Effectiveness of different border control strategies for reducing mpox importation risk: a modelling study

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Summary

Background The Clade Ib monkeypox virus can be more transmissible through non-sexual routes compared to the previous Clade IIb strain. With imported cases sporadically reported globally, concerns have emerged about the potential of widespread transmission in the general community after importation events. Border control measures, such as screening and quarantining of arriving travellers, may help mitigate this risk and prevent localised outbreaks in the event of global spread.

Methods We developed an agent-based model to simulate individual disease progression and testing. We then evaluated the effectiveness of nine border control strategies in reducing importation risk. The simulations incorporated varying disease prevalence levels (0.001%, 0.005%, and 0.01%) in the country of origin.

Findings The proposed border-control measures would reduce missed cases by 40.1% (39.1%–41.0%), 49.8% (48.8%–50.8%), and 58.1% (57.1%–59.0%) for pre-departure, on-arrival, and both tests, respectively. Replacing the on-arrival test with a 7-day quarantine and post-quarantine testing would lower the proportion to 21.8% (20.9%–22.6%). Quarantine-only strategies showed a linear increase in effectiveness against duration, reaching a 90.4% (89.8%–91.0%) reduction with a 28-day quarantine.

Interpretation When disease prevalence in the country of origin is low (0.001%), less restrictive approaches such as single on-arrival testing or a 14-day quarantine can maintain very low imported case counts of one or below. At higher prevalences, 7-day quarantining followed by post-quarantine testing, or 28-day quarantining is required to maintain similar effects. Border management will require risk assessments between importation risk, based on origin country prevalence, and the negative impacts of control on travellers.

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Introduction

Mpox is a viral zoonotic disease caused by the monkeypox virus (MPXV), typically characterised by symptoms such as skin rashes, fever, headache.[1] Clade Ib MPXV, the new strain in circulation in the ongoing 2024 mpox outbreak, is estimated to have emerged in late 2023 in the Democratic Republic of the Congo (DR Congo). This new clade has resulted in large number of infections in the DR Congo, and has spread to the neighbouring African countries, leading to over 100 confirmed cases in Burundi, Kenya, Rwanda, and Uganda as of Aug 14, 2024.[2] Cases of infections

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Research in context

Evidence before this study

As of March 2025, Clade Ib monkeypox virus continues to circulate in the Democratic Republic of the Congo and its neighbouring countries, with imported cases being identified globally. Emerging evidence suggests higher transmissibility of the new strain, particularly through non-sexual routes, compared to the previous Clade IIb strain. This raises concerns about its potential spread in the general population following importation events. Meanwhile, border containment measures, such as screening and quarantining travellers, have proven effective in outbreak control, as demonstrated during the COVID-19 pandemic.

Added value of this study

Our simulations evaluated the impacts of PCR testing at different time points and varying quarantine duration on reducing importation risk. Increased testing frequency and longer quarantine duration significantly reduced the number of undetected importations. Testing and quarantining may be equally effective in outbreak control. When the disease prevalence in the country of origin is as low as 0.001%, less restrictive measures, such as single on-arrival test or a 14-day quarantine, can keep imported case at one or fewer. At higher prevalences, however, a seven-day quarantine followed by post-quarantine testing, or 28-day quarantining is required to maintain similar effects.

Implications of all the available evidence

An importation-triggered mpox outbreak can be substantially mitigated through proper implementation of border control strategies. The level of control should be adjusted based on the disease prevalence in the country of origin, with more stringent approaches, such as a combination of quarantining and testing or a minimum 21-day quarantine, becoming necessary at higher prevalence levels. Stakeholders must balance the trade-off between reducing importation risk and minimising adverse impacts of the intervention strategies.

returning from Africa have also been identified and reported in countries outside the continent, such as Sweden, Thailand, and India.[3,4]

Clade IIb MPXV, the circulating strain in the 2022 mpox outbreak, was predominantly transmitted through sexual contact with minimal spread outside the community of men who have sex with men (MSM).[5,6] In contrast, the new Clade Ib has been found to transmit more easily than Clade IIb through non-sexual routes, such as skin-to-skin contact and contact with contaminated surfaces to some extent.[7,8] Despite the great uncertainty surrounding transmissibility estimates,[9] concerns have arisen on the potential for transmission in the general population globally[10,11] due to its observed fast spread and the overall low immunity against mpox, particularly Clade Ib strain, in most countries outside the African continent.

