

How can a community protect everyone from disease?



Authors:

Corey M. Peak, Amanda L. Reilly,
Andrew S. Azman, Caroline O. Buckee

Associate Editors:

Seda Dawson & Madeleine Corcoran

Abstract

Did you know that you protect yourself and those around you by getting vaccinated? Diseases can't spread easily when enough people in a population get vaccinated. This effect is called *herd immunity*. *Cholera* is a big threat in countries that don't have safe water and toilets for everyone. These countries sometimes vaccinate large numbers of people (*mass vaccination*). This creates herd immunity and prevents disease outbreaks. But, it is hard to know how long herd immunity will last.

In one camp in South Sudan, people who had fled their homes during a war received mass vaccination. However, there was a cholera outbreak the following year. We

developed a *mathematical* model to find out what affects how long herd immunity lasts. We found that it lasts for a shorter time when (a) a lot of people move into and out of an area, and (b) the vaccine gets less effective for each person over time. Our results suggest that herd immunity lasts longer if authorities do two things: 1. vaccinate everyone; 2. always give vaccines to new arrivals to the camp and to those who were vaccinated a long time ago

Introduction

Some people can be nervous about going to the doctor, but getting your vaccinations is important. Vaccines make you *immune* to many diseases. They are also important for the health of our community. How? *Infectious diseases* cannot spread easily when enough people are vaccinated against them. In this situation, vaccinated people protect unvaccinated (or *susceptible*) people. This form of group protection is called herd immunity. Thanks to mass vaccination and herd immunity some diseases have disappeared (e.g. smallpox) or are now very rare (e.g. polio).

However, other diseases like cholera continue to threaten millions of people worldwide. Cholera causes severe diarrhea and dehydration and can be fatal. The disease spreads where people don't have access to safe water and toilets. In such environments, the feces (poop) of an *infected* person can get into the drinking water (Fig. 1).



Figure 1:

The Congo River in Africa is the main source of water for drinking, cooking, and washing for many people. Conditions like this are perfect for the transmission of cholera and many other diseases.

Source: Oxfam East Africa on Wikimedia Commons

Oral (taken via the mouth) cholera vaccines can be used to help prevent cholera outbreaks in at-risk populations. One such population is *displaced people* in the Protection of Civilians Camp in Bentiu, South Sudan. Camp residents were vaccinated in 2014 and 2015. However, in 2016 a cholera outbreak occurred. How could this happen? We know that an individual person can expect the cholera vaccine to protect them for at least 3 years. What we don't know is how long a population can have herd immunity when lots of people are coming and going, and the vaccines wear off. We did research to find out more.

Explainer: Different vaccinations work in different ways and to different degrees. Some vaccines are given as shots, while others are swallowed as a liquid (oral vaccines). Oral vaccination is ideal for cholera because the bacteria that cause it live in the gut. Some vaccinations protect you from a disease for life (e.g., the measles vaccine), while others reduce the chances of getting sick from the disease for a period of time (e.g., the flu vaccine). Vaccines are given at different ages or repeatedly throughout a lifetime. The cholera vaccine can't be given until a baby is over one year old.

Methods

We created a mathematical model (a computer simulation) to analyze the key factors affecting herd immunity. We considered:

Declining vaccine efficacy: A measure of how well the vaccine protects the person who receives it. We created stages where the vaccine wears out over time (Fig. 2).

Vaccination Strategies: We analyzed two strategies -

- Mass vaccination – most of the population is vaccinated on one particular day.
- Routine vaccination – a smaller part of the population is vaccinated whenever necessary. For example, the vaccine is given to those who are new to the camp, or those who have recently become old enough.

Migration rates: This is how much the people are on the move. Migration rates capture the average number of years people live in a population. The camp residents in Bentiu, South Sudan moved every 4.8 years on average.

The **rate of births and deaths** in the camp.

We also included these concepts in our model:

- We considered all those who entered the camp as being susceptible to cholera.
- We chose at random whether those leaving the camp were vaccinated or susceptible.
- We estimated that one sick person in the camp would typically infect two susceptible people.

