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Travel-related importation risk of mpox from Hong Kong to Shenzhen in 2023: A modeling study

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A B S T R A C T

Mpox, a viral zoonotic disease formerly known as monkeypox, has gained global attention following a multi-country outbreak in 2022-23, primarily linked to close intimate contact. In China, mpox cases surged in June 2023, with nearly a quarter of new cases concentrated in Guangdong Province, particularly Shenzhen. This study aimed to estimate the importation risk of mpox cases from Hong Kong to Shenzhen in 2023, utilizing cross-regional population mobility data from January to October 2023. The analysis focused on local transmission in Hong Kong and the probability of mpox importation into Shenzhen. Results revealed a significant importation risk, with over a 50 % chance of at least one travel-based mpox case from Hong Kong in June 2023. The study underscores the necessity of enhancing inbound surveillance for travelers from high mpox prevalence regions. It is suggested that regional governments implement tailored strategies, including enhanced surveillance and dynamic risk assessment for effective cross-border disease management, supported by robust monitoring and coordinated actions across jurisdictions.

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1. Introduction

Mpox (formerly monkeypox) is a viral zoonotic disease first identified in Denmark (1958) in monkeys, which affects both humans and animals. Mpox primarily involves transmission between animals and from animals to humans, with human-to-human transmission becoming more significant in recent years. Following eradication of smallpox in 1980, mpox steadily emerged in west and central Africa, occasionally causing limited outbreaks elsewhere in the world. A global outbreak occurred in 2022-23 with the first confirmed case in the United Kingdom on May 7, 2022, followed by Europe, North America, and Oceania successively. On July 23, 2022, the WHO declared the multi-country outbreak of the mpox virus a Public Health Emergency of International Concern, a status that remained in effect until May 11, 2023. However, in China, mpox activity did not elevate until June 2023, probably delayed by the stringent COVID-19 related travel restriction until early 2023. As of September 8, 2023, 1451 cases had been reported in China (Mathieu et al., 2022). Nearly a fourth of new cases were centered in Guangdong Province from June 2023 to August 2023, in which there were 161 cases in the city of Shenzhen (Chinese Center for Disease Control). China managed mpox for prevention and control in the same way as a Class B infectious disease (e.g., COVID-19), starting from September 20, 2023 (Xiaoyu).

The city of Shenzhen in Guangdong province has a GDP of more than US$0.5 trillion in 2021, ranking the third largest economy in China (Shenzhen has become the first). Before COVID-19 pandemic, the total number of tourists received in Shenzhen reached 67.2 million people in 2019 (Statistical Analysis of the total). The risk of case importation in Shenzhen was therefore high, especially after China canceled implementing continual a dynamic zero-COVID policy. The first mpox case in Shenzhen was officially announced on June 9, 2023 (onset on May 27) and Hong Kong on September 6, 2022. During January 8 to October 17, 2023, it is estimated that about 77 million people traveled from Hong Kong to Shenzhen (Entry and exit personnel at), indicating a risk of imported mpox cases originating from Hong Kong. Therefore, we estimated the local transmission in Hong Kong, and the probability of the first mpox importation into Shenzhen from Hong Kong during the period of January 8 to October 17, 2023.

2. Method

By the time Shenzhen reopened its ports, Hong Kong was beyond the initial phase of the mpox outbreak, although sporadic and low case numbers were reported. Due to the dispersed nature of case reporting, cumulative confirmed cases were used for modeling purposes instead of incident cases. To effectively account for the extended time span, the monkeypox cases in Hong Kong were segmented into two distinct waves for fitting purposes. These waves were subsequently combined to perform a comprehensive calculation. The following sections detail the specific data and models utilized. The notation and values of the parameters are provided in Supplementary Table S1.

2.1. Data

Diagnosed suspected cases and confirmed cases of mpox should be reported through the Chinese Information System for Disease Control and Prevention (CISDCP). If the case is imported from abroad, the country or region of importation should be included. Thus, the Shenzhen mpox cases were provided by the Shenzhen Center for Disease Control and Prevention (SZCDC) (Shenzhen Center for Disease Control). And we obtained public datasets of Hong Kong mpox cases from the Centre for Health Protection, Department of Health in Hong Kong (Centre for Health Protection), and the daily passenger traffic from the Hong Kong Immigration Control (Statistics on daily passenger traffic).

