In order to understand how varying vaccination rates affects the transmission of measles in a theoretical constant population of prisoners, the traditional SEIR model was adapted to account for the unique timeline of measles symptoms/contagiousness as well as for MMR vaccination rates. Drawing from research literature for parameters, the relative timeline for symptom onset was accounted for and the vaccination rates were varied on different runs in Big Green Differential Equation Machine software. Increasing vaccination rates while keeping all other parameters constant resulted in a decrease in the number of susceptible individuals, and thus, a lower overall transmission throughout the population. A 95% population vaccination percentage, the herd immunity threshold for measles, was the most effective means to control the spread of measles in a small prison environment.

Methodology

1) Produced theoretical values for each population
2) Collected values for the parameters from literature
3) Formulated equations for the rate of change relative to time for S, E, I, Ei, Rp, and R
4) Inputted equations, initial conditions, and parameters into Big Green Differential Equation Machine software to yield graphs of population over time
5) Conducted multiple runs with different percentages of the population vaccinated

Explanation of Model

Parameter | Value | Meaning | Formula
--- | --- | --- | ---
R | 100 | Number of susceptible individuals | \( \frac{dS}{dt} = \frac{\beta S(I + E) - \gamma S}{N} \)
\( \gamma \) | | Rate at which exposed become contagious without showing rash | \( \frac{dE}{dt} = \beta S(I + E) - \gamma E - \epsilon E \)
\( \epsilon \) | | Rate at which exposed become contagious due to showing rash | \( \frac{dE_i}{dt} = \epsilon E \)
\( \beta \) | | Rate at which infected become contagious | \( \frac{dI}{dt} = \beta S(I + E) - \gamma I - \epsilon I \)
\( \gamma \) | | Rate at which infected recover | \( \frac{dR}{dt} = \gamma S + \epsilon E + \epsilon E_i + \epsilon I + \epsilon R \)
\( \epsilon \) | | Rate at which vaccinated recover | \( \frac{dR_v}{dt} = \epsilon S + \epsilon E + \epsilon E_i + \epsilon I + \epsilon R \)
\( \phi \) | | Vaccination rate | \( \phi \)

Assumptions:
- Homogenous and constant population of prisoners
- No death from measles (since it is negligible in the US)
- Standardization of the timeline of measles to a set number of days
- Vaccination rate is assumed 100% effective for the sake of simplification
- Theoretical numbers of prisoners in each compartment
- Measles is an acute viral infectious disease that is spread through coughing and sneezing. It is highly contagious.
- Once a person is infected with measles once, their body develops life-long immunity via antibodies.
- Symptoms include: fever, dry cough, runny nose, sore throat, conjunctivitis, skin rash, and Koplak’s spots (white spots lining mouth)
- MMR vaccine, used since the 1960s, is given in two doses: first dose administered between the ages of 12 to 15 months after birth and the second dose between the ages of 4 to 6 years old
- Those who receive both doses, are effectively 99% immune to measles.
- Some people, due to religious and other personal reasons, have not vaccinated their children and/or do not get the MMR vaccine themselves
- Measles is on the rise in the past decade in the US because of ‘holes’ in herd immunity (95% or more population need to be vaccinated for population to be protected)
- In a prison setting, it is important to consider:
  - access to vulnerable social groups from many times disadvantaged socioeconomic and educational backgrounds who may not have used national health services
  - high risk of contraction due to overcrowding, and lack of hygiene
- how minimum-security prisoners are constantly in contact with rest of community

References

[9] References

Conclusion

Increasing the vaccination rate for each run yielded a faster decay of exposed people with every increment. Due to more susceptible people being vaccinated, less people were likely to be exposed and move from one compartment to the next. When the vaccination rates were increased, the number of people who automatically became recovered as a result of the vaccination were also increased, and thus, the flow from susceptible to recovered from measles was stunted. This is a clear, effective model for the spread of measles in a closed population. Even a slight vaccination increase in vaccination rates will yield more protection to the prison population against a measles outbreak. The rate of change in recovered people drastically increases with every vaccination percentage increment. This model strongly supports that the MMR vaccination does increase protection for susceptible inmates in prison. It adds to previous models (simple SEIR) through additional compartments and a timeline specific to measles chronology, addresses the rates at which susceptible subgroups transmit the disease as well as cases wherein vaccination protects individuals.

Throughout the past few decades, large achievements have been reached regarding infectious disease control. However, measles elimination is still a pressing concern. False information (i.e. how the MMR vaccine may cause autism), religious affiliation that prevents vaccination, and lack of access to vaccination services, to list a few, are all pertinent barriers of entry for susceptible inmates in prison. It adds to previous models (simple SEIR) through additional compartments and a timeline specific to measles chronology, addresses the rates at which susceptible subgroups transmit the disease as well as cases wherein vaccination protects individuals.

These models demonstrate that increasing vaccination rates is an effective strategy to control measles outbreaks in closed settings. However, the success of these strategies depends on various factors, such as vaccine effectiveness, compliance rates, and the dynamics of the local population. Therefore, a comprehensive approach that includes vaccination campaigns, public health education, and surveillance systems is essential to control measles outbreaks effectively.