1918 Influenza deaths

Deaths/1000/year (from weekly statistics)

Boston
Fig. 1.—Annual death rates, by weeks, per 1,000 population, for cities.

Fig. 2.—Annual death rates, by weeks, per 1,000 population, for cities.
Seasonal Excess P&I
Time to Death

Mills, compilation of 94 autopsy reports from Wolbach 1919, MacCallum 1921, Klotz 1919
Time Course of Infectiousness

Modeled proportion infectious

Log Viral Titer (H1N1, Hayden et al. JCI 1998)
Infectious = \sum b_i Inc(t-i)

R = kS \sum_{i=1}^{8} b_i

Inc(t) = kS \sum b_i Inc(t-i)

(1-CFP)

(CFP)

D
Estimated $R$: 41 cities (seasonal excess P&I)
<table>
<thead>
<tr>
<th>City</th>
<th>Seasonal Excess</th>
<th>Serial Interval (1,3)</th>
<th>Serial Interval (3, 6)</th>
<th>Initial Slope (1.38,3.39)</th>
<th>Entire Curve with CFP (0.4%,0.78%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean Range</td>
<td>1.92 (1.52,2.34)</td>
<td>1.47 (1.28,1.65)</td>
<td>2.75 (1.93,3.73)</td>
<td>2.58 (1.46,3.02)</td>
<td>2.23 (0.56%)</td>
</tr>
<tr>
<td>Baltimore</td>
<td>2.34</td>
<td>1.65</td>
<td>3.73</td>
<td>3.37</td>
<td>3.02 (0.62%)</td>
</tr>
<tr>
<td>Boston</td>
<td>1.87</td>
<td>1.46</td>
<td>2.66</td>
<td>2.72</td>
<td>2.02 (0.72%)</td>
</tr>
<tr>
<td>Buffalo</td>
<td>1.87</td>
<td>1.46</td>
<td>2.55</td>
<td>2.07</td>
<td>2.37 (0.50%)</td>
</tr>
<tr>
<td>Chicago</td>
<td>1.77</td>
<td>1.39</td>
<td>2.37</td>
<td>2.87</td>
<td>1.97 (0.40%)</td>
</tr>
<tr>
<td>Cleveland</td>
<td>1.80</td>
<td>1.42</td>
<td>2.47</td>
<td>1.89</td>
<td>1.88 (0.42%)</td>
</tr>
<tr>
<td>Los Angeles</td>
<td>1.52</td>
<td>1.28</td>
<td>1.93</td>
<td>1.38</td>
<td>1.46 (0.66%)</td>
</tr>
<tr>
<td>New York</td>
<td>1.86</td>
<td>1.46</td>
<td>2.65</td>
<td>3.39</td>
<td>1.85 (0.48%)</td>
</tr>
<tr>
<td>Philadelphia</td>
<td>2.11</td>
<td>1.53</td>
<td>3.19</td>
<td>2.16</td>
<td>2.64 (0.78%)</td>
</tr>
<tr>
<td>San Francisco</td>
<td>2.25</td>
<td>1.61</td>
<td>3.39</td>
<td>3.37</td>
<td>2.73 (0.46%)</td>
</tr>
<tr>
<td>Washington</td>
<td>1.81</td>
<td>1.46</td>
<td>2.53</td>
<td>2.56</td>
<td>2.35 (0.52%)</td>
</tr>
</tbody>
</table>
Interpretation

• $R$ around 2
• Most but not all of the population susceptible
  – Herald wave
  – Prior immunity from recycling?
• $R_0$ likely 2-4
• Upward slope calculations most reliable – fewer assumptions
• Robust to reasonable assumptions about baseline, serial interval
Epidemic control

• Reduce R to <1, and keep it there
• Other $R_0$ values (approximate and population-dependent)
  – Measles 15-20
  – Pertussis 10-20
  – SARS ~3
  – Smallpox 2-5
  – HIV: ???? 1.4 -> ?
  – Malaria: ? <1 - ~100
Factors that make an epidemic controllable by methods depending on diagnosis

1918-like flu vs. SARS

• Comparable $R_0$
• Flu more difficult to control by isolation/quarantine because
  – More rapid transmission
  – Shorter time to id contacts
  – Less definitive symptoms
• Advantages in controlling a 1918-like flu outbreak
  – Antivirals
  – Vaccines
  – Rapid diagnostics
• → Advance planning, prophylaxis, pre-outbreak preparedness
R distribution subtracting annual baseline
R distribution: total P&I

mills_suppfig4
Sensitivity of mean $R$ to latent & infectious periods

![Sensitivity of mean $R$ to latent & infectious periods](image)
$R_0 \text{ vs. } R$

- $R_0 = 3$
  - basic reproductive number

- $R = 2$
  - effective reproductive number
  - only part of population susceptible