2.2. Estimating daily passengers from Hong Kong to Shenzhen

In light of the fact that the policy has just been loosened and there is a relatively homogeneous way of traveling between Shenzhen and Hong Kong, we count the population imported at the most important control points. Specifically, we compiled statistics on the passenger data from Hong Kong to Shenzhen from six major control ports ("Lo Wu", "Lok Ma Chau Spur Line", "Heung Yuen Wai", "Lok Ma Chau", "Man Kam To" and "Shenzhen Bay") (Statistics on daily passenger traffic).

2.3. Estimating presymptomatic prevalence of mpox

We compared multiple models and selected the best-performing model, the Chapman-Richards nonlinear model, to study the non-exponential growth curve of the number of mpox infections. The Chapman-Richards growth model is given by (chapmanRichards, 2023):

$$Y(t) = \alpha\left(1 - \beta e^{-kt}\right)^{m} \tag{I}$$

where $Y(t)$ is the cumulative number of confirmed cases at time t; α represents the asymptotic value of the model; β is a constant related to the growth range of mpox; k and m are the growth rate and the slope of growth, respectively. The parameters of the model are estimated using nonlinear least square fitting. Then we determine the incidence curve, $I_O(t)$, at time t as given by:

$$I_O(t) = Y'(t) = \alpha\left(1 - \beta\, e^{-kt}\right)^{m-1} m\beta\, ke^{-kt}. \tag{II}$$

We back-projection estimated the time series of reported cases by incubation period and delay period between onset and reporting to estimate the number of infected cases who have not yet developed symptoms, $I_{O_{asy}}(t)$; and the cumulative not yet developed symptoms infections, $\Phi_O(t)$ at time t as given by:

$$I_{O_{asy}}(t) = \sum_{d=0}^{D_i^o + D_i^r} I_O(t-d) \cdot P \tag{III}$$

$$\Phi_O(t) = \sum_{d=0}^{D_i^o} I_{O_{asy}}(t-d) \cdot S \tag{IV}$$

where P is the total probability for delay d; S is the probability that incubation lasts at least d days.

The pre-symptomatic incidence was then summed and divided by the Hong Kong population (N_O) to obtain the prevalence, $P_O(t)$, at time t as:

$$P_O(t) = \Phi_O(t)/N_O. \tag{V}$$

2.4. Estimating importation risk of mpox

Then, we combined the daily passengers with daily prevalence of mpox to yield the importation force of cases. To calculate the imported cases from Hong Kong to Shenzhen on day t, we assumed that the number of imported cases per day followed the Poisson distribution from the region O at time t, $\Gamma_O(t)$, at time t as:

$$\Gamma_O(t) = P_O(t) * M_O(t). \tag{VI}$$

With the assumption that the number of imported cases per day followed the Poisson distribution, we evaluated the mean, and 95 % confidence interval of the imported cases based on 100 simulations. The sliding-window probability of at least one infected case by time Δt, $\Psi_O(t, \Delta t)$, following non-homogeneous Poisson (Du et al., 2021):

$$\psi_O(t, \Delta t) = 1 - exp\left[-\int_{i=t}^{t+\Delta t} \Gamma_O(i) di\right]. \tag{VII}$$

2.5. Scenario & sensitivity analysis

We employed scenario analysis to evaluate how border control policies influence both the temporal progression and magnitude of epidemic importation risk. Specifically, an intervention scenario simulating the implementation of daily movement caps. The simulation accounted for dynamic changes in population mobility patterns while tracking corresponding fluctuations in importation risk probabilities. In addition, one-way sensitivity analysis for reporting rate to quantify how much the importation risk changes due to variations in reporting. The reporting rate ρ scales the estimated prevalence $P_O(t)$ to estimate true prevalence $P_O(t)/\rho$, which directly modifies the importation force $\Gamma_O(t)$ in Equation *(VI)*. The analysis considers reporting rates ranging from 55.78 % to 86.85 % (Ward et al., 2024). Hong Kong Mpox cases and travel volume data were extracted from government bulletins and compiled using structured Excel (Version 2504 Build 16.0.18730.20122) to ensure consistency in date, and statistical analyses were conducted in R (version 4.5.0).

