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Assessing exit screening of SARS-CoV-2 in Japan: an analysis of the airport screening data of passengers from the United Kingdom, 2020–2022

Shiqi Liu¹, Asami Anzai¹ and Hiroshi Nishiura^{1,2*}

Abstract

Background Japan implemented strict border control measures and all incoming passengers were subject to entry screening with reverse transcription–polymerase chain reaction or antigen testing. From late 2020, exit screening within 72 h of departure to Japan also became mandatory. In this study, we evaluated the effectiveness of the exit screening policy in Japan by analyzing airport screening data from October 2020 to April 2022.

Methods In addition to assessing entry screening data over time of passengers from the United Kingdom, we examined the prevalence of coronavirus disease 2019 (COVID-19) in the United Kingdom based on the Office of National Statistics infection survey. We constructed a statistical model that described entry screening positivity over time using Office of National Statistics prevalence data as the explanatory variable. Ideally, the time-dependent patterns of entry screening and Office of National Statistics prevalence data should resemble each other; however, we found that, sometimes, they were different and regarded the difference to statistically partly reflect the effectiveness of exit screening.

Results The average proportion positive in one month before mandatory exit screening was implemented among Japanese passengers was 0.67% (95% confidence interval [CI]: 0.45, 0.98), whereas the proportion positive decreased to 0.49% (95% CI: 0.21, 1.15) in the first month of exit screening. Adjusting for time-dependent prevalence at the origin, we concluded that exit screening contributed to reducing passenger positivity by 59.3% (95% CI: 19.6, 81.3). The overall positivity values among passengers during the Delta and Omicron variant periods were 3.46 times and 1.46 times that during the pre-Delta variant period, respectively.

Conclusions We used a simplistic statistical model and empirical data from passengers arriving in Japan from the United Kingdom to support that exit screening helped to reduce the proportion positive by 59%. Although the proportion positive later increased considerably and precluded preventing the introduction of imported cases, submitting a certificate for a negative test result contributed to reducing the positivity among travelers.

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Keywords Severe acute respiratory syndrome coronavirus 2, Border control, Quarantine, Travel, Statistical estimation, Effectiveness

Background

In response to the coronavirus disease 2019 (COVID-19) pandemic that led to a substantial epidemiological burden, countries worldwide adopted considerably different intervention approaches. In particular, the strictness of border control policies varied considerably by region and country, and ranged from total border closure and quarantine of all incoming travelers to only a brief screening of travelers [1–3]. As population-wide vaccination progressed, interference with the freedom of movement gradually ceased or was occasionally coupled with the request for vaccine certificates [4–6]. However, the remaining border control measures were maintained throughout the pandemic until at least early 2023, particularly in countries in the Western Pacific region [7].

Screening travelers at international borders is a less intrusive border control measure than travel bans, regardless of the means of transportation (i.e., air, sea, or land) [8]. Screening is divided into exit screening, which occurs at the origin, and entry screening, which occurs at the destination. In Japan and many other countries, exit screening for COVID-19 required passengers to submit a certificate for a negative real-time reverse transcription-polymerase chain reaction (RT-PCR) or antigen test result carried out within 72 h before the departure time [9, 10]. At the beginning of the pandemic, entry screening primarily consisted of thermal scanning [11]. However, entry screening was soon substantially strengthened by combining thermal scanning with symptom checks on arrival and RT-PCR or antigen testing, either immediately on arrival or within a few days after arrival [12, 13].

Although many countries imposed mandatory exit screening, little is known about the quantitative performance of such screening. In a limited number of studies, researchers used epidemiological or simulation-based approaches to evaluate the effectiveness of exit screening [11, 14–18]. The results of a simulation study indicated that the population-level transmission risk from importation decreased when anterior nasal polymerase chain reaction (PCR) testing occurred within 3 days before departure [14]. Similarly, another study indicated that a 10–29% decrease in transmission risk was observed when testing 3 days before travel was implemented [15], whereas testing on the day of travel resulted in a more significant reduction of 44–72%. From March 20 to September 3, 2022, pre-departure testing was associated with a 52% reduction in post-arrival severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) positivity in the United States [16], and the strategy of conducting rapid antigen testing immediately before departure was

shown to be associated with reducing the proportion positive by 37.4–46.7% on arrival [17]. A United Kingdom (UK) study showed that pre-flight testing reduced the number of infectious travelers entering the community, with a relative risk of 0.69 compared with the risk of no testing either before departure or after arrival [18]. However, few studies inferred effectiveness from actual exit screening data; the shortage of such empirical evidence is attributable to the difficulty in connecting exit screening at the origin to the identification of infections at the destination.

