INFECTIOUS DISEASES

House-level risk factors for triatomine infestation in Colombia

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Accepted 9 March 2007

Background Chagas disease, transmitted domestically by triatomine bugs, is the most important vector-borne disease in Latin America. The association between triatomine infestation and housing characteristics was investigated based on a standardized survey in 41,971 houses in 15 Departments in Colombia.

Methods Multivariate logistic regression was used to test for associations of two highly correlated infestation measures of infestation (householders reporting having seen triatomines inside the house, and sending triatomines to the survey team), with 15 household-level risk factors. Risks were measured relative to a reference category of houses with up to three inhabitants, area up to 50 m², unplastered adobe walls, thatch roof and no outbuildings or domestic animals.

Results The probability of seeing triatomines was highest for households with over seven inhabitants (OR = 1.24, 95% CI 1.11–1.39), overhead storage space (OR = 1.16, 95% CI 1.03–1.32), grain shed (OR = 1.25, 95% CI 1.02–1.52), cats (OR = 1.27, 95% CI 1.14–1.42) and pigs (OR = 1.16, 95% CI 1.03–1.30). Lowest risks were in houses with wooden walls (OR = 0.46, 95% CI 0.34–0.61), fully plastered walls (OR = 0.78, 95% CI 0.68–0.88), roofs made of tiles (OR = 0.51, 95% CI 0.33–0.78) and flagstone floors (OR = 0.57, 95% CI 0.42–0.76). Results for householders returning triatomines support this set of risk factors, but with wider confidence intervals.

Conclusions Surveillance of a few easily assessed household characteristics provides an accurate, rapid assessment of house-level variation in risk. Measured effect sizes for specific structural characteristics could be used to maximize the cost-effectiveness of programmes to reduce vector infestation and interrupt Chagas disease transmission by improving house quality.

Keywords Triatominae, risk factors, housing, Chagas disease, Colombia

Introduction Chagas disease, caused by Trypanosoma cruzi and transmitted by triatomine bugs living inside houses, causes a larger burden of disease in Latin America than all other vector-borne diseases combined.¹ Large-scale control programmes, mainly based on household spraying of residual insecticides, have achieved...
cost-effective local eradication of domestic vectors and interruption of T. cruzi transmission in large areas of the southern cone of the continent, but control efforts in other regions are less advanced.

In Colombia, the Ministry of Health and collaborating institutions have carried out a large-scale survey of infection in children, domestic rates of triatomine infestation and quality of housing, in order to measure the magnitude and the geographic distribution of transmission risk. They have defined guidelines for individual departments to use the resulting information to identify priority areas for intervention, and apply both residual spraying and house improvements to decrease domestic vector infestation rates and cut transmission.

This survey provides an opportunity to measure the association between the characteristics of individual houses, and the risk of infestation with domestic triatomines. This can serve two purposes. First, identification of house-level risk factors can provide additional information on risk that is relatively rapid and inexpensive to collect, and complements other sources of risk information that are more specific, but may have lower sensitivity. These include vector infestation (due to inevitable occasional failure to capture triatomines in houses that are truly infested), and human infection rates (only samples from children are informative of recent risk, and households with transmission risk may either not include children, or children may not yet have been infected). Adding house-level risk factor information can therefore help to target any selected control intervention. Secondly, it can help to identify the specific characteristics of houses that should be prioritized in house improvement programmes.

Previous studies have already demonstrated the importance of a range of housing characteristics on the prevalence of triatomine infestation in and around houses. These analyses have usually been carried out as well-controlled localized studies of a limited number of villages or municipalities, either in North/Central America, or in the southern cone countries of Latin America. In addition, a previous study has assessed risk factors in 56 houses in 30 villages in Santander Department in Colombia. The current survey provides important additional information, as it is based on an unusually large sample size, over a large geographic area. As the first large-scale, standardized cross-sectional survey of vector infestation and housing within the northern region of South America, it is of particular relevance to Colombia and neighbouring countries with the same principal vector (Rhodnius prolixus), and similar housing characteristics. It should therefore support current efforts to scale-up control activities within this region.

