Effectiveness of MMR Vaccination in Orthodox Jewish Neighborhoods

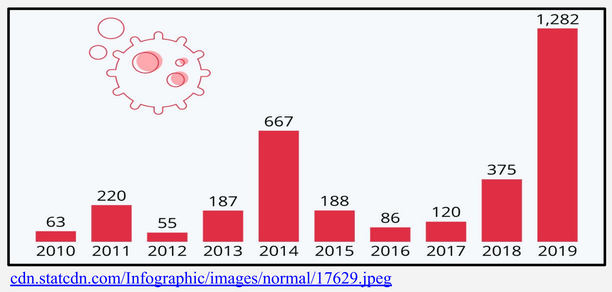
Meenu Mundackal
State University of New York College at Geneseo

Abstract

Measles is a highly contagious disease, where large outbreaks arise by direct contact between susceptible (unvaccinated) and infectious individuals. Many Orthodox Jewish neighborhoods were affected by measles from 2018-2019. To quantify the vaccination effort on this susceptible population, a retrospective analysis was used to study the NYC and Rockland County populations using a differential equations model. A subsequent model, known as a realistically-structured network model, studied only the NYC population, in relation to typical household size. Vaccination strategies were applied to three cohorts: unvaccinated family members, members with 1 prior MMR dose, and members with 2 prior MMR doses. The differential equations model suggested the need for earlier vaccination effort and no significant increase was found in the number of associated complications as prior vaccination dosage increased. The network model suggested significantly fewer sick individuals with 1 prior MMR dose ($p < 0.001$) compared to none, and even more so with 2 prior doses. This study demonstrates the effectiveness of vaccinations, with the potential vulnerability for future complications not being as severe this epidemic, most probably due to rapid vaccination efforts and isolation of exposures.

Introduction

- Epidemiology of Measles
  - *Transmission:* Airborne, direct contact
  - *Incubation Period*: 7-14 days
  - *Symptoms*: Body skin rash, koplik spots, flu-like symptoms
  - *Ro*: 12-18 (highly contagious)
- Measles outbreak within Orthodox Jewish communities mainly in Rockland County and NYC (2018-2019)
- MMR vaccine refusals led to a lack of herd immunity
  - Elders were skeptical of autism and other minor illnesses (ear infections, viruses, etc.) spreading through their community
- Presented as an issue because a similar epidemic occurred a few years back in the same location within the same community
  - 2019 cases were at a larger scale than 2014's epidemic
  - The back to school rush in the fall worsened the effects
- Measles-associated complications (further hospitalizations, pneumonia) were also evident
- No deaths were reported in this epidemic



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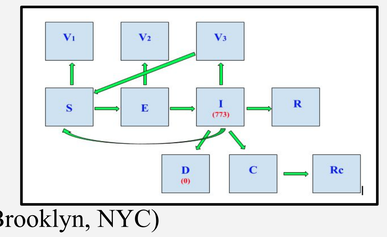
Methods

- Retrospective study
- Differential Equations Model (Rockland County and NYC)
  - Closed system where everyone is essentially connected
  - A potential vaccine could have been given within 3 days of being susceptible, after the incubation period at 15 days, or after recovery at 22 days
  - Individuals receiving a dosage at 22 days have a higher probability of becoming susceptible again
  - This model analyzed the effects of increasing the rate that individuals were vaccinated at 22 days. These effects were then used to analyze the impact on measles-associated complications

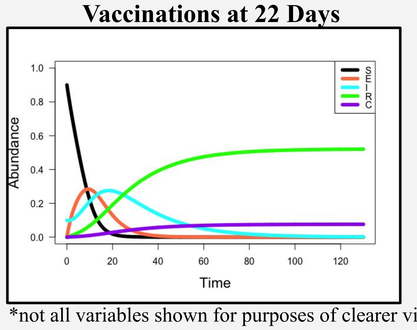
$$
\begin{aligned}
dS &= -B1*S*I - N1*.05*S + alpha*N3*S \\
dE &= B1*S*I - B2*E - N2*E \\
dI &= B2*E - N3*I - a*I - q*I \\
dR &= v*I \\
dC &= a*I \\
dD &= q*I \\
dV1 &= N1*.05*S \\
dV2 &= N2*E \\
dV3 &= N3*I - alpha*N3*S
\end{aligned}
$$



