Reprints from the JOURNAL OF THE AMERICAN VETERINARY MEDICAL ASSOCIATION,
Vol. 155, No. 12, Pages: 2141–2145

Ecology of Venezuelan Equine Encephalitis Virus in Panama

Margaret A. Grayson, Ph.D., and Pedro Galindo

SUMMARY

Venezuelan equine encephalitis (VEE) is widespread in Panama, occurring in man, his domestic animals, and a wide variety of wild mammals, birds, and reptiles. It is enzootic in forest rodents of which the cotton rat (*Sigmodon hispidus*) appears to be the principal reservoir. Many species of arboreal and terrestrial vertebrates, however, may contribute to the maintenance or amplification, or both, of virus activity in a given region. Birds may play a role, not only in local transmission cycles, but in the geographic dissemination of this agent. Although VEE virus has been isolated from several species of mosquitoes, proof of transmission has not yet been obtained with those species found naturally infected in Panama. However, the prevalence of infection in *Culex taeniopus* mosquitoes coupled with their breeding habits and host preferences suggest that this species is an important vector in transmission cycles involving rodents. In other endemic areas where VEE has been extensively studied, namely, Trinidad[10] and Florida,[4] the requisite factors for the establishment of enzootic foci of infection also appear to be *Culex* (*Melanoconion*) mosquitoes and small ground rodents in a lowland tropical rainforest environment.

THE VIRUS of VEE was first isolated and described during investigations of an equine disease which occurred in Venezuela from 1936 to 1938.[1,11] Subsequently, human and equine disease caused by this virus was reported from Trinidad,[12] Ecuador,[18] Colombia,[15] and other South American countries.[17] In 1961, 25 years after the discovery of this agent, a case of human infection with VEE virus was found in Panama.[9] Since then, the geographic distribution of this agent has been extended to Central America,[24] Mexico,[16] and the southeastern United States,[3] areas in which it is apparently endemic. This report considers some of the ecologic aspects of VEE virus infections in Panama.

From the Gorgas Memorial Laboratory, Panama, Republic of Panama.

The investigative work done at the Gorgas Memorial Laboratory was supported in part by Grant AI-02984 from the National Institute of Allergy and Infectious Diseases, National Institutes of Health.

Vertebrate Reservoirs

Man.—Although human infections with VEE have been found in widely scattered areas of Panama, from Darien province in the east to Bocas del Toro in the west,[20] the most extensive epidemiologic studies of this agent have been done in an area of tropical rainforest near the town of Almirante, a seaport located on the Atlantic coast of northwestern Panama.[7] In this study, VEE virus infections

TABLE 1—Natural Infections of Venezuelan Equine Encephalitis in Wild Mammals of Panama

Order	Species	Detection of	
		Virus	Antibody
Rodent	Cotton rat (*Sigmodon hispidus*)	+	+
	Spiny rat (*Proechimys semispinosus*)	+	+
	Thorny rat (*Hoplomys gymnurus*)	....	+
	Rice rat (*Oryzomys caliginosus*)	....	+
	Common rat (*Rattus rattus*)	....	+
	Paca (*Agouti paca*)	....	+
	Red squirrel (*Sciurus granatensis*)	....	+
	Variegated squirrel (*Sciurus variegatoides*)	....	+
Marsupial	Murine opossum (*Marmosa* spp.)	+	+
	Common opossum (*Didelphis marsupialis*)	....	+
	Four-eyed opossum (*Philander* opossum)	....	+
Edentate	Two-toed sloth (*Choloepus hoffmanni*)	....	+
	Silky anteater (*Cyclopes didactylus*)	....	+
Primate	Night monkey (*Aotus trivirgatus*)	....	+
	Marmoset (*Saguinus geoffroyi*)	....	+
Bat	Big fruit-eating bat (*Artibeus lituratus*)	....	+

were found to be widespread in the indigenous population, occurring in about 36% of the Almirante residents examined. Prevalence rates were nearly uniform in both sexes, and infections were positively correlated with length of residence in the area, indicating that the virus was endemic in this region. Among children, infections were encountered most frequently in residents of 2 slum sectors bordered by extensive swamp forests and open freshwater marshes, habitats which produced the greatest number of infected insects and wild vertebrates.[5,7]

