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HOUSEHOLD PREVALENCE OF SEROPOSITIVITY FOR *TRYPANOSOMA CRUZI* IN THREE RURAL VILLAGES IN NORTHWEST ARGENTINA: ENVIRONMENTAL, DEMOGRAPHIC, AND ENTOMOLOGIC ASSOCIATIONS

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Abstract. Environmental, demographic, and entomologic variables were analyzed by logistic multiple regression analysis for their association with the likelihood of being seropositive for *Trypanosoma cruzi* in three highly infested rural villages of northwest Argentina. The prevalence of seropositivity for *T. cruzi*, as determined by the composite results of three serologic tests, was 34% among 338 persons in 1992. The strongest positive predictors of the adjusted odds of being infected were the household number of dogs, the density of *T. cruzi*-infected *Triatoma infestans* in bedroom areas, and each person's age. Dwellers from houses with roofs made completely or partly with a grass called simbol, or which used insecticides rudimentarily and nonsystematically, had a significantly lower odds of being seropositive for *T. cruzi* than residents from other types of dwellings. The adjusted odds of infection also increased with the number of *T. cruzi*-infected dogs or cats and the presence of chickens in bedroom areas. No significant effects on the adjusted odds of infection of a community-wide deltamethrin spraying carried out in one of the villages seven years before were detected. Socioeconomic indicators, such as domiciliary area, and numbers of corrals and livestock, were inversely related to being infected. Our study identified several manageable variables suitable for control actions, most of them not examined before in univariate or multivariate analyses. Environmental management based on low-cost housing with appropriate local materials and removal of domestic animals from domiciliary areas have a crucial role to play in the control of Chagas' disease in rural areas.

Chagas' disease is highly prevalent in the Chaco, a natural landscape unit of about 1,000,000 km^2 extending over northern Argentina, Bolivia, Paraguay, and southwestern Brazil. In this region, *Triatoma infestans* is the main or only domiciliary vector of *Trypanosoma cruzi*, the causative agent of Chagas disease, and mud-and-thatch houses are the typical rural dwellings.[1,2] The Chaco is one of the most endemic regions for Chagas' disease in the Americas, where an estimated 16–18 million people are infected and an additional 90 million people are at risk of contracting the infection.[3]

Although mud-and-thatch houses are usually regarded as homogeneous, the density of triatomines varies widely among them for reasons that are becoming increasingly understood. Triatomine infestation is closely connected to thatched roofs and cracked or unplastered walls,[4–7] the household number of resident people,[8] and the presence of dogs and hens in bedroom areas.[9,10] In northwest Argentina, houses with thatched roofs made of simbol *(Pennisetum sp.,* a long-leaved grass arranged in compact bundles), walls well-plastered with mud, and where domestic insecticides were rudimentarily and nonsystematically applied by house dwellers had a significantly lower density of *Triatoma infestans* and dog infection rates with *T. cruzi* than other typical rural dwellings.[9,11] Studying the relationship between house characteristics and the household prevalence of *T. cruzi* may help assess the real impact of different construction features on the transmission of *T. cruzi* to people. If such simbol, well-plastered rural dwellings were associated with low risks of transmission of *T. cruzi*, they could serve as a viable option for community-based control programs with low-cost housing using autochthonous appropriate materials.

Only a few studies attempted to relate house construction characteristics[5,12] or triatomine infestation,[5,13,14] to the household prevalence of *T. cruzi* in a well-defined population. None of these studies, however, considered the joint effects of environmental variables (such as type of walls, roof thatch, and insecticide use by house dwellers), demographic factors (such as the number of resident people and domestic animals), and vector-related variables on human *T. cruzi* infection using a multivariate analysis. Such an approach is clearly indicated because the household transmission of *T. cruzi* is likely multicausal, with distal socioeconomic determinants and proximate environmental and entomologic factors at work. As stated by Mott and others,[15] "Description and analysis of the characteristics of household clustering of seropositivity to *T. cruzi* are of particular interest".

Host prevalence of infection with *T. cruzi* is expected to increase with the number of potentially infective bites (or contacts) per time unit by vectors on the host population, among other factors; this index is the product of vector density per host, vector infection rate, and feeding frequency on the target host species.[16] In northwest Argentina, most of the variation among individual households in the density and proportion of domiciliary *Triatoma infestans* infected with *T. cruzi* was explained by the proportion of bugs that fed on dogs or cats and the prevalence of infected dogs or cats.[17] As part of a larger project aimed at building an empirically based mathematical model of *T. cruzi* transmission, in this study we use logistic multiple regression analysis to explain variations among persons in the likelihood of being seropositive for *T. cruzi*, as the dependent variable, and environmental, demographic, and entomologic factors, as the independent variables, in three rural villages of northwest Argentina. In doing so, we address whether the likelihood of being infected is related to simbol roofs and the surface structure of walls, the presence of dogs, cats, and chickens in bedroom areas, and type of peridomiciliary environment.

MATERIALS AND METHODS

Study area. Studies were undertaken in the rural villages of Amamá, Trinidad, and Mercedes (27°12′S, 63°2′W), Province of Santiago del Estero, northwestern Argentina, which were described elsewhere.[7,9] Amamá was first sprayed with insecticides in 1985, after which the proportion of houses reinfested by *Triatoma infestans* increased to 96% in 1992.[7] Trinidad and Mercedes, which were adjacent and similar to each other, had never been sprayed with insecticides before the present study. In March 1992, Amamá was inhabited by 260 people in 48 inhabited houses; Trinidad and Mercedes were inhabited by 217 people in 42 inhabited houses.

