village (population = 160), inhabited mainly by gold prospectors, had been regularly attacked by bats (Figure 4), but no case of human rabies had been reported prior to the survey. All houses with people present on the days of the survey were visited (87.5% of the total), and inhabitants were interviewed (90.4% of the total) either directly or by proxy in the case of children or absent family members (35%). The data obtained included the number of persons per house, their gender, age, profession, length of residence in the area, number and time of attacks by bats.

Bat population. In addition to interviewing the people, nightly captures of bats were conducted to determine if the rabies virus was circulating in the area. The researchers chose houses with a high probability of being targets of common vampire bats, such as those with domestic animals or with people who had been attacked over the previous few



FIGURE 2. The village of Mina Nova, on the island of Aurizona, where 23.33% of the population had been attacked by bats in the last 12 months.

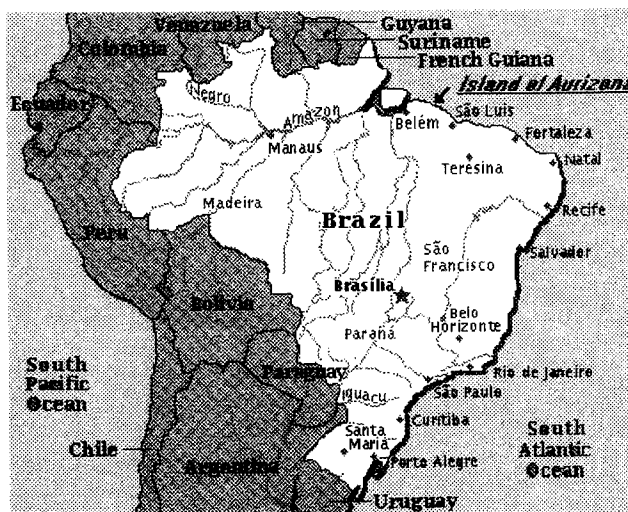


FIGURE 3. The island of Aurizona, Municipality of Godofredo Viana, State of Maranhao, in Amazonian Brazil where the field work was carried out.

days. The nets to capture bats were placed one time close to houses over an approximately 5-hr period from 5:00 PM to 9:30 PM. Ten nets, each six meters in length, were set up near five houses to trap the bats. The captured bats were sent to the Rabies Diagnostic Laboratory at the Center for Control of Zoonoses (Sao Paulo, Brazil) to be examined for rabies infection (immunofluorescence and biological tests) and for the analysis of the contents of the digestive tract to establish what kind of blood the animals had been ingesting in the previous 72 hr.⁷

Positing a hypothetical outbreak of rabies in the vampire bat population of the region, the force of the infection was calculated, using the data obtained in the field study in Mina Nova, as well as some information from the literature.

RESULTS

Thirty (23.33%) of the 129 people who were interviewed had been attacked by bats in Mina Nova during the previous



FIGURE 4. A foot of a person in the region studied showing a recent bat bite.

TABLE 1

Number of people in the study, number of people attacked, percentage of people attacked, number of bites, and average number of bites per person attacked in Mina Nova, Brazil

| Group of people | No. of people | No. attacked | % attacked | No. of bites | Average number of bites per person attacked |
|-------------------|---------------|--------------|------------|--------------|---|
| Total population* | 129 | 30 | 23.33 | 84 | 2.80 |
| Gender | | | | | |
| Females | 44 | 5 | 11.36 | 10 | 2.00 |
| Males | 85 | 25 | 29.41† | 74 | 3.00 |
| Age group‡ | | | | | |
| Children | 36 | 3 | 8.33 | 8 | 2.67 |
| Adults | 92 | 27 | 29.35† | 76 | 2.81 |

* 81% of 160, the estimated population of Mina Nova.

† $P < 0.05$, by chi-square test.

‡ The age of one interviewed person was not recorded.

12 months (Table 1). The average number of bites for people who had been attacked was 2.80 bites per year.

In the analysis of the results of the cross-sectional study, it was observed that males (29.41%) were attacked more often than females (11.36%); also, adults (29.35%) were attacked more often than children (8.33%) (Table 1).

Twelve bats belonging to three different species (Phyllostomidae) were captured in Mina Nova: nine *Desmodus rotundus*, a hematophagous species, and two *Carollia perspicillata* and one *Dermanura cinerea*, both frugivorous species. The bats captured in Mina Nova were tested for rabies, with negative results. The precipitin test was carried out on the contents of the digestive tract of three of the nine captured *Desmodus* and one of the samples was positive for human blood.

Parameters used to calculate the force of the infection.

Ratio of bat bites per person per year. In 129 interviews, it was determined that 30 (23.33%) persons had been bitten in Mina Nova within the previous 12 months. The average number of bites per year was calculated as 0.23 bitten persons/year \times 2.80 bites/person/year = 0.64 bat bites/person/year.

