Sexually transmitted diseases outbreak prediction and transmission dynamics using agent-based modeling: take the global spread of male-dominated and MSM-dominated mpox outbreak as an example

Liu Ming, Huang Zhiguang, Ma Xinyang, Chen Xiaohan, Ming Wai-kit
Department of Infectioous Disease and Public Health,City University of Hong Kong
Department of Infectious Diseases and Public Health
香港城市大學
City University of Hong Kong

MSR72

Background

- Social and behavioral factors play a critical role in the emergence, spread, and containment of human diseases, including sexually transmitted infections (STIs)[1,2]. Heterogeneous social networks have been found to influence the spread and demographics of STIs, which affect more than 1 million people worldwide every day[3].

- Sexually transmitted diseases (STDs) have a higher risk among men who have sex with men (MSM), including HIV and mpox, which has recently caused an outbreak in many countries, with the majority of cases being male and identified as MSM.

- Disease modeling, such as SEIR[2], agent-based[4], and metapopulation models[5], has become a key tool in global pandemic prediction and public health response. Agent-based models (ABMs) can fully depict individuals' social and sexual behavior, making them a valuable tool in predicting the transmission and interventions of STIs like mpox, and understanding their transmission dynamics for outbreak prevention and control.

Key feature of global mpox cases

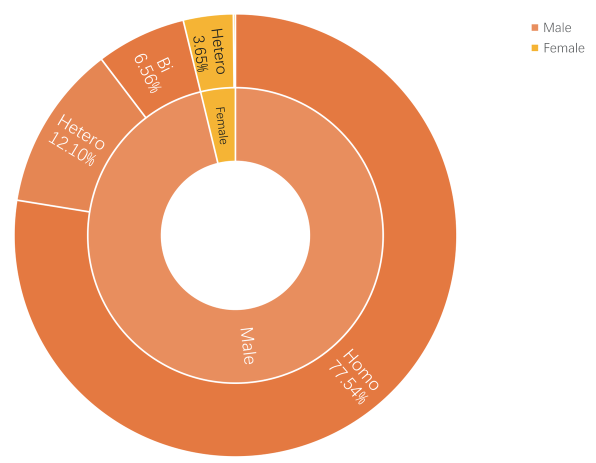
Sex
96.2% (77610/80643) of cases with available data are male, the median age is ***34*** years (IQR: 29 - 41). 3.8% (3033/80643) are female

Age
Males between ***18-44 years old*** continue to be disproportionately affected by this outbreak as they account for ***78.9%*** of cases.

Sex orientation
84.1% (25718/30593) identified as ***MSM***. Of those identified as MSM, 2009/25718 (***7.8%***) were identified as ***bisexual(bi) men***.
Female:Of the cases where sexual orientation is reported, the majority are ***Heterosexual(Hetero)*** (979/1021; 96%).

STD
A ***sexual encounter*** was reported most commonly, with 15,578 of 18,969 (***82.1%***) of all reported transmission events.

Exposure setting
the most common was in ***party setting with sexual contacts***, with 3,864 of 5,685 (***68.0%***) of all reported exposure events.



Source: WHO 2022-23 Mpox (Monkeypox) Outbreak: Global Trends(lasted update: Apr. 25 2023)

Aim

- The aim of the study was to use ABM to predict and understand the transmission dynamics of the STIs outbreak and take men dominated and MSM dominated mpox outbreak as an example.