Houses typically had thatched roofs, floors of beaten earth and walls of mud-stick (palo a pique) or sun-dried mud-bricks (adobe, either unplastered or plastered with mud showing various degrees of cracking). The flat roof was built with locally available brushwood covered with a layer of earth; we classified thatched roofs into those of simbol *(Pennisetum sp.*, a grass), forming a compact mass, or other flexuous shrubs such as jarilla (*Larrea sp.*), quebracho blanco (*Aspidosperma quebracho-blanco*), or afata (*Solanum sp.*), which left many cracks where insects could hide.[9] Some houses had roofs of a mixed type; for example, one bedroom had simbol, while the other had other thatch.

Study design. The data collection comprised a house-to-house census, questionnaire, and entomologic and serologic surveys. All of 48 houses from Amamá, 19 of 20 from Trinidad, and only five of 22 from Mercedes, due to operational constraints, were visited in late March 1992. Usually the mother from each household was interviewed to record for each resident, name, age, gender, position in the family, and place of birth. Additional information requested included age of the house, length of family residence in it, recent improvements to the building (type and date), number and type of animals owned, presence of brooding hens in domiciliary areas, the current use of insecticides in domiciliary areas (type and mode of application), if any family member spent nights in other areas (who, where, how long, were there any bugs in that place?), and history of blood transfusion.[10] Movement of residents to a different house within the study area arose through comparison with our previous records over the last 5–7 years. Destination of family members who migrated permanently or temporarily was also noted.

Each house was identified by a numbered plaque. The outbuildings (bedrooms, storeroom, kitchen, corrals) were mapped, and the perimeter and the distance to bedroom areas were measured by steps. The materials used in the construction of walls and roof and the surface state of wall plaster were assessed and recorded in a specific form by one of us (MCC). The degree of cracking of indoor walls was categorized in three levels: many, few, or no cracks; for the purpose of this study, a crack was considered any crevice that could serve as a refuge for triatomine nymphs or adults.

Triatomine surveys. *Triatoma infestans* nymphs or adults were collected from 92% of the houses.[18] A two-person expert team from the Argentine Chagas Disease Service visited each house and collected domiciliary triatomines by flushing-out in late March 1992. Bug collectors first searched all bedroom areas for bugs, then sprayed walls and roofs repeatedly with a dislodging agent (0.2% tetramethrin) and captured triatomines as they emerged during 30 min (one person-hr per house). After flushing-out collections in Amamá, triatomine bugs were collected by knockdown after applying one insecticide fumigant canister per bedroom (Aguvac; Aguvac, Argentina). Triatomines were separately collected from peridomestic sites using ⅓ person–hr per house. All houses were sprayed with deltamethrin in October 1992;[19] the triatomines knocked down during the first 24 hr after spraying were collected by house dwellers and the research team.

Triatomines were identified to species, counted by instar, and a sample (20–50%) of third instar nymphs and older stages were individually examined for infection within 10 days of capture as reported elsewhere.[17] Fecal drops obtained by abdominal pressure were diluted with one drop of saline solution, covered with 22 × 22 mm^2 coverslips, and microscopically examined for active trypanosomes at 400×. Triatomines were then dissected and their individual blood meals were identified by agar double-diffusion tests using five family-specific antisera (human, dog, cat, chicken, and goat–sheep);[20] dogs, humans, and chickens were the main blood-feeding sources of domiciliary *Triatoma infestans.* For a given blood meal source, we calculated the proportion of reactive *Triatoma infestans* that fed on that blood source (the host blood index), whether or not the bugs had fed on any other host.

Serology. The Ethical Review Committee of the National Chagas Institute Dr. Mario Fatala Chaben of the Argentine Ministry of Health and Social Welfare reviewed and approved the procedures of the project in 1992. The objectives of the study were explained to house residents and all participants signed an informed consent form. In Amamá only, seropositivity for *T. cruzi* was detected in 34% of 225 people and in 65% of 83 dogs tested; parasitemia was detected by xenodiagnosis in 29% of 41 seropositive persons and in 85% of 34 seropositive dogs.[21] Blood samples were obtained by venipuncture; infants were bled by fingerprick. All serologic tests were carried out at the National Chagas Institute (Buenos Aires, Argentina) following standard procedures.[22,23] Seroreactivity for *T. cruzi* of human sera was demonstrated by titers of 1:32 or greater for the indirect hemagglutination test (IHA) and the immunofluorescent antibody test (IFAT), and by an optical absorbance of 0.2 or greater by an ELISA. Seroreactivity for *T. cruzi* of dog sera was demonstrated by IHA and IFAT titers of 1:16 or greater and ELISA readings of 0.2 or greater in 1992. For human and dog sera, seropositive refers to samples reactive by at least two different serologic tests in any one year. Some new blood samples obtained in 1993 and 1994 (after deltamethrin spraying) were used for a definitive diagnosis of a few cases that had been serologically discordant or missing in March 1992.

