The Effect of Vaccination and Quarantine on Cholera Transmission Control

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ABSTRACT

In this project, we develop a stochastic model for cholera transmission to predict the number of deaths in a 100 day period. We incorporate two treatment strategies, vaccination and quarantine, into our model. We find that assuming costs are the same, vaccination is more effective than quarantine in reducing the number of deaths in 100-day cholera transmission simulation.

Keywords

stochastic simulation, SIR model, cholera transmission, vaccination, quarantine.

Introduction

Cholera is an infectious and deadly bacterial disease that is typically contracted from contaminated water supply. On the one hand, combating Cholera poses great challenges in public health research, as cholera occurs in the dynamic interactions between human host, bacterial, and the environment in a complex system. On the other hand, effective intervention strategies are in urgent need, as cholera outbreak is inflicting a great many of developing countries around the globe.

To find the best cure for cholera, we conduct a stochastic simulation study to model a 100 day epidemic of the cholera transmission. We choose two intervention strategies, namely vaccination and quarantine. We investigate the most effective combination of the two intervention strategies in reducing the number of deaths from cholera.

Model Setup

We base our simulation study on the model introduced in Lenhart [1]. We modify the model by adding vaccination (v) and quarantine (q) parameters. The two parameters take on value between zero and one with an increment of 0.1, where zero means that no intervention is taken and one means full intervention is taken. For vaccination, the vaccination program vaccinates up to 10 % of the susceptible population per day. Those who receive vaccination will move from the susceptible population to recovered population. For the quarantine program, a fraction of the symptomatic infected people are directed to use a separate and unused water supply to avoid shedding. With the quarantine program, the symptomatic shedding rate will decrease accordingly. For example, if the original symptomatic shedding rate is η_2. Then, the effective symptomatic shedding rate will be $(1-q)\eta_2$, where q is the quarantine parameter, measuring the fraction of symptomatic population quarantined.

Table 1. OLS Regression Results

Variable	(1) No. Deaths	(2) Log (No. Deaths)
Vaccination	-38.44***	-2.890***
	(2.520)	(0.107)
Quarantine	-19.81***	-2.123***
	(2.520)	(0.107)
Constant	43.09***	4.469***
	(1.952)	(0.0832)
Observations	121	121
R-squared	0.714	0.904

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

In our simulation study, we experiment with all possible combinations of vaccination and quarantine strategies, which yield a total of 121 possible strategies. We simulate each strategy 20 times and report the average number of deaths with a 95 % confidience interval in table 2. We expect that as vaccination and quarantine become more stringent, the number of deaths decrease accordingly.

Data Analysis

Table 2 summarizes the simulated data from the our model, where each column represents the fraction of population quarantined (q) and each row represents the fraction of population receiving vaccination (v). Each cell in the table represents the predicted number of deaths (d)and the plus and minus sign indicates a 95 % confidence interval. Not surprisingly, the number of deaths becomes the least (1.15 ± 0.35) when the maximum percentage (%) of the susceptible population is vaccinated and all symptomatic people are quarantined. Figures 1 visualize the number of deaths against the fractions of quarantined and vaccinated population. We can see that the number of deaths decreases more sharply when q and $v$are small. As q and v become larger, the decrease

Figure 1. Predicted Deaths Based on Vaccination and Quarantine

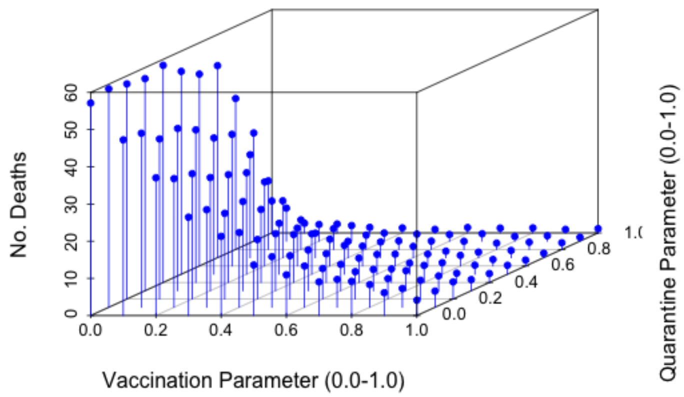
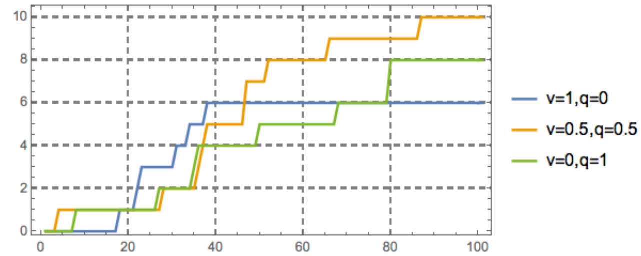


Figure 2. Dynamic No. Deaths in a 100 Day Period based on Three Treatment Schemes



slows down, as shown by a relatively flat plane formed by q, v, and d.

While the simulated data provide a simple yet intuitive idea about intervention: to vaccinate and quarantine as many as possible, in reality we have reasons to believe that vaccination and quarantine are costly. In other words, there is a trade-off between implementing stringent treatment strategies and incurring higher costs. In the next section, we make some assumptions about the cost structure of the intervention strategies, and draw statistical inference accordingly.