Domestic Animals.—Naturally occurring infections in domestic animals, namely, horses, mules, cows, dogs, and chickens, have also been found in Panama.[7] The scanty evidence available, however, suggests that Panamanian strains of VEE virus produce little or no clinical disease in equine animals. In July, 1961, a peak year for VEE virus activity in Almirante, 74 horses and mules in the area were examined.* Illness was not detected in any of these animals, and reports of equine sickness or death during the preceding 2 months were not obtained, even though 84% of the animals tested had antibodies to VEE virus at that time.[7] The following year, some 200 equine animals died from eastern equine encephalitis which occurred in the central part of Panama.[13] Although isolations of VEE virus were not made from equine animals during investigations of this epizootic, several cases of VEE occurred concomitantly in the human population of the same geographic area.

Wild Animals.—At least 29 species of indigenous vertebrates have been found naturally infected with VEE virus[7,8,20] (Tables 1 and 2). In the Almirante area, infections were more prevalent in mammals than in birds and reptiles and occurred with the greatest frequency in rodents, particularly the cotton rat (*Sigmodon hispidus*) and spiny rat (*Proechimys semispinosus*).[7] In 1961, for example, approximately 4% of the cotton rats examined were viremic, and nearly half had antibodies to the virus.

Nonlethal infections with VEE virus have been experimentally produced in a number of native Panamanian vertebrates. Investigators at the Middle America Research Unit demonstrated that 4 species of small ground rodents, including the cotton rat and spiny rat, circulated virus in the blood for several days after subcutaneous injection with moderate doses.[23] At the Gorgas Memorial Laboratory, 15 species of mammals and birds thus far tested have been found with viremia within a few days of injection

* By Dr. Otto Alvarez, a veterinarian whose services were obtained through the Veterinary Department of the Ministry of Agriculture in Panama.

TABLE 2—Natural Infections of Venezuelan Equine Encephalitis in Wild Birds and Reptiles in Panama

Class	Species	Detection of	
		Virus	Antibody
Bird	Green heron (*Butorides virescens*)	+	+
	Groove-billed ani (*Crotophaga sulcirostris*)	+	....
	Social flycatcher (*Myiozetetes similis*)	+	....
	Gray-capped flycatcher (*Myiozetetes granadensis*)	+	....
	Black-cowled oriole (*Icterus prosthemelas*)	+	....
	Scarlet-rumped tanager (*Ramphocelus passerinii*)	+	+
	Catbird (*Dumetella carolinensis*)	....	+
	Keel-billed toucan (*Ramphastos sulfuratus*)	....	+
	Swainson's toucan (*Ramphastos swainsonii*)	....	+
	Collared aracari (*Pteroglossus torquatus*)	....	+
	Black vulture (*Coragyps atratus*)	....	+
Reptile	Cayman (*Caiman fuscus*)	....	+
	Common iguana (*Iguana iguana*)	....	+

with low to moderate doses of VEE virus.[8] Most of these animals tolerated the infection quite well, with little or no ill effects. However, the duration and intensity of viremia varied according to species. Virus concentrations reached highest titers in the blood of certain rodents and edentates, namely, the variegated squirrel (*Sciurus variegatoides*) and the three-toed sloth (*Bradypus griseus*) (Table 3). Viremias persisted for the greatest length of time (1 to 2 weeks) in sloths, a phenomenon probably due to their lower body temperature[2,22] and possibly related to delayed immune response.[8]

With 2 of the experimentally infected species, the variegated squirrel and the yellow-backed oriole (*Icterus chrysater*), evidence was obtained that the initial infection conferred immunity to subsequent challenge with low doses of virus for at least a year.[8]

Insect Vectors

Venezuelan equine encephalitis virus has been isolated from at least 5 species of anopheline and culicine mosquitoes in Panama.[5,7,14] In the Almirante area, infection rates were highest in *Culex* (*Melanoconion*) *taeniopus* followed by *Culex* (*M.*) *vomerifer*, 2 closely related species which are quite common in this region and usually occur there throughout the year. However, in experiments with golden hamsters and wild-caught *Culex* (*Melanoconion*) mosquitoes from Almirante, laboratory transmissions of VEE virus were not obtained from the bites of