Data analysis. Data were scrutinized for discrepancies between concurrent census and interview records and corrected as reported.[17] For present purposes, the human population was divided into children (less than 16 years of age) and adults (16 years of age or more) because prevalence rates increased markedly with age (but not by gender), and to reflect different degrees of relatedness to the current house; adults from this population tended to migrate transiently in search of jobs and thus were exposed to other undetermined risks of *T. cruzi* infection. We excluded from analyses three urban-type houses with a metal or brick-tile roof, well-plastered walls and cement floors; thus, the study base comprises 68 households. Missing data for the numbers of chickens or ducks (in 12 houses) or corral animals (in seven houses) were substituted by values predicted by a linear multiple regression in which the independent variables were family size, domiciliary area, and the number of corrals.

The relationship between seropositivity for *T. cruzi* (SEROPOS, the dependent variable) and its determinants was studied by maximum likelihood logistic multiple regression analysis. Because household clustering of infection among siblings has been reported,[15] the data might violate the standard regression assumption of independent response probabilities across observations, in which case it may lead us to underestimate standard errors. To avoid this, odds ratios (ORs) were estimated using the logistic–binomial random effects model for distinguishable data from EGRET software,[24] which includes a random effects parameter that measures a residual household effect on the probability of being infected. Backward and forward stepwise procedures were used to obtain the most parsimonious model that retained independent variables at the 10% nominal significance level. Interaction terms were then added to this model and tested for significance.

Two types of regression models were used: one with environmental and demographic factors, and the other with entomologic factors as the independent variables. Environmental variables were village (Amamá, indexed as 1, and Trinidad–Mercedes indexed as 0), age of house (in years), roof type (completely or partly of simbol, indexed as 0, versus no simbol, indexed as 1), wall type (no or few cracks, indexed as 0, versus many cracks, indexed as 1), domiciliary area (the area sharing a common roof with, and including, human sleeping quarters), insecticide use (none at all, indexed as 0, or occasional or more often, indexed as 1), and the number of corrals. Demographic variables were each person's age (a surrogate of length of exposure) and gender, and the number (x) of people, dogs, cats, chickens or ducks, and corral animals (goats, sheep, pigs, horses, mules, cows) in the household. Count and continuous variables were transformed to $\log_{10}(x + 1)$ to stabilize variances.

The entomologic model included as independent variables the number of *Triatoma infestans* captured by one person-hr of search in bedroom areas (bug density) or the number of triatomines infected with *T. cruzi* per person-hr, the human blood index (the proportion of reactive *Triatoma infestans* with human blood meals), and each persons' age (in years). The number of infected bugs per person-hr was calculated as bug density times the age-standardized proportion of infected bugs; the latter is the product of the instar-specific infection rate at each house times the instar-specific total number of bugs examined for infection in the data base divided by the total number of bugs examined in March–October 1992. At a second stage, the entomologic model was extended by including other terms representing the effects of the presence of infected dogs or cats (the main domestic reservoirs of *T. cruzi),* and chickens (which are insusceptible to *T. cruzi)* in domiciliary areas. These variables were alternatively the household number or proportion of infected dogs or cats and the chicken blood meal index (proportion of reactive *Triatoma infestans* with chicken blood meals). For these particular analyses, the data base was restricted to 44 houses with a complete data set for all variables.

RESULTS

Community-wide data. Of 391 residents, 338 (86%) were tested for *T. cruzi* antibodies; transitory absence was the main reason for subjects not examined. The overall prevalence rate of infection, as determined by a positive result by two different serologic tests, was 34% (116 of 338). No child less than three years of age was seropositive for *T. cruzi,* thus ruling out the possibility of false-positive serology due to maternal anti-*T. cruzi* antibodies. Approximately 70% of all residents were natives of their current village. Of 180 children less than 16 years of age that were censused, 164 (91%) were born and raised in the current village and were mostly lifetime residents of the current house. Four (25%) of immigrant and 26% of native children were seropositive for *T. cruzi.*

Environmental and demographic factors. Table 1 shows unadjusted (i.e., factor-specific) age-specific rates of seropositivity for *T. cruzi* according to village, house characteristics, domestic use of insecticides, family size, and number of domestic animals. Child prevalence rates were significantly and negatively associated with insecticide use, domiciliary area, and number of chickens or ducks, and increased in a highly significant way with the number of dogs in chi-square tests. Adult prevalence rates were significantly and negatively related to a roof made of simbol, domiciliary area, and the number of corrals, corral animals, and chickens or ducks. Most notably, domiciliary area and the number of corrals showed an inverse dose-response relationship to both child and adult odds of *T. cruzi* infection. Children residing in homes less than 40 m^2 had a 10-fold increase in prevalence odds in comparison with children from houses larger than 80 m^2; in a similar comparison for adults, the unadjusted OR was 5.2. The household number of dogs appeared to be a strong predictor of *T. cruzi* infection among children, also showing a positive dose-response relationship; children who resided in houses with four or more dogs had a nine-fold increase in the odds of infection in relation to children who cohabited with one or no dog. Child or adult seropositivity rates for *T. cruzi* did not differ significantly in relation to age of the house, the degree of cracking of indoor walls, gender, the household number of people, people per bedroom or cats, and the reports or observations of hens brooding indoors (not shown in table). A similar nonsignificant relationship was observed between child or adult infection status and village or a previous deltamethrin spraying; however, seropositivity rates for children less than eight years of age (born after the spraying) from Trinidad and Mercedes (23%, 7 of 31) were greater than for children from Amamá (13%, 8 of 60).

