Precision Public Health Approaches to Surveillance & Response to Infectious Diseases

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Outline

Precision Medicine & Precision Public Health

Examples from Pacific Islands:
- Leptospirosis
- Lymphatic filariasis
- Travel networks

Precision Environmental Health?
Precision Medicine Initiative

• Launched by President Obama at State of the Union Address 2015
• ... accelerate progress toward a new era of precision medicine – improve understanding of diseases, improve precision of prevention and treatment

NIH awards $55 million to build million-person precision medicine study
What is Precision Medicine?

Aims:

• *Understand why* people respond differently to treatments

• *More precisely tailor* treatment to:
  – subcategories of disease, or
  – subpopulations

What is Precision Medicine?

Enabled by recent dramatic advances in:

- **Large-scale biological databases** (e.g. human genome)

- **Biomedical sciences** – our ability to generate and/or collect biomedical information about people, including genomic, molecular, laboratory, clinical, behavioural, physiological, environmental

- Information and communication **technologies**, mobile technology, computational tools, data science

What is Precision Public Health?

1. Apply emerging methods and cutting-edge technologies:
   - **Measure** disease, pathogens, exposures, behaviours, and susceptibility in populations
   - Improve **data** collection, quality & management: Volume, Variety, Speed, Validity
   - More sophisticated **analytics**

What is Precision Public Health?

2. Use advances in DATA and TECHNOLOGY to:
   – Improve *knowledge discovery*: understand exposures and interactions between social, environmental, behavioural and genetic factors
   – Better *stratify* populations and diseases: deliver more precise interventions at the right *time* and right *place* to the right *population*
   – Empower and optimise *decision-making*
More innovative approaches are needed to improve understanding & optimise action

- A “one size fits all” approach focuses on the average person and average place, and will produce average outcomes.

There is no such thing as an average person or an average place… each is UNIQUE…..

- Can we do better than average by improving PRECISION?
Modernising Public Health

**Metrics**
- Genomics, Biometrics, Laboratory, Environment
- Social, Economic, Demographic, Technology

**Sources**
- Surveillance, Demographics
- Vital statistics, Satellite
- Air quality, News feeds
- Internet, Social media

**Data Collection**
- Electronic surveillance, Mobile technologies, Internet, Cloud,
  Electronic Med Records,
- Participatory surveillance,
- Cell phone data, Travel data

**Analysis**
- Visualisation, GIS, Mapping,
- Machine learning, Modelling,
- Artificial intelligence, System dynamics, Real-time,
- Interactive and dynamic

Reshape the distribution of optimal outcomes
A. “One size fits all” intervention

Optimal: most effective & efficient allocation of resources, best outcomes, reduce NNT
Too little: less effective, less efficient, less timely, lost opportunities
Too much: waste/inefficient allocation of resources, potential for harm
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**B. Specific interventions for subgroups**

**C. Improved stratification of subgroups**
Using PRECISION to reshape distribution of optimal outcomes

A. “One size fits all” intervention

B. Specific interventions for subgroups

C. Improved stratification of subgroups

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Examples from the Pacific Islands
Leptospirosis

- One of the most common zoonotic diseases worldwide
- ~1 million severe human cases per year globally
- ~60,000 deaths per year
- ~3 million DALYs lost
- Common in Pacific Islands
- Also a significant veterinary health problem

Leptospirosis Exposure Pathways

- **Bacteria in Environment**: >250 serovars
  - Soil & Water
    - Occupational exposure
    - Outdoor recreation
    - Flooding
    - Poor sanitation
  - Direct Contact
    - Occupational exposure
    - Rodents
    - Livestock
    - Pets
    - Wildlife

- **Animals**
  - Enzootic cycle
  - Urine

- **Humans**
  - Infection
Importance of One Health Approach

• Improve understanding
  – Eco-epidemiology & transmission dynamics

• Optimise action
  – Surveillance
  – Prevention and control
  – Mitigation
  – Response

• Need expertise from all 3 domains

(Environment)  →  (Animals)  ↔  (Human)
1. Risk factors and drivers of transmission vary between places and subgroups

2. Dynamic and evolving

But it’s complex!!