3. Result

This study covers the period from January 8, 2023, marking the first-phase resumption of normal travel between Hong Kong and Mainland China, through October 17, 2023, capturing critical post-reopening transmission dynamics. Fig. 1 illustrates the estimated daily number of cases, along with a 15-day moving average trend line. The moving average reduces day-to-day variability, clarifying underlying patterns and revealing two distinct waves of infection. This provides a clearer view of the contrast between estimated incidence and the underlying transmission trajectory.

The quantitative importation risk estimates are only available for the Hong Kong-Shenzhen route, while other regions are subject to qualitative assessments based on case reports. Except for Guangdong province where Shenzhen is located, Hong Kong accounts for the highest percentage of imported cases (nearly one-fifth) to Shenzhen, followed by Thailand, and other provinces in China. And except Thailand, no imported case was reported from other countries. The first mpox case (local case) in Shenzhen was initially presented clinically on May 27, 2023, before the first introduction from Hong Kong on June 8,

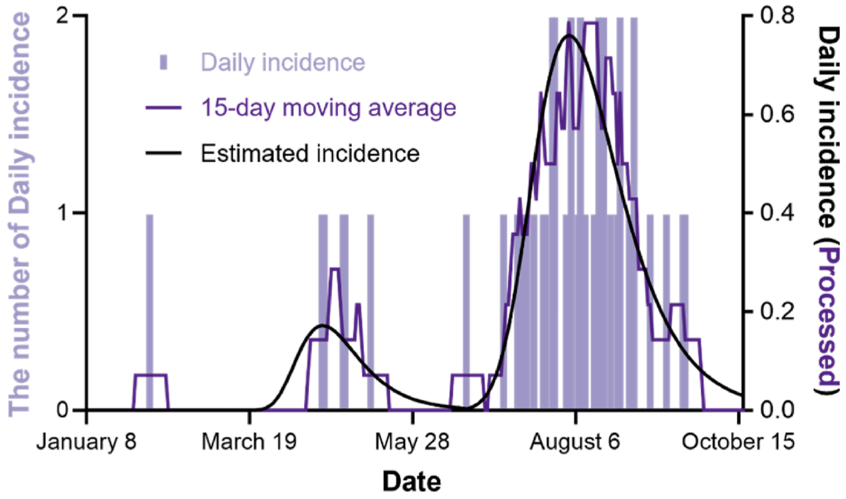

Fig. 1. The fitting results of incidence cases in Hong Kong. The light purple histogram represents daily reported cases, corresponding to the left y-axis. The dark purple line and black line stand for the 15-day moving average of the daily reported cases after denoising and the estimated incidence curve. By estimating the incidence curve, we aim to compare the patterns of mpox cases, identifying critical points such as peaks which may indicate surges in case numbers.

2023 (Fig. 2). While Hong Kong represented the first documented importation source, potential introductions from other regions cannot be excluded. In Fig. 2(a), we estimated that the cumulative umber of imported cases in Shenzhen during the same week as the first imported case from Hong Kong became clinically onset was 1.13 (95 % CI: 0.33, 3.86). As of October 17, the estimated number of imported cases was 9.49 (95 % CI: 4.74, 19.85), and the actual number of imported cases was 6, which fell within the 95 % confidence interval. Based on our sliding importation risk maps of at least one travel-related Mpox case from Hong Kong, the first peak for both different sliding window curves was earlier than the actual importation date, with the probability of at least 1 new import within a 1-week sliding window period being 23.08 % (95 % CI: 9.08 %, 46.78 %) and the probability of a 2-week sliding window period being 36.88 % (95 % CI: 14.77 %, 69.02 %) (Fig. 2(b)).

