A Game-Theoretic Model of Monkeypox to Assess Vaccination Strategies

Sri Vibhaav Bankaru
Samuel Kossol
William Hou
Parsa Mahmoudi
Jan Rychtar

Follow this and additional works at: https://scholarscompass.vcu.edu/uresposters

© The Author(s)

Downloaded from
Bankaru, Sri Vibhaav; Kossol, Samuel; Hou, William; Mahmoudi, Parsa; and Rychtar, Jan, "A Game-Theoretic Model of Monkeypox to Assess Vaccination Strategies" (2020). Undergraduate Research Posters. Poster 279.
https://scholarscompass.vcu.edu/uresposters/279

This Book is brought to you for free and open access by the Undergraduate Research Opportunities Program at VCU Scholars Compass. It has been accepted for inclusion in Undergraduate Research Posters by an authorized administrator of VCU Scholars Compass. For more information, please contact libcompass@vcu.edu.
Introduction

- Monkeypox virus (MPXV) is a rare zoonotic Orthopoxvirus that causes monkeypox (MPX), a disease endemic to the Democratic Republic of the Congo and Nigeria.
- There are likely less than 1000 cases of MPX worldwide. In 2003, 47 cases were reported in USA and in 2018, 3 cases reported in UK.
- Common symptoms of MPX, though relatively milder than smallpox, include fever, severe headaches, skin lesions, and myalgia.
- The case fatality rate is over 10%.
- A smallpox vaccine is an effective prevention against MPX.
- Administration of the smallpox vaccine has ceased since the disease’s eradication in 1980, resulting in lowered immunity against Orthopoxviruses in general.
- We analyze a game theoretical model of MPX with voluntary smallpox vaccinations.

MPX overview

- MPX is capable of being transmitted amongst rodents, and primates.
- The majority of reported human cases originate from an interaction with an infected animal.
- We consider only a moribund rope squirrel (Funisciurus anerythus) and sun squirrels (Heliosciurus rubrobrachium).
- The incubation period for the virus ranges from 5 to 21 days.
- MPX infection is split into 2 distinct phases: the invasion period (fever, lymphadenopathy, intense asthenia, severe headaches, and myalgia) and the skin eruption period (rash and fluid filled blisters, the number vary from a few to thousands across the body).

Scheme of MPX transmission

Fig. 1: Susceptible (S), Exposed (E), Infectious (I), Recovered (R), Vaccinated (V). 0 - humans, 1 - squirrels. The rates are explained in Table 1.

ODE model of MPX transmission

| Symbol | Meaning | Value |
|--------|---------|-------|
| $\Lambda$ | Human Birth Rate | 0.001 |
| $\beta$ | Human-to-human transmission rate | 0.001 |
| $\mu$ | Human mortality rate | 0.02 |
| $\rho$ | Human-to-squirrel transmission rate | 0.002 |
| $\nu$ | Squirrel reproduction rate | 0.04 |
| $\mu_s$ | Squirrel mortality rate | 0.008 |
| $\beta_s$ | Squirrel-to-human transmission rate | 0.003 |

Results - Equilibria of the dynamics

| Disease-free (\(\mathcal{D}\)) | Fully Endemic (\(\mathcal{F}\)) | Semi-endemic (\(\mathcal{S}\)) |
|--------------------------------|-----------------|-----------------|
| $N_0$ | $N^0_0$ | $N^0_0$ |
| $E_0$ | 0 | 0 |
| $I_0$ | 0 | 0 |
| $R_0$ | 0 | 0 |
| $N^\mathcal{D}$ | see preprint | see preprint |
| $S^\mathcal{D}$ | $\frac{\mathbf{N}}{\mathbf{N}^\mathcal{D}}$ | $\frac{\mathbf{N}}{\mathbf{N}^\mathcal{D}}$ |
| $E^\mathcal{D}$ | $\mathbf{E}$ | $\mathbf{E}$ |
| $I^\mathcal{D}$ | 0 | 0 |
| $R^\mathcal{D}$ | 0 | 0 |

Results - Herd immunity and Nash equilibrium

- Herd immunity is impossible to achieve in the fully endemic equilibrium (due to the reservoir of MPX in squirrel population).
- In the semi-endemic equilibrium, one can achieve herd immunity when the vaccination rate reaches

$$\alpha_{H} = \max \left\{ \frac{\nu_k \beta_k \mu_k}{(\rho_k + \delta_k + \mu_k)(\mu_k + \rho_k)} - \mu_k \right\}$$

The Nash equilibrium vaccination rate $\alpha_{NE}$ is given as a solution of

$$C_{\text{min}}(\alpha_{NE}) = C_{\text{MPX}}$$

**Fig. 2:** Costs vs. Vaccination rate when the effective human-to-human transmission rate is high, $\beta_{HH} = 0.1$. Left: the fully endemic state. Right: the semi-endemic state ($S_{\text{min}} = \beta_{HH} \mu_{HH}$). The same scenario occurs when $\beta_{HH} < 1$. A change in $\beta_{HH}$ is arbitrary. All other parameters as in Table 1.

Conclusions

- We provided closed form formulas of the equilibrium states of the dynamics.
- We showed a potential existence of the previously neglected semi-endemic equilibrium, in which there is no infection in the animal population and the disease still persists in the human population.
- We demonstrated that $\alpha_{NE}$ is about 10 times more sensitive to parameters related to vectors than to a corresponding parameter related to humans. It is therefore important to provide accurate estimates.
- As cases of MPX become increasingly reported among humans, we hope that the models like ours may serve as a predictive tool to better study the spread of MPX.

Acknowledgements

The work on this project was done as part of the course MATH/BIOL 380 - Introduction to mathematical biology. We acknowledge the help and support of our classmates, the instructor Dr. Rychtár, and Dr. Taylor.