Biology, diversity and strategies for the monitoring and control of triatomines - Chagas disease vectors

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Despite the relevant achievements in the control of the main Chagas disease vectors Triatoma infestans *and* Rhodnius prolixus, *several factors still promote the risk of infection. The disease is a real threat to the poor rural regions of several countries in Latin America. The current situation in Brazil requires renewed attention due to its high diversity of triatomine species and to the rapid and drastic environmental changes that are occurring. Using the biology, behaviour and diversity of triatomines as a basis for new strategies for monitoring and controlling the vectorial transmission are discussed here. The importance of ongoing long-term monitoring activities for house infestations by* T. infestans, Triatoma brasiliensis, Panstrongylus megistus, Triatoma rubrovaria *and* R. prolixus *is also stressed, as well as understanding the invasion by sylvatic species. Moreover, the insecticide resistance is analysed. Strong efforts to sustain and improve surveillance procedures are crucial, especially when the vectorial transmission is considered interrupted in many endemic areas.*

Key words: Triatominae - behaviour - sylvatic species - colonization - control strategies - Chagas disease

The study of the biology, diversity and distribution of triatomines began after the discovery of the American trypanosomiases by Carlos Chagas, in 1909 (Neiva 1910, Neiva & Lent 1941, Lent & Wygodzinsky 1979, Galvão et al. 1998, 2003). The precise mapping of their occurrence, domestic infestations and the natural infection rates for the different triatomine species is critical for understanding the challenges and threats posed by vectorial transmission (Silveira & Vinhaes 1999, Silveira 2000, Costa et al. 2002, 2003, López-Cardenas et al. 2005). Understanding their host searching behaviour and activity patterns (Guerenstein & Lazzari 2009) as well as their choice of environments (Guarneri et al. 2002, 2003) is also necessary. In addition to the previously mentioned characteristics, dispersion and reproductive strategies are essential for creating models to predict re-infestation processes (Gurevitz et al. 2006). Altogether, these aspects represent most of the variables needed for the development of pro-active control actions against domiciliary infestation.

Currently, there are 140 species of triatomines described and recognised as valid taxa (Lent & Wygodzinsky 1979, Galvão et al. 2003, Forero et al. 2004, Garcia et al. 2005, Costa et al. 2006, Galvão & Angulo 2006, Bérenger & Blanchet 2007, Costa & Félix 2007, Martinez et al. 2007, Sandoval et al. 2007, Patterson et al. 2009, Schofield & Galvão 2009). Of this total, 61 species are present in Brazil (Galvão et al. 2003), where the most diverse triatomine fauna is found. This is due to the continental dimension of Brazil, comprising distinct biomes that include some of the richest biodiversity on our planet: the Amazon, the Atlantic Forest, the Pantanal and the Cerrado (IBAMA 2009). To better illustrate triatomine diversity, it is important to mention that in the North-Eastern Region of Brazil, 21 species have been collected that are either infesting or invading domiciles, even though most of those species were considered strictly sylvatic (Costa et al. 2003). A specific example can be found in the state of Pernambuco, which is relatively small, encompassing only 98,938 Km^2 (IBGE 2008), but comprises five differentiated mesoregions: Sao Francisco, Araripe, Agreste, Zona da Mata and the Metropolitan Region. In this state, 12 species have been captured in domiciliary ecotopes and, recently, 13 distinct phenotypes of *Triatoma brasi-liensis* Neiva, 1911 were reported in a variety of natural and artificial ecotopes. This geographical variation could also influence triatomine diversity. Nevertheless, the correlation between the distinct phenotypes of *T. brasiliensis* and their vectorial capacity still needs to be investigated (Neiva-Lima et al. 2008, Costa et al. 2009).

For both the states of Minas Gerais and Bahia (BA), 14 triatomine species have been captured in domiciliary units, representing a significant diversity in terms of triatomine fauna (Costa et al. 2003). In the almost unexplored Amazon Region, 18 triatomine species have been recorded (Coura et al. 2002). This region corresponds to more than 40% of the Brazilian territory and possesses one of the highest biodiversities on the planet. According to government sites, more than 700,000 km2 of the Amazon Forest has been devastated, representing 6.5% of the total area (IBGE 2008). The lack of data on probable new habitats for triatomines that are losing their original habitat due to environmental pressures, the

Financial support: CNPq
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Received 17 May 2009
Accepted 10 June 2009