In this context, Japan is one of the countries that implemented several border control measures, primarily at three designated international airports, that is, Tokyo-Narita, Tokyo-Haneda, and Kansai, which were then gradually expanded to other airports. From March 2020 to December 2022, all foreign visitors were required to enter the country at one of these airports, and all incoming passengers, including Japanese citizens, were subject to testing (mostly using real-time RT-PCR and antigen testing from late July 2020) as part of entry screening on arrival. Moreover, to fly to Japan, all foreign visitors were required to submit a negative test certificate as part of exit screening. Japanese nationals were exempt from exit screening until late 2020; however, given the high positivity rate during entry screening, submitting a certificate for a negative test result also became essential in January 2021 for Japanese nationals [9]. Such an abrupt policy change offered the opportunity to explicitly estimate the effectiveness of exit screening. In contrast to some nations that experienced a prolonged (i.e., for several consecutive weeks) absence of visitors, a consistent influx of travelers from the UK entered Japan during this period [19]. Moreover, a country-wide prevalence survey that was jointly conducted by the Office of National Statistics (ONS) in the UK and university researchers from April 2020 yielded a gold standard estimate of the prevalence of infection in the UK throughout the pandemic [20, 21]. The ONS infection survey results can be assumed to mirror the risk of infection among UK residents, including those flying to Japan over time.

We evaluated the effectiveness of the exit screening policy imposed by the Japanese government on passengers arriving from other countries by analyzing the airport screening data of passengers entering Japan from the UK between October 2020 and April 2022.

Methods

Brief description of the border control policy in Japan

From September 1, 2020, (Table 1) to enter Japan, foreign nationals were required to undergo exit screening, which involved presenting a certificate of a negative RT-PCR or quantitative antigen test result obtained within 72 h before departure. The sample collection methods were nasopharyngeal swabs, saliva, nasopharyngeal and oropharyngeal swabs, or nasal swabs. Japanese nationals were subjected to the same requirement from January 13, 2021 (Fig. 1A). Japanese nationals were additionally mandated to undergo exit screening given the emergence of the Alpha variant (B.1.1.7), which had higher transmissibility than the previous variant [13]. Entry screening of arriving passengers was conducted continuously from May 16, 2020 [22]. In addition to the screening policy, changes to entry and residence permit rules were made

Table 1 Airport screening policy and border control measures from September 2020 to March 2022 in Japan

9/1/2020	The prohibition of re-entry* of foreign nationals holding residence permit in Japan was temporarily lifted, and submission of a certificate of negative RT-PCR testing was mandated for this group.
10/1/2020	New entry [#] of foreign nationals was temporarily permitted, and submission of a certificate of negative RT-PCR testing was mandated for this group.
12/24/2020	The new entry of foreign nationals from the United Kingdom was prohibited.
12/26/2020	Quarantine at the designated facility was enforced, and testing was conducted on the third day after entry.
12/27/2020	A certificate of negative pre-departure RT-PCR test result was mandated for Japanese nationals returning from the United Kingdom.
12/28/2020	The new entry of foreign nationals from all countries was prohibited.
1/13/2021	A certificate of negative RT-PCR test result was mandated for all travelers including Japanese and foreign nationals.
6/4/2021	Quarantine at the designated facility for 6 days was enforced, and testing was conducted on the third and sixth days after arrival.
10/01/2021	A vaccination passport [§] was requested for all travelers.
11/8/2021	The new entry of foreign nationals from all countries was permitted.
11/30/2021	The new entry of foreign nationals from all countries was stopped.
11/30/2021	The vaccination passport policy was canceled.
3/1/2022	The new entry of foreign nationals from all countries was permitted.

*The re-entry policy applied to foreign nationals holding a residence permit in Japan and allowed them to return to and enter Japan after their temporary exit to travel to a country other than Japan

[#]New entry refers to the entry permit to Japan among foreign nationals traveling to Japan for the first time under their current visa category. The tourist visa was suspended throughout the study period

[§]Vaccination passports altered only the duration of quarantine among passengers arriving in Japan

that corresponded with the dynamically changing number and infection risk among passengers entering Japan. For instance, new entry was suspended for an extended period of time during the pre-vaccination period (Table 1).

Once the rollout of primary series vaccination became widespread, Japanese government launched a vaccination passport policy. Whether a passenger had a vaccination passport did not influence the individual's entry to Japan, but did help to relax the duration of quarantine.

Epidemiological dataset

Japan allowed international arrivals and departures mostly via three international airports—Narita, Haneda, and Kansai—during most of the course of the COVID-19 pandemic (i.e., from 2020 to 2022). All passengers arriving in Japan regardless of nationality were subjected to RT-PCR testing or antigen testing on disembarkation and before immigration inquiry. During testing, all passengers were asked to immediately provide sputum in a tube container and self-collected saliva samples were sent to a testing center located in each international airport. All passengers were asked to remain in a waiting space in the airport until their test results were available. Approximately 1–2 h or more were required to obtain results, depending on the volume of passengers arriving. Travelers who tested negative were allowed to proceed to the immigration gate. If positive, