Chagas disease vector control through different intervention modalities in endemic localities of Paraguay

A. Rojas de Arias,¹ E. A. Ferro,² M. E. Ferreira,¹ & L. C. Simancas³

In a field study carried out in three rural communities in Paraguay in a zone endemic for Chagas disease, we implemented three different vector control interventions — spraying, housing improvement, and a combination of spraying plus housing improvement — which effectively reduced the triatome infestation. The reduction of triatome infestation was 100% (4/47) in the combined intervention community, whereas in the community where housing improvement was carried out it was 96.4% (53/55). In the community where fumigation alone was used, the impact was 97.6% (40/41) in terms of domiciliary infestation. In all the houses where an intervention was made, an 18-month follow-up showed reinfection rates of less than 10%. A serological survey of the population in the pre- and post-intervention periods revealed a shift in positive cases towards older age groups, but no significant differences were observed. The rate of seroconversion was 1.3% (three new cases) in the community with housing improvement only, but none of these cases could have resulted from vector transmission. The most cost-effective intervention was insecticide spraying, which during a 21-month follow-up period had a high impact on triatome infestation and cost US$ 29 per house as opposed to US$ 700 per house for housing improvement.

Introduction

Chagas disease, or American trypanosomiasis, is most commonly spread by vectors in areas where inadequate housing, crowding, and poor hygienic conditions facilitate proliferation of triatomines and help to maintain their domestic cycle (1). Chagas disease is widely distributed in America, from the southern USA to southern Argentina, with a prevalence that varies from 5% to 60% (2). Among the 360 million people living in countries where the disease is endemic, 90 million run the risk of acquiring it, and 16–18 million are infected (2).

In Paraguay, infection by *Triatoma sanguisuga* and its main vector, *Triatoma infestans*, are widely distributed. The prevalence of infestation ranges from 11% to 60% in the eastern region of the country (3–5); however, serological surveys have shown the highest rate of infection (72%) to be among native groups in the western region (6). Studies performed in Paraguay between 1983 and 1986 by the National Malaria Eradication Service of the Ministry of Public Health and Social Welfare revealed rates of domiciliary triatome infestation and *T. cruzi* human infection of 14% and 20%, respectively (7). A similar serological survey performed by the Institute of Health Sciences Research in highly endemic areas of the eastern region of Paraguay in 1986, showed a prevalence of 22% infection among a representative sample of 1601 subjects (8).

Chemical control of the vector by conventional spraying or by community participation during the surveillance phase has been successfully implemented in Argentina, Brazil, and Venezuela (9–14). However, these programmes were only temporarily effective; results were mitigated by interruption of spraying or the poor residual effect of the insecticides used, particularly pyrethroids, which keep houses free of triatomines for no more than 1 year (9–11). Moreover, although during the surveillance phase infestation rates drastically decreased in domestic areas, peridomestic areas showed high infestation rates after 1 year (15,16). In Paraguay the Chagas disease control programme is currently being carried out at the national level. However, in previous years only small-scale sprays were performed in isolated areas, with no systematic control or post-spraying evaluations. Although several regional follow-up studies have been conducted on various triatome control interventions, none has compared vector control interventions simultaneously in order to determine their impact on triatome populations.

In view of the importance of Chagas disease, a multidisciplinary project was developed by the Appropriate Technology Centre, Catholic University, and the Institute of Health Sciences Research, Asuncion National University, with the support of...
the International Development Research Centre. The goal was to determine the effectiveness of three methods of intervention for control of Chagas disease in rural areas of Paraguay: insecticide application, housing improvement, and a combined insecticide and housing improvement treatment. The results of each intervention were evaluated by determining the household triatomine infestation and by serological evidence of human infection with *T. cruzi*.

This article presents the results of both baseline and post-intervention surveys of seropositivity of *T. cruzi* infection and household infestation by triatomine vectors.