possible existence of new species and the lack of detailed studies for some of the already recorded species impair the estimation and precision of predictions for the spread of Chagas disease in the Amazon Region. A biogeographical revision of the triatomine species based on ecological patterns shows different degrees of synanthropism interpreted as a behavioural gradient starting with the mere invasion of a single house by an adventitious adult and eventually leading to the stable infestation of human dwellings by large breeding vector colonies (Abad-Franch & Monteiro 2007). Recently, the entomological investigation of the first autochthonous case of Chagas disease in the western Brazilian Amazon was reassessed and specimens of *Rhodnius pictipes* Stål 1872 and *Rhodnius robustus* Larrousse, 1927 infected with trypanosomatids were collected in the intradomicile and in the sylvatic ecotopes. These findings emphasise the increasing risk of *Trypanosoma cruzi* infection transmission in the Amazon Region (Fé et al. 2009). Nevertheless, studies suggest that the degradation of sylvatic environments promotes the dislodgment of insects into new ecotopes, fundamentally affecting humans and their associated domestic animals (Forattini et al. 1978, Romaña et al. 2003). Unconventional vectorial transmission related to professional activity was also observed in the municipalities of Santa Isabel do Rio Negro and Barcelos, which are located in the microregion of the Negro River in the state of Amazonas. *Rhodnius brethesi* Matta, 1919, a sylvatic species known as *piaçavas*' lice that is present in the native palm tree *Leopoldinia piassaba* Wallace, 1853, has been incriminated as the responsible vector for the transmission of Chagas disease to those who as collectors of *piaçaba* fibres. This species has been documented to voraciously feed on humans (Mata 1919, Coura et al. 1994).

Distinct from the majority of the Amazon Region, other vast areas of Brazil were colonised at least 200 years ago. Today, field data have shown that the following sylvatic species are frequently found in domiciliary and peridomiciliary areas: *Triatoma vitticeps* (Stål, 1859), *Triatoma rubrovaria* (Blanchard, 1843) and *Panstrongylus lutzi* (Neiva & Pinto, 1923) (Gonçalves et al. 1998, Almeida et al. 2000, Freitas et al. 2004, Souza et al. 2008), among others. More recently, *Triatoma sherlocki* Papa, Jurberg, Carcavallo, Cerqueira & Barata 2002 was captured in Gentio do Ouro, in the north central part of BA, colonising human dwellings (Almeida et al. 2009, unpublished observations). The area in which these colonies were found is not covered by the Control Programme of Chagas Disease. In addition, it is important to mention the increasing infestation rates by *T. brasiliensis* (Costa et al. 2003, Sarquis et al. 2004) in semi-arid areas of the Brazilian Northeast and by *Triatoma sordida* Stal, 1859 in wide Cerrado areas (Diotaiuti et al. 1995, Pelli et al. 2007). Therefore, the positive results achieved with the control measures intended against *Triatoma infestans* (Klug, 1834) should not be interpreted as an endpoint in the struggle against vectorial transmission. The diverse findings reporting sylvatic populations of relevant vectors, together with increasing reports about sylvatic species invading and colonising domiciles, make it evident that new challenges have the possibility of occurring.

Previous studies carried out by Mazza (1943) in Argentina, Torrico (1946) in Bolívia and Barreto et al. (1963) in Brazil have called attention to the fact that *T. infestans* could be found in different sylvatic ecotopes. Recently, in this ever-changing epidemiologic scenario, new tools exploiting the behaviour and the genetics of *T. infestans* revealed that wild foci of this species may be much more widespread than previously thought. Moreover, the high genetic diversity observed in a microregion suggests that the Andean Region is the starting point for the dispersion throughout several South American countries (Noireau et al. 2000, 2002, 2005, Panzera et al. 2004). The increasing migration movements and current environmental changes (Briceno-Leon & Galvan 2007) could also favour new passive dispersion processes for the species and the urbanisation of the vectors. In areas of Cochabamba, Bolívia, *T. cruzi* infection is now considered an urban health problem and is no longer restricted to rural areas and small villages. The high infection risk in children was correlated to the high percentage of the natural infection rates of the vector and qualitative and quantitative evidence for the current active transmission of *T. cruzi* in urban areas of Cochabamba was demonstrated (Medrano-Mercado et al. 2008).

The domiciliation of vectors in the Andean Region has been discussed since 1950, when Torrico (1950) suggested that the synanthropic process of triatomines was facilitated by the habits of the inhabitants of that area, including the practice of rearing guinea pigs in their domiciles, which attracts the insect vectors to the domiciliary ecotopes. In this sense, molecular tools for detecting gene flow between wild and domiciliated populations of triatomines could aid proactive control and provide a better understanding of the colonization and reinfestation potential of this species (Abad-Franch & Monteiro 2005, Dumonteil et al. 2007, Almeida et al. 2008).

Rhodnius prolixus Stäl, 1859 is also another example of how wild foci (Guhl et al. 2005, Pinto et al. 2005) impair the effective control of vectorial transmission and how molecular tools may help with the understanding of the eco-epidemiology of Chagas disease vectors (Fitzpatrick et al. 2008).