By comparing a baseline scenario with unrestricted movement against an intervention scenario capping cross-border traffic at 100,000 persons per day (around one-third of peak volume), we quantify the policy's effectiveness in delaying risk progression and reducing transmission likelihood. The analysis reveals that such mobility controls can reduce the risk of an imported case's first peak by 50 %. The one-way analysis shows how importation risk changes when varying the reporting rate between 55.78 % and 86.85 %, with the 1-week dynamic risk estimate for the first peak ranging from 26.06 % to 37.51 % and the 2-week dynamic risk estimate for the first peak ranging from 41.13 % to 56.18 %. If reporting is incomplete (e.g., only 55.78 % of cases detected), the true risk may be underestimated by 18.66 %. These findings highlight the critical dependence of risk assessment accuracy on surveillance system performance.

4. Discussion

In contrast to cases of the mpox before 2022, where the majority of cases reported outside of Africa were due to animal-to-human transmission. In the past two years 2022 and 2023, the most common route of mpox transmission was through sexual contact among men who have sex with men (Laurenson et al., 2023). From our analysis, the number of imported cases to Shenzhen started to increase in June 2023. The 2023 celebration of June Pride Month may fuel the rise, as same-sex sexual intercourse groups were highly likely to engage in high-risk unsafe sexual behavior (Scott, 2023).

To effectively manage cross-border disease transmission risks, tailored strategies are needed for both high- and low-prevalence areas. In areas of high prevalence, perhaps implementing a real-time surveillance system and adopting digital case reporting, as in Hong Kong, would achieve higher reporting rates. Of note, if reporting is incomplete (for example, reporting only 55.78 % of cases), the true risk may be underestimated by approximately 20 %. Higher reporting rates can reduce this uncertainty. For lower-risk areas like Shenzhen, dynamic border controls can be implemented in advance, such as strict movement caps (e.g., 100,000 people per day) during high-risk periods, which have been shown to reduce the peak import risk by 50 %. Furthermore, Deng's research (Deng et al., 2024) demonstrated that strict border entry policies reduced mpox imports by 69 %, highlighting the importance of proactive measures. Crucially, strong upstream monitoring and coordinated implementation across interconnected jurisdictions, along with optimal border controls, are essential.

Our study has several limitations. Our analysis was necessarily constrained to laboratory-confirmed cases with clear epidemiological links. Besides, our method for estimating disease prevalence relies on the reported mpox cases in Hong Kong, which may be biased due to the surveillance capacity. The smaller number of reported mpox infections would result in an underestimated importation risk. We assumed that only infected mpox cases who had not developed symptoms could be admitted, while asymptomatic or mildly infected individuals may also go through ports undetected, resulting in

