HERD IMMUNITY AS A RESULT OF MODEL COMPLEXITY

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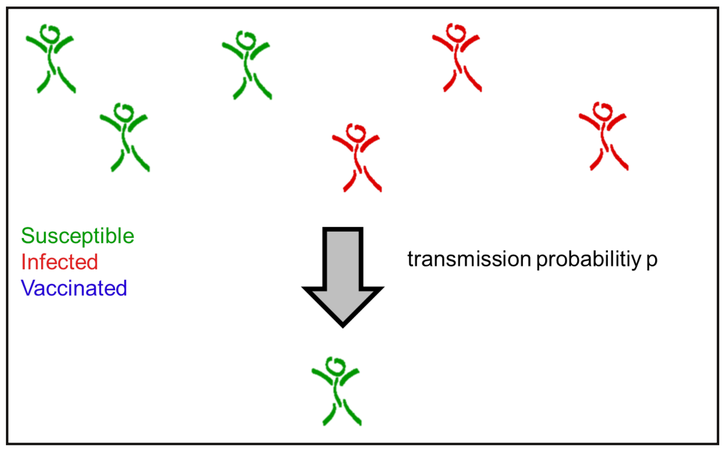
Introduction

Herd immunity describes a dynamic effect of contagious diseases: When parts of the population cannot carry the pathogen they indirectly protect susceptible parts of the population. While everyone acknowledges herd immunity as an effect that increases the effectiveness of vaccination programs there is no exact definition how to calculate or measure it as numerical value. Most current models use approximated factors to assess the impact of herd immunity.



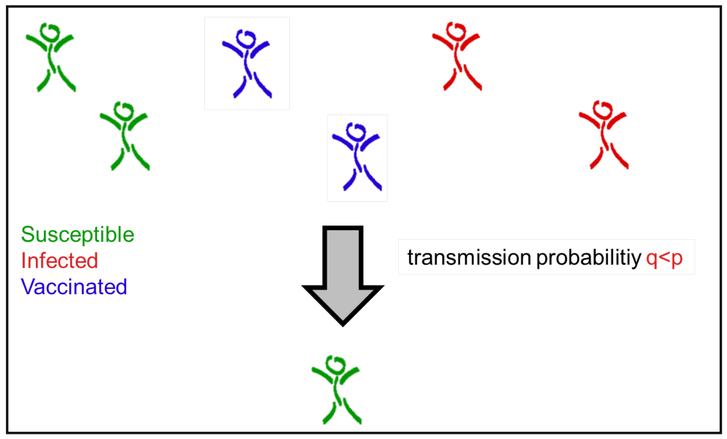


Figure 1: Principle of herd immunity: The transmission probability for a person is p. When some people get resistant the transmission probability decreases to q < p because a susceptible person meets less infected people.

Goals

- Find exact definitions of herd immunity for certain models.
- Develop calculation methods to measure herd immunity.
- Describe how various models use herd immunity.
- Show that more accurate modelling of the spread of the pathogen induces herd immunity.
- Show how vaccination and herd immunity correlate.
- Point out problems of a global concept.

Definition:
Herd immunity is the relative reduction of damage for not vaccinated people.

Methods

- Investigate models that simulate contacts of people and how they indirectly considerate the reduction of possible infectious contacts when introducing resistent people.
- Learn about the influence when a susceptible person does not meet as many carriers during one time step when there are lots of vaccinated people.
- Modelling not only contacts but also the space where contacts happen and its consequences on herd immunity.
- Analysis of the benefit of resistent (for example vaccinated) individuals within several epidemiological models.
- Developing calculation methods for simple SIS (people can be susceptible S, get infected I and after some time get susceptible again) models.
- Transfering the definition on SIR-models (figure 2).
- Revising definitions and formulas.
- Testing the new calculation methods on current and further models.