- Climate
- Geography
- Land use
- Social
- Occupation
- Demographics
- Behaviour
- Lifestyle
- Recreation
- Biodiversity
- Natural disasters
- Flooding
Many drivers likely to intensify with global environmental and demographic change

For Leptospirosis

- Colours and shapes might represent urban/rural areas, environmental settings, age groups, ethnic groups, gender, genetic profile, *Leptospira* strains, etc.
Examples: Leptospirosis in Fiji

Exploring different methods to:

- Improve subgroup stratification
- Improve geographic precision
- Improve model predictive accuracy
- Improve timeliness of analyses
Scenario Analysis – Urban/Rural

Relative importance of exposure to different animal species

(a)

<table>
<thead>
<tr>
<th>% of population exposed to animal species</th>
<th>% predicted seroprevalence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban: n = 579</td>
<td></td>
</tr>
<tr>
<td>Peri-urban: n = 287</td>
<td></td>
</tr>
<tr>
<td>Rural: n = 1286</td>
<td></td>
</tr>
</tbody>
</table>

Animal species:
- Cat
- Cow
- Dog
- Goat
- Horse
- Mongoose
- Pig
- Rodent

Significant at $p < 0.05$
- No
- Yes

Lau et al. Env Mod & Softw 2017.
Improving Geographic Precision

Geographically Weighted Regression: Spatial Variation in the Relative Importance of Covariates

A: Cattle density
B: Rainfall
C: Distance to rivers
D: Poverty rate
E: Residential setting
Improving Model Predictive Accuracy

Bayesian Networks

Conditional probabilities
Machine learning

Including multiple correlated variables in models

(a) RI-A
(b) RI-B
(c) RI-C

Spatial Bayesian Networks

- Scenario analysis
- Interactive and dynamic
- Rapidly incorporate new data
- Improve timeliness

Improving Timeliness

Predictive risk mapping of an environmentally-driven infectious disease using spatial Bayesian networks: A case study of leptospirosis in Fiji

Lymphatic filariasis elimination in Samoan Islands

- Mosquito-borne parasitic infection
- WHO Global Programme to Eliminate Lymphatic Filariasis (as a public health problem) through:
  - Interrupting transmission through mass drug administration
  - Controlling morbidity of affected persons
  - One of the largest public health programs globally
    - >7.7 billion MDA treatments delivered to 68 endemic countries since 2000.

- Challenges in the endgame:
  - Surveillance when prevalence has dropped to very low levels
  - Early detection of resurgence and hotspots
  - Delineating transmission zones

Images: CDC & IMA World Health
Parasite population genetics to delineate transmission zones

Genetic epidemiology of lymphatic filariasis in American Samoa after mass drug administration

Shannon M. Hedtke a,b,e,1, Patsy A. Zendejas-Heredia a,1, Patricia M. Graves c, Sarah Sheridan d, Meru Sheel e, Saipale D. Fuimaono f, Colleen L. Lau d, Warwick N. Grant a,b

S.M. Hedtke, P.A. Zendejas-Heredia, P.M. Graves et al.

International Journal for Parasitology 51 (2021) 137–147
Machine learning to identify residual hotspots

Supporting elimination of lymphatic filariasis in Samoa by predicting locations of residual infection using machine learning and geostatistics

Helen J. Mayfield, Hugh Sturrock, Benjamin F. Arnold, Ricardo Andrade-Pacheco, Therese Kearns, Patricia Graves, Take Naseri, Robert Thomsen, Katherine Gass & Colleen L. Lau

Figure 1. Proportion of individuals that tested positive (Individuals), proportion of households with at least one positive resident (Households) and proportion of households with two or more positive residents (Multi-positive households), stratified by PHR and PLR locations. The complete sample of all houses (random) is also shown. Values listed under each column indicate the total number of individuals or households in each category.
Network analysis to improve risk assessment of the international spread of infectious diseases

BMJ Open  Implications of a travel connectivity-based approach for infectious disease transmission risks in Oceania

Angela Cadavid Restrepo,1,2 Luis Furuya-Kanamori,2,3 Helen Mayfield,1,2 Eric Nilles,4,5 Colleen L Lau1,2

Figure 4. Chord diagram plot of total travel volume flows between countries in Oceania (A) including Australia and New Zealand and (B) without Australia and New Zealand. The interactive versions of these figures are available at https://isbee.com/figsaim174281 and https://isbee.com/figsaim174306.
Time to develop framework for Precision Environmental Health?
The Elements of Precision Medicine

Precision medicine, as envisioned by UCSF, is a fluid, circular process. Findings from basic, clinical, and population sciences research, data from digital health, 'omic technologies, imaging, and computational health sciences and ethical and legal guidelines are integrated into a knowledge network, creating a sort of "Google maps for health," which informs both science and care for individuals and populations.
Extra elements needed for Precision Environmental Health?

- Pathogens
- Animals
- Environment
- Prevention, surveillance & response
- Scenario analysis
- More sophisticated tools and models
- Account for complexity, uncertainty, unpredictability
- Others……..

Source: www.precisionmedicine.ucsf.edu
Precision Environmental Health

IMPROVE
Understanding, Surveillance, Mitigation
Prevention, Control, Prediction,
Forecast, Early warning, Response
Precision Public Health Approaches to Surveillance & Response to Infectious Diseases

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