**Materials and methods**

**Study area and project design**

The study covered the period from October 1988 to July 1991 and was carried out in three villages (Nandúa, Ypaú, and Caía) in Paraguay Department, in the eastern region of Paraguay. These villages are located 50–100 km from Asunción, the capital city, and are easily accessible by asphalt roads, although Caía is very isolated. The houses in all the villages were poorly constructed, consisting mainly of mud walls and thatched roofs.

The study was designed to compare pre- and post-interventions in the three communities. Two dependent variables were considered: the level of *T. cruzi* infection in the population; and the level of household triatomine infestation. The independent variables were the type of intervention: improved housing, insecticide application, and application of insecticide combined with improved housing. The study was divided into four phases, and although there was some overlap, each phase initiated a distinct set of activities, as described below.

- **Phase I**: A pre-intervention database was created to characterize villagers’ health, social milieu, and shelter (3 months).
- **Phase II**: To begin the intervention process and to stimulate interest in the interventions, we set up education and participatory activities in each community. This phase also initiated a triatomine monitoring programme for each village (3 months).
- **Phase III**: Each of the selected communities committed themselves to carry out a specific intervention over a 21-month period.
- **Phase IV**: Post-intervention evaluation was conducted in each community, and the resulting data were analysed (9 months).

**Baseline**

*Census of inhabitants and sample collection.* The names, surnames, ages, sex, and lengths of residence of the household’s permanent residents were obtained from each family head. After the free and informed consent of inhabitants had been obtained, blood samples were collected from all those older than 6 months of age by digital puncture using disposable sterile lancets after the digital pad had been disinfected with 95% ethanol. The blood samples were collected on filter-papers until two marks corresponding to 50 μl were full, and the filter-papers were kept at −20 °C until the test was performed no later than 1 month after sample collection.

**Evaluation of the seropositivity for *T. cruzi* infection by ELISA and IIF.** One of the two blood samples collected on the filter-papers was cut and eluted with a buffer solution until diluted 1:50 before being processed using enzyme-linked immunosorbent assay (ELISA) to detect antibodies against *T. cruzi*. A locally produced ELISA kit (Chagas Test, IHSR, Asunción, Paraguay) was used, following the procedure recommended by the manufacturer. Results were read from an ELISA plate reader (TiterTek Uniskan I, Finland) connected to a printer. Samples were considered positive if they had a reading that was greater than or equal to that of a reference sample whose indirect immunofluorescence (IIF) titre was 1:20. The second ELISA-positive sample was eluted to 1:40 dilution, and the presence of antibodies against *T. cruzi* was evaluated by IIF using antigen from *T. cruzi* epimastigotes (Multitest, Buenos Aires, Argentina). An FITC anti-human immunoglobulin G (IgG) conjugate (Sigma, St. Louis, MO, USA) was used at a 1:800 dilution. A total of 10% of the ELISA-negative samples were randomly selected and further tested by IIF to discard false-negative samples in the ELISA screening.

**Triatomine survey.** Baseline evaluation of household triatomine infestation was carried out in both domestic and peridomestic environments for 30 min and 15 min, respectively, by two trained technicians. The presence of live as well as dead triatomines, adults and nymphs, fertile eggs and/or fresh faeces was recorded to certify active infestation. The presence of vestiges, i.e. hatched eggs and dry faeces, was also recorded. A post-fumigation survey was performed every 6 months for 2 years, consisting of an active search by trained personnel to detect faeces on a calendar attached to the inner wall of the dwelling and an examination of the insects collected in plastic bags by the inhabitants. Each container was labelled and identified by household and date of collection. The peridomestic environment included a 20-m radius around the house as well as other permanent structures such as chicken coops situated further away. Faeces of all triatomines were individually examined for the presence of *T. cruzi* at ×400.