At the frontline, border control measures can be employed to reduce importation rates and delay the epidemic peak.[12] Complete border lockdown and travel bans introduce many social and economic challenges[13] and are therefore not recommended by the WHO.[14] Nevertheless, implementing less disruptive containment approaches, such as screening and quarantining international arrivals from affected countries, can assist in the timely detection of imported cases and prevention of secondary infections in the wider community, as well as provide treatment to infected travellers. These measures were widely applied, either individually or in combination, during the early phase of the COVID-19 pandemic, with varying levels of stringency level. Two typical examples are the zero-COVID strategy, aimed at preventing local disease transmission, and the coexistence strategy, which sought to maintain the outbreak at a manageable level.[12,15] The zero-COVID strategy usually required long-duration quarantines and repeated testing events, whereas the coexistence approach often adopted less prohibitive measures, such as single testing and home-based quarantine.[15,16] As of December 2024, border control measures implemented for mpox included surveillance, symptomatic screening, and isolation of suspected cases, health declarations and risk profiling of passengers based on their origin destination.[17,18] The effectiveness of these measures, however, remains uncertain as mpox has different transmission timescales from COVID-19, including a substantially longer infectious period (14–28 days).[1,19]

In this study, we proposed a range of border control strategies and projected their effectiveness in reducing mpox importation risks. We employed agent-based simulations to quantify the risk of importation per 100,000 travellers from countries with varying levels of disease prevalence. We explored the use of diverse containment measures, including quarantine and PCR testing before departure, upon arrival, and post-quarantine. We estimated and compared the number of missed and detected cases across a range of border control strategies at different disease prevalences (0.001%, 0.005%, 0.01%) in the source countries. Our findings aim to provide quantitative evidence for the designing of border control interventions for any country at risk of case importation from any other country globally. The guidance will facilitate countries around the world to contribute as a united community to curb the global spread of mpox,[20] while supporting the focusing of interventions and treatment of communities currently affected.

Methods

An agent-based model for disease progression and testing was employed to generate individual infection profiles, testing procedures and outcomes under various border control measures. We assumed that no disease transmission occurred during travel (e.g., on flights or at airports).[21] Details of the models and the proposed containment strategies are described in sections below.

Model of disease progression

The infection process was simulated independently for each infected traveller, who was assumed to contract the virus at some point within 30 days prior to departure. This 30-day timeframe was selected to account for travellers at varying stages of infection. We used the time from departure as time scale, defining $t = 0$ as the day of departure for all travellers. For an infected traveller i, his or her infection time point was denoted as τ_i, followed by an incubation period θ_i and an infectious period ϕ_i. We assigned τ_i a uniform distribution ranging from −30 to 0, assuming time-invariant disease prevalence (i.e., proportion of exposed or infectious individuals) in the source countries, but an alternative assumption of exponential growth in the source countries was tested in a sensitivity analysis (Supplementary Fig. S8). Both θ_i and ϕ_i were modelled using lognormal distributions to account for their heavy-tailed nature, with parameters derived from statistics disclosed by the WHO[1] (Fig. 1, Table 1).

Model of PCR testing

The PCR testing methods considered in the simulations include sampling from skin lesions and oropharyngeal sites. Test sensitivity over time for the two PCR types, denoted as σ_{skin} and σ_{oral}, was inferred utilising a logistic regression model and the test outcome data from Yang and colleagues (Fig. 1, Table 1), in which PCR positivity was defined as viral load exceeding 4.77 $\log_{10}$ copies per mL.[23] Given the higher PCR testing accuracy when samples from skin lesions were used, individuals presenting with skin rashes ($S_i = 1$) were assumed to undergo testing with skin lesion swabs, while others ($S_i = 0$) would provide oropharyngeal samples for PCR testing. We set $P(S_i = 1) = 60\%$ based on the symptomatic rate and the documented proportion (85%) of patients with mpox reporting skin lesions,[24,25] but performed a sensitivity analysis to explore alternative scenarios where the rate was 10%, 30%, or 90% (Supplementary Figs. S4–S6). The probabilities of correctly identifying an infection in the two groups at testing time t_i were assumed to be

$$P(X_i = 1|S_i = 1) = \sigma_{skin}(t_i - \tau_i - \theta_i)1_{t_i \in (\tau_i+\theta_i, \phi_i+\tau_i+\theta_i)}, \quad (1)$$

and

$$P(X_i = 1|S_i = 0) = \sigma_{oral}(t_i - \tau_i - \theta_i)1_{t_i \in (\tau_i+\theta_i, \phi_i+\tau_i+\theta_i)}, \quad (2)$$

respectively, where 1_x is an indicator function which equals one if and only if the condition x is satisfied. In the main analysis, we assumed that PCR tests could only detect infected travellers who had completed their incubation period. However, this assumption was tested in a sensitivity analysis, where 80% of the infections