Methods

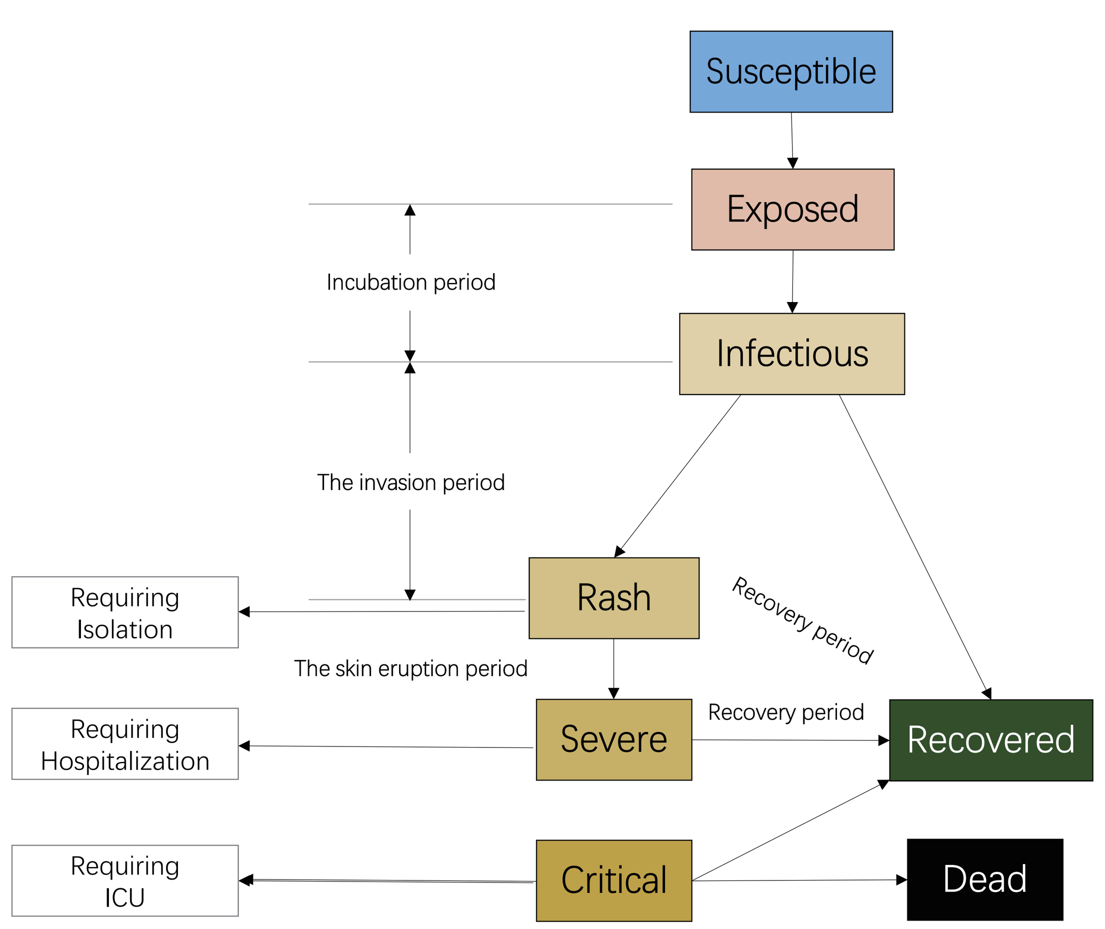
- The study used Covasim, an agent-based model for simulating infectious disease spread, to create a model of a mpox outbreak in a simulated population with sexual and social contact networks of people with ***multiple concurrent partners (MCPs)***. Demographic data from California, the state with the most confirmed mpox cases in the US, was used. Five scenarios with nonpharmaceutical interventions were tested, and the results included the median number of mpox cases and demographic information such as sex ratio, sexual orientation distribution, and exposure setting segmentation.

- Disease Progression

In order to accurately model the spread of mpox, our study carefully considered the disease period and progression. We evaluated the length of each period in the disease cycle, including the incubation period, invasion period, skin eruption period, and recovery period, as well as the probabilities of transitioning between each period. To inform these estimates, we relied on information from WHO fact sheets on mpox.

In addition, we took into account the effects of the smallpox vaccine on mpox susceptibility, progression, and mortality. Specifically, we estimated age-linked probabilities of disease susceptibility, progression, and mortality, considering the effectiveness of the smallpox vaccine in protecting against mpox and the potential for decreased effectiveness over time.By carefully considering the disease progression, we were able to develop a robust model that accurately captures the spread of mpox. The disease progression in our model is shown in ***Figure 1***.