**Triatomine monitoring.** Triatomine infestation was monitored every 6 months using the procedures described below.

- A calendar was affixed to the interior wall of each house above the bed. These sheets, which measured 32 cm × 22 cm and were identified by house and date of affixing, were taken down and replaced every 6 months. Removed calendars were examined using a code to identify triatomine and other insect faeces (17).
• An active triatomine survey was conducted as explained above.
• A plastic bag was placed in each house, and the family (including children) was encouraged to capture and kill triatomines at home and to store them in the bags.

Interventions

**Insecticide application programme.** The intervention in Cañada consisted of an insecticide application programme. Lambdacyhalothrin (WHO 3021) was used in a wettable powder formulation (Icon WP10, Zeneca, Brazil). The field application procedure has been published previously (10).

**Housing improvement programme.** A housing improvement programme intervention was carried out in Nandua. The specific intervention included improving each house in the community by using the existing structures and modifying them with materials in such a way as to ensure smooth, flat, and crack-free walls and ceiling surfaces and improving openings for ventilation and illumination (18).

**Housing improvement programme, including a one-time insecticide application.** In Ypui, a combined approach was carried out. Each head of family agreed to the housing improvement as well as to the conditions, following the same procedures used in Nandua. Heads of families were informed that the intervention included insecticide spraying prior to housing improvement, and their permission to perform the spraying was solicited. The spraying was performed not more than 1 month before the improvement activities were carried out in each house.

Post-intervention period

In a community where insecticide spraying was the only intervention, the post-intervention period was 21 months. After at least 3 months during which no intervention occurred, serodiagnosis, vector density, and triatomine infection rate were determined in the same way as for the pre-intervention baseline data.

Patient consent

The aim and the procedures involved in this study were clearly explained to the community. Consent to participate was voluntarily given by all inhabitants.

Analysis of data

Paired sample testing for nominal scale data (McNemar’s test) was carried out in order to determine significant changes in the triatomine status of the households examined before and after control interventions. Changes in the serology prevalence of the population in the three villages during the pre- and post-intervention processes were determined using the \( \chi^2 \) test and a \( \chi^2 \) test of the trends. \( P \)-values < 0.05 were considered to be statistically significant.

Results

A total of 88% of the houses in Cañada were fumigated, a task that was completed in less than 1 week. The housing improvement intervention in Nandua had the highest coverage (90%), but took a longer period (21 months). In Ypui, where housing improvement was preceded by fumigation only in the houses scheduled for improvement, the coverage was the lowest (67%), and it was achieved over quite a long period (36 months). The houses in the three communities were similar, with thatched roofs and brick walls, most without plaster or mud.

Triatomine infestation

A total of 182 dwellings were evaluated in the initial study of the three communities. In the pre-intervention phase, based on the domiciliary presence of any stage of live triatomines (embryonic eggs or fresh faces detected by the research team), high triatomine infestation levels were found, ranging from 33% to 49% (Table 1). Period domiciliary infestation, as indicated by the presence of triatomines or vestiges, was low in the communities, ranging from 3% to 27% (Table 1). The three intervention procedures were all effective in terms of reducing the vector of Chagas disease. Domiciliary and period domiciliary infestation rates exhibited dramatic changes after the interventions. In Nandua, Ypui, and Cañada the infestation rates for the domestic environment decreased from 32.8% to 3.4%, 48.6% to 16.4%, and 45.1% to 2.4%, respectively; in all cases the differences were statistically significant (Table 1). The most effective intervention in terms of reducing triatomine infestation over a short-term evaluation period was fumigation with insecticide, which achieved an almost 19-fold reduction of the baseline infestation with a control impact of 97.6% (40/41). If only houses subject to intervention were considered, the reduction of triatomine infestation was 100% in Ypui, which received combined interventions (47/47), whereas in Nandua (housing improvement alone) the impact was 96.4% (53/55). Analysis of triatomine infestation showed that although initially low triatomine densities were found, colonization and triatomine infection indexes were high. Ypui (combined interventions) and Cañada (sprayed) showed the highest risk for T. amazonensis transmission (Table 1). Nevertheless, although Nandua (improved) showed a low percentage of colonization, over 10% of the triatomines captured were infected with T. amazonensis. However, in the post-intervention period none of the triatomines captured was naturally infected, and none of the households participating in the interventions was colonized.

