Chagas Disease: the Silent Killer

Sara Krueger, Bethany Lutheran College

Mentored by: Dr. May Boggess and Dr. Jay Walton,
Texas A&M Math Department
History of Chagas disease

- Discovery by Carlos Chagas in 1909, Brazil
- Considered a neglected tropical disease
  - WHO and CDC
- Chagas disease is
  - caused by the parasite *Trypanosoma cruzi*
  - transmitted to humans and animals (reservoir) by insect vectors, mainly *Triatoma sp.* insects.
Triatoma sp. Insect

- Carrier of Trypanasoma cruzi parasite.
- Blood sucking insect
- Ingests the parasite from the blood of person or animal (reservoir) already infected
- When feeding, secretes feces containing the parasite near the bite site
- Lives in mud, thatch or adobe houses
- Feeds on faces ("kissing bugs")

0.75 to 1.25 inches in length
Location of disease

South America 2004

South America 2008
<table>
<thead>
<tr>
<th>Stage</th>
<th>Symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acute</td>
<td>Swelling at infection site, fever, fatigue, rash, aches, nausea, Romana's sign</td>
</tr>
<tr>
<td>Latent</td>
<td>Asymptomatic, test positive with blood tests</td>
</tr>
<tr>
<td>Chronic</td>
<td>Irregular heartbeat, congestive heart failure, cardiac arrest, enlarged esophagus, colon, and heart.</td>
</tr>
</tbody>
</table>
Animals that the T. cruzi parasite might affect

- Are bitten by the kissing bugs and then can either
  - carry the parasite
  - become infected by it
  - transfer it to other kissing bugs

- opossums, armadillos, raccoons, monkeys, rats, coyotes, dogs, cats, birds, reptiles, livestock, and many others.
Prevention and Treatment

- Antibiotics available for those who are in the acute stage only, other treatments are not available.

- Prevention:
  - Nets and insecticides are the most efficient.
  - Avoid living in mud, thatch, and adobe houses.
The Problem

- “Neglected” status repercussions
- Lack of information
- Combining Treatments, prevention strategies, general form of the spread of the disease, etc.
- Death rates
- Devillers Model (2008)
• Susceptible Insects (Sb)
• Susceptible People (Sp)
• Infected People in the Acute stage (Ipa)
• Infected People in the Latent stage (Ipl)
• Infected People in the Chronic stage (Ipc)
• Infected Insects (Ib)

* These values vary but typically set at 30% for Ib and 40-44% distributed for Ipa, Ipl, and Ipc
### Table 1: Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Description</th>
<th>Value</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\alpha_a$</td>
<td>Transmission rate from insect to human</td>
<td>?</td>
<td>This study</td>
</tr>
<tr>
<td>$\alpha_l$</td>
<td>Rate from acute to latent stage</td>
<td>0.125</td>
<td>Prata (2001)</td>
</tr>
<tr>
<td>$\alpha_c$</td>
<td>Rate from latent to chronic stage</td>
<td>0.0001</td>
<td>Prata (2001)</td>
</tr>
<tr>
<td>$\beta_a$</td>
<td>Transmission rate human to insect in acute stage</td>
<td>$\beta_c/4$</td>
<td>This study</td>
</tr>
<tr>
<td>$\beta_l$</td>
<td>Transmission rate human to insect in latent stage</td>
<td>$\beta_c/2$</td>
<td>This study</td>
</tr>
<tr>
<td>$\beta_c$</td>
<td>Transmission rate human to insect in chronic stage</td>
<td>?</td>
<td>This study</td>
</tr>
<tr>
<td>$\gamma_a$</td>
<td>Human mortality from the acute stage</td>
<td>0.00003</td>
<td>Sanchez-Guillen et al. (2006)</td>
</tr>
<tr>
<td>$\gamma_l$</td>
<td>Human mortality from the latent stage</td>
<td>0.00001</td>
<td>Devillers (2008)</td>
</tr>
<tr>
<td>$\gamma_c$</td>
<td>Human mortality from the chronic stage</td>
<td>0.0005</td>
<td>Prata (2001)</td>
</tr>
<tr>
<td>$\delta_p$</td>
<td>Human death rate from other causes</td>
<td>0.003</td>
<td>Devillers (2008)</td>
</tr>
<tr>
<td>$\delta_b$</td>
<td>Insect death rate</td>
<td>0.05</td>
<td>Canals et al. (1991)</td>
</tr>
<tr>
<td>$\mu_p$</td>
<td>Human birth rate</td>
<td>0.000323</td>
<td>This study</td>
</tr>
<tr>
<td>$\mu_b$</td>
<td>Insect birth rate</td>
<td>0.05</td>
<td>This study</td>
</tr>
<tr>
<td>$\theta$</td>
<td>Transmission rate from reservoir to insect</td>
<td>?</td>
<td>This study</td>
</tr>
</tbody>
</table>
\[
\begin{align*}
\frac{dS_p}{dt} &= -\alpha_a S_p I_b + \mu_p S_p - \delta_p S_p, \\
\frac{dI_{pa}}{dt} &= \alpha_a S_p I_b - \alpha_l I_{pa} - \delta_p I_{pa} + \mu_p (I_{pa} + I_{pl} + I_{pc}) - \gamma_a I_{pa}, \\
\frac{dI_{pl}}{dt} &= \alpha_l I_{pa} - \alpha_c I_{pl} - \delta_p I_{pl} - \gamma_l I_{pl}, \\
\frac{dI_{pc}}{dt} &= \alpha_c I_{pl} - \delta_p I_{pc} - \gamma_c I_{pc}, \\
\frac{dS_b}{dt} &= -\beta_a S_b I_{pa} - \beta_l S_b I_{pl} - \beta_c S_b I_{pc} + \mu_b (S_b + I_b) - \delta_b S_b - \theta S_b, \\
\frac{dI_b}{dt} &= \beta_a S_b I_{pa} + \beta_l S_b I_{pl} + \beta_c S_b I_{pc} - \delta_b I_b + \theta S_b.
\end{align*}
\]
Approximate Numerical Solutions