TABLE 3—A Comparison of Venezuelan Equine Encephalitis Virus Concentrations in the Peripheral Blood of Experimentally Infected Wild Animals

Class	Species	Maximum titer*
Mammal	Collared peccary (*Tayassu tajacu*)	<1.0
	Raccoon (*Procyon lotor*)	<1.0
	Kinkajou (*Potos flavus*)	1.3
	Coatamundi (*Nasua nasua*)	1.6
	Two-toed sloth (*Choloepus hoffmanni*)	1.9
	Common agouti (*Dasyprocta punctatus*)	2.3
	Common opossum (*Didelphis marsupialis*)	2.4
	Wooly opossum (*Caluromys derbianus*)	2.5
	Paca (*Agouti paca*)	3.6
	Olingo (*Bassaricyon gabbii*)	3.6
	Three-toed sloth (*Bradypus griseus*)	4.4
	Variegated squirrel (*Sciurus variegatoides*)	5.0
Bird	Black vulture (*Coragyps atratus*)	1.4
	Yellow-backed oriole (*Icterus chrysater*)	3.6
	Striated heron (*Butorides striatus*)	4.1

* Expressed as $\log_{10}$ LD_{50}'s/0.02 ml. of plasma or serum injected intraperitoneally in weanling mice.

nearly 4,000 *C. vomerifer* tested,[6] even though the virus was being actively transmitted to sentinel hamsters exposed in the area at that time.[19] The fact that several isolations were made from *C. vomerifer* mosquitoes obtained from the same collecting pools which furnished specimens for the transmission experiments suggests that this species, although susceptible to infection, is not capable of transmitting virus to susceptible vertebrate hosts.[8]

The number of wild-caught *C. taeniopus* tested in transmission experiments was not sufficient to permit any conclusions concerning its vector potential. However, observations on the bionomics of this species incriminate it as the most likely vector of the virus among rodents at least. This species is known to breed in deeply-shaded permanent swamps such as those found on the outskirts of Almirante. It is a nocturnal, sylvan species inhabiting both the forest canopy and floor which occasionally invades peridomestic habitats. Rodents are the preferred hosts, but females will frequently attack man and, occasionally, horses and birds. On several occasions, virus isolations from sentinel mice have been associated with natural infections in this species.[7]

The possibility of man to man transmission of VEE virus by *Culex* (*Culex*) *pipiens quinquefasciatus* should not be excluded from consideration. On 2 separate occasions, natural infections of these mosquitoes were found in close association with human infections.[7]

Aedes (*Ochlerotatus*) mosquitoes, specifically *Aedes* (*O.*) *angustivittatus,* have also been found naturally infected with VEE virus in Panama.[7] These mosquitoes feed mostly on large mammals such as horses and, less frequently, on birds.[5]

Members of the crab-hole breeding genus, *Deinocerites*, have also been incriminated as potential vectors of VEE virus. *Deinocerites pseudes*, which proved to be an efficient vector of the virus in transmission experiments employing laboratory-reared mosquitoes,[8] has been found naturally infected in Mexico.[21] In Panama, this species has been found to feed on both homoiothermic and poikilothermic animals, and may be instrumental in transmitting the virus to reptiles and birds, their preferred hosts.[21]