Follow-up performed in the households 18 months after intervention showed that infestation of improved or sprayed houses was less than 10% (Table 2). The most sensitive procedure for detecting triatomines following improvement interventions was to compare the results of the search performed with the participation of inhabitants at the beginning.
### Table 1. Triatomine infestation indices in the three study villages, according to control interventions

<table>
<thead>
<tr>
<th></th>
<th>Nandua</th>
<th>Ypaú</th>
<th>Canadá</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of households</td>
<td>61</td>
<td>70</td>
<td>51</td>
</tr>
<tr>
<td>Intervention</td>
<td>Housing improvement</td>
<td>Insecticide + housing improvement</td>
<td>Insecticide</td>
</tr>
<tr>
<td>No. of households subjected to intervention Indices (%)</td>
<td>55/61 (90.2) a</td>
<td>47/70 (67.1) f</td>
<td>45/51 (88.2)</td>
</tr>
<tr>
<td>Triatomine density b</td>
<td>0.6</td>
<td>1.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Triatomine infection c</td>
<td>11.4</td>
<td>27.1</td>
<td>4.6</td>
</tr>
<tr>
<td>Colonization d</td>
<td>7</td>
<td>100</td>
<td>83.3</td>
</tr>
<tr>
<td>Domiciliary pre-intervention infestation rate</td>
<td>20/61 (32.8) e</td>
<td>34/70 (48.6) f</td>
<td>23/51 (45.1) e</td>
</tr>
<tr>
<td>Domiciliary post-intervention infestation rate</td>
<td>2/59 (3.4) e</td>
<td>9/55 (16.4) f</td>
<td>1/41 (2.4) e</td>
</tr>
<tr>
<td>Peridomiciliary pre-intervention infestation rate</td>
<td>2/59 (3.4) e</td>
<td>19/70 (27.1) f</td>
<td>4/51 (7.8) e</td>
</tr>
<tr>
<td>Peridomiciliary post-intervention infestation rate</td>
<td>1/59 (1.7) e</td>
<td>2/55 (3.6) f</td>
<td>0/41 (0) e</td>
</tr>
</tbody>
</table>

* a Figures in parentheses are in percentages.
* b Density index = number of triatomines captured/number of examined houses.
* c Triatomine infection index = (number of infected triatomines/number of triatomines examined) x 100.
* d Colonization index = (number of nymphs captured/number of triatomines captured) x 100.
* e P < 0.01 (McNemar's test).
* f P < 0.001 (McNemar's test).
* g No significant difference (McNemar's test).

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### Table 2. Ability to detect *T. infestans* by manual sampling, calendar sensors, or occupants in improved and sprayed houses

<table>
<thead>
<tr>
<th>Locality and month of post-intervention evaluation</th>
<th>No. of infested houses a</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manual sampling b</td>
</tr>
<tr>
<td>Nandua</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0/45 (0.0) a f</td>
</tr>
<tr>
<td>12</td>
<td>1/30 (3.3) g</td>
</tr>
<tr>
<td>18</td>
<td>0/18 (0.0)</td>
</tr>
<tr>
<td>Ypaú</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>0/39 (0.0)</td>
</tr>
<tr>
<td>12</td>
<td>2/37 (5.4)</td>
</tr>
<tr>
<td>18</td>
<td>1/15 (6.6)</td>
</tr>
<tr>
<td>Canadá</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>1/42 (2.4)</td>
</tr>
<tr>
<td>12</td>
<td>0/41 (0.0)</td>
</tr>
<tr>
<td>18</td>
<td>1/41(2.4)</td>
</tr>
</tbody>
</table>

* a The difference between the number of households observed in this and Table 1 is due mainly to temporarily or permanently unoccupied houses, or missing calendars or bags at the instant the search was made for triatomines.
* b Manual sampling: live triatomine presence, fresh faeces, or embryonic eggs found by trained personnel of the project.
* c Calendar: detection of dried triatomine faeces in the calendars exposed for 6-month periods.
* d Plastic bags: triatomine presence in any stage inside the plastic bag that was used by the household inhabitants.
* e Figures in parentheses are percentages.
* f χ2 test = 2.2; P = 0.06 (Fisher's exact test).
* g χ2 test = 1.4; P = 0.19.
* h χ2 test = 1.3; P = 0.20.
of the process with those of the 1 hour per person sampling test (Table 2). However, households that were positive according to the deposits on the calendars were repeatedly positive during the follow-up period but considered negative by their occupants and also by the survey performed by the research team. At the end of the study a final manual sampling was carried out, and all the houses declared positive according to the calendars were also found to be infested by the research team. All the insects captured by the inhabitants or by the research team were adult *T. infestans* and/or *T. vinckeii*.

**Serological evaluation**

A total of 149 individuals (19.6%) out of a total of 762 people studied were positive serologically for *T. cruzi* infection in the three communities at baseline. All positive cases were confirmed as such by IIF. Evaluation of a randomly chosen 10% of negative samples by ELISA did not reveal any false-negatives (Table 3). Distribution of positive results according to the titres was reflected by the values of the geometric mean of the inverse of the ELISA titres in positive individuals as well as in the total population. In both instances, the highest geometric mean inverse titres were observed in Cañada (sprayed) with values of 97 and 19 for the positive and total population, respectively. The lowest geometric mean inverse titres were found in Ñanduá (improved), with values of 53 and 13 for the positive cases and general population, respectively (Table 3).

At baseline, positive cases were found in all age groups in the three communities. The age strata 10–14 years, 40–44 years, and 60–64 years showed the highest prevalence, with 10, 10, and 12 positive cases, respectively. Comparison of seropositivity adjusted for age did not reveal any significant difference among the three populations (data not shown). However, the distribution of positive cases exhibited different tendencies in the three communities. The highest number of positive cases was observed in the age strata 5–9 years and 15–19 years in Ñanduá (Fig. 1a). In Ypau, positive cases were more homogeneously distributed, mostly involving the age groups 5–9 years and 60–64 years (Fig. 1b). In Cañada, positive cases showed a bimodal distribution, with a significant number of cases involving the age strata 25–29 years as well as 60–64 years and 75–79 years (Fig. 1c).

The second serological evaluation repeated 21 months later on 621 people showed that 96 (35.5%) had positive serology for *T. cruzi* infection in the three study communities. A total of 10% of the randomly chosen negative ELISA cases were also negative in the IIF assay. In the post-intervention evaluation similar figures for the geometrical mean values were obtained (Table 3). In contrast to the pre-intervention evaluation, post-intervention seroprevalences increased with the age of individuals in all the villages. But only in Cañada was it statistically significant ($\chi^2$ test for trend $P < 0.01$).

There were no positive cases among the 40 children aged 0–4 years in Ñanduá (Fig. 1a). A reduction in positive cases was found in the groups aged 5–9 years and 15–19 years, and a shift towards higher age groups for positive cases was also observed in the age groups up to 14 years. There were no relevant changes in the remaining age groups. Two positive cases out of 39 in Ypau and 2 positive cases out of 21 in Cañada were detected in the group 0–4 years, but none of them could be ascribed to vector transmission within the community (Fig. 1b, c). Comparison of the seropositivity rates adjusted for age showed no significant
Table 3. Chagas disease serology in the three study villages