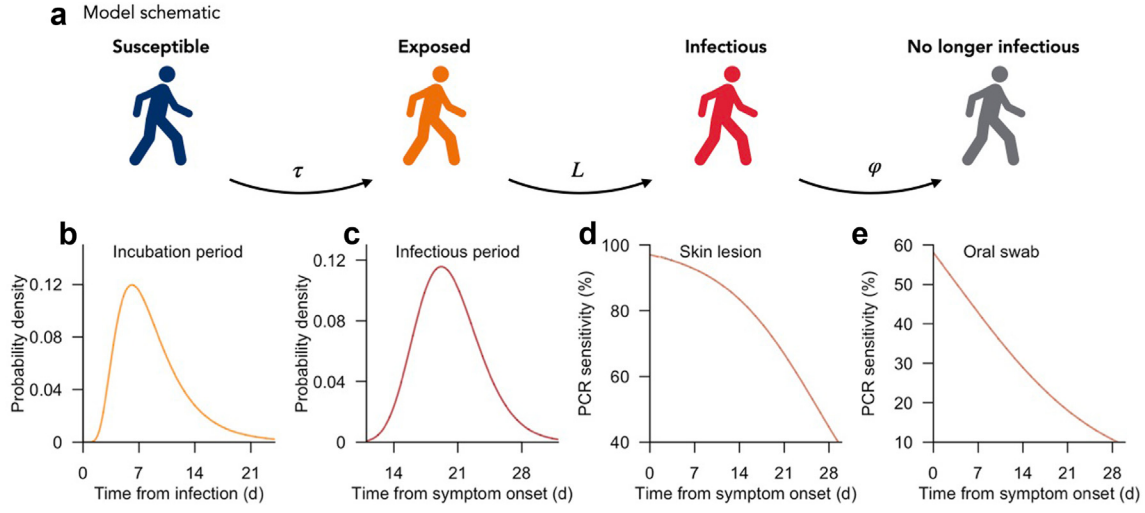

Fig. 1: Model schematic and parameter values for the model of disease progression. The subfigures include a model schematic illustrating progression through different disease stages (a), probability density for incubation period (b) and time from symptom onset to loss of infectiousness (c),[1] and sensitivity of PCR test using samples of skin lesions (d) and oropharyngeal samples (e) over time.[22] All durations are measured in days. Note that the time points with relatively low probability density (b and c) or sensitivity (d and e) may not be fully displayed in corresponding subfigures but are considered to have non-zero values in simulations.

Variables	Value, range or distribution	Definition
τ_i	Uniform distribution ranging from −30 to 0	Day of infection of individual *i* before departure
L	Lognormal distribution with mean 8.72 and standard deviation (SD) 4.44	Incubation period duration of individual *i*; derived from the WHO[1] with a 95% confidence interval of [3,20]
ϕ_i	Lognormal distribution with mean 20.11 and standard deviation (SD) 3.58	Infectious period duration of individual *i*; derived from the WHO[1] with a 95% confidence interval of [14,28] (i.e., 2–4 weeks)
$\sigma_{skin}(t)$	Function of PCR testing sensitivity against time from symptom onset, determined from logistic regression	Post infection time-dependent sensitivity of PCR test using samples of skin lesions; derived from Yang et al.[22]
$\sigma_{oral}(t)$	Function of PCR testing sensitivity against time from symptom onset, determined from logistic regression	Post infection time-dependent sensitivity of PCR test using oropharyngeal samples; derived from Yang et al.[22]
X_i	Binary, i.e., 0 or 1	Indicator for positive PCR test result
S_i	Binary, i.e., 0 or 1	Indicator for developing skin rashes

Table 1: **Parameters used within the model.**

were assumed to become detectable up to four days prior to this time point (Supplementary Fig. S2).[26] A turnaround of three days was assumed to account for laboratory processing and administrative procedures.[27] False-positive results[28] were not considered in our simulations. Asymptomatic infections were assumed to be equally infectious as their symptomatic counterparts, following the same incubation and infection period profile, and therefore were not estimated separately. We explored this further in the Supplementary Information (Supplementary Fig. S7).

Proposed strategies

Based on their historical uses and demonstrated effectiveness in other disease contexts,[12,17] we considered four border control measures in this study targeting inbound travellers from countries experiencing mpox outbreaks. These include pre-departure testing, and on-arrival testing, post-arrival quarantine, and post-quarantine testing. Pre-departure tests would be performed three days prior to departure with travellers not subject to any activity restrictions during this period. Only those with a negative test result would be permitted entry into the destination country. On-arrival testing would be conducted upon arrival and incoming travellers would be quarantined in designated facilities for three days whilst waiting for their test results. Individuals with a positive result would be transferred to local healthcare facilities for isolation and treatment until loss of infectiousness, while others would be released into the community unless under quarantine. Post-arrival quarantine would last 7–28 days, during which no test would occur. Post-quarantine testing would take place at the end of the quarantine period. Similar to on-arrival testing, travellers tested negative would be released following an additional 3-day quarantine due to test result delays, while those tested positive would also be isolated and treated in healthcare facilities until recovery. In addition, complete adherence was assumed during quarantine, isolation, or treatment process with no leakage expected.