All 11 variables in Table 1, in addition to each individual's age and gender and the reported or observed indoor habit of brooding hens, were fitted to a logistic multiple regression model to adjust for confounding variables. The full model was statistically significant for all individuals (likelihood ratio statistic [LRS] = 30.57; degrees of freedom [df] = 14, $P = 0.006$) and children (LRS = 41.82; df = 14, $P < 0.001$).

TABLE 1

Prevalence rates of seropositivity for *Trypanosoma cruzi* in 168 children less than 16 years of age and in 156 adults (16 years of age or more) according to village (or previous deltamethrin spraying), house construction features, domestic use of insecticides, family size, and number of domestic animals; Amamá, Trinidad, and Mercedes, March 1992

		Children			Adults		
Factor*	No. of houses†	No. tested	% positive	Odds ratio (CI)‡	No. tested	% positive	Odds ratio (CI)
Village							
Trinidad–Mercedes	24	57	28	1.0	56	34	1.0
Amamá	44†	111	25	0.9 (0.4-1.8)	100	48	1.8 (0.9–3.5)
Age of house (years)							
<5	9	26	31	1.0	19	42	1.0
5–19	22	60	33	1.1 (0.4–3.0)	55	51	1.4 (0.5–4.1)
≥20	37	82	20	0.5 (0.2–1.5)	82	38	0.8 (0.3–2.3)
Roofs of simbol							
Completely	11	20	15	1.0	25	16	1.0
Partly	7	20	15	1.0 (0.2–5.7)	27	44	4.2 (1.1–15.6)
Other thatch	50	128	30	2.4 (0.7–8.6)	104	49	5.1 (1.6–15.7)
Cracks in walls							
No	14	27	22	1.0	34	44	1.0
Few	37	89	25	1.1 (0.4–3.2)	93	43	1.0 (0.4–2.1)
Many	17	52	31	1.6 (0.5–4.6)	29	41	0.9 (0.3–2.4)
Insecticide use							
Yes	41	94	17	1.0	95	39	1.0
No	27	74	38	3.0 (1.5–6.1)	61	49	1.5 (0.8–2.9)
Domiciliary area (m^2)							
81–100	20	44	7	1.0	62	34	1.0
40–80	39	98	31	6.0 (1.7–21.0)	83	46	1.6 (0.8–3.3)
20–39	9	26	42	10.0 (2.5–40.9)	11	73	5.2 (1.2–21.7)
No. of persons							
1–4	32	27	15	1.0	59	41	1.0
5–9	31	113	32	2.2 (0.7–7.0)	73	48	1.3 (0.7–2.7)
10–14	5	28	14	1.0 (0.2–4.3)	24	33	0.7 (0.3–2.0)
No. of dogs							
0–1	20	33	9	1.0	36	44	1.0
2–3	36	97	24	3.1 (0.9–11.1)	86	41	0.9 (0.4–1.9)
4–7	12	38	47	9.0 (2.3–34.6)	34	47	1.1 (0.4–2.8)
No. of corrals							
4–6	7	10	10	1.0	23	22	1.0
2–3	24	61	31	2.8 (0.3–23.6)	49	39	2.3 (0.7–7.2)
0–1	37	97	25	3.0 (0.4–26.0)	84	51	3.8 (1.3–11.1)
No. of corral animals§							
31–100	10	16	19	1.0	29	14	1.0
11–30	20	50	26	1.5 (0.4–6.2)	46	50	6.3 (1.9–20.8)
0–10	31	81	27	1.6 (0.4–6.2)	66	52	6.6 (2.1–21.2)
No. of chickens and ducks¶							
31–100	20	52	12	1.0	54	35	1.0
11–30	22	62	39	4.8 (1.8–13.1)	47	51	1.9 (0.9–4.3)
0–10	14	28	25	2.6 (0.8–8.5)	36	58	2.6 (1.1–6.1)
Total	68	168	26		156	43	

* Seropositivity rates did not differ significantly with gender, the number of people per bedroom or cats, and the reports or observations of hens brooding indoors.

† Excludes three urban-type houses with a metal or brick-tile roof, well-plastered walls, and cement floors with 14 resident people.

‡ Odds ratio is the number of seropositive individuals/number of seronegative individuals in this category divided by the same ratio of seropositive to seronegative individuals for reference category. CI = 95% confidence interval.

§ Includes goats, sheep, pigs, cows, horse, mules; seven houses with missing data.

¶ Twelve houses with missing data.