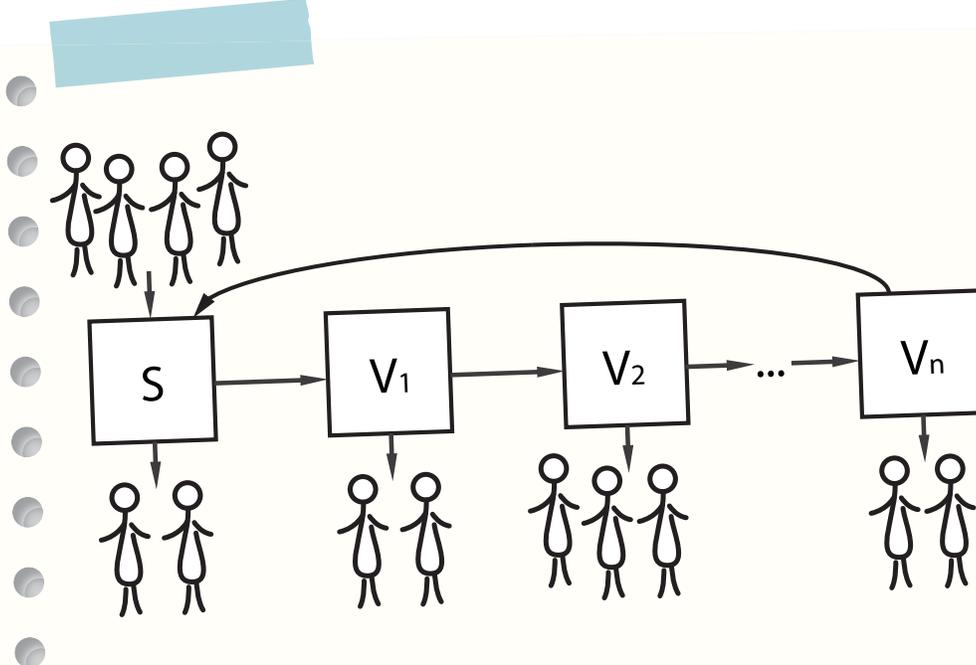


Figure 2:

Our simulation of declining vaccine efficacy. After vaccination, susceptible individuals (S) moved into the first stage of vaccine protection (V₁). Every 30 days, they moved into the next stage where the vaccine efficacy is slightly lower. At the last stage (V_n) the vaccine doesn't provide protection any more, so these individuals become susceptible again (S). Throughout this process, new people enter into the camp (arrow pointing into S), and some of those who are vaccinated move out of the camp (arrows pointing out of the S and V stages).

Results

- 1 Mass vaccination can quickly protect an at-risk population through herd immunity. This effect weakens over time depending mostly on how long the vaccine effect lasts and how quickly members of a population move in and out.
- 2 Two large mass vaccination campaigns in 2014 and 2015 protected the camp population as it grew from about 4,000 people to over 100,000 people (Fig. 3a).
- 3 By the end of 2016, however, less than half of the camp population had been recently vaccinated because of
- 4 the high numbers of people moving in. This was not enough to maintain herd immunity. Our model suggests that the camp population was highly susceptible to cholera when it first broke out in October 2016 (Fig. 3b).
- 4 Herd immunity can be maintained for a longer period of time by combining two strategies. First, perform mass vaccination and then routinely vaccinate anyone who needs it. Using both strategies together was better than either strategy alone.

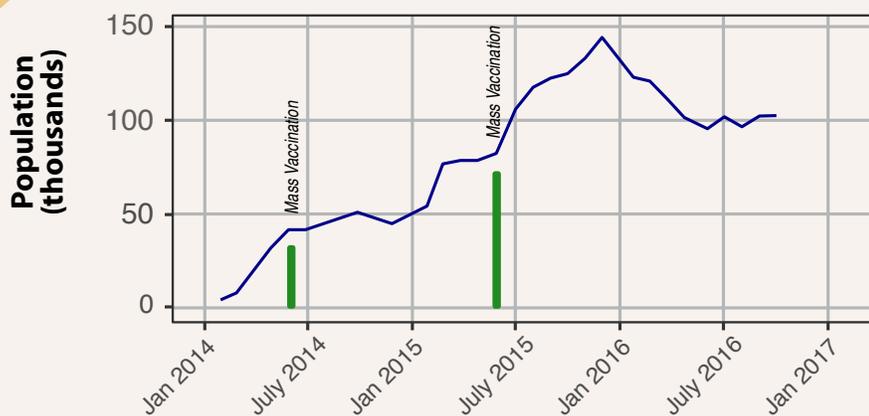


Figure 3a:

This line graph shows the population size of the camp in Bentiu between January 2014 to January 2017. Vertical lines mark the time when mass vaccinations took place.

Question:

Analyze these two graphs. How does the protected population change after mass vaccination? What about as the camp population increased? What percentage of the camp was protected close to the end of 2016 when the outbreak happened?

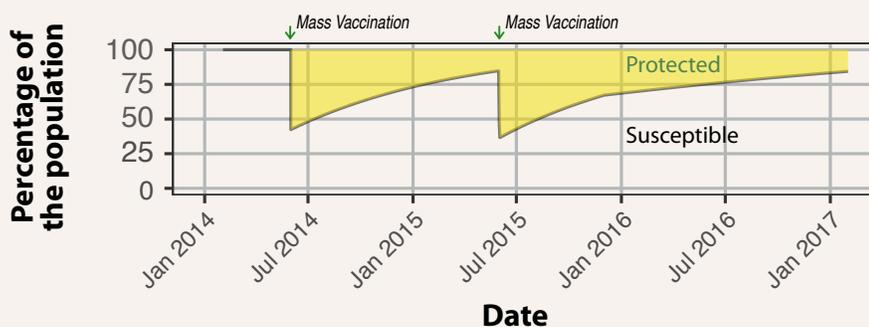


Figure 3b:

This graph shows the part of the population that is protected from cholera (in the shaded region) versus the part that is susceptible to the disease.