Materials and methods
Survey methodology

Estimates for Colombia were derived from the results of the first phase of a survey of presence of triatomine vectors, serological evidence of T. cruzi infection in children and housing quality, carried out in 1998–2001. This is described in detail by Guhl et al. Briefly, a team of four Colombian institutions worked with Ministry of Health Personnel to carry out a national survey of a random sample of villages in all 15 (out of 33) departments considered endemic, following WHO guidelines. The survey was stratified, first by excluding areas over 2000 m above sea level (above which vectorial transmission of Chagas disease has not been reported), and departments where previous surveys had failed to find evidence of significant triatomine infestation. Within the remaining area, study villages were randomly selected within clusters of contiguous municipalities located within the same Holdridge life zone. Typically, 10–20 houses were randomly selected within each village according to village size.

Within each village, trained health workers used standardized teaching materials to allow householders to identify triatomines, and to distinguish them from morphologically similar insects. Householders were then (i) asked whether they had seen triatomines inside their houses, and (ii) left plastic pots, in which they were instructed to collect any triatomines that they found within their house, over a pre-determined period (average 4–5 days). The pots were recollected, and the triatomines sent to entomological laboratories for identification to species level. The health workers applied a standardized questionnaire to record housing characteristics and the presence of domestic animals in all of the sampled houses.

Statistical analysis

Risk factor analyses were carried out using multivariate logistic regression. Separate analyses were carried out defining the outcome variable as a positive householder response for (i) seeing at least one triatomine bug within the house, (ii) returning a pot with at least one triatomine to the survey team and (iii) returning a pot with a particular species of triatomine to the survey team.

The majority of housing characteristics are categorical variables (e.g. type of floor, presence or absence of specific types of domestic animal). For ease of interpretation, the remaining continuous variables (number of inhabitants, area of house) were divided into three categorical groupings with approximately equal numbers of observations in each. All housing characteristics recorded in the survey were included as predictor variables in each of the models. Each model further adjusts for variation between the 15 departments (to take account of broad geographic differences in vector abundance determined by environmental characteristics and historical dispersal patterns), and for clustering at the village level (as houses within the same village are likely to have more similar probabilities of infestation than those from different villages, partly through house-to-house movement of bugs).

The logistic regression model was also used to estimate the effect of making improvements in various aspects of housing quality on the proportion of households reporting triatomines. The model was applied separately to predict average rates of infestation for the observed data set, and ‘dummy’ data sets in which the relevant variables for house structure were all set to either the lowest risk condition, or the highest risk condition.
Results

Survey distribution and comparison of sampling methods

The distribution of survey activity is shown in Figure 1. Sampling covered all municipalities in the 15 north-central departments of the country in which the altitude of the municipality centre was below 2000 m. The total sample size was 41,971 houses in 3375 villages from 539 municipalities from the 15 departments.15,16

Out of the total 41,971 households, 36,873 provided information on whether or not they had seen triatomines inside their houses, with the remaining responses recorded as either ‘don’t know’, or missing data. Out of the 36,873, 8,576 (23.26%) reported having seen triatomines.

Of the households, 1,319 (3.14%) returned triatomines in pots. The most common species returned were R. prolixus from 554 households (1.32%), Panstrongylus geniculatus from 220 (0.52%), Triatoma dimidiata from 205 (0.49%), T. maculata from 188 (0.45%), R. pallescens from 93 (0.22%) and T. venosa from 70 (0.17%). Individuals of 13 other species were returned by a total of 74 (0.19%) households.