Figiure 1. Model structure of disease progression



- Contact Network

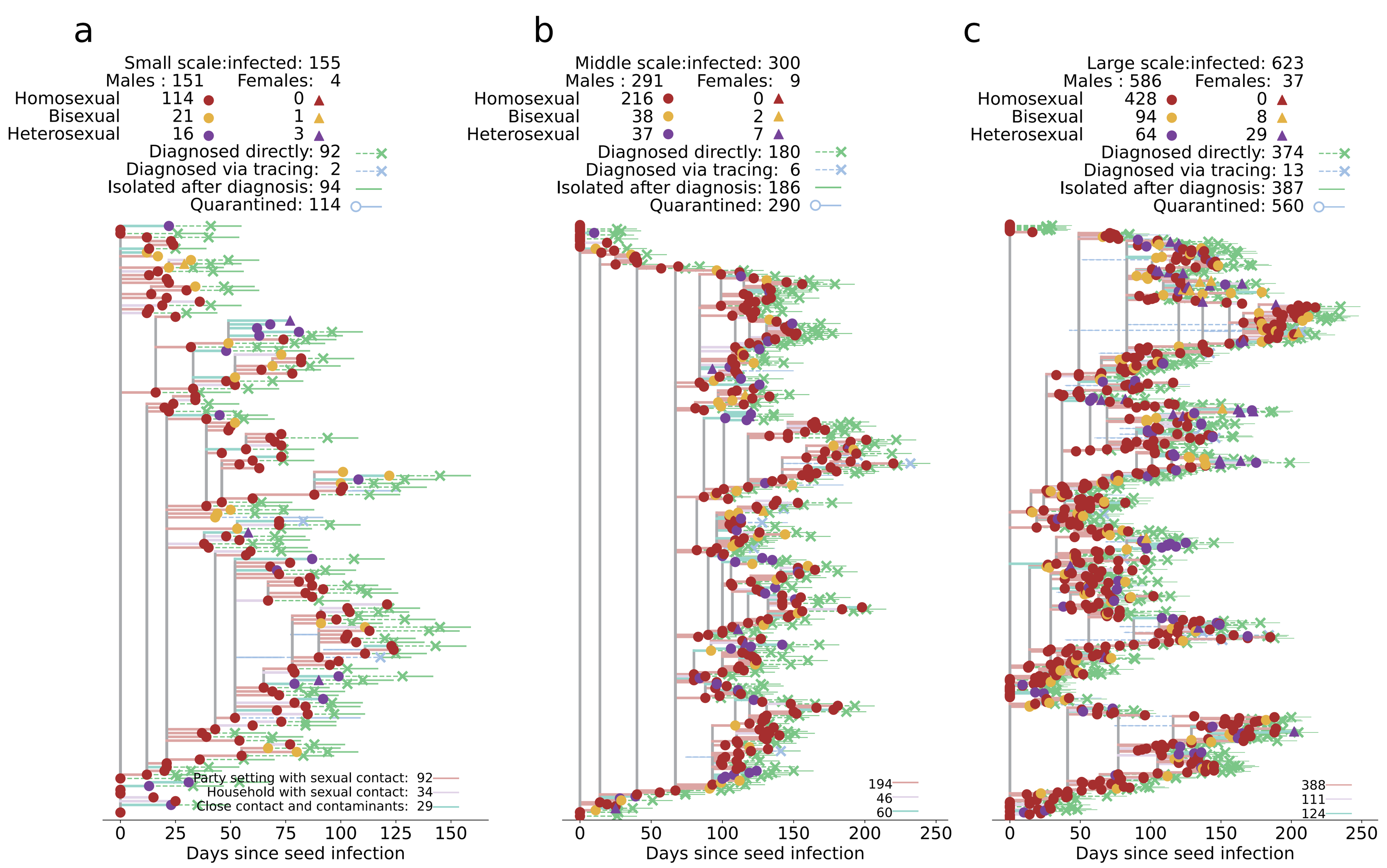
Sexual contact network:
The study divided the population into different groups based on sexual orientation and estimated the number of sexual partners for each group. The sexual partners network was formed based on sexual orientation, age, and anal sex roles. Bisexual groups were allowed to choose partners from other groups. The frequency of virginal, anal, and oral sex was estimated for each group. The study also simulated transmission in sex parties, where attendees were sampled based on sexual orientation and formed sexual contacts within their orientation and anal sex roles. Attendees were categorized into gay, female, and mixed subgroups, and contacts were assumed to happen daily with the same proportion in each sexual orientation group. The ***inter-course-wise risk*** estimation was implemented based on sex intercourse type, condom use probability, and anal sex roles.