After backward stepwise elimination of nonsignificant variables, both for all individuals and children, the likelihood of being infected with *T. cruzi* significantly increased with age, no simbol roofs, the number of dogs, and lack of insecticide use (Table 2). For all individuals, the odds of infection decreased significantly with the number of corrals and marginally with the number of chickens or ducks. No significant effects of village and the presence of cracks in walls on the odds of infection were detected. For children less than 16 years of age, the relative odds (OR) of being infected adjusted for confounding variables was 17.53 per unit increase in the log-number of household dogs, 2.97 if living in a no simbol house, 1.29 per year increase in age, and 0.29 if residing in a house whose dwellers reported the use of in-

TABLE 2

Adjusted odds ratios and 95% confidence intervals for significant predictors of prevalence rates of seropositivity for *Trypanosoma cruzi* as determined from a logistic multiple regression analysis of data from Table 1; Amamá, Trinidad, and Mercedes, March 1992

Independent variables*	All ages: Adjusted odds ratio	All ages: 95% confidence interval	Children: Adjusted odds ratio	Children: 95% confidence interval
Number of dogs†	5.95	1.24–28.52	17.53	0.87–352.10
Roof type‡	1.87	0.97–3.62	2.97	0.88–10.05
Age (in years)	1.016	1.005–1.028	1.29	1.14–1.47
Insecticide use§	0.57	0.33–0.98	0.29	0.11–0.78
Number of corrals†	0.0032	0.00–0.77	Not significant	
	HOUSEFF¶ = 0.367 ± 0.257, $P > 0.4$		HOUSEFF¶ = 0.693 ± 0.413, $P > 0.4$	
	LRS# = 21.93, 5 degrees of freedom (df), $P < 0.001$		LRS# = 36.99, 4 df, $P < 0.001$	

* Only includes variables significant under the 10% nominal level.
† Transformed to $\log_{10}(x + 1)$.
‡ Roofs completely or partly of simbol were indexed as 0; other thatched roofs, as 1.
§ No use of domestic insecticides was indexed as 0; use, as 1.
¶ HOUSEFF = household effect parameter; coefficient ± standard error.
# LRS = likelihood ratio statistic.

secticides in domiciliary areas. Both for all individuals and children, neither the random effects parameter measuring the excess effect of household nor any interaction term was statistically significant.

Table 3 shows prevalence rates of seropositivity for *T. cruzi* in children less than 16 years of age in relation to the joint distribution of type of thatch, number of dogs, and insecticide use. We pooled categories corresponding to roofs made completely or partly of simbol, and two or more dogs per house, because of the limited sample size leading to some empty cells. No *T. cruzi*-seropositive child lived in insecticide-using houses with roofs made completely or partly of simbol and one or no dog, as compared with 49% of seropositive children residing in houses using no insecticide, roofed with other thatch, and having two or more dogs. Exclusion of immigrant children did not affect these results to any significant extent. The houses with no simbol in the roof in which insecticides were not used sheltered 57% (25 of 44) of the children that were seroreactive for *T. cruzi*, although these houses comprised 34% (23 of 68) of the total.

Entomologic factors. Table 4 shows the results of the logistic multiple regression analysis of the household rates of seropositivity for *T. cruzi* on the density of *Triatoma infestans* or the density of *T. cruzi*-infected triatomines, each person's age, and the human blood index. The best fitting models of household and child prevalence rates of *T. cruzi* that minimized the deviance included the density of *Triatoma infestans* or the density of infected *Triatoma infestans* and age, which were statistically significant and did not show significant interactions. The adjusted relative odds of being infected was 3.83 (confidence interval [CI] = 1.84–7.98) per unit increase in the log-number of infected bugs per person-hr for children less than 16 years of age, and 2.30 (CI = 1.48–3.59) for all individuals. Figure 1 shows the logistic fit of child infection rates to the log-density of infected triatomines and age. In the data subset that included observations with no missing data, addition of the human blood index to every model was not significant, nor were the effects of the previous deltamethrin spraying. In contrast, addition of a term representing the density of *Triatoma infestans* in peridomestic sites to the model including infected

TABLE 3

Prevalence rates of seropositivity for *Trypanosoma cruzi* in children less than 16 years of age according to the joint distribution of type of roof, number of dogs, and domestic use of insecticides; Amamá, Trinidad, and Mercedes, March 1992

Roofs made of simbol	No. of dogs	Using insecticides: No. of houses	Using insecticides: No. tested	Using insecticides: % sero-positive	Not using insecticides: No. of houses	Not using insecticides: No. tested	Not using insecticides: % sero-positive
Completely or partly	0–1	4	3	0	1	1	0
	≥2	10	23	13	3	13	23
Other thatch	0–1	8	16	6	6	13	15
	≥2	19	52	23	17	47	49
Total		41	94	17	27	74	38

TABLE 4

Logistic multiple regression analysis of the models that regressed the proportion of individuals seropositive for *Trypanosoma cruzi* (SEROPOS, the dependent variable) on the domiciliary density of *Triatoma infestans*, the density of bugs infected with *T. cruzi* (INFBUG), dweller's age (AGE, in years), the human blood index and the household effects parameter (the independent variables); Amamá, Trinidad, and Mercedes, March–October 1992

Terms in model	Deviance	Degrees of freedom	Likelihood ratio statistic	*P*
All ages, Intercept	411.48	0		
Bug density	401.25	1	10.23	<0.001
Bug density + age	395.25	2	16.23	<0.001
Infected bug density	399.69	1	11.78	<0.001
Infected bug density + age	394.34	2	17.13	<0.001
Best fitting model: SEROPOS = –1.592 (0.274)* + 0.835 × INFBUG (0.227) + 0.013 × AGE (0.006) + 0.401† (0.246)				
Addition of human blood index to every model:‡ not significant.				
Children, Intercept	187.56	0		
Bug density	174.89	1	12.66	<0.001
Bug density + age	155.30	2	32.26	<0.001
Infected bug density	171.43	1	16.13	<0.001
Infected bug density + age	153.19	2	34.37	<0.001
Best fitting model: SEROPOS = –3.930 (0.711)* + 1.343 × INFBUG (0.375) + 0.222 × AGE (0.061) + 0.556† (0.452)				
Addition of human blood index to every model:‡ not significant.				