The baseline strategy was set to involve no screening or quarantine measures (i.e., Strategy 1), where all international arrivals were granted entry and free movement upon arrival. We also explored eight other strategies, with the first four incorporating different subsets of the four border control measures, and the latter four focusing exclusively on quarantine with varying durations to model the scenario where testing was not available. The effectiveness of quarantine combined with pre-departure and/or post-quarantine testing in reducing missed cases was further assessed as a Supplementary analysis. Fig. 2 visualised the nine strategies included the main analysis, with detailed combinations summarised in Supplementary Table S1 and listed below:

S1) No screening or quarantine,
S2) On-arrival testing (followed by a 3-day quarantine),
S3) Pre-departure testing,
S4) Pre-departure testing + on-arrival testing (followed by a 3-day quarantine),
S5) Pre-departure testing + post-arrival quarantine (7 days) + post-quarantine testing (followed by an additional 3-day quarantine),
S6) Post-arrival quarantine (7 days),
S7) Post-arrival quarantine (14 days),
S8) Post-arrival quarantine (21 days), and
S9) Post-arrival quarantine (28 days).

We quantified the effectiveness of individual strategies in reducing importation risks through the proportion of missed cases, defined as individuals who were infectious or still in their incubation period by the time they were able to interact with the local community. These estimates were derived from the outputs of 10,000 simulations per strategy, each with 10,000 infectious or exposed arrivals. We further explored three hypothetical disease prevalence levels: 0.001%, 0.005%, and 0.01%, among travellers from a source country or region, informed by disease surveillance data from Africa (details in the Supplementary Information).[29] For each combination of the nine border control strategies and three disease prevalence levels, we summarised the number of missed cases per 100,000 travellers, based on

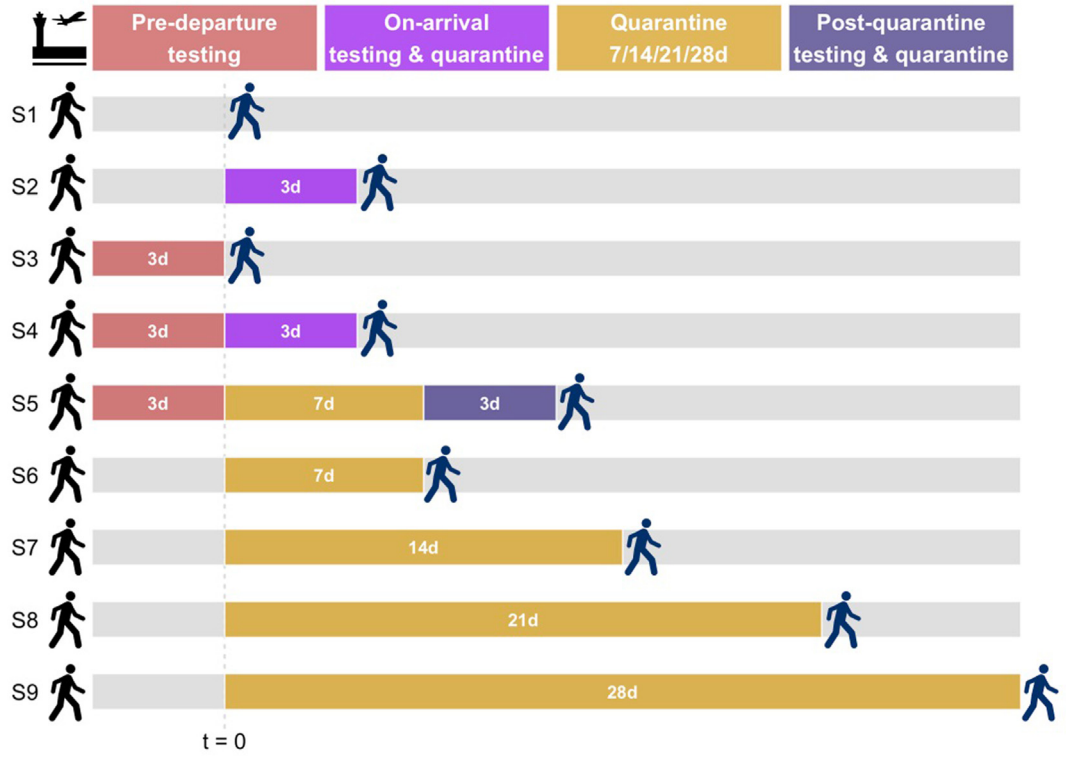

Fig. 2: Descriptions of Strategies 1–9. Individuals in blue indicate the time points when travellers enter the local community. The number of days required for each border control measure is presented in white within the rectangles. Pre-departure testing is performed three days prior to travel with no movement restrictions imposed, while both on-arrival and post-quarantine testing are followed by a 3-day quarantine due to test result delays. Infections may lose infectiousness during quarantine or be identified through testing. The time scale (t) is the time from departure for all the travellers.