Social contact network:
The simulation included different social contact networks such as household, workplace, school, community, and parties without sexual contact. The party network represents settings where close contacts occur, such as bars, restaurants, festivals, and sports events. These settings have a higher likelihood of contacting the virus due to intimate close contacts with infected individuals or contaminated surfaces. The contact rate in these settings is higher within the same gender than opposite genders due to same-gender friends being more likely to attend these events. The detail design of conctact network can be seen in ***Figure 2***.

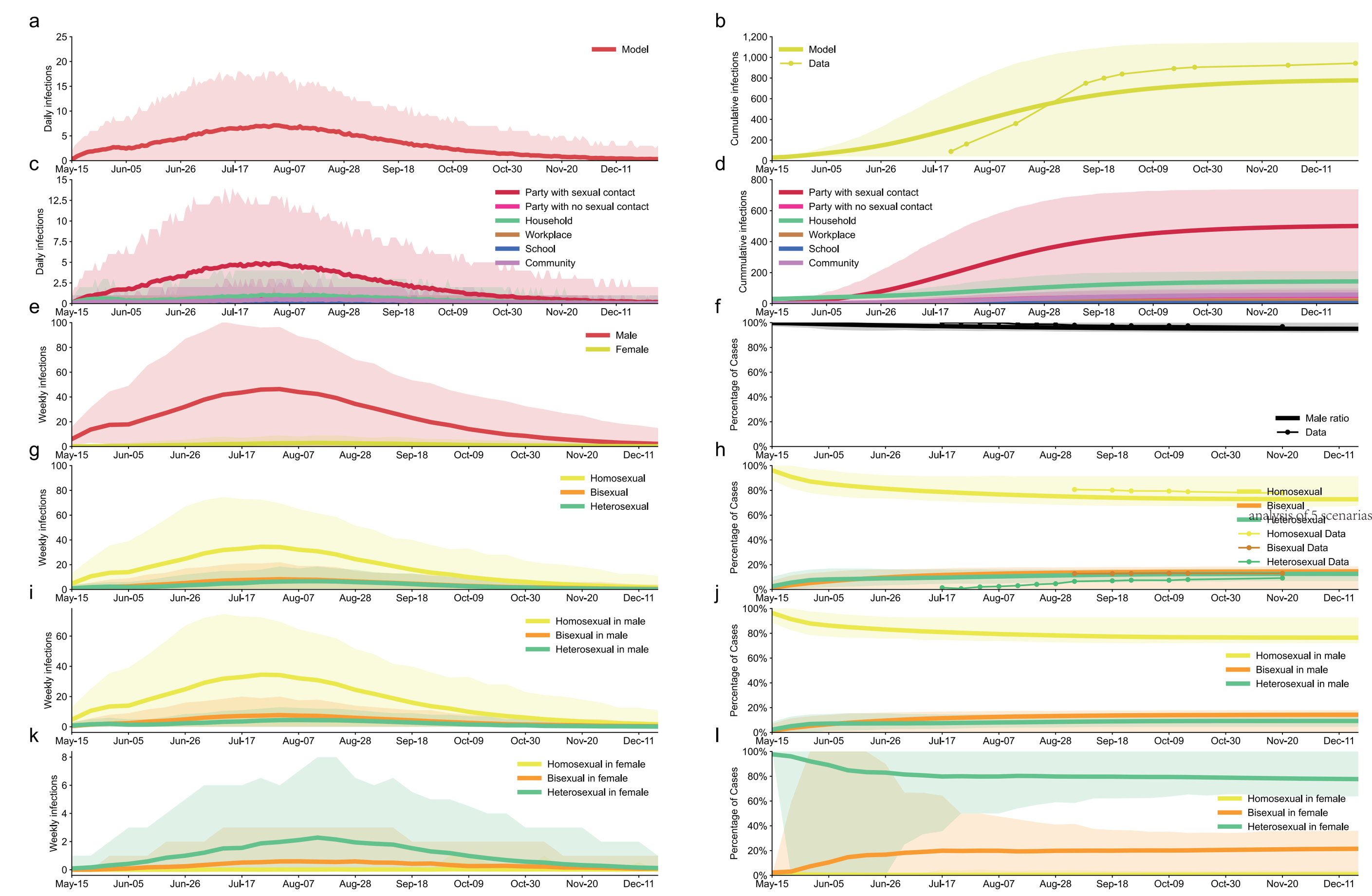
Figiure 2. Model structure of sexual contact network and social contact network