* Standard error of coefficient.
† Household effect parameter.
‡ Includes cases with no missing data for the variables in the model.

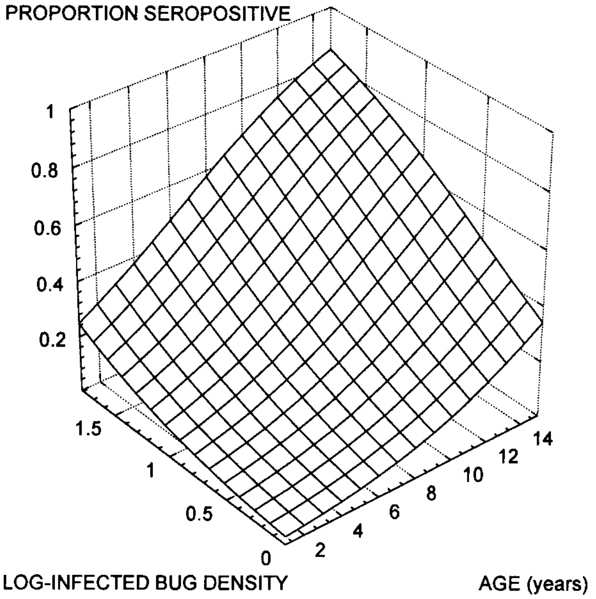

FIGURE 1. Proportion of children less than 16 years of age seropositive for *Trypanosoma cruzi* in relation to the domiciliary density of *Triatoma infestans* infected with *T. cruzi* and age as determined by logistic multiple regression analysis in Amamá, Trinidad, and Mercedes, March–October 1992.

bug densities and age resulted in a significant improvement of the fit and a negative effect on the adjusted odds of infection both for all individuals (deviance = 389.19, OR = 0.57, CI = 0.36–0.91) and children (deviance = 145.90, OR = 0.46, CI = 0.19–1.12). The density of peridomestic *Triatoma infestans* was also a significant negative predictor of the likelihood of being infected when added to the models shown in Table 2.

We added a term that represented the effects of the presence of chickens in bedroom areas on *T. cruzi* prevalence to the best fitting entomologic model obtained in Table 4. A significant and positive effect of the chicken blood index (*P* = 0.03) on household, but not child, prevalence rate of *T. cruzi* was detected (Table 5). Using a similar procedure for testing the effects of numbers or proportions of infected dogs or cats, significant predictors were the domiciliary density of *Triatoma infestans* and the number or proportion of infected dogs or cats; the latter term displaced age from the regression model. No significant effects of numbers or proportions of infected dogs or cats were detected in relation to child odds of infection. However, child or adult rates of seropositivity for *T. cruzi* showed a positive dose-response relationship with the household number of *T. cruzi*-infected dogs or cats for 49 houses with both animals and people examined for infection (Table 6). The unadjusted odds of being infected for individuals cohabiting with infected dogs or cats was three- or five-fold that of individuals from houses with no infected dogs or cats.

The full model included significant environmental, demographic, and entomologic predictors appearing in Tables 2 and 4. For all individuals, predictors that contributed significantly to the likelihood of being infected were age (OR = 1.018, CI = 1.006–1.030), infected bug densities (OR = 1.90, CI = 1.23–2.92), numbers of dogs (OR = 4.59, CI = 1.02–20.59) and corrals (OR = 0.01, CI = 0–1.53), peridomestic bug densities (OR = 0.63, CI = 0.38–1.05), and type of roof (OR = 1.74, CI = 0.94–3.22). The deviance for the full model was 377.16 (df = 315). For children, significant predictors were age (OR = 1.276, CI = 1.139–1.430), infected bug densities (OR = 2.48, CI = 1.19–5.17), the number of dogs (OR = 18.58, CI = 1.18–292.90), and peridomestic bug densities (OR = 0.46; CI = 0.19–1.06); the deviance was 140.35 for 160 df.

DISCUSSION

Our study included environmental factors considered to be causally inversely related to triatomine infestation and likely transmission of *T. cruzi*, such as insecticide use and refuges for triatomines in roof and walls. Other factors, such as domiciliary area and the numbers of corrals or livestock, were included as possible indicators of wealth and well-being within the community. Although mud-brick and thatch houses are usually considered precarious, building them demands resources that otherwise could be directed to increase the scarce family cash income or satisfy other basic needs. Simbol was not available in the immediate vicinity of most houses, but had to be collected and transported several kilometers. Not unexpectedly, families showing attributes of

TABLE 5

Multiple logistic regression analysis for the best fitting model of the proportion of individuals seropositive for *Trypanosoma cruzi* (SEROPOS, the dependent variable) in Table 4 with an added term representing the effects of the presence of chickens in bedroom areas (CKBI, the chicken blood index), the proportion (PINFDC) or number (NINFDC) of *T. cruzi* infected dogs or cats, and the household effects parameter (the independent variables); Amamá, Trinidad, and Mercedes, March–October 1992