Discussion

What happened in the camp? Was it a vaccine failure? Our study shows that the protection provided by herd immunity can disappear if vaccines wear out over time and the population changes a lot. These factors explain why the camp was susceptible to an outbreak despite two recent mass vaccinations.

Our mathematical model reveals periods of time during which a population maintains herd immunity. Based on these results, we suggest a “mass and maintain” vaccination

strategy for the camp setting: The whole population gets vaccinated once. Routine vaccinations are then given to new arrivals and those who have become old enough to be vaccinated. This vaccination strategy could help protect vulnerable populations with high rates of migration.

Our model can help in the fight against infectious diseases. It explains the outbreaks. In turn, this can help us develop effective vaccination strategies and determine how to best supply vaccines.

Conclusion

Vaccination is one of the greatest breakthroughs in modern medicine. It has saved countless lives and completely wiped out some diseases. Some other diseases are now so rare that it's easy to underestimate the importance of vaccinations.

But, if many people decide not to have their vaccinations, herd immunity will be broken and outbreaks can occur. How mindful are you about your health and others?

- Get all your recommended vaccinations. By getting vaccinated you are protecting the most vulnerable in your community as well as yourself.
- Educate others about the importance of immunization. We all depend on each other for herd immunity.
- Do your homework before traveling to other countries and get the required vaccination(s).

Glossary of Key Terms

Cholera – a treatable yet potentially fatal disease caused by some strains of the bacteria *Vibrio cholerae*. The cholera bacteria infects the gut and causes severe diarrhea which in turn causes dehydration.

Contamination – polluting something. Whether it is food, air, water, when something is contaminated it is polluted, impure, or poisoned. Water that is contaminated by human waste is not safe to use or drink.

Displaced people/person – someone forced to leave their home region or country because of war, persecution or disaster; a refugee.

Herd immunity – As more and more people in a population are vaccinated, the chance that a disease can spread decreases and everyone gets extra protection thanks to those who have been vaccinated. When enough people are vaccinated, the chance for that disease to spread gets so low that we say this population has herd immunity.

Immunity or being immune – the ability of your body's defense system (immune system) to fight off disease. We gain immunity either by being exposed to the disease or by vaccination.

Infected – when a person is affected by a disease-causing germ.

Infectious disease – a disease that can pass from person to person.

Mathematical (aka scientific) model – a computer program which attempts to simulate a particular system and to predict how the system would behave in the real world.

Outbreak – the sudden increase in the occurrences of a disease in a particular time and place.

Susceptible / Susceptibility – being at risk of becoming sick with a disease. People with weak immune systems are susceptible to many diseases, as are people who have not been vaccinated against a disease.

Vaccinations (also called immunizations) – are typically made from very small amounts of weak or dead germs that can cause diseases — for example, viruses, bacteria, or toxins. Your immune system produces antibodies to fight against them. This prepares your body to fight the disease faster and more effectively when you come into contact with the actual germ or virus, so you don't get sick.

Vaccine efficacy – a measure of how well the vaccine protects the person who gets it. For example, in our study, we ran some simulations for the perfect vaccine which protected forever, and also some which waned over time.

Check your understanding

- 1** Herd immunity is crucial to protect those who cannot get vaccinated, such as infants, pregnant women, and the elderly. What is herd immunity? How does it work?

- 2** Cholera is very rare in developed (wealthy) countries but kills thousands of people in developing (poorer) countries every year. Why does cholera continue to be a threat in those areas?

- 3** People in the camp had been vaccinated two times in the previous two years. Why did a cholera outbreak occur in the camp?

- 4** Scientists suggest a “mass and maintain” vaccination strategy to prevent outbreaks. Explain this vaccination strategy.

- 5** Why are vaccinations against infectious diseases still important, even in countries where infectious diseases are less common? What happens if some people decide not to get vaccinated?

REFERENCES

Peak CM, Reilly AL, Azman AS, Buckee CO (2018) Prolonging herd immunity to cholera via vaccination: Accounting for human mobility and waning vaccine effects. PLoS Negl Trop Dis 12(2):e0006257.

<https://doi.org/10.1371/journal.pntd.0006257>

Vaccine Knowledge Project

<http://vk.ovg.ox.ac.uk/herd-immunity>

5 GIFs that show why herd immunity is so important

<https://www.buzzfeed.com/carolynkylstra/vaccines-and-herd-immunity>

Cholera - World Health Organization

<https://www.who.int/news-room/fact-sheets/detail/cholera>