Proportion of infectious bats. A hypothetical value was estimated positing a rabies outbreak among the bats in the area. The value of 10% (0.1) of the infectious bats used for this parameter was obtained from the literature about the outbreak of human rabies transmitted by vampire bats in Trinidad.⁸

Proportion of bites of humans by infectious bats that actually transmit rabies. The probability that from one single exposure to the virus the subject can develop a clinical case of human rabies depends on the species of the animal, on the location of the bite, and on the severity of the attack.⁸ The proportion of attacks by rabid animals that cause human cases of rabies has been reported for several species, but the most commonly studied case has been that of dogs attacking humans, for which the proportion was found to average approximately 15%.^{9,10} The closest situation to that of Mina Nova was a rabies outbreak among gold prospectors also located in the Amazonian region of Brazil, in which five or seven (two presented symptoms, but left the area) among the 40 people living in a camp in the rain forest died of rabies

TABLE 2

Bat bites/person/year (ma), force of the infection (λ) for each group of people, and the risk ratio for gender and age group in Mina Nova, Brazil

| Group of people | ma | λ^* | Risk ratio |
|------------------|------|-------------|------------|
| Total population | 0.64 | 0.0096 | |
| Men | 0.87 | 0.0131 | 3.97† |
| Women | 0.22 | 0.0033 | |
| Adults | 0.81 | 0.0122 | 3.81‡ |
| Children | 0.21 | 0.0032 | |

* Infectious bat bites that actually transmit rabies/person/year.

† Risk ratio between men and women.

‡ Risk ratio between adults and children.

following attacks by bats. This report suggests the same percentage of 15% (0.15) found to reflect the infectious rate caused by transmission of the virus by dogs.

There is no evidence of the presence of the rabies virus in the area at present, but it could be introduced at any time, and given the lack of surveillance in animals in the region, an outbreak of human rabies could well occur.

Positing a hypothetical outbreak of rabies in the vampire bat population of the region, the force of the infection was calculated for the total human population and for the subgroups that were shown to present different risks of becoming infected by the disease (males, females, adults, and children, Table 2).

Calculation of the potential force of infection. Using the above-listed parameters, the potential force of the infection for the transmission of rabies by bats to people in Mina Nova was estimated in the hypothetical case of a rabies outbreak within the common vampire bat population located in the area. For the total population, the force of the infection would be $\lambda = mayb$, where: $ma = 0.23$ attacked persons/year \times 2.80 average number of bites/person/year = 0.64 bat bites/person/year; $y = 0.10$, $b = 0.15$, and $\lambda = 0.0096$ infectious bat bites that actually transmit rabies/person/year. The force of the infection estimated for the different groups can be seen in Table 2.

DISCUSSION

If an outbreak were to occur in the study area, the force of infection for the total population would be 0.0096 infectious bat bites that transmit rabies/person/year, i.e., among 100 people, 0.96 cases of rabies caused by bats would be estimated to occur per year. If we were to make an estimate for the population in Mina Nova (approximately 160 inhabitants), 1.54 human cases would be expected to occur per year. The number of reported deaths in outbreaks in Brazil in 1990 and 1991 totaled 19: five outbreaks accounted for 14 of these deaths, two deaths in each of the two outbreaks by M. Pereira Filho (unpublished data), one by G. A. Almeida (unpublished data), four by J. F. Konolsaisen (unpublished data), and five by M. C. Schneider (unpublished data). These numbers are not very different from the estimated number in this study. Unfortunately, since the Brazilian reports do not have accurate information about the populations at risk in the outbreaks, a better comparison is not possible.

The Brazilian outbreaks appear to be smaller in the number of human cases than those that occurred in Peru, in

which 29 people died of rabies in two jungle communities.¹ The larger number of human cases in Peru might be associated with a different habitat for the bat colonies. The caves involved in the Peru outbreak would support larger colonies than the tree hollows in the Amazonian region of Brazil. Larger colonies would be expected to lead to greater transmission of rabies among bats, increasing the proportion of bats infected. However, comparing attack rates across national boundaries is difficult because of differing definitions of communities at risk.

In an outbreak of human rabies transmitted by bats in Trinidad, the proportion of people affected was reported to be very close to the force of infection estimated in this study. The locality of Valencia (seven cases/839 inhabitants) had 0.83 human cases for 100 people and Santa Cruz Valley and San Juan (39 cases/3,655 inhabitants) had 1.07 per 100 people.¹¹ We do not have information about the ecology in the regions of the outbreaks in Trinidad.

The analysis developed in this study carried out in Mina Nova, a region populated by gold prospectors in the Brazilian Amazon basin, suggests that hematophagous bat attacks on people do not follow a homogenous pattern. Using the attack risk ratio (ratio of force of infection), it appears that such exposures would be roughly four times more likely to affect males than females and roughly four times more likely to affect adults than children (Table 2).

