Epidemics & infectious disease dynamics

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Session objectives

1. Understand terms and key concepts of transmission often used in media reporting on outbreaks and epidemics

2. Understand epidemic parameters and types of data needed to understand the dynamics of contagion
What does infectious disease dynamics cover?

Study of contagion

• Who gets infected?
• At what rates?
• How does transmission occur?
• What factors affect transmission?
• What are the impacts of interventions or control measures?
• What is the temporal progression?
Defining endemic, outbreak, epidemic, and pandemic

**Endemic**: disease is consistently present in a particular region or population.

**Outbreak**: Number of cases of a disease in a population increases above the normally expected (baseline) level.

**Epidemic**: when the disease spreads to a large proportion of the population in a certain area or region.

**Pandemic** when it spreads globally or across multiple countries or regions.

Image Source:
Endemic diseases: Malaria and Plague

Cases of bubonic plague are reported every year.

“Worldwide, we tend to see between one to two thousand cases of plague per year, and most of these will be the bubonic form.”

“In the US, we expect about seven cases every year, which are mostly seen in the western part of the country – California, Colorado, New Mexico, Arizona. Most cases will appear in Africa – particularly Madagascar and the Democratic Republic of Congo – as well as Peru. Urban outbreaks are very uncommon, with most infections occurring in rural areas.”

Human-to-human transmission is rare.

Source: Imperial College London

Source: Livestrong.com

How the Plague Outbreak in Madagascar Got So Bad, So Fast

By Dyan Sabin  October 18, 2017

A council worker sprays disinfectant in a market in Antananarivo, the capital city of Madagascar. (Image: © Bjjasia/AFV/ Getty)

Source: Livestrong.com
Pathogens and mode of transmission

### Pathogen- a disease causing organism/agents

<table>
<thead>
<tr>
<th>Agent</th>
<th>Disease example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Virus</td>
<td>Rabies, Common cold, Influenza, Measles, HIV</td>
</tr>
<tr>
<td>Bacteria</td>
<td>Staphylococcus, meningitis, Chlamydia</td>
</tr>
<tr>
<td>Parasites</td>
<td>Malaria, Leishmaniasis, Hookworm</td>
</tr>
<tr>
<td>Fungi</td>
<td>Ringworm, Invasive Candidiasis, Athletes Foot</td>
</tr>
</tbody>
</table>

### Mode of transmission

**Direct** – e.g. person to person

- Airborne transmission (influenza, TB)
- Sexual transmission (HIV)

**Indirect** – intermediate carrier

- Fomite transmission (e.g. doorknobs)
- Water-borne transmission (e.g. cholera & diarrheal diseases)
- Vector-borne disease (malaria – mosquitos, plague: fleas > rats > people)
The epidemiological triangle

Agent

What agent is causing the disease?

Host

Who is the host that is either exposed to and harbor the disease?

Environment

Where are the favourable surroundings and conditions external to the host that cause or allow the disease to be transmitted?
Example: Multiple transmission routes from bat pathogens

Transmission dynamics: Basic reproduction number ($R_0$)

New disease/ susceptible population:

\[ R_0 (R \text{ naught}) = R0 = \beta \times \kappa \times D \]

- $\beta$ is the risk of transmission per contact
- $\kappa$ is the contact rate
- $D$ is the duration of infectiousness

$R_0$ establishes a threshold for an epidemic to occur in a totally susceptible population:

- If $R0 > 1$, disease can spread and an epidemic can occur
- If $R0 = 1$, disease spread is stable, or endemic, and the number of infections is not expected to increase or decrease
- If $R0 < 1$, each infection does not (on average) replace itself, so the disease can’t spread

Adapted from presentation by Derek Cummings, Johns Hopkins University
Transmission dynamics: Basic reproduction number ($R_0$)

New disease/ susceptible population:

$$R_0 = R_0 = \beta \kappa D$$

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Adapted from presentation by Derek Cummings, Johns Hopkins University
Transmission dynamics: Basic reproduction number ($R_0$)

<table>
<thead>
<tr>
<th>$R_0$</th>
<th>DISEASE</th>
<th>HOW IT SPREADS</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 to 18</td>
<td>Measles (Whooping cough)</td>
<td>Airborne droplets</td>
</tr>
<tr>
<td>12 to 17</td>
<td>Pertussis</td>
<td>Airborne droplets</td>
</tr>
<tr>
<td>6 to 7</td>
<td>Rubella</td>
<td>Fecal-oral route</td>
</tr>
<tr>
<td>5 to 7</td>
<td>Polio</td>
<td></td>
</tr>
<tr>
<td>5 to 7</td>
<td>Smallpox</td>
<td>Airborne droplets</td>
</tr>
<tr>
<td>4 to 7</td>
<td>Mumps</td>
<td>Airborne droplets</td>
</tr>
<tr>
<td>2 to 4</td>
<td>SARS</td>
<td>Airborne droplets</td>
</tr>
<tr>
<td>1 to 4 people</td>
<td>Ebola</td>
<td>Bodily fluids</td>
</tr>
</tbody>
</table>