- Euler’s Method
Devillers' Parameters

- Problems with Devillers model
  - Unrealistic parameters

\[
\begin{align*}
\alpha_a &= 0.01 \\
\alpha_l &= 0.125 \\
\alpha_c &= 0.001 \\
\beta_a &= 0.05 \\
\beta_l &= 0.001 \\
\beta_c &= 0.003 \\
\gamma_a &= 0.00003 \\
\gamma_l &= 0.00001 \\
\gamma_c &= 0.0001 \\
\delta_p &= 0.0003 \\
\delta_b &= 0.05 \\
\mu_p &= 0.003 \\
\mu_b &= 0.05
\end{align*}
\]
Table 2: Stochastic Model Equations

<table>
<thead>
<tr>
<th>Equation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>a1 = μ_p S_p</td>
<td>Birth for S_p</td>
</tr>
<tr>
<td>a2 = δ_p S_p</td>
<td>Death for S_p</td>
</tr>
<tr>
<td>a3 = α_a S_p I_b</td>
<td>Transition from S_p to I_p</td>
</tr>
<tr>
<td>a4 = μ_p (I_p + I_pl + I_pc)</td>
<td>Birth for I_p</td>
</tr>
<tr>
<td>a5 = δ_p I_p + γ_a I_p</td>
<td>Death for I_p</td>
</tr>
<tr>
<td>a6 = α_l I_p</td>
<td>Transition from I_p to I_pl</td>
</tr>
<tr>
<td>a7 = δ_p I_pl + γ_l I_pl</td>
<td>Death for I_pl</td>
</tr>
<tr>
<td>a8 = α_c I_pl</td>
<td>Transition from I_pl to I_pc</td>
</tr>
<tr>
<td>a9 = δ_p I_pc + γ_c I_pc</td>
<td>Death for I_pc</td>
</tr>
<tr>
<td>a10 = μ_b (S_b + I_b)</td>
<td>Birth for S_b</td>
</tr>
<tr>
<td>a11 = δ_b S_b</td>
<td>Death for S_b</td>
</tr>
<tr>
<td>a12 = β_a S_b I_p + β_l S_b I_pl + β_c S_b I_pc + θ S_b</td>
<td>Transition from S_b to I_b</td>
</tr>
<tr>
<td>a13 = δ_b I_b</td>
<td>Death for I_b</td>
</tr>
</tbody>
</table>
• Gillespie Algorithm, 1977

• Probabilities
  \[ b_1 = \frac{a_1}{a_0} \]
  \[ b_2 = \frac{a_1 + a_2}{a_0} \]
  \[ b_3 = \frac{a_1 + a_2 + a_3}{a_0} \]
  ...

• \( a_0 \) is the sum of all \( a \)'s
Results of Continuous Time Model

One Simulation

Population Changes

Mean Prevalence

Insect: approx. 25%
Human: approx. 40%

50 Simulations
Results of ODE Model

\[ \alpha = 0.0000001 \]
\[ \beta = 0.00001 \]
\[ \theta = 0.015 \]
Sensitivity Analysis for ODE Model

$\text{betac}=0.00001, \theta=0.015$

- Susceptible People
- Susceptible Bugs
- Infected People: Acute
- Infected People: Latent
- Infected People: Chronic
- Infected Bugs
Sensitivity Analysis for ODE Model

\[ \alpha = 0.0000001, \theta = 0.015 \]
Sensitivity Analysis for ODE Model

\[ \text{betac}=0.00001, \ \text{alphaa}=0.0000001 \]
Further Research

With this model we can include the effects of

- Making medicines available
- Available nets
- Spraying techniques
Brenière, Simone Frédérique, Marie France Bosseno, François Noireau, Nina Yacsik, Pascale Liegeard, Christine Aznar, and Mireille Hontebeyrie. "Integrate Study of a Bolivian Population Infected by Trypanosoma Cruzi, the Agent of Chagas Disease." Memórias Do Instituto Oswaldo Cruz 97.3 (2002). Print.