Terms in model for all ages*	Deviance	Likelihood ratio statistic†	*P*
Infected bug density + age + chicken blood index:	280.50	3.37	0.07
SEROPOS = –1.176 (0.329)‡ + 0.423 × INFBUGS (0.238) + 0.009 × AGE (0.007) + 0.893 × CKBI (0.483) + 0.00§ (0.529)			
Infected bug density + age + dog or cat infection rate:	304.02	5.72	0.02
SEROPOS = –1.793 (0.386) + 0.485 × INFBUGS (0.235) + 0.001 × AGE (0.006) + 1.044 × PINFDC (0.439) + 0.00§ (0.544)			
Infected bug density + age + no. of infected dogs or cats:	309.05	3.55	0.06
SEROPOS = –1.536 (0.321) + 0.431 × INFBUGS (0.266) + 0.011 × AGE (0.006) + 0.223 × NINFDC (0.123) + 0.162§ (0.505)			

* Includes cases with no missing data for the variables in the model.
† In relation to the best fitting model including intercept, infected bug density, age and random effects parameter. One degree of freedom.
‡ Standard error of coefficient.
§ Household effects parameter.

TABLE 6

Prevalence rates of seropositivity for *Trypanosoma cruzi* in children less than 16 years of age and adults (16 years of age or more) according to the household number of infected dogs or cats; Amamá, Trinidad, and Mercedes, March–October 1992

		Children			Adults		
Number of infected dogs or cats	No. of houses*	No. tested	% positive	Odds ratio (CI)†	No. tested	% positive	Odds ratio (CI)
0	12	28	11	1.0	25	24	1.0
1–2	24	54	30	3.5 (0.9–13.3)	64	48	3.0 (1.7–17.7)
3–5	13	51	39	5.4 (1.2–20.2)	33	64	5.5 (1.1–8.4)
Total	49	133	29		122	47	

* Only includes households both with animals and people examined for infection.
† CI = 95% confidence interval.

relative prosperity reported a more frequent use of insecticides and had simbol roofs. These houses harbored lower densities of *Triatoma infestans* in a previous[9] and in the concurrent survey,[11] and in turn had lower household prevalence rates of infection. Simbol was used in compact bundles that left few refugia for triatomines, whereas roofs made with other brushwood were among the most important refugia for bugs. Since no appropriate and inexpensive technology has been developed for roofing rural houses,[25] simbol is a good candidate for further research on low-cost housing. Although household aggregation of *T. cruzi* infection according to the infection status of siblings or parents has been reported,[15] the way in which socioeconomic, environmental, and entomologic factors concatenate to produce household clustering of infection has long been suspected but not substantiated. The significant and inverse relationship between socioeconomic indicators and the household prevalence of *T. cruzi* underscores the close links between rural underdevelopment and impoverishment, certain low-quality rural dwellings, triatomine infestation, and human *T. cruzi* infection.

Community-wide spraying of residual insecticides substantially affects the age-prevalence profile of *T. cruzi*.[2] In our study, Amamá was sprayed only once with deltamethrin, which mostly eliminated domiciliary infestations between 1985 and 1987,[7] whereas in neighboring Trinidad and Mercedes, no spraying was ever carried out. Therefore, exposures to *Triatoma infestans* were not homogeneous over time between villages. However, seven years after the spraying and four years after domiciliary infestations were readily detectable in Amamá, prevalence rates of *T. cruzi* adjusted for age and other predictors were indistinguishable between villages as determined from logistic multiple regression. Assuming that the prevalence of *T. cruzi* infection had been similar between villages before control actions were undertaken in Amamá, our results suggest that the effects of a single and geographically isolated insecticide spraying on *T. cruzi* transmission faded away in a few years, or were close to doing so, in the absence of continuous and effective vector surveillance.

The household is probably the relevant spatial scale of vector-mediated transmission of *T. cruzi* to humans. In our logistic multiple regression analysis, the effect of household was measured by the random effects parameter. This parameter reflects the degree to which the likelihood of being infected depends on the infection status of cohabitating family members or other household-linked factors beyond the effects accounted for by predictors in the regression model. The lack of a significant residual household effect suggests that most or all relevant determinants of *T. cruzi* infection linked to the household were included in the models designed.

Seropositivity rates for *T. cruzi* were negatively and significantly associated with the reported use of domestic insecticides by house dwellers. Considering the mode, frequency of application, and type of insecticides reported by house dwellers,[11] it is somewhat surprising that these insecticides exerted such significant effects on bug density and household seropositivity rates. Furthermore, because differential misclassification of insecticide-using families may arise from the respondent's concern for social appropriateness, a positive response would be less accurate than a negative one; as a result, the true effects of insecticide use would be underestimated. A complementary explanation is that the reported use of insecticides (and simbol roofs) also constituted a surrogate variable for certain attitudes of house dwellers toward triatomine bugs and house hygiene. Triatomine infestation has been found associated with a subjective classification of house sanitary conditions.[8,26]

The surface structure of indoor walls had a significant role in explaining variations among household rates of infection in northeast Brazil.[5] In our study area, the presence of cracks in walls was a significant predictor of the number of *Triatoma infestans* collected from walls per person-hr,[11] but did not explain variations among human rates of *T. cruzi* infection. This may be due to the presence of other dominant determinants of triatomine infestation and transmission.