The degree of association between households reporting having seen triatomines and those sending triatomines to the survey teams is shown in Table 1. The measures are highly correlated, with agreement in 78.45% of cases ($\chi^2 = 1958, P < 0.0001$). The majority of those households which sent triatomines back in pots (75.34%) had also previously reported having seen them within the house. The probability of sending back triatomines was 10.1 times higher among those that had reported seeing bugs than among those who had not. Reporting having seen triatomines is clearly a much more sensitive measure, but may be less specific. Only a small minority (10.94%) of those reporting having seen triatomines inside the house sent vectors back in pots.

Risk factors for householder reports of seeing triatomines inside the house

Table 2 shows positive and negative responses separately for each of the risk factors. Odds ratios and associated significance tests and confidence intervals, adjusted for the influences of other factors in the model, geographic variation and clustering, are shown relative to houses with 0–3 inhabitants, with an area of 0–50 m², unplastered adobe walls, thatch roof and with no outbuildings or domestic animals. The advantage of carrying out a multivariate analysis can be seen for several risk factors (e.g. wall or roof type) where the adjusted odds ratios suggest a different ordering or magnitude of effect than the unadjusted observed prevalences, which are partially confounded by an uneven distribution of the risk factors throughout the survey sample, particularly in different geographic regions.

The probability that inhabitants report having seen triatomines within their house increases significantly with higher numbers of inhabitants, and possession of overhead storage space, grain shed, cats and pigs. In contrast, risk decreases significantly in houses with brick or wooden walls, plastered walls, roofs made of tiles or zinc and floors made of cement or flagstone.

Risk factors for confirmed presence of triatomines inside houses

The alternative measure of householders returning triatomines in pots is less sensitive, but completely specific, making the reasonable assumption that there are no identification errors by the survey teams. Results are presented in Table 3. The direction and size of the effects of individual risk factors are highly consistent with the analysis of householder reports of seeing triatomines, although confidence intervals around the odds ratios are wider, presumably due to the smaller number of positive observations. The presence of overhead storage and at least one cat are associated with an increased risk. Walls made of brick/blocks, wood or tin and floors made of cement, are associated with significantly decreased risk compared with the reference situation. The presence of a chicken shed is also associated with decreased risk. Confidence intervals for the odds ratios of the effect of each risk factor on the probability of householders returning triatomines overlap with those for householders reporting having seen triatomines. This is consistent with a difference in overall sensitivity, rather than sampling biases between the two methods.
Risk factors by triatomine species

Table 2 shows results of logistic regression analyses applied separately for *R. prolixus*, which is the most commonly returned vector in the Colombian survey, and is also considered to be the most effective in transmitting *T. cruzi* in the northern region of South America. Estimated effect sizes for risk factors are generally consistent with the estimates either for households reporting seeing triatomines, or for sending back any species of bug, but confidence intervals are considerably wider. Only the presence of brick/block walls (decreasing risk), and overhead storage (increasing risk) show significant changes. The ORs are often 1.00 or lower, indicating a decrease in risk.