One of the most important achievements in the history of American trypanosomiasis was the demonstration by Dias and Pellegrino (1948) that this disease could be controlled by targeting vectors by means of spraying houses with insecticides. All control programmes targeting the interruption of vectorial transmission were developed and applied based on this finding. Today, however, the environmental pressures of deforestation, the increase of human populations and climate change require that strategies be adjusted to efficiently monitor and control the different vector species. Chagas disease vectors are obliged haematophagous insects that need at least one blood meal until repletion in each of the five nymphal instars in order to complete their life cycles. In general, these insects are eclectic in relation to food sources and are able to feed on different hosts. However, some specificity can be found among the species in natural environments. For instance, *Dipetalogaster maxima* (Uhler, 1894) is associated with lizards in deserts, *Cavernicola pilosa* Barber, 1937 is associated mainly with bats and the genera *Rhodnius* Stål, 1859 and *Psamolestes* Bergroth, 1911 are strictly associated with birds (Lent & Wygodzinsky 1979). However, most of the triatomines studied feed efficiently on different hosts, including mammals, birds, reptiles and amphibians. This kind of food eclecticism is probably one of the most important characteristics allowing the triatomines to invade new habitats and to colonise artificial ecotopes (Alencar 1987, Lent & Wygodzinsky 1979, Costa et al. 1998). The biology of the vectors studied under laboratory conditions also shows that they are able to reproduce well; for instance, they can present high fertility and egg viability, even when they are fed on animals distinct from those with which they are normally associated in their natural environment (Costa et al. 1986, Diotaiuti & Dias 1987). This aspect of the biology of the vectors was recently explored by focusing on the manipulation of transgenic insects as a possible strategy to control the natural infection rates in endemic areas. This method utilises genetically modified symbiotic bacteria expressing anti-parasitic agents in the gut of the triatomine bug where the trypanosomes also are found. Previous studies have shown that it is possible to transform *Rhodococcus rhodnii* with a shuttle plasmid that contains the gene for cecropin A, an insect anti-microbial peptide (Dotson et al. 2003). Once transformed, the bacteria expressed this peptide and promoted a reduction in the number of trypanosomes or even their elimination in the digestive tube of the bug *R. prolixus*. Whether the paratransgenic triatomines will actually be able to interact with wild ones and spread *R. rhodnii* into the population needs further analysis (Beard et al. 2002).

During the last decade, increasing evidence suggests that the main vectors of Chagas disease present relevant sylvatic populations that pose a new control challenge, probably indicating no real chance to eliminate the vector insects from large endemic areas (Noireau et al. 2005, Sanchez-Martin et al. 2006, Feliciangeli et al. 2007, Rojas Cortez et al. 2007). This can be summed to the control challenges posed by other vectors that are already considered not eliminable due to the large rates of domiciliary infestation promoted by their sylvatic foci, such as *T. brasiliensis*, *Panstrongylus megistus* (Burmeister, 1835) and *Triatoma dimidiata* (Latreille, 1811). This scenario is associated with the fact that some vector species are already present in populations characterised as resistant to insecticides (Vassena et al. 2000, Piccolo et al. 2005). This process was likely the consequence of the chronic application of insecticides during the past decades. The permanent use of insecticides promoted by recurrent re-invasion processes may bring other control challenges and reveal the need to use more environmentally friendly control methods.

The Special Programme for Research and Training in Tropical Diseases has recently issued a call for proposals for the development of new control tools based on the existing knowledge of triatomine behaviour. This call was promoted by the need for new alternatives to increase the efficiency of insect control measures, especially when sylvatic populations represent an additional threat. Guerenstein and Lazzari (2009) have thoroughly reviewed the existing information about host orientation in triatomines. This ample knowledge reported by the authors indicates that the development of sampling or detection devices can be based on solid information. Other aspects of triatomine behaviour, such as aggregation and sexual signals, are being studied and may generate further alternatives for interfering with insect communication processes and manipulating their behaviour (Lorenzo et al. 2000, Manrique et al. 2006, Pontes et al. 2008).

During searches for triatomines, home owners commonly claim that no insects have been observed. However, in many cases, the houses are later shown to be infested. Traps that can monitor insects during the night when the inhabitants of the house are generally sleeping would be of great help for the control of domiciliary infestations. Also, the application of high resolution and low cost technologies, such as geometric morphometrics, is crucial to answer the relevant questions related to taxonomy and eco-epidemiologic features, assessing systematics and the analysis of domiciliated vector population dynamics (Dujardin et al. 2009).

Finally, it is important to stress that due to the dramatic impact of Chagas disease on public health and considering the level and amount of information already gathered concerning its epidemiologic aspects (Coura 2007), several recommendations were recently defined by the Andean Countries Initiative (Guhl 2007), by the Southern Cone Initiative (Dias 2007) and by the Brazilian Consensus on Chagas Disease, in 2005, aiming for the standardisation of strategies for diagnosis, treatment, prevention and control (SVS 2005).

Here, we present a list of priorities based on some of the vectorial aspects and challenges discussed in the present review: (i) the development of new strategies to explore the biological and behavioural traits of the triatomines; (ii) continuous political actions to keep the long-term monitoring activities in endemic areas, checking for the colonization and reinfestation of domiciles; (iii) more attention directed to new triatomine species that have recently emerged as a threat for the transmission of Chagas disease; (iv) implementing an effective educational programme directed at those living in communities at a high risk of Chagas transmission and, the last but not the least, (v) the improvement of the professional capacity of the technicians responsible for the execution of the vectorial control actions, a crucial step for facing the new challenges in this area (Argolo et al. 2008).

ACKNOWLEDGMENTS

To Dr. Carlos Eduardo Almeida, two anonymous referees, associated editors and Ricardo Bittencourt von Sydow, for valuable suggestions and critic review.

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