<table>
<thead>
<tr>
<th>Villages</th>
<th>Nandua</th>
<th>Ypaú</th>
<th>Cañada</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-intervention serology rate, overall</td>
<td>37/265 (14.0%)&lt;sup&gt;a,b&lt;/sup&gt;</td>
<td>63/325 (19.4%)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>49/172 (28.5%)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>By sex:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>18/138 (13)</td>
<td>30/154 (19.5)</td>
<td>24/103 (23.3)</td>
</tr>
<tr>
<td>Female</td>
<td>19/127 (15)</td>
<td>33/171 (19.3)</td>
<td>25/69 (36.2)</td>
</tr>
<tr>
<td>Post-intervention serology rate</td>
<td>29/229 (12.7%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>44/260 (16.9%)&lt;sup&gt;c&lt;/sup&gt;</td>
<td>23/132 (17.4%)&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>Geometric mean titre in pre-intervention serology:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total population</td>
<td>13</td>
<td>15</td>
<td>19</td>
</tr>
<tr>
<td>Positive cases</td>
<td>53</td>
<td>76</td>
<td>97</td>
</tr>
<tr>
<td>Post-intervention serology by sex:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Male</td>
<td>16/112 (14.3)</td>
<td>29/127 (22.8)</td>
<td>10/72 (7.6)</td>
</tr>
<tr>
<td>Female</td>
<td>13/117 (11.1)</td>
<td>20/137 (14.6)</td>
<td>13/60 (21.7)</td>
</tr>
<tr>
<td>Geometric mean titre in post-intervention serology:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total population</td>
<td>12</td>
<td>14</td>
<td>17</td>
</tr>
<tr>
<td>Positive cases</td>
<td>43</td>
<td>91</td>
<td>216</td>
</tr>
<tr>
<td>Seroconversion rate during post-intervention evaluation</td>
<td>3/229 (1.3)</td>
<td>0.260 (0)</td>
<td>0/132 (0)</td>
</tr>
</tbody>
</table>

<sup>a</sup> Figures in parentheses are percentages.
<sup>b</sup> χ² test = 0.18; P = 0.67.
<sup>c</sup> χ² test = 0.59; P = 0.44.
<sup>d</sup> χ² test = 5.06; P = 0.02.

Differences among the communities in the post-intervention period (data not shown). With respect to sex and infection, distribution of positive cases was generally homogeneous in the three communities during the pre- and post-intervention periods (Table 3). However, in Cañada 56% of the women were serologically positive, whereas men constituted only 30% of positive cases. It is interesting to note the tendency of women to present a higher rate of infection in this community. About 80% of the baseline population was evaluated at the end of the project, mainly due to out-migration from the area. The seroconversion rate was 0.5% in the three communities (three new cases), i.e. three cases of seroconversion (1.5%) observed in Nandua and no seroconversion cases observed in either Ypaú or Cañada (Table 3).

Discussion

Even considering that interventions were not performed in all the houses in each community, a strong impact was observed on both the entomological and serological parameters of Chagas disease. The three methods tested — spraying, housing improvement, and the combined interventions — proved effective in reducing infestations in a short period of time. Of the control methods used, insecticide spraying had the most dramatic impact on domiciliary infestation in the communities as a whole. In a community-based comparison, fumigation was twice as effective as housing improvement interventions, and when combined with housing improvement proved the most effective method of control. The time frame associated with carrying out the interventions should also be considered. Fumigation could be performed in a short period of time, but housing improvement required several months to complete. Fumigation was carried out early in the intervention period, enhancing the possibility of having a demonstrable effect in the other two communities, where the presence of the research team was more frequent. These factors along with the coverage of the intervention in the different communities could explain the reinfection process. For example, the combined intervention consisting of domiciliary and peridomiciliary spraying before improvement guaranteed control during a 21-month follow-up period. There was no peridomiciliary intervention in the community where house improvement alone was carried out, and some houses were not improved; this could explain the recovery of triatomine intradomiciliary populations. The sprayed locality had a reinfection rate of 2.4% at month 21 of follow-up, probably due to the poor surveillance operations.
system or deficiencies in the spraying process. The dose used in fumigating the sprayed village (31.5 mg active ingredient per m²) was enough to keep houses free of triatomines up to 21 months after spraying (10).