10,000 simulations of 1,000,000 arrivals per scenario. For each projected outcome, the summary statistics include the mean and the corresponding 95% confidence interval to capture variation arising from stochastic effects. All the analyses and result visualisations were performed with R software.[30] Ethics approval was not obtained because this study uses publicly available information only.

Role of the funding source

The funding sources were not involved in study design, in collection, analysis, and interpretation of data, in the writing of the report, or in the decision to submit the paper for publication.

Results

Overall effectiveness of proposed border control strategies

The simulation results showed that pre-departure PCR testing (S3) and on-arrival PCR testing (S2) could detect 40.1% (95% CI: 39.1%–41.0%) and 46.2% (95% CI: 45.2%–47.2%) of all imported cases, respectively. In addition, 3.6% (95% CI: 3.3%–4.0%) of the infected travellers would lose infectiousness during the 3-day quarantine while awaiting the on-arrival PCR test results. Combining both pre-departure and on-arrival testing (S4) would reduce the proportion of missed cases to 41.9% (95% CI: 41.0%–42.9%). The proportion of missed cases was expected to further decline to 21.8% (95% CI: 21.0%–22.6%) when the on-arrival testing in S4 was replaced with a 7-day post-arrival quarantine and post-quarantine PCR testing (S5). In this scenario, while 28.5% (95% CI: 27.6%–29.4%) of the infected travellers were captured through post-quarantine testing in addition to the 40.1% (95% CI: 39.1%–41.0%) captured from pre-departure testing, another 9.7% (95% CI: 9.1%–10.3%) became non-infective during the overall 10-day quarantine period (i.e., a 7-day quarantine followed by a 3-day PCR test turnaround time; Supplementary Table S1). When quarantine was implemented as the exclusive border control measure, the proportion of infected travellers who would lose infectiousness with each additional week of quarantine would be 20.7% (95% CI: 19.9%–21.5%) after one week, 45.5% (95% CI: 44.6%–46.5%) after two weeks, 70.9% (95% CI: 70.0%–71.8%) after three weeks, and 90.4% (95% CI: 89.8%–

91.0%) after four weeks (Fig. 3). The addition of pre-departure testing and/or post-quarantine testing would further lower the number of missed cases, but their marginal effects were projected to diminish with the increase in quarantine duration (Supplementary Fig. S1).

Number of missed cases across scenarios with varying disease prevalence levels

When the disease prevalence in the country of origin was low (0.001%), the number of missed cases per 100,000 travellers was projected to be 1.0 (95% CI: 0.4–1.7) in the baseline scenario without interventions. The corresponding estimate was reduced to 0.5 (95% CI: 0.1–1.9), 0.6 (95% CI: 0.2–1.1), and 0.4 (95% CI: 0.1–0.9) for the scenarios solely implementing on-arrival testing (S2), pre-departure testing (S3), and both (S4), respectively, while the substitution of the on-arrival testing in S4 with a 7-day quarantine and post-quarantine testing (S5) further decreased the number to 0.2 (95% CI: 0.0–0.5). By comparison, in the quarantine-only scenarios, the number of missed cases was 0.8 (95% CI: 0.3–1.4), 0.5 (95% CI: 0.1–1.0), 0.3 (95% CI: 0.0–0.7), and 0.1 (95% CI: 0.0–0.3) when the quarantine duration was 7, 14, 21, and 28 days, respectively (Fig. 4).

As the disease prevalence increased to 0.005%, the number of missed cases per 100,000 travels in the baseline scenario was projected to be 5.0 (95% CI: 3.7–6.5). Performing PCR testing before departure, upon arrival, or at both time points would reduce the case count to 2.5, 3.0, and 2.1, with 95% CIs of 1.6–3.5, 2.0–4.1, and 1.3–3.0, respectively. Adopting the strategy with a 7-day quarantine followed by post-quarantine testing would further decrease the number of missed cases to 1.1 (95% CI: 0.5–1.8). By comparison, the 7, 14, 21, and 28-day quarantine without testing would lower the number to 4.0 (95% CI: 2.8–5.3), 2.7 (95% CI: 1.8–3.8), 1.5 (95% CI: 0.8–2.3), and 0.5 (95% CI: 0.1–1.0), respectively. Similar trends were observed when the disease prevalence in the country of origin reached the hypothetical peak of 0.01%. Strategies which performed well in the lower-prevalence scenarios continued to substantially reduce the number of missed cases. Particularly, 2.2 (95% CI: 1.3–3.1) cases were missed for the strategy requiring pre-departure PCR testing, a 7-day quarantine, and post-quarantine testing, increasing to 5.4 (95% CI: 4.0–7.0) for 14-day quarantine, and reducing to 1.0 (95% CI: 0.4–1.6) for 28-day quarantine (Fig. 4).