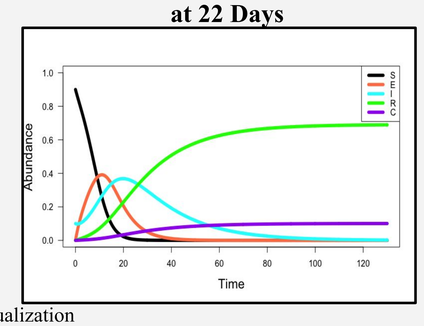
- Realistically-structured Network Model (Brooklyn, NYC)
  - Studied household caves (n = 1800) with an avg. of 7 members/family
  - Excluded individuals with unknown vaccine history
  - Three cohorts for the implementation of vaccination strategies: unvaccinated, 1 prior dose (93% efficiency), 2 prior doses (97% efficiency)
  - Households were tied into rings with individuals becoming randomly infected
  - Once certain individuals transitioned from a state of susceptible to infectious, random vertices would be vaccinated, until no more infectious individuals remained
  - The model stimulated how the epidemic would spread as infectious individuals tried to make their neighbors of their family sick
  - Both vaccine efficiency and vaccine effort were analyzed

Results

Figure 1: SEIR Model for No Vaccinations at 22 Days

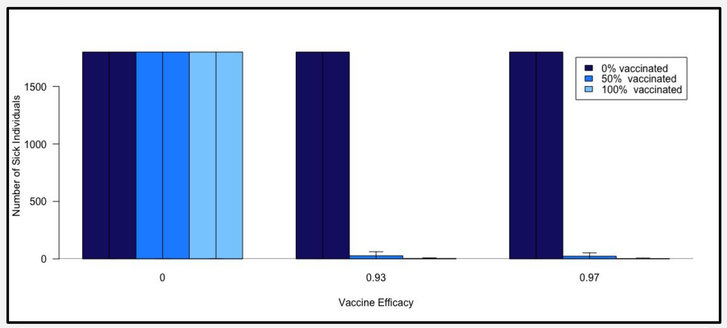


SEIR Model for Max Vaccinations at 22 Days



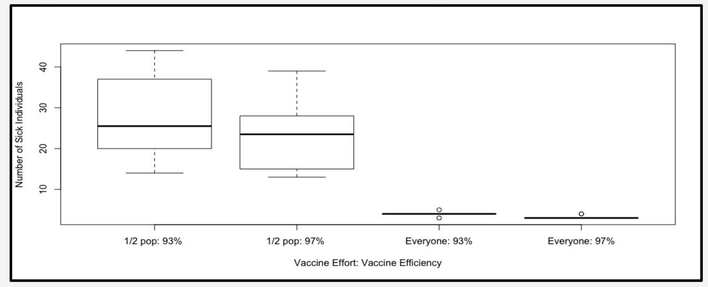
*not all variables shown for purposes of clearer visualization

Figure 2: Association of Vaccine Effort with Vaccine Efficiency



	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
sum.vacc.effort	2	28312418	14156209	722711	<0.001	***
sum.vacc.efficacy	2	28309350	14154675	722632	<0.001	***
sum.vacc.effort:sum.vacc.efficacy	4	14156259	3539065	180678	<0.001	***
Residuals	81	1587	20			

Figure 3: Vaccine Effort and Efficiency for 1 Dose vs. 2 Doses



	Df	Sum Sq	Mean Sq	F value	Pr(>F)	
sum_vacc_effort	2	42468628	21234314	7.227e+05	<2e-16	***
sum_vacc_efficacy	1	42	42	1.418e+00	0.239	
sum_vacc_effort:sum_vacc_efficacy	2	50	25	8.460e-01	0.435	
Residuals	54	1587	29			

Analysis & Discussion

- Differential Equations Model
  - The number of individuals becoming sick increases as the rate for vaccinating individuals at the 22 day mark increases; fewer individuals become sick when only 3 day and 15 day vaccinations were administered
  - With a later vaccination time, more individuals become susceptible, leading to greater numbers of exposed and infectious individuals
  - Increasing later MMR dosage administration has no effect on measles-associated complications; both graphs in fig. 1 illustrate relatively similar hospitalization cases
- Network Model
  - As vaccination effort increases, the number of individuals getting sick is reduced as indicated by the lighter bar colors in fig. 2
  - As vaccination efficiency increases, there is a significant reduction in the number of sick individuals when comparing unvaccinated vs. vaccinated ($p < 0.001$)
  - A decrease in numbers is observed between 1 dose (93% efficiency) vs. 2 doses (97% efficiency), but this difference is not statistically significant ($p > 0.05$) as depicted by fig. 3

Conclusion

- Vaccines are especially important within tight-knit communities
- Complications were not associated with how early vaccinations were administered
- It is more beneficial to implement tighter restrictions for these populations in terms of early vaccination practices. Administering 1 MMR dosage will decrease the likelihood of future measles outbreaks from rapidly spreading

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