The relationship between household size or numbers of animals and the household prevalence of *T. cruzi* has not been studied before in multivariate analysis, despite a reported positive association between the number of resident people and the density of *Triatoma infestans*.[8] In our study, the number of people or people per bedroom (a residential crowding index) were not significant predictors of child or adult prevalence of *T. cruzi* either in univariate or multivariate analyses, possibly because domestic dogs and indoor-brooding hens played such important roles as predictors of triatomine infestation or infection rates.

The outstanding role of dogs as a risk factor for the household transmission of *T. cruzi* in this area has been firmly established.[17,20,21] Here we show for the first time a strong association between the household number of dogs or of infected dogs or cats and human infection with *T. cruzi* after adjusting for the statistical effects of other factors. Chuit (1995, *Household Level: Surveillance and Control of Chagas' Disease.* PhD thesis. Yale University, New Haven, CT) also found a positive and strong association between child rates of *T. cruzi* and the number of dogs or cats in northwest Santiago del Estero.

The presence of brooding hens in bedroom areas appears to have two important effects on the domestic ecology of Chagas' disease: increasing the domiciliary density of *Triatoma infestans*[10] and the number of *T. cruzi*-infected triatomines, and decreasing the proportion of infected bugs because chickens are not susceptible to *T. cruzi.*[17] In line with these findings, our present results show a positive and significant relationship between the likelihood of humans, both children and adults, being infected with *T. cruzi* and the proportion of domiciliary bugs that fed on chickens, an index of the presence of chickens in bedroom areas. Evidence is clearly against the use of chickens for zooprophylaxis.

Our results show that both *Triatoma infestans* density and the density of infected triatomines were significant predictors of household and child rates of seropositivity for *T. cruzi;* thus, these predictors may be helpful indices of potential transmission to residents. Although the flushing-out method lacks sensitivity in detecting low-density triatomine infestations,[18] the number of bugs collected per person-hr has been proportionally related to the absolute density of triatomines subsequently censused by house demolition in Venezuela,[27] and were in close agreement with estimates obtained by subsequent knock-down collections (Gürtler RE and others, unpublished data).

Previous studies that reported a positive relationship between human prevalence or incidence of *T. cruzi* and densities of infected triatomines[13,28] did not assess variability among households. In the present study, we observed great variability among household infection patterns, probably related to the stochastic nature of transmission by contamination with infected triatomine feces. Frequently, no infected child was detected in houses harboring high infected–vector densities, while in a few cases the presence of a single infected child was observed in houses with no or very few infected bugs in 1989 and 1992. In two of these cases, their mothers reported that they spent one or two weeks a year at their relatives' heavily infested homes in other rural villages. It is highly likely that these children acquired *T. cruzi* during those visits, rather than at their parents' home or from infected adult triatomines flying into houses but not colonizing them, though these alternatives cannot be ruled out. No child had a history of blood transfusion, and blood donors have been systematically screened for *T. cruzi* antibodies in Argentina starting in the 1960s. The relationship between the incidence of *T. cruzi* and entomologic variables between 1989 and 1992 will be reported separately.

The human blood index played no role in explaining variations in household prevalence rates, possibly because it does not distinguish whether the bugs have fed on humans once or repeatedly.[20] Therefore, the additional labor required for monitoring human blood indices aimed at assessing or predicting the human risk of *T. cruzi* infection does not seem to be justified.

Variables representing peridomestic availability of refuges (number of corrals) and host blood sources (corral animals or poultry) were inversely related to the odds of being infected, and so was the number of *Triatoma infestans* captured per person-hr in peridomestic sites. The latter result may be explained by the fact that peridomestic *Triatoma infestans* densities correlated positively with the numbers of chickens or ducks (Cécere MC and others, unpublished data), or alternatively, that result may have arisen purely by chance. In any case, the density of triatomines in peridomestic sites did not increase the odds of human *T. cruzi* infection. The negative association between number of corrals or livestock and human *T. cruzi* infection may be interpreted as an indirect effect of improved living conditions and concomitant attitudes toward house hygiene but not as a zooprophylactic effect for at least two reasons. First, corral animals have been very seldom found infected with *T. cruzi* or serving as hosts of domiciliary triatomine bugs.[29] Second, most chickens roosted on peridomestic trees well separated from human sleeping quarters, making it unlikely that they served as a regular blood source for domiciliary triatomines, and thereby contributing to a decrease in bug infection rates.

Environmental management has re-emerged as a strategy for the control of vector-borne diseases.[30] It certainly has an important role to play in the control of Chagas' disease. Our study identified manageable variables that could reduce the likelihood of *T. cruzi* transmission by reducing the density of infected bugs: 1) improving housing with appropriate local materials to eliminate or reduce permanently conditions that favor vector colonization and population growth rate; 2) excluding domestic animals (dogs, cats, chickens, etc.) that are important blood sources for triatomine bugs and/or reservoirs of *T. cruzi* from human sleeping quarters, thus lowering the prevalence and density of infected bugs; and 3) installing an effective continuous vector surveillance program with community participation in which appropriate residual insecticides are applied when circumstances mandate. Development of the rural economy through sustainable management of forest and other biotic resources and other activities that may give permanent employment and improve the living standards of local rural residents[1] cannot be overemphasized as the ultimate key to the control of Chagas' disease and other similarly pressing rural health problems.

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