References

1. Beck, C. E., and Wyckoff, R. W. G.: Venezuelan Equine Encephalomyelitis. Science, 88, (1938): 530.
2. Britton, S. W., and Atkinson, W. E.: Poikilothermism in the Sloth. J. Mammal., 19, (1938): 94–99.
3. Chamberlain, R. W., Sudia, W. D., Coleman, P. H., and Work, T. H.: Venezuelan Equine Encephalitis Virus from South Florida. Science, 145, (1964): 272–274.
4. Chamberlain, R. W., Sudia, W. D., Work, T. H., Coleman, P. H., Newhouse, V. F., and Johnston, J. G., Jr.: Arbovirus Studies in South Florida, with Emphasis on Venezuelan Equine Encephalomyelitis Virus. Am. J. Epidem., 89, (1969): 197–210.
5. Galindo, P., Srihongse, S., Rodaniche, E., and Grayson, M. A.: An Ecological Survey for Arboviruses in Almirante, Panama, 1959–1962. Am. J. Trop. Med., 15, (1966): 385–400.
6. Galindo, P., and Srihongse, S.: Transmission of Arboviruses to Hamsters by the Bite of Naturally Infected *Culex* (*Melanoconion*) Mosquitoes. Am. J. Trop. Med., 16, (1967): 525–530.
7. Grayson, M. A., and Galindo, P.: Epidemiologic Studies of Venezuelan Equine Encephalitis Virus in Almirante, Panama. Am. J. Epidem., 88, (1968): 80–96.
8. Grayson, M. A., and Galindo, P., Gorgas Memorial Laboratory, Panama, Republic of Panama: Unpublished data, 1966–1969.
9. Johnson, K. M., Shelokov, A., Peralta, P. H., Dammin, G. J., and Young, N. A.: Recovery of Venezuelan Equine Encephalomyelitis Virus in Panamá: A Fatal Case in Man. Am. J. Trop. Med., 17, (1968): 432–440.
10. Jonkers, A. H., Spence, L., Downs, W. G., Aitken, T. H. G., and Worth, C. B.: Arbovirus Studies in Bush Bush Forest, Trinidad, W.I., September, 1959–December, 1964. VI. Rodent-Associated Viruses (VEE and Agents of Groups C and Guamá): Isolations and Further Studies. Am. J. Trop. Med., 17, (1968): 285–298.
11. Kubes, V., and Rios, F. A.: The Causative Agent of Infectious Equine Encephalomyelitis in Venezuela. Science, 90, (1939): 20–21.
12. Kubes, V.: Venezuelan-type Equine Encephalomyelitis Virus in Trinidad. Science, 99, (1944): 41–42.
13. Medina, G., Gleiser, C. A., and MacKenzie, R. B.: Brote de Encefalomielitis Equina en la República de Panamá. Bol. Ofic. san. panam., 58, (1965): 390–394.
14. Peralta, P. H., and Shelokov, A.: Isolation and Characterization of Arboviruses from Almirante, Republic of Panama. Am. J. Trop. Med., 15, (1966): 369–378.
15. Sanmartin-Barberi, C., Groot, H., and Osorno-Mesa, E.: Human Epidemic in Colombia Caused by the Venezuelan Equine En-

cephalomyelitis Virus. Am. J. Trop. Med., 3, (1954): 283–293.

16. Scherer, W. F., Dickerman, R. W., Wong Chia, C., Ventura, A., Moorhouse, A., and Geizer, R.: Venezuelan Equine Encephalitis Virus in Veracruz, Mexico, and the Use of Hamsters as Sentinels. Science, 145, (1964): 274–275.

17. Smith, H. P., and Contreras, L. F.: La Encefalomielitis Equina. Rev. Inst. nac. Biol. Animal, 4, (1953): 3–9.

18. Sotomayor, C. G.: A Study of the Virus of Equine Encephalomyelitis in Ecuador. J.A.V.M.A., 109, (Dec., 1946): 478–480.

19. Srihongse, S., Scherer, W. F., and Galindo, P.: Detection of Arboviruses by Sentinel Hamsters During the Low Period of Transmission. Am. J. Trop. Med., 16, (1967): 519–524.

20. Srihongse, S., Gorgas Memorial Laboratory, Panama, Republic of Panama: Personal communication, 1969.

21. Tempelis, C. H., and Galindo, P.: Feeding Habits of Five Species of *Deinocerites* Mosquitoes Collected in Panama. J. Med. Entomol., 7, (1970): In press.

22. Wislocki, G. B., and Enders, R. K.: Body Temperatures of Sloths, Anteaters and Armadillos. J. Mammal., 16, (1935): 328–329.

23. Young, N. A., Johnson, K. M., and Gauld, L. W.: Viruses of the Venezuelan Equine Encephalomyelitis Complex. Experimental Infection of Panamanian Rodents. Am. J. Trop. Med., 18, (1969): 290–296.

24. Young, N. A., and Johnson, K. M.: Antigenic Variants of Venezuelan Equine Encephalitis Virus: Their Geographic Distribution and Epidemiologic Significance. Am. J. Epidem., 89, (1969): 286–307.