As far as vector surveillance is concerned, manual sampling had low sensitivity compared with detection by calendars and capture performed by occupants. Moreover, manual sampling is an expensive system owing to the cost of transportation and the necessity for trained personnel. The results obtained in this study are corroborated by other entomological studies in which triatomine density was low, making triatomine capture during short visits very difficult (12, 13). In addition, Marsden (20) demonstrated that a high percentage of households with indirect evidence of infestation were further declared positive, showing that manual sampling is not efficient.

The use of calendars or similar surveillance instruments has proved effective in detecting triatomine colonization, which is difficult to confirm with manual sampling at low densities (2, 11-13, 19, 21). Comparison of the efficacy of manual sampling with this passive method showed no significant differences (11, 12, 22). The limitation of calendars is that only a small area inside a room is covered, and an experienced technician is needed to identify triatomine faeces. Nevertheless, investigations involving schoolchildren to evaluate calendars used in entomological surveillance phases have demonstrated that the children's success level justifies incorporating information about Chagas disease and its control into regular educational programmes in endemic areas (23). In our study, the presence of fresh triatomine faeces was included as evidence of household infestation owing to the expertise of the project team in this type of work. However, it is important to note that intradomiciliary colonization by triatomines and the possible circulation of other insects in houses, which can reduce the specificity of the calendar method, were also taken into account during the data analysis. In terms of control of infestation, community participation was measured in this study by involving inhabitants in capturing triatomines and subsequent use of plastic bags during the post-intervention period. Undoubtedly, this was the most sensitive follow-up test, particularly at the beginning of the surveillance phase.

Changes in the serological parameters of the population are also useful for comparing the effects of the interventions. Although the evaluation period was too short to observe dramatic changes in the serology of the population, a highly significant reduction in positive cases was seen in the sprayed community. It is also interesting that serological titres in the sprayed community were observed both at baseline and during the post-intervention period. There is no consistent evidence to explain this, since this village had the lowest levels in triatomine density and natural infection indices. Serocconversion was negative for the sprayed community as well as the community that participated in the combined interventions, but a seroconversion rate of 1.5% was recorded in the community where housing improvement alone was carried out. Temporal migrations of seroconverted inhabitants and triatomine infestations in their houses were not confirmed. However, these observations suggest a need to include insecticides in control campaigns in domestic and peri-domestic areas as an important tool in triatomine elimination.

Seroconversion in noninfested houses in the improved village arose because either bug densities were below detectable levels in both domestic and peri-domestic areas (24) or individuals spent nights in other infested houses. Moreover, serology performed by filter-paper screening is not without limitations. The blood-drying process and low titres in certain individuals may affect antibody detection (25). It is important to note that a migration process among the population was observed in these villages. Although losses might have influenced serological results, it is unlikely that they affected follow-up of the seronegative population cohorts analysed in these villages. A more sensitive parameter for detecting T. cruzi transmission is the serology of children aged 0–4 years who were born after the interventions began. A few positive cases were detected in this stratum, but these could not be attributed to vector transmission, which corroborates the concept of successful vectorial interruption of the T. cruzi transmission in these communities during this period. However, it is important to note that congenital transmission might be possible because of the confirmed positive serology of the mothers.

Selecting an appropriate vector control intervention for large-scale application should be based on an analysis of cost-effectiveness. Taking into consideration the general cost of each intervention of US$ 700 for housing improvement and US$ 29 for the spraying process (18), insecticide spraying was the most cost-effective means of vector control over the post-intervention period of 21 months. However, the combined intervention of housing improvement plus insecticide spraying and housing improvement alone as a large-scale campaign is economically feasible. Moreover, longitudinal studies have shown that housing improvement without community surveillance did not alter the triatomine prevalence in households (12, 26). On the other hand, some studies confirm that making appropriate housing improvements after insecticide application might be the best way of avoiding triatomine infestation (22), whereas others showed that this combination did not prevent triatomine reinfestation (16). Thus, for large-scale campaigns, the most appropriate application of control tools for successful vector elimination would appear to require a carefully thought out community component.

