Using mathematical models for health economic analyses

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Outline

• Introduction to modeling
• Infectious disease modeling
  ▫ Introduction; $R_0$
• How models can be used to estimate health outcomes
  • Example: Potential impact of ART for prevention
  • What study data can you use to parameterize models
• When to use which model
An introduction to Mathematical Models

- Framework for understanding and communicating infectious disease*
- Explicit assumptions help delineate which parameters are based on evidence
- Quantitative or qualitative results are compared with observed or experimental data
- Validated models can be used to estimate the potential impact of interventions (e.g. ART for prevention) on health outcomes
  - HIV incidence cases
  - HIV associated death
  - HIV associated disability adjusted life years (DALYs)

Models in health economic analyses

- Used to structure the economic question and compare all relevant alternatives
- Extrapolate beyond observed data
- Link intermediate and final endpoints
- Generalize results to other settings/patient groups
- Synthesize evidence to simulate comparisons where RCTs don’t exist
- Indicate the need for further research

HERC short course, Oxford, 2012
Types of models

- Static models – equilibrium (time-invariant)
- Dynamic models – time dependent change
  - Force of infection can change over time
  - Includes herd immunity
- Both static and dynamic models can be either deterministic or stochastic (constrained random variables)
- Choice of model depends on scientific question
Where do models fit in the path from discovery to implementation?
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The basic and effective reproductive numbers

$R_0$ The Basic Reproductive Number - The number of new infections caused by one infection in an entirely susceptible population

$R_t$ The Effective Reproductive Number - The number of new infections caused by one infection at a given time

$R_0 = D \cdot C \cdot \beta$

$R_t = R_0 \cdot x$

Mean length of time infectious

Rate at which sexual contact occurs

Likelihood of transmission on a sexual contact

Proportion of contacts susceptible

-Vaccination
$R_0 = 2$

- Transmission
- No Transmission
- Infectious
- Susceptible
Transmission

No Transmission

$R_0 = 2$

$R_t = R_0 \cdot \text{prop susceptible} = 0.5$
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ART implementation
Methods: Intervention package (1)

Community Sensitization → Household Consent → Individual
- Consent
- Questionnaire
- Pre-test counseling
- HIV test

HIV+ Linkage to care and treatment

HIV- Linkage to prevention

Data collection
### Results

Initiation of antiretroviral therapy and viral suppression after home HIV testing and counselling in KwaZulu-Natal, South Africa, and Mbarara district, Uganda: a prospective, observational intervention study

Ruanne V Barnabas, Heidi van Rooyen, Elioda Tumwesigye, Pamela M Murnane, Jared M Baeten, Hilton Humphries, Bosco Turyamureeba, Philip Joseph, Meighan Krows, James P Hughes, Connie Celum

- Ankole region, southwest Uganda, and KwaZulu-Natal, South Africa
- Sept. 2011 – May 2013

<table>
<thead>
<tr>
<th>Findings</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adults tested</td>
<td>3,393 (96%)</td>
</tr>
<tr>
<td>HIV+ identified</td>
<td>635 (19%)</td>
</tr>
<tr>
<td>Visited a clinic by month 12</td>
<td>96%</td>
</tr>
<tr>
<td>Started ART by month 12 (among those eligible for ART)</td>
<td>74%</td>
</tr>
<tr>
<td>Virally suppressed by month 12 (among those on ART)</td>
<td>77%</td>
</tr>
</tbody>
</table>
Model: community structure & partnerships

Outside community – no intervention
Community – receives home HTC

Key
- Household
- Woman
- Man
- Stable partnership
- Temporary partnership

Individual-based model structure

**SUSCEPTIBLE**
- S
- Tested uninfected

**INFECTED**
- $I_{>500}$
- $I_{>201,500}$
- $I_{201,500}$
- $I_{<200}$

- Tested ≥500
- Tested 201-500
- Tested ≤200
- Clinic visit ≥500
- Clinic visit 351-500
- Clinic visit 201-500
- Clinic visit ≤200
- ART ≥500
- ART 351-500
- ART 201-500
- ART ≤200

Additional labels:
- Births and HIV-related deaths
- HIV infection
- HIV disease progression
- HIV care cascade
- ART drop-out
- + natural mortality not shown
Model prediction compares well with observed data

A.

- Model: women
- Model: men
- KZN 2004–11: women
- KZN 2004–11: men

Incidence (per 100 py)

Age group

ART coverage among HIV+ in cohort (%)

ART at ≥ 200 cells mm⁻³, status quo

ART at ≥ 350 cells mm⁻³, HBCT

ART at ≥ 500 cells mm⁻³, status quo

ART for all HIV+ positive, status quo

ART for all HIV+ positive, HBCT
Home HTC and linkage has the potential to decrease HIV incidence by 36% and total DALYs by 21% over 10 years.

- Under new South African ART initiation criteria (CD4 ≤ 500 cells per µL), home HTC and linkage has the potential to reduce HIV incidence by 36% and total DALYs by 21% over 10 years.
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What data do we need for models?

- Demographics
- Mixing patterns
- Natural history
- Transmission probability
- Factors that change susceptibility
- Factors that change infectiousness
- Effectiveness of interventions
- Engagement in health care
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How to choose the appropriate model for health outcomes

**What model should I use?**

- **Is the interaction between patients important (e.g. transmission)?**
  - No
  - **Do you need to model recursive events?**
    - Yes
      - **Do you need to model individuals?**
        - Yes
          - Discrete Event Simulation
        - No
          - Decision Tree Model
    - No
      - Markov Model
  - **Do you require your model to represent a lot of health states?**
    - Yes
      - Individual sampling model?
    - No

Adapted from Barton et al. 2004
Summary

• Infectious disease modeling is a useful tool – assumptions are explicit, characterize uncertainty
• Study data can be used to parameterize models
• Models can be used to estimate health outcomes
• Consult with a health economist and/or modeler to choose an appropriate model to answer your question

• Contact: rbarnaba@uw.edu
Thank you

Study Participants
ICOBI and HSRC Staff

Connie Celum, Carol Levin, Jared Baeten, Roger Ying, Aditya Khanna, Monisha Sharma, Sarah Roberts, Susie Cassels, Jim Hughes, Geoff Garnett, Meighan Krows, Hilton Humphries, Bosco Turyamureeba, Katherine Murray, Elioda Tumwesigye, Heidi van Rooyen & Judy Wasserheit

Funding
NIH NCRR Grant 5 KL2 RR025015
NIH CFAR Grant P30 AI027757