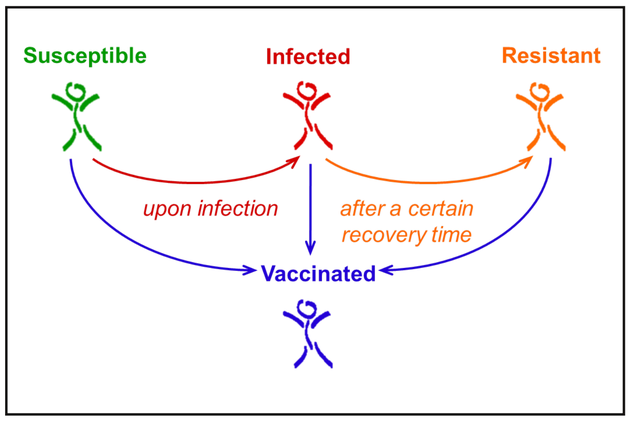
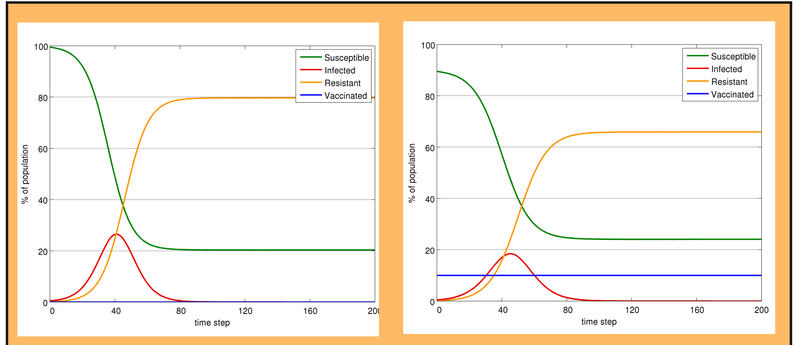


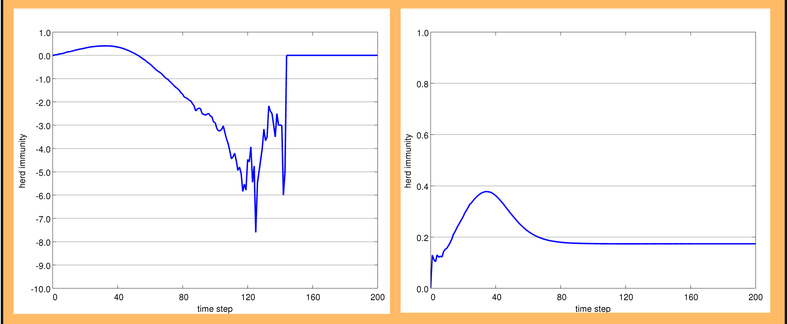
Figure 2: SIR-Model: People can be susceptible and get infected upon infection. After a certain time they get resistant. Resistant and vaccinated people cannot get infected again.

Results

- Calculations for herd immunity can either be based on carrier rates or on new infections.
- Depending on the assumptions the results can be equivalent.
- Herd immunity can be seen as punctual event or effect over a certain time frame.
- The concept of herd immunity is of varying complexity depending on the used model.
- Transferring a definition of herd immunity from one group of models to others, for example SIS to SIR, can lead to strange results that can be hard to interpret, therefore definitions have to be adapted.
- Vaccination coverage has an impact on herd immunity.
- When looking at more than one serotype herd immunity and serotype shifting effects cannot be split up into two separate problems. Therefore definitions have to be expanded to fit occuring problems and to be able to make statements with numerical values for both dynamic effects.



Susceptible, infected, resistant and vaccinated fractions of the population with and without vaccination



Herd immunity calculated as current reduction of new infections and reduction since vaccination start

Herd immunity in SIR-models

For this analysis an agent based SIR-model was used. After vaccination the carrier rate decreases. The relative reduction of new infections within the not vaccinated group at a certain time is positive at the beginning but gets negative although when measuring herd immunity effect over time it remains positive. This happens because vaccination not only reduces new infections but also changes the shape of the spread of the epidemic. Seeing herd immunity as a positive effect calculations over timeframes is necessary.

Conclusion

- Herd immunity always depends on many factors and should never be seen as a constant factor.
- Models which consider the reduction of the overall carrier rate when some people are vaccinated can calculate herd immunity.
- Accurate simulations of the spreading of viruses / bacteria deliver herd immunity as an indirect result without using parameters of clinical studies which can only show a snapshot in time of a dynamic process.

Outlook

Currently we want to find a definition which allows us to calculate herd immunity for models simulating several serotypes and also adresses occuring serotype shifting.