In a study that analyzed eight human rabies outbreaks transmitted by bats in Peru and Brazil in recent years, it was possible to ascertain that 76% of the reported cases were males; 38% of the cases occurred in areas populated by gold prospectors, in which most of the population was adult males, undoubtedly increasing this percentage. In the same study but in outbreaks that occurred in the agricultural regions, more cases were found in children than in adults.⁴ A study of all human cases recorded by the Brazilian Ministry of Health between 1980 and 1990 found that 55% of the cases were children equally distributed between the sexes; among the adults, most of the cases (83%) were males. One of the outbreaks in Brazil occurred in a gold mining area and all the cases were male adults. In an outbreak caused by bats in neighboring Suriname, seven deaths were reported and they were all children.¹¹

In an outbreak of attacks in Brazil by *Desmodus rotundus*, where no cases of rabies occurred, the bitten persons had an average age 24.16 years and the ratio of males to females was 3:1; this also suggests that males and adults are more likely to be bitten.² Another study of an outbreak of bat attacks was carried out among the Yanomamis Indians in the Amazonian region of Venezuela and yielded the following result: no child less than five years of age had been attacked, which is probably due to the fact that small children sleep embraced by their mothers in the same hammock.¹²

The observation that the proportion of attacks on children is lower in some outbreaks in Brazil may be related to the social organization of the community. In a region of gold prospectors, children are less numerous and can be more protected, as was mentioned for the indigenous Yanomani community, and therefore are not available to be exposed. However, in other areas, such as agricultural ones, where families normally have a large number of children, the proportion of attacks on children has not been observed to be

lower. Nonetheless, it generally holds in Brazil that men are attacked more often and die more often of bat-transmitted rabies. A study of the sleeping habits of people living in the areas affected by bat attacks would be needed to ascertain this aspect of the problem. However, each region presents different characteristics, and a full analysis would therefore require various studies of different risk situations.

A limiting factor for our study is that the values of two of the parameters used in the force of infection are based only on studies conducted elsewhere. The appropriateness of the reported values in the event of a rabies outbreak in Mina Nova cannot be assured. Another limitation is that we studied only one locale, Mina Nova, that may not be representative of the entire Amazonian region. We need to be cautious in the generalization of these results to all areas at risk for rabies transmitted by hematophagous bats. The influence of gender and age on attack rates by the bats appears to be important. More male than female victims are reported and children appear to be less involved than adults. However, these trends require confirmation by studies of other Amazonian communities in which age and sex distribution of the population at risk is clearly defined.

Rabies control is important in Brazil, although the number of deaths has been low compared to other infectious diseases. Since the discovery of Pasteur's vaccine in 1885,¹³ there exist technical means to control rabies, although not always easy to implement; however, we are dealing with human losses that could be avoided.

The Health Ministry of Brazil has recommended two kinds of preventive treatment for rabies, either preexposure immunization (four doses on 0, 2, 4, and 28 days) or postexposure immunization (10 doses on consecutive days and three boosters on the 10th, 20th, and 30th days after finishing the initial series (Fundacao Nacional de Saude, unpublished data). Pre-exposure immunization should be combined with some postexposure immunization, depending on the immunization history of the patient. The prophylactic treatment for rabies is free in Brazil, but is still not available in all localities, mainly where access is difficult. Availability will depend on the structure of local health services. The northern region of Brazil, where the Amazonian region is located, has the highest ratio in the country of the number of inhabitants to the number of centers with rabies preventive treatment (Schneider MC, *Estudo de Avaliacao Sobre Area de Risco Para a Raiva no Brasil*. Master's Thesis in Science/School of Public Health, Rio de Janeiro, Brazil, 1990).

Gold prospectors in that region have a very long working day (averaging 12 hr a day and at times working for 24 hr nonstop); their salary is proportional to the amount of gold they find. The person attacked by bats would have to travel to a nearby town on 13 days (10 doses and three boosters) to be treated. This would mean forfeiting almost half of his monthly salary because the miner would not be looking for gold during the period of treatment. This makes it extremely improbable that these individuals would seek treatment after being attacked by a bat. In the interviews that were carried out, people were asked about the treatment they would prefer and 72% opted for the pre-exposure treatment.

The introduction of rabies into the population of bats of the region is expected to generate about 1.54 cases of human rabies in the community of Mina Nova. This number, esti-

mated by the force of infection calculated for the hypothetical outbreak using the parameters obtained in the field work done in Mina Nova, is reasonably consistent with the incidence reported for other attacks by bats that occurred in Brazil.

The force of the infection calculated for the different affected groups was found to be higher in males and adults. In case a rabies outbreak were to take place among the hematophagous bats of the region, these groups would be most at risk. This suggests that adult males should be considered as the main target of the control actions for the disease.

In case the rabies virus were circulating in the bats of the region, perhaps the most successful control action would be preventive treatment for rabies using the pre-exposure schedule, since it requires fewer days of treatment. These doses could be administered to all subjects at risk in the same period by a health service worker at the actual site. Only the subjects exposed to the virus should receive a booster or complete the number of doses for the postexposure treatment, far from the camp.

The conceptual model was developed to be applied to all risk situations of vampire bat transmission of rabies. However, here it is being implemented within the reality of Mina Nova, a village that has its social and physical characteristics; therefore, these results cannot be extrapolated to apply to all regions where attacks by bats occur. It would be useful to develop other analyses of different productive processes in areas affected by outbreaks, such as agricultural settlements and areas of traditional subsistence farming. It would be most interesting to carry out these studies in areas where a change in the productive process is taking place, such as where felling of trees for farming purposes occurs, and where abandonment of cattle ranching and other actions may alter the habitat and behavior of common vampire bats.

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