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Total</th>
<th>Positive (%)</th>
<th>OR</th>
<th>P</th>
<th>95% CI</th>
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<td></td>
<td>4–6</td>
<td>17 186</td>
<td>22.45</td>
<td>1.02</td>
<td>0.704</td>
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<td></td>
<td>7–21</td>
<td>10 349</td>
<td>26.42</td>
<td>1.24</td>
<td>0.000</td>
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<tr>
<td>House 0–50</td>
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<td>area (m²) 50–100</td>
<td>11 226</td>
<td>24.03</td>
<td>1.02</td>
<td>0.740</td>
<td>0.91–1.15</td>
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<td></td>
<td>100–1000</td>
<td>14 030</td>
<td>21.36</td>
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<tr>
<td>Earth</td>
<td>11 475</td>
<td>23.33</td>
<td>0.83</td>
<td>0.024</td>
<td>0.71–0.98</td>
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<td>Tin</td>
<td>733</td>
<td>25.24</td>
<td>0.78</td>
<td>0.284</td>
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<td>Brick/block</td>
<td>9479</td>
<td>19.97</td>
<td>0.59</td>
<td>0.000</td>
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<td>Wood</td>
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<td>11 376</td>
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<td>Partial</td>
<td>8233</td>
<td>25.05</td>
<td>0.84</td>
<td>0.003</td>
<td>0.76–0.94</td>
</tr>
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<td>Full</td>
<td>7431</td>
<td>19.73</td>
<td>0.78</td>
<td>0.000</td>
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<td>772</td>
<td>31.22</td>
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<td>Palm</td>
<td>7677</td>
<td>26.05</td>
<td>0.86</td>
<td>0.500</td>
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<td>21.86</td>
<td>0.53</td>
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<td>Tiles</td>
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<tr>
<td>Cement</td>
<td>16 369</td>
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<td>0.83</td>
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<td>flagstone</td>
<td>1217</td>
<td>13.23</td>
<td>0.57</td>
<td>0.000</td>
<td>0.42–0.76</td>
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<tr>
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<td>25 261</td>
<td>24.87</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Any</td>
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<td>20.66</td>
<td>0.98</td>
<td>0.783</td>
<td>0.83–1.15</td>
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<td>22.90</td>
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<td>storage Yes</td>
<td>9523</td>
<td>25.84</td>
<td>1.16</td>
<td>0.017</td>
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<td>17 594</td>
<td>24.40</td>
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<tr>
<td>shed Yes</td>
<td>16 859</td>
<td>23.04</td>
<td>1.02</td>
<td>0.763</td>
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<td>1.25</td>
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<td>20.38</td>
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<td>Cat No</td>
<td>18 055</td>
<td>22.08</td>
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<td>20.71</td>
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<td>Pig No</td>
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<td>23.40</td>
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<td>Yes</td>
<td>9154</td>
<td>28.44</td>
<td>1.16</td>
<td>0.015</td>
<td>1.03–1.30</td>
</tr>
</tbody>
</table>

The ORs are often 1.00 or lower, indicating a decrease in risk. Only the presence of brick/block walls (decreasing risk), and overhead storage (increasing risk) show significant changes.
storage (increasing risk) are statistically significant. Analyses for the next two most commonly returned species, *T. dimidiata* and *P. geniculatus*, fail to show differences in the effect of risk factors between species, with the exception that *T. dimidiata* is more strongly associated with the presence of cats than are the other two species (data not shown).

### Estimated effects of improvements to house structure

Assuming the relationships between risk factors and triatomine infestation are directly causal, then the results indicate that making structural improvements to houses would bring about large decreases in infestation risk. Improving all houses from their current conditions to the best observed structure (i.e. converting to fully plastered wooden walls, tile roofs and flagstone floors, but without making any changes to numbers of inhabitants, outbuildings or domestic animals), would decrease the overall proportion of houses reporting triatomine infestation by 60%. Among the houses which currently have the worst conditions, the specified improvements should bring about a 76% reduction in infestation risk.

The analyses indicate that the same set of changes would bring about an ~37% reduction in the proportion of houses sending back triatomines, with a 58% reduction amongst those houses which currently have the worst structural conditions.

### Discussion

The cross-sectional survey of triatomine infestation in Colombia provides an important source of information to inform control programmes for Chagas disease, and specifically to identify house-level risk factors for triatomine infestation. The most important characteristics of the survey are (i) standardized collection methods for both infestation and housing quality, (ii) large sample size and geographic coverage and (iii) use of local control services and householders to collect information, in a manner that could be replicated in future large-scale surveys and monitoring programmes.