Discussion

Our results demonstrated important reductions in the number of missed cases across all eight border containment strategies compared to the baseline, while quantitatively comparing the effectiveness of varying

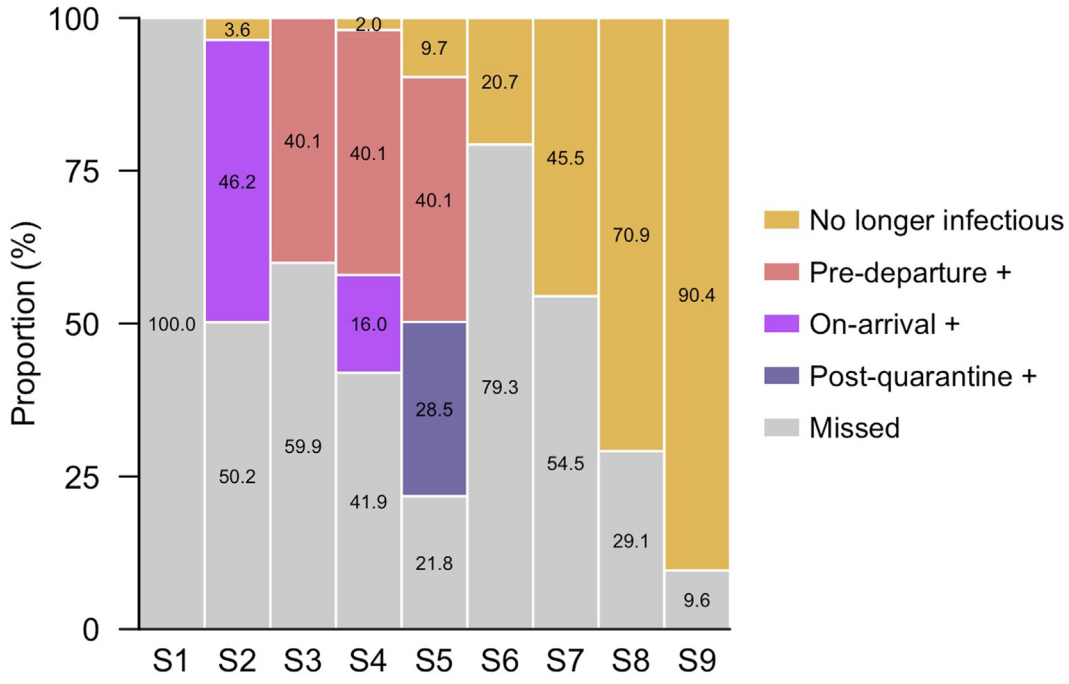

Fig. 3: Proportion of cases missed, detected by PCR tests, and losing infectiousness during quarantine among infected travellers across Strategy 1–9. The five sections in the legend bar represent cases who lost infectiousness during quarantine or when awaiting PCR results ('No longer infectious'), cases testing positive before departure ('Pre-departure +'), upon arrival ('On-arrival +'), and post-quarantine ('Post-quarantine +'), as well as cases missed and leaked into the local community ('Missed'), respectively.