Statistical Inference

While the costs of the vaccination and quarantine are unknown, we assume that they are the same so that we can directly compare the effects of the two interventions on the number of deaths. To estimate the effects, we run ordinary least square (OLS) regression to estimate the simulated data. In column 1 of table 1, the dependent variable is the number of the deaths and the independent variables are the fractions of vaccination (v) and quarantine(v). We can see that v has a coefficient estimate of -38.43 and q has a coefficient estimate of -19.81, meaning that a 0.1 increase in v decreases the number of deaths by 3.84 and a 0.1 increase in q decreases the number of deaths by 1.98. In column 2, the dependent variable is the logarithm of the number of deaths and the independent variables are the same as those in column 1. The results from column 2 show that a 10% increase in v is approximately associated with a 2.89 decrees in the number of deaths while a 10% increase in q is only associated with a 2.1 decrease in the number of deaths.

The regression results suggest that vaccination is more effective than quarantine in cholera intervention. To verify this, we look at the counter diagonal of table 2 (highlighted in blue). The number of death increases from (1.0, 0.0) to (0.0,1.0), meaning that if we have 10 points to distribute among the two strategies, it is more most effective to distribute them all to vaccination. As a final check, we plot the numbers of deaths in a 100 day period based on three treatment strategies. As shown in figure 2, the combination of $v = 1$ and $q = 0$ produces the smallest number of deaths.

In conclusion, we suggest exhausting all fractions for vaccination before using quarantine. To explain, if we want to target at a number of deaths of 4 or more, we should choose vaccination only. To put it differently, we should only move along the first column of the table 2. If we want to target at a number of deaths that is more ambitiously than 4, we should exhaust a vaccination rate of 10 % (the maximum) and then choose corresponding quarantine rate. As shown in table 2, the cells highlighted in red are the best intervention combinations targeting at different numbers of deaths.

Conclusion

In this project, we study the best treatment strategies combination that curbs the transmission of cholera. Our findings suggest that, assuming the same costs, vaccination is more effective than quarantine in reducing the number of deaths in a cholera transmission. Based on our findings, we suggest policy markers exhaust vaccination before resorting to quarantine.

References

[1] R. Neilan, E. Schaefer, H. Gaff, K. Fister, and S. Lenhart, *Modeling Optimal Control Strategies for Cholera*, Bulletin of Mathematical Biology, 2010, 72, 2004-2018.

Table 2. Predicted Deaths Based on Vaccination (v) and Quarantine (q)

v/q	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0.0	57.15 ± 3.03	58.75 ± 3.16	57.85 ± 3.52	57.05 ± 4.17	58.4 ± 2.25	54.55 ± 3.36	51.6 ± 3.29	51.65 ± 3.87	40.6 ± 4.21	29.1 ± 3.18	8.6 ± 1.35
0.1	47.25 ± 2.8	46.8 ± 4.1	43.05 ± 3.14	43.65 ± 3.06	41.05 ± 3.32	36.65 ± 2.69	35.4 ± 3.5	27.7 ± 2.62	18.45 ± 2.91	8.9 ± 2.05	2.6 ± 0.52
0.2	37.05 ± 3.19	34.6 ± 3.15	33.7 ± 2.62	30.45 ± 3	29 ± 3.31	27.3 ± 3.9	22.6 ± 3.72	15.3 ± 2.61	7.95 ± 2.17	4.5 ± 1.04	2.4 ± 0.5
0.3	26.45 ± 2.74	26.25 ± 2.8	23.05 ± 2.64	24 ± 3.9	19.65 ± 3.34	13.7 ± 3.34	10.2 ± 2.18	6.6 ± 1.68	5.6 ± 1.49	4.2 ± 1.05	1.5 ± 0.52
0.4	21.3 ± 1.82	20.1 ± 1.97	16 ± 1.89	15.35 ± 2.25	12.9 ± 2.45	10.85 ± 2.17	7.2 ± 1.63	4.4 ± 1.29	3.85 ± 1.13	2.2 ± 0.69	1.35 ± 0.51
0.5	13.6 ± 2.88	13.6 ± 1.97	11.65 ± 2.36	10.95 ± 2.41	7.75 ± 1.52	7.75 ± 1.84	5.35 ± 1.16	4.25 ± 1.09	2.3 ± 0.72	1.9 ± 0.61	0.95 ± 0.36
0.6	10.95 ± 2.29	11.1 ± 2.77	8.2 ± 1.77	7.1 ± 0.63	6.55 ± 1.53	5.35 ± 1.45	3.2 ± 0.71	3.05 ± 0.85	2.25 ± 0.86	1.8 ± 0.67	1.45 ± 0.57
0.7	9.05 ± 1.95	7.5 ± 2.01	7.35 ± 1.59	5.75 ± 1.41	3.65 ± 0.89	3 ± 0.71	3.2 ± 0.79	1.75 ± 0.49	2.2 ± 1.04	2 ± 0.66	1.3 ± 0.49
0.8	9.2 ± 2.06	6.1 ± 1.36	5.5 ± 1.44	5.4 ± 1.48	4.6 ± 1.15	3.1 ± 0.88	2.85 ± 1.08	1.5 ± 0.61	1.7 ± 0.37	1.3 ± 0.49	1.35 ± 0.47
0.9	6.15 ± 1.4	5.05 ± 1.28	5.05 ± 1.18	4 ± 1.45	2.5 ± 0.87	2.45 ± 0.84	1.75 ± 0.6	1.95 ± 0.68	1.95 ± 0.54	1.45 ± 0.5	0.95 ± 0.41
1.0	4.15 ± 1.08	4.35 ± 1.25	4.6 ± 1.45	3 ± 0.88	2.4 ± 0.7	2.4 ± 0.77	1.6 ± 0.57	1.2 ± 0.5	1.8 ± 0.52	1.05 ± 0.5	1.15 ± 0.35