Results

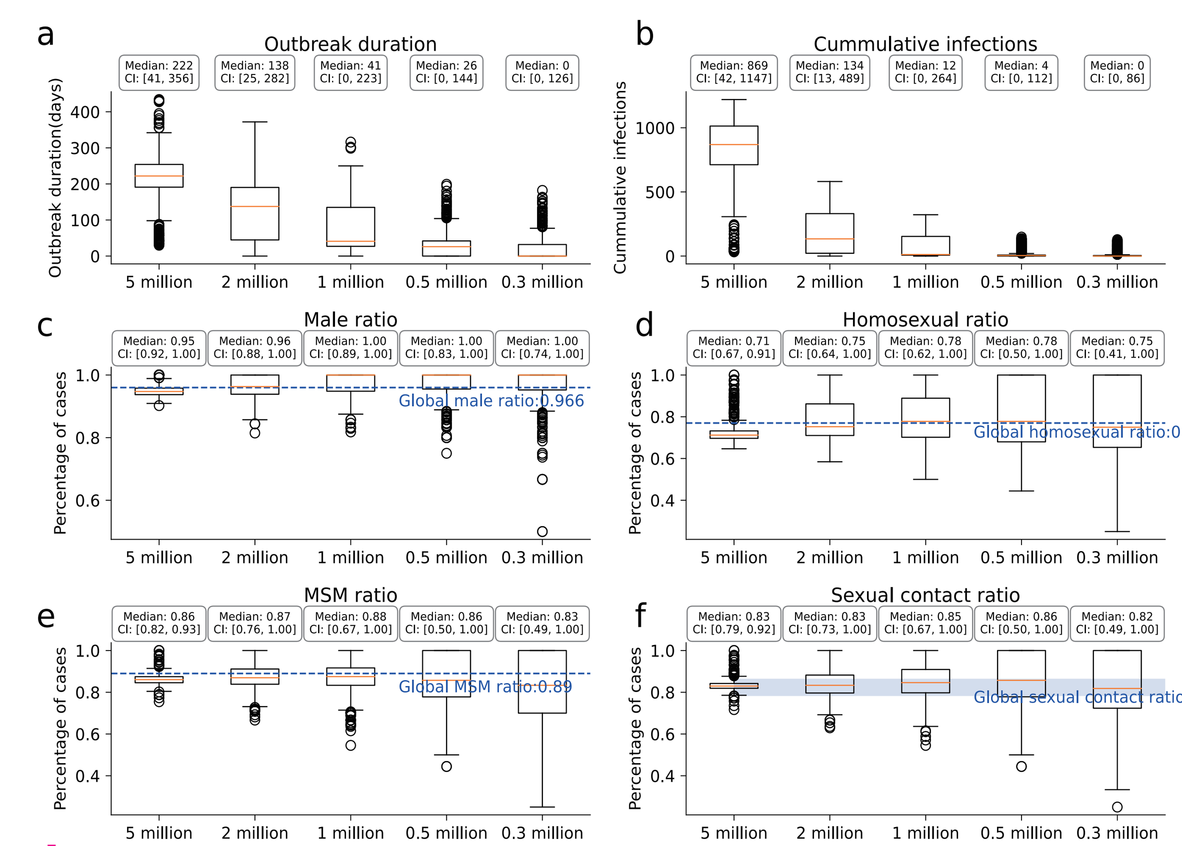
Figiure 3. Transmission trees of three mpox outbreak in small, middle, large population size of 1 million, 2 million and 5 million people with seed cases of 6,12,30 respectively



