The Effect of Healthcare Environments on a Pandemic Influenza Outbreak

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Context: Influenza transmission within healthcare settings

- **Patients, staff, visitors** bring influenza into healthcare settings
  - Outbreaks cause morbidity and mortality among staff, inpatients, long term residents (Bridges 2003)

- **Control measures in healthcare settings** include
  - Negative pressure rooms
  - Use of PPE
  - Screening
  - Voluntary home quarantine of exposed staff
  - Visitor limitations
  - Prophylactic medications, vaccine

- **Applied by severity/pathogenicity**
  - Limit transmission in healthcare settings?
  - Few clinical studies of efficacy (Loeb 2009)
Context: Influenza transmission from healthcare settings

- **Few reports of transmission** of respiratory viruses from healthcare settings to communities
  - Biologically plausible

- **Exception: 2002-2003 SARS experience:**
  - Healthcare settings were high-risk environments for transmission
  - Healthcare settings were source of infection for large percentage of victims who transmitted to community members
  - A ‘healthcare centered’ epidemic
    (Lloyd-Smith 2003, Possamai 2007)
Context: Related Work

- **Nuno et al. (2008)**
  - Compartmental model of a community with an embedded acute care hospital.
  - Open admittance policy rendered non-pharmaceutical measures ineffective on within-healthcare control of influenza transmission.

- **Lloyd-Smith et al. (2003)**
  - Estimated effects of patient isolation, contact tracing and quarantine on community SARS outbreak.
  - Quarantine of healthcare workers was the key measure in preventing transmission to community.
Context: Previous studies on influenza epidemic mitigation using this model

- **Glass et al. EID 2006**: determined the critical importance of children in influenza epidemic propagation. Closing schools and social distancing of children reduced infections by 90%

- **Davey et al. EID 2008**: evaluated thresholds for rescinding community mitigation strategies

- **Glass & Glass BMC Public Health 2008**: surveyed children and teenagers found teens had most contacts that could serve as influenza transmission ‘backbone’

- **Davey & Glass PLoS One 2008**: a systematic evaluation of feasible mitigation strategies at wide range of pandemic severities and found critical enablers of success—rapid, stringent, regional implementation with high compliance

- **Perlroth et al. CID 2009**: evaluated cost-effectiveness of mitigation strategies, finding that the addition of school closure to adult and child social distancing and antiviral treatment and prophylaxis is not cost-effective for viral strains with low infectivity (Ro 1.6 and below) and low case fatality rates (1% and below)
Objectives

• To determine if healthcare settings serve as intensive transmission environments for influenza epidemics, increasing effects on communities.

• To determine which mitigation strategies are best for use in healthcare settings and in communities to limit influenza epidemic effects.

• To determine which mitigation strategies are best to prevent illness in healthcare workers.
A community in a networked agent-based model:

- Explicit social contact network
- Stylized US community of 10,000
- Agents: Children 18%, Teen 11%, Adult 59%, Senior 12% (US Census, 2000)
- Individuals live in overlapping groups of varying sizes: households, schools, workplaces, neighborhoods, extended families, gatherings, random meetings (RJ Glass et al. 2006; L Glass et al. 2008)
- Model constructs links between individuals that are potential connections; the numbers of links and configurations determined by pre-defined network topology (here: random, ring, fully connected)
Methods: Influenza Transmission

Process of influenza transmission

- **Links** are assigned an associated mean frequency of contacts per link per day, depending on group type (e.g. classroom or household)

- **Contacts** (realized links) present opportunity for influenza transmission

- Successful transmission = infectious contacts that result from a set of stochastically scheduled events that vary with each simulation
Methods: Influenza Transmission

Influenza transmission occurs as two events

- **First event**: State transition—describes an individual’s experience with influenza illness

- State transitions are based on observed and experimental human influenza infections (Carrat 2008, Ferguson 2006, Germann, 2006, Monto 1985)
Methods: Influenza Transmission

Second event: individual to individual influenza transmission

- Probability that a contact will occur, $p_c$, in a small time interval, $dt$, along a link with contact frequency $v_c$ is: $p_c = v_c dt$