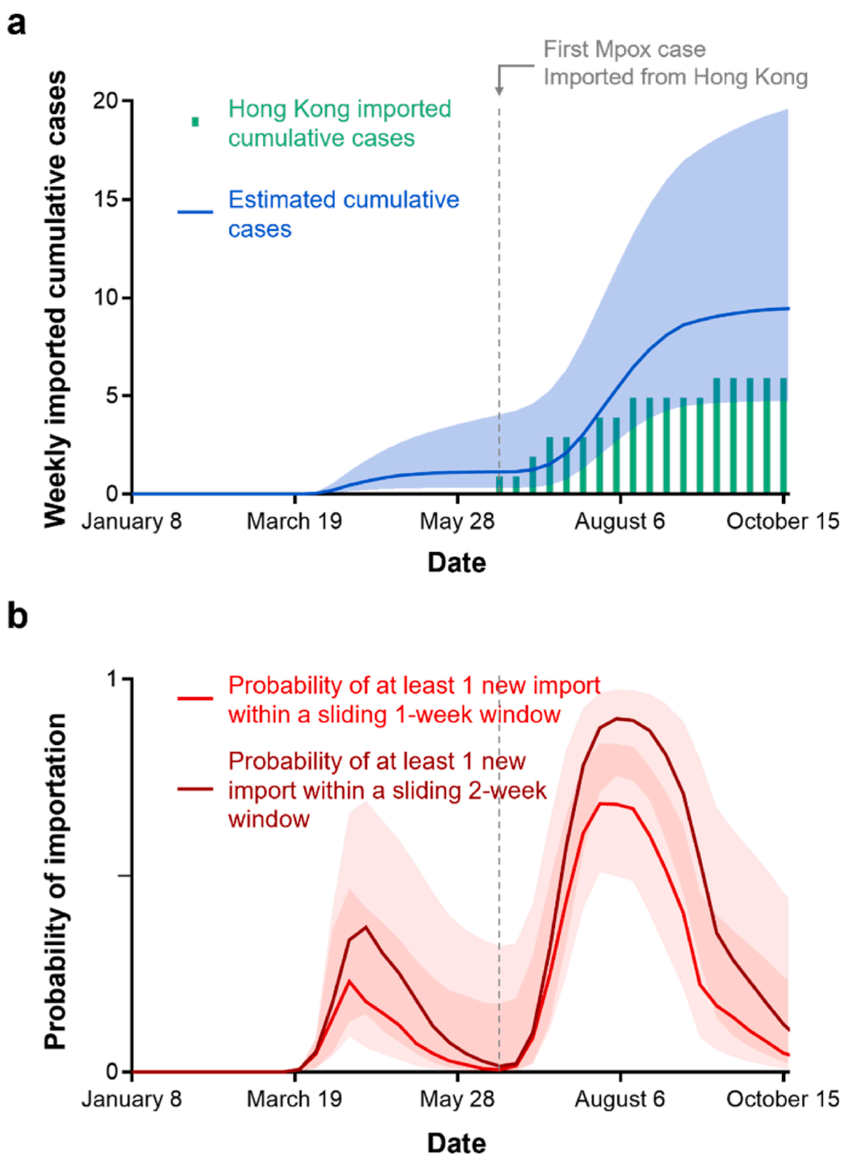

Fig. 2. Mpox cases were imported to Shenzhen from January 8 to October 17, 2023. Panel (a) presents the estimated weekly cumulative cases compared with actual cases. We visualized the actual importation mpox case since January 8, 2023, sourced from Shenzhen Center for Disease Control and Prevention. Panel (b) displays the estimated real-time risk of mpox introduction from Hong Kong to Shenzhen. We estimated the probability that at least one person infected with the mpox virus arrived in Shenzhen from Hong Kong by the date indicated on the x-axis based on Hong Kong's reported mpox cases and traffic passengers' data. The light red curve corresponding to the left y-axis shows the probability of at least 1 case importation within sliding 1-week window during the study period, along with a 95 % confidence interval in the red region. The dark red curve stands for probability of 1 new import within 2-week window. The dashed vertical line indicates the first importation case from Hong Kong to Shenzhen on June 8, 2023.

underestimated importation risk. Finally, our findings highlight the need for cross-border preparedness strategies, such as surveillance and dynamic risk assessment, while further cost-effectiveness evaluations are warranted to justify specific interventions.

We estimated the importation risk of mpox cases introduced from Hong Kong to Shenzhen in 2023. The city of Shenzhen is able to prevent the cross-border spread of infectious diseases by deploying in advance, monitoring importation risks in real time, and implementing certain prevention and control measures.

CRediT authorship contribution statement

Ruohan Chen: Writing – review & editing, Writing – original draft, Visualization, Methodology, Formal analysis, Conceptualization. **Jia Wan:** Resources, Investigation. **Dongfeng Kong:** Resources, Investigation, Data curation. **Cong Niu:**

Resources, Investigation, Data curation. **Zengyang Shao:** Writing – review & editing, Methodology. **Chijun Zhang:** Writing – review & editing. **Mingda Xu:** Writing – review & editing, Methodology. **Yuan Bai:** Writing – review & editing, Methodology. **Eric Lau:** Writing – review & editing. **Zhen Zhang:** Supervision, Resources, Conceptualization. **Zhanwei Du:** Writing – review & editing, Supervision, Methodology, Conceptualization.

Ethical approval statement

This modeling study did not require institutional review board review or approval because only simulated data and public-available data are used.

Code availability

Code developed R (version 4.5.0) are available from GitHub (https://github.com/RuohanCHEN01/Import_risk_Mpox).

Conflicts of interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.idm.2025.09.005.

Data availability

The Shenzhen mpox case data that support the findings of this study are available on request from the corresponding author, ZZ, upon reasonable request. The raw data for Hong Kong are now shared in Supplementary Dataset S1.

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