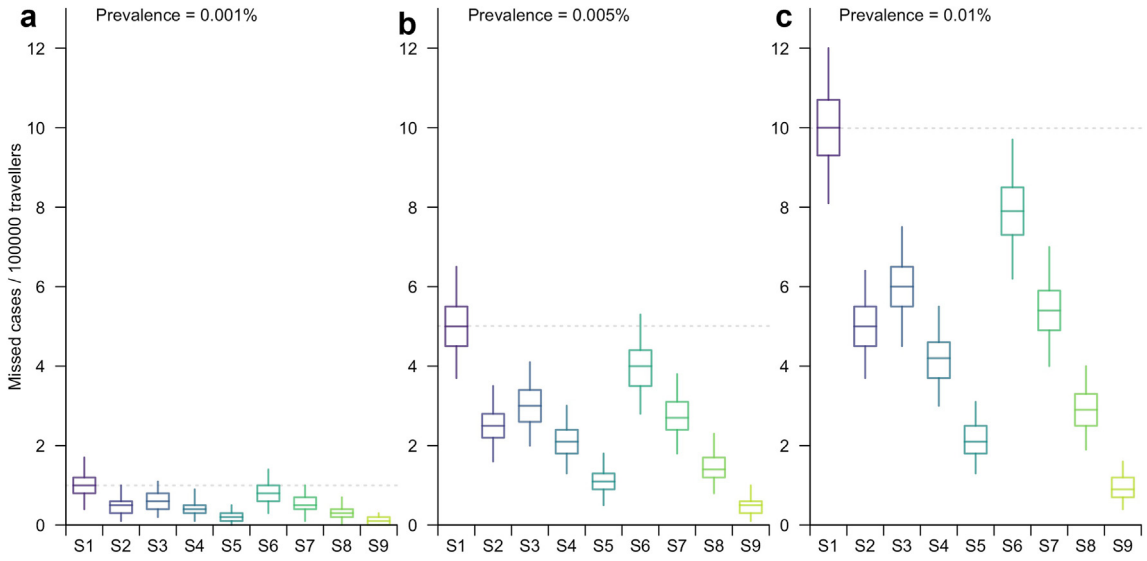

Fig. 4: Number of missed cases per 100,000 travellers. Summary statistics include medians, interquartile ranges, and 95% confidence intervals (CIs) for Strategy 1–9 when the disease prevalence was 0.001% (a), 0.005% (b), or 0.01% (c) in the country of origin. The grey dotted line in such subfigure represents the expected number of missed cases in the absence of intervention.

screening and/or quarantine measures at the border in mitigating the risk of further mpox transmission in the local community. These findings could inform data-driven decision-making whenever border control measures are required to prevent importation and pre-empting subsequent local mpox transmission triggered by importation.

The comparison between timing of PCR testing showed higher effectiveness of on-arrival tests than pre-departure in reducing missed case counts. This difference could be partially attributed to the fact that some infectious arrivals would lose infectiousness during the 3-day quarantine while waiting for test results. These individuals, who were in the late stages of infection, would likely not have been captured by pre-departure screening (Fig. 1). More importantly, the delay in testing allowed the detection of some arrivals who were yet to be symptomatic three days before departure to become infectious by the time they arrived at the border. Postponing testing until 7 days post-arrival would further inflate the number of travellers losing infectiousness or developing symptoms, thereby improving the detection of infectious individuals and lowering the number of missed cases. Meanwhile, the decrease in the number of missed cases for the strategies involving two rounds of PCR testing could also be explained by the reduced likelihood of false negatives, as dual tests would increase chances of detecting infections missed by a single test.[31]

The effectiveness of quarantine was projected to increase linearly with duration. While a 7-day quarantine provided only modest benefits in reducing importation risk, extending the period to 28 days lowered the risk by over 90%. This is primarily due to the long incubation and infectious periods of mpox, often requiring over three weeks from exposure to full recovery.[32,33] Decreasing viral shedding over the infectious period suggests a potential reduction in infectivity and thereby a further decline in the risk of local disease spread after quarantine ends.[34] Beyond containment, the quarantine-only strategies offer several advantages, including minimal demand for PCR testing and associated costs. Existing infrastructure, such as hotels and hostels, can be repurposed to accommodate the incoming travellers,[35] while household-based quarantine coupled with symptom screening at the border emerges as another practical option[36] despite its carrying an increased risk of leakage due to non-compliance (Supplementary Fig. S3). As mpox is primarily transmitted through physical contact or sexual contact, the management of these options is more feasible relative to COVID-19, which was airborne.[37] Nonetheless, the adverse impact of quarantine on individuals' mental health is of concern.[38,39] In addition, adopting long quarantining periods could economically harm many countries that rely on tourism as a major source of national revenue.[39,40] These downsides may collectively make long-duration quarantine unsustainable in the long run.

Through balancing the minimisation of importation size of infected travellers and alleviating the negative secondary effects caused by border restrictions, differentiated border management policies based on prevalence levels in countries of origin can be adopted.[12] The marginal distinctions in effectiveness between various

testing schemes or quarantining, such as single on-arrival testing and 14-day quarantine for arrivals from countries with low disease prevalence, also provides options depending on available testing and isolation facility infrastructure. In contrast, for travellers from countries with higher prevalences (e.g., >0.005%), more stringent approaches, such as a 7-day quarantine followed by post-quarantine screening or a quarantine with a minimum length of 21 days, may need to be employed to minimise the disease importation risk. The continuation of increased efforts and support to estimate outbreak sizes and prevalence in affected countries as part of a robust global surveillance system for real-time monitoring of transmission could facilitate the timely adjustment of countries at risk of exporting infections and their level of risk,[41] which also aligns well with the WHO recommendations on border health and points of entry for mpox.[14]