Source: Reuters graphics
Caution when reporting $R_0$

The basic reproduction number ($R_0$), also called the basic reproduction ratio or rate or the basic reproductive rate, is an epidemiologic metric used to describe the contagiousness or transmissibility of infectious agents. $R_0$ is affected by numerous biological, sociobehavioral, and environmental factors that govern pathogen transmission and, therefore, is usually estimated with various types of complex mathematical models, which make $R_0$ easily misrepresented, misinterpreted, and misapplied. $R_0$ is not a biological constant for a pathogen, a rate over time, or a measure of disease severity, and $R_0$ cannot be modified through vaccination campaigns. $R_0$ is rarely measured directly, and modeled $R_0$ values are dependent on model structures and assumptions. Some $R_0$ values reported in the scientific literature are likely obsolete. $R_0$ must be estimated, reported, and applied with great caution because this basic metric is far from simple.

$R_0$ estimates for Measles
- England and Wales, 1950-1968 16-18
- Ontario, Canada, 1912-1913 11-12
- Kansas, USA, 1918-1921 5-6
- Ghana, 1960-1968 14-15
- Niger, 2003 5-6
Transmission dynamics: Effective reproductive number ($R_e$ or $R_t$)

Norway’s response three weeks from $R_e = 3.8$ to $R_e = 0.6$

Source: nationalgeographic.com
Epidemic curve – What is it and what can it tell us?

Continuous common source

Point source

Propagated outbreak

Source cdc.gov
Epidemic curve – What is it and what can it tell us?

Epi-curve for Ebola cases in Sierra Leone and Guinea, August 2015

Source: CDC, Morbidity and Mortality Weekly Report (MMWR), Ebola Virus Disease — Sierra Leone and Guinea, August 2015
Flattening the (epidemic) curve

We usually see cumulative case curves

Flatter cumulative case curves indicate less new cases

Not good enough for new cases to be constant. To stop pandemic new cases must decrease (downward slope)

Source: John Hopkins coronavirus tracker

Source: CDC
Speed of an outbreak depends on two factors

1. The number of individuals infected by each infectious case. \((R_0, R_t)\)

2. The time it takes between when a case is infected and when that case infects other people (serial interval)
Epi-curves help us understand time intervals of disease transmission

**Incubation Period** – average length of time between infection and the onset symptoms in each case

**Latent Period** – average length of time between infection and the onset of transmissibility

**Serial Interval** – average length of time between a case being infected and that case infecting subsequent cases (also called the Generation Time)
Transmission parameters

Infection
Latent
Infectious
Incubation
Disease

Serial Interval

Contagious

Latent
Infectious
Incubation
Disease

E.g COVID-19

Symptoms

Infected with pathogen e.g. SARS-CoV-2

Patient 1

Patient 2

Adapted from presentation by Derek Cummings, Johns Hopkins University
Measures of transmission: Doubling time

Time interval in which the cumulative incidence of a disease doubles if rate of testing and reporting remains the same.

It’s often used to compare the rate of increase in cases across settings.

Herd immunity

- The resistance to the spread of a contagious disease within a population that results if a sufficiently high proportion of individuals are immune to the disease, especially through vaccination.
- When more people are immune, the effective reproductive number (R) is less than 1
- Can be achieved through widespread infection or vaccination

WHO and partners vaccinate over 94,019 children against measles in Aweil

The campaign that ended on 3 July 2020 was implemented within the national and WHO guidelines for implementing mass vaccination campaigns in the context of COVID-19.
Measures of death

**Mortality rate:** The number of people who died in a defined population for a given time interval. For this reason, it is often expressed as x deaths per 100,000 people.

**Case fatality rate** - the ratio of the number of deaths divided by the number of *confirmed* (preferably by nucleic acid testing) cases of disease.

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**East Africa: Kenya Has Highest Rate of Deaths in the Region**

Kenya’s Covid-19 death toll is high and continues to rise compared to other countries in the Eastern Africa region.

With over 10,000 cases, Kenya has registered 197 deaths—nearly five times more than the second highest death toll in the region -- South Sudan at 38.
Challenges reporting case fatality rate

\[ \text{CFR} = \frac{\text{Number of cause-specific deaths among incident cases}}{\text{Total number of incident cases}} \]

What is the denominator?
How do we account for pre-symptomatic or asymptomatic cases?
Lower levels of testing (missed infections)?
Lack of contact tracing
Can lead to both over and under estimation
Next week we will go through the 10 steps of outbreak investigation

1. Confirm the diagnosis
2. Confirm that an epidemic exists
3. Define a case and count them
4. Descriptive epidemiology: arrange the data
5. Determine who is at risk of disease
6. Implement methods of control and prevention
7. Analytic epidemiology: develop a hypothesis and test it
8. Environmental and laboratory investigation
9. Implement a surveillance system
10. Communicate your findings