Although our sample size was not optimal for comparing communities participating in interventions or follow-up comparisons between pre- and post-intervention periods, a dramatic reduction in
household infestation was observed in the three localities following intervention. However, seroconversion still occurred (Table 3). Thus, additional measures such as educational programmes or permanent community participation in the entomological surveillance phase should be incorporated. Moreover, a national programme for the control of the vector of Chagas disease should involve control tasks at two different levels: first, radical control of vector density based on systematic spraying of the communities and vector surveillance conducted by the community itself; and second, long-term control that incorporates housing improvement. The latter should not be considered only as one alternative in the control of Chagas disease vector, but a choice that will improve the quality of life in rural populations located in areas endemic for the disease.

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Résumé
Diverses modalités de lutte contre les vecteurs de la maladie de Chagas dans des zones d’endémie au Paraguay
Lors d’une étude menée sur le terrain dans trois localités rurales du Paraguay situées dans une zone d’endémie chagasiqque, nous avons mis en œuvre trois modalités de lutte antivectorielle — la pulvérisation d’insecticide, l’amélioration des logements et une association de ces deux interventions — qui ont réduit efficacement l’infestation par les triatomines. L’association du traitement insecticide et de l’amélioration des logements a fait reculer l’infestation de 100% (47/47), la réduction étant de 96,4% lorsque l’intervention ne concernait que l’amélioration des logements (53/55). Là où l’on s’était borné à pulvériser un insecticide, le recul de l’infestation domiciliaire était de 97,6% (40/41). Dans toutes les habitations où nous sommes intervenus, le taux de réinfestation était inférieur à 10% 18 mois après les interventions. Une enquête sérologique menée sur la population avant et après les interventions a mis en évidence une augmentation de l’âge des sujets séropositifs, sans toutefois que les différences observées soient significatives. Le taux de séroconversion a été de 1,3% (trois nouveaux cas) dans la localité où l’on s’était contenté d’améliorer les logements, mais chacun de ces cas aurait pu s’expliquer par une transmission vectorielle. L’intervention plus économique a été le traitement insecticide, qui a continué d’avoir un effet marqué sur l’infestation pendant les 21 mois de la période de suivi, pour un coût unitaire de US $29 contre les US $700 par habitation qu’a coûté l’amélioration des logements.

Resumen
Lucha contra los vectores de la enfermedad de Chagas mediante distintas modalidades de intervención en localidades endémicas del Paraguay
En un estudio sobre el terreno que se llevó a cabo en tres comunidades rurales del Paraguay, en una zona donde la enfermedad de Chagas es endémica, aplicamos tres medidas de lucha antivectorial — rociamiento, mejoramiento de las viviendas y una combinación de ambas — que redujeron de manera eficaz las infestaciones por triatomídos. La disminución de las infestaciones fue del 100% (47/47) en la comunidad sometida a la intervención combinada, mientras que en la comunidad donde se introdujeron mejoras en las viviendas fue del 96,4% (53/55). En la comunidad donde se utilizó únicamente el rociamiento, el impacto sobre las infestaciones domiciliarias fue del 97,6% (40/41). En todas las viviendas en que se intervino, 18 meses después de la intervención la tasa de reinfección era inferior al 10%. El examen serológico de la población antes y después de la intervención reveló un desplazamiento de los casos positivos hacia los grupos de mayor edad, pero las diferencias observadas no eran significativas. La tasa de seroconversión fue del 1,3% (tres nuevos casos) en la localidad donde sólo hubo mejoramiento de las viviendas, pero cualquiera de esos casos pudo ser debido a la transmisión vectorial. La intervención más eficaz en relación con el costo fue el rociamiento con insecticida, operación que durante los 21 meses subsiguientes tuvo un gran efecto en las infestaciones y que costó US $29 por vivienda, frente a los US $ 700 por vivienda que supuso el mejoramiento de éstas.
References