It should be noted that directly comparing the effectiveness of PCR testing and quarantine requires caution owing to the large uncertainties surrounding the testing sensitivity. At this time, uncertainties lie on the proportion of infections who develop skin rashes, which renders the use of skin lesion swabs that substantially reduce the probability of false negatives.[42] In the main analysis, we assumed this proportion to be 60% but assessed in a subsequent sensitivity analysis how variations in this parameter could influence the effectiveness of border control strategies (Supplementary Figs. S4–S6). When fewer cases presented with skin rashes, PCR testing did not outperform long-term quarantine. Furthermore, the effectiveness of PCR testing could be undermined by fluctuations in accuracy across different testing kits or protocols applied in different locations.[22] Such potential inconsistencies, together with the resource demands of PCR testing, particularly for repeated tests, might make the quarantine-only strategies a more feasible and reliable option in controlling border risks.

Furthermore, assessing the cost-effectiveness of the proposed border control strategies remains challenging. The costs of PCR testing and accommodation can vary substantially across countries and are influenced by supply and demand dynamics. More critically, the secondary infections resulting from importation are difficult to quantify, as contact patterns between travellers and local residents may differ substantially from those within the local population. Much is also unknown on the transmissibility of the current Clade Ib MPXV as well as what the contribution of transmission is through community contact and sexual contact.[9] The potentially high costs and relatively low number of active infections detected compared to travellers screened or quarantined may raise concerns, especially in countries with relatively limited budget for outbreak preparedness. Nonetheless, they do not diminish the importance of implementing border control measures. In practice, both border control and contact tracing measures upon case identification are required to minimise the risk of outbreaks. As border control becomes more robust, fewer cases can enter, providing better healthcare for infected travellers and reducing the risk of local transmission. Ascertaining the payee for such measures in lower income economies does however bring challenges.

Overall, in addition to the increasing national and international mobility, the risk of future large-scale outbreaks in both endemic and non-endemic countries are heightened by the shifting epidemiology of MPXV to sustained human-to-human transmission through both physical and sexual contact among the general population,[43] as well as the waning population immunity from historical smallpox vaccination over time.[44] Such outbreaks, if not intervened promptly, are likely to impose substantial disease burdens due to the high case-fatality rates of mpox.[45] Therefore, countries receiving substantial passenger volumes from those affected by local outbreaks, including the DR Congo and Burundi as of January 2025,[29] may consider the implementation of border control strategies, where the risk of missed cases under each strategy can be estimated by multiplying the simulated number of missed cases per 100,000 travellers in this study with country-specific travel volumes.

There are a few other limitations in our analyses worth noting. These include the uncertainties surrounding key parameters necessary for our simulation model. We relied on existing statistics for Clade IIb MPXV and general MPXV to derive parameters related to mpox infection progression, including distributions for incubation and infectious periods, as well as PCR testing sensitivity, hypothesising that similar patterns would apply to different strains. Assuming the same viral shedding capacity and infectivity between symptomatic infections, we did not explicitly account for asymptomatic infections, but possibilities exist that they were less infectious compared to their symptomatic counterparts, leading to a potential overestimation of infectious missed cases in our simulations (Supplementary Fig. S7). In addition, we assumed that no infections occurred during the travelling period and that the prevalence remained constant in the source countries throughout the simulation window. However, rising case counts in the country of origin may result in a substantial increase in missed infections (Supplementary Fig. S8). In the main analysis, we also presumed complete adherence to quarantine protocols and no-cross infection among quarantined individuals. Although there has been limited evidence that mpox spreads through air, transmission via contaminated surfaces, apart from close contacts, remains possible,[46] making it difficult to rule out this risk.

Despite these limitations, our study provides an evaluation of the effectiveness of nine border control strategies on managing the mpox importation risk across different levels of disease prevalence in the

country of origin. The projected outcomes of the proposed methods, including quarantine and screening at the border, demonstrate the potential of maintaining the risk at a manageable level. The varying intervention effects based on the disease prevalence in the country of origin underscore the imperative of implementing tailored border policies which account for mpox outbreak scales. Such differentiated strategies would help mitigate the negative impacts of interventions on individual well-being, social resources, and the economy, while effectively preventing a potential importation-driven outbreak.

Contributors

SJ, TG, and BLD conceived and designed the study. SJ and TG implemented the statistical analysis and created the figures and tables. SJ wrote the original draft of the manuscript. TG, AE, GG, AJ, GH, KE, JTL, BLD reviewed and edited the manuscript.

Data sharing statement

Source data and analytical scripts are available at https://github.com/ShihuiJin/mpox_border.

Declaration of interests

We declare no competing interests.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lansea.2025.100565.

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