The current trend towards decentralization of public health services in Latin America has increased the importance of community surveillance of vector-borne disease in general, and Chagas disease in particular. Previous studies have shown that capture and reporting of triatomines by householders is an effective strategy in monitoring reinfection after insecticide-spraying interventions. The current investigation shows that community participation can also be highly effective in surveys to map infestation over large areas, and identify risk factors at the household level. It further suggests that householders can provide reliable data not only by capturing triatomines, but also through verbal reports of having seen vectors; infestation is over 10 times more likely to be confirmed in a household that has reported having seen triatomines than one that has not. The true reliability of the sampling methods also depends on the extent to which households that report having seen bugs but fail to send them to the survey team are either (i) incorrectly reporting infestation when none exists (i.e. false positive for reporting having seen triatomines), or (ii) failing to capture or send bugs when the house is genuinely infested (i.e. false negative for sending triatomines). The ultimate utility of the sampling methods also depends on the relative importance of wasting resources in investigating or...
controlling false positives, vs risking additional infections through failing to control false negatives.

Analysis of the survey results indicates statistically robust relationships between specific house-level characteristics and the probability of domestic infestation with triatomine vectors. The risk factors identified are consistent with existing knowledge of triatomine ecology, and both support and add to the list of risk factors identified in previous studies; presence of domestic animals and other animals such as rodents, squirrels and opossums, storage of crops, agricultural products and building materials, or the specific characteristics of walls, roofs and floors are associated with large decreases in risk, presumably by reducing availability of resting and breeding sites.

The results of this study have implications for maximizing surveillance efficiency, which is likely to become increasingly important if control interventions succeed in reducing infestation rates. The analyses suggest that future surveys could capture a large proportion of the inter-house variability in infestation risk by recording a limited number of key structural factors, and that the most important of these (wall and roof type) could be recorded without needing to enter individual houses. This would constitute an important complement to, but not replacement for, active searching of houses in large scale surveys. This would constitute an important complement to, but not replacement for, active searching of houses in large scale surveys.

The results are also directly relevant to the design of programmes to reduce infestation rates and interrupt transmission through improving housing quality. Such programmes have been successfully implemented both in controlled research trials, and as a component in control programmes at both the subnational level in Colombia, and at the national level in neighbouring Venezuela. They can provide an important long-term alternative or complement to insecticide-based interventions, particularly where there is potential reinfestation from sylvatic or other domestic sources.

The current study indicates that a limited number of structural housing improvements would decrease infestation prevalence across all households by 37–60%, depending on the infestation measure used and by 58–76% amongst the houses with the worst conditions. These are important reductions, but they are lower than those measured in controlled intervention trials (e.g. 96% in ref.29), probably because (i) houses within each structural category in the survey are likely to be more heterogeneous than in a control trial, and (ii) the results represent the long-term equilibrium prevalence, rather than that measured immediately after a control intervention.

While housing improvements are clearly effective, unit costs for overall house improvements are relatively high; US$700 compared with US$29 for insecticide spraying in Paraguay. The effect sizes for each of the housing characteristics provide a basis for the rational prioritization of changes in house design to reduce triatomine infestation. This could be combined with information on the costs of making each specific change, to design a package of house improvements that optimizes cost-effective reduction in infestation rates.

This analysis has focused on identifying determinants of inter-house variation in risk of vector infestation. In order to maximize efficiency, however, it is also essential to investigate risk patterns over larger spatial scales, and to combine infestation data with other sources of risk information. Future analyses will investigate environmental determinants of the geographic distribution of vectors, as well as the inter-relationships between measures of vector infestation and infection risk in humans, in order to optimize allocation of surveillance and control effort.

Acknowledgements
We thank the Wellcome trust for financial support, under the grant ‘A comparison of targeting strategies for Chagas disease control in the Andean region’.

Conflict of interest: None declared.

KEY MESSAGES
- A survey of over 40,000 households in Colombia allowed measurement of effect sizes of household characteristics on the risk of infestation with triatomine vectors of Chagas disease.
- Risk factors include high numbers of inhabitants, agricultural storage areas and selected domestic animals. Wood and plastered walls, tile roofs and flagstone floors decrease risk.
- The measurement of effect sizes provides quantitative evidence for targeting control and prioritizing house improvements to control transmission.
References