Figiure 4. Modeling result of Mpox outbreak in Los Angeles. Actual Data was collected from the Los Angeles County Department of Public Health.a)The daily number of mpox cases over time. b) The cumulative number of mpox cases of model and actual mpox data in LA over time c) The daily number of mpox cases in different layers over time. d) The cumulative number of mpox cases in different layers over time. e) The weekly number of mpox cases over time and by sex. f) The cumulative male ratio of mpox cases of model and actual data in LA over time. g) The weekly number of mpox cases for different sexual orientation over time. h) The cumulative distribution of mpox cases in different sexual orientation of model and actual data in LA over time. i) The weekly number of mpox cases for different sexual orientation in males over time. j) The cumulative number of mpox cases for different sexual orientation in males over time. k) The weekly number of mpox cases for different sexual orientation in females over time. l) The cumulative number of mpox cases for different sexual orientation in females over time.



Figiure 5. Modeling result of Mpox outbreak for different size of population. Actual Data was collected from the WHO[4]a)The duration of mpox outbreak. b) The cumulative number of mpox cases of mpox outbreak c) The male ratio of mpox outbreak. d) The homosexual ratio of mpox outbreak. e) The MSM ratio of mpox outbreak. f) The sexual contact ratio of mpox outbreak, global sexual contact ratio is calculated with exposure settings with sexual contact including household as the lower bond and other exposure type were added as the upper bond.



Conclusion

Our research explains how mpox is transmitted and shows that sexual transmission, particularly through anal sex among MSM, is the most common way of transmission. This leads to a higher number of infected males and MSM. Transmission through close contact or contamination is less common than sexual transmission. Our agent-based model for STI transmission can help predict and understand how mpox spreads, making it a valuable tool for public health policy makers.

References

1. Bedson, J., et al., A review and agenda for integrated disease models including social and behavioural factors. Nature Human Behaviour, 2021. 5(7): p. 834-846.
2. Huo, H.-F., Q. Yang, and H. Xiang, Dynamics of an edge-based SEIR model for sexually transmitted diseases. Mathematical Biosciences and Engineering, 2020. 17(1): p. 669-699.
3. Sexually transmitted infections (STIs). World Health Orignization. Available from:https://www.who.int/news-room/fact-sheets/detail/sexually-transmitted-infections-(stis).
4. Jones, J., et al., Proportion of Incident Human Immunodeficiency Virus Cases Among Men Who Have Sex With Men Attributable to Gonorrhea and Chlamydia: A Modeling Analysis. Sex Transm Dis, 2019. 46(6): p. 357-363.
5. Jing, F., et al., Modelling the geographical spread of HIV among MSM in Guangdong, China: a metapopulation model considering the impact of pre-exposure prophylaxis. Philosophical Transactions of the Royal Society A, 2022. 380(2214): p. 20210126.