- The percentage of total contacts between two linked individuals that actually result in transmission is scaled by $I_D I_R I_A S_P S_A$ where
  
  $I_D =$ the infectivity of the disease
  $I_R =$ the relative infectivity of the disease state
  $I_A =$ the relative infectivity of the individual who is transmitting
  $S_P =$ the susceptibility of people to the disease (here taken as 1.0)
  $S_A =$ is the relative susceptibility of the individual being infected

- The probability of an influenza transmission event along a given link between an infectious and a susceptible individual, $p_i$, is given by:
  
  $$p_i = I_D I_R I_A S_P S_A v_c dt$$
Methods: Healthcare Sites

- **Two healthcare delivery sites**
  - Outpatient
  - Capacity maximum 60 patients and escorts; 24/7 operation

- **3 shifts of healthcare workers (mean shift size: 20; range 10-50)**
  - Healthcare workers are of many disciplines
  - Equal likelihood to expose or be exposed to influenza at healthcare site

- **Community members come to healthcare site**
  - Patients receive care for influenza or other illness
    - 50% of symptomatic influenza patients seek healthcare (HHS Pandemic Influenza Plan 2005)
    - 70% of entire community population seeks healthcare at least once per year for any reason (VA Benefits and Healthcare Utilization, 2008)
  - **Escorts accompany patients**
    - Asymptomatic teenager, adult, or senior family member if available.

- **At healthcare site**
  - Infected and non-infected patients and escorts mingle in waiting area
  - Patients are assigned to one of 4 intake queues with shortest waiting time
  - Mean visit times determined from published data (Nat’l Health Statistics Reports 2008)
Methods: Design of Healthcare Sites

- **Patients’ and escorts’ links, contacts, and infectious contacts** are formed independently

- **Links are:**
  - Patient to patient
  - Patient to escort
  - Escort to escort
  - Healthcare worker to patient
  - Healthcare worker to escort
  - Healthcare worker to healthcare worker

- **#s of links are scaled** according to occupancy of site

- **Frequencies of contacts per link** are assigned and determine #s of infectious contacts

- **If healthcare workers are not able to work**, the number of patients able to be seen is decreased linearly according to proportion available.

- **Healthcare workers with influenza return to work** after a 7 day recovery period
# Community-Based Interventions

<table>
<thead>
<tr>
<th>S</th>
<th>Close Schools</th>
<th>Schools closed, all school contacts reduced by 90%, household contacts doubled</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTsd</td>
<td>Social Distance Children and Teenagers</td>
<td>Child &amp; Teens social distancing, all non-school and non-household contacts with or between children and teens reduced by 90%, household contacts doubled</td>
</tr>
<tr>
<td>ASsd</td>
<td>Social Distance Adults and Seniors</td>
<td>Adults &amp; Seniors social distancing, all non-household non-work contacts with or between adults and seniors reduced by 90%, work contacts reduced by 50%, household contacts doubled</td>
</tr>
<tr>
<td>T</td>
<td>Antiviral Treatment</td>
<td>Antiviral Treatment, % of people (by level of compliance) given antiviral course immediately after diagnosed, reduces infectivity by 60% (from Ferguson et al., 2006)</td>
</tr>
<tr>
<td>P</td>
<td>Household antiviral prophylaxis</td>
<td>Antiviral Prophylaxis, % of household members (by level of compliance) given antiviral for 10 days immediately after individual is diagnosed, reduces susceptibility by 30%, and if they become infected: reduces probability of symptomatic by 65%, reduces infectivity by 60% (from Ferguson et al., 2006)</td>
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### Healthcare Worker Interventions

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Description</th>
<th>Details</th>
</tr>
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<tbody>
<tr>
<td><strong>PPE</strong></td>
<td>Personal Protective Equipment for Healthcare Workers</td>
<td>Healthcare workers wear masks, gloves, gowns, protective eyewear with probability based on a compliance factor from the first day of strategy implementation until there are 0 community cases in 7 days. We assume PPE reduce susceptibility and infectivity by 50%.</td>
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<tr>
<td><strong>ObP</strong></td>
<td>Outbreak Prophylaxis for Healthcare Workers</td>
<td>Healthcare workers take daily antivirals with probability based on a compliance factor from the first day of strategy implementation until there are 0 community cases in 7 days. Reduces susceptibility by 30%, probability of becoming symptomatic by 65% and infectivity by 60%.</td>
</tr>
<tr>
<td><strong>PPV</strong></td>
<td>Partially Effective Pandemic Vaccine</td>
<td>Healthcare workers get vaccine with probability based on a compliance factor prior to the local onset of the epidemic. We assume vaccine reduces the probability of infection by 50%.</td>
</tr>
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Outcome measures

- Number of simulations that yield epidemics
- Infection rates, community members and HCW
- Illness attack (symptomatic) rate
- Deaths
- Peak infected, community and HCW
- Time to peak infected
- Peak symptomatic
- Time to peak symptomatic
- Epidemic duration (from implementation threshold to last diagnosed)

- Total time of effects (from initial seeding to last person recovered)
- Number of days strategies imposed
- Number of containment cycles needed
- Number of external infections
- Number of antiviral courses given
- Number of days adults are at home (either sick, quarantined, or tending sick or children sent home from school)
- Healthcare site patient throughput
Simulations

- Three community compliance rates: 30%, 60%, and 90%
- Two healthcare worker compliance rates: 60% and 90%
- Three attack rates
- Twenty combinations of community mitigation strategies
- Eight combinations of healthcare worker strategies
- 100 simulations for each configuration
- Total of 18,000 simulations for base community (no healthcare delivery sites) and 270,000 simulations with healthcare delivery sites (288,000 total)
Effect of Healthcare Sites on Number of Infections

![Chart showing the effect of healthcare sites on the number of infections over time.]

Days of Epidemic

# of Infected

0 1 8 15 22 29 36 43 50 57 64 71 78 85 92 99 106 113

# of Infected

0 500 1000 1500 2000

No HC  With HC

Days of Epidemic
Healthcare Worker Infections: Effects of Community-Based + Healthcare-Based Mitigation Strategies

- None
- PPE
- Best Comm
- Best Comm + PPE
- Best Comm + PPE + ObP
- Best Comm + PPE + ObP + PPV
Effect of Community Compliance on HCW Infections

![Graph showing the effect of community compliance on healthcare worker infections over the course of an epidemic. The graph compares the number of infections under different compliance levels: unmitigated, 30% compliance, 60% compliance, and 90% compliance.](image-url)
Effect of HCW Compliance on HCW Infections
Ranking of HCW Interventions

- None
- PPE
- PPV
- ObP
- PPE + PPV
- PPE + ObP
- ObP + PPV
- PPE + ObP + PPV

Total HCW Infections
Ranking of HCW Interventions with Community Measures

![Bar chart showing the ranking of HCW interventions with community measures. The x-axis represents different interventions, and the y-axis represents the total HCW infections. The chart compares 'No Community Strategies' and 'Best Community Strategies.' The interventions include None, PPE, PPV, ObP, PPE+PPV, PPE + ObP, ObP + PPV, and PPE + ObP + PPV. The chart shows a significant reduction in infections with the implementation of community strategies.]
Patient Throughput at Healthcare Sites, by Mitigation Strategies

- None--All Pts
- PPE + ObP + PPV--All Pts
- Best Comm + PPE + ObP + PPV--All Pts

Day of Epidemic

# of patients seen

0 10 20 30 40 50 60 70 80
1 14 27 40 53 66 79 92 105 118 131 144
Conclusions

- We extended the model to study effects of presence of healthcare sites in community on pandemic effects.
- Healthcare sites accelerate the pace and peak of the pandemic wave.
- Use of community mitigation measures protects HCW, and decreases surge on healthcare sites.
- Use of HCW measures significantly protects healthcare workers, keeps HCW available to meet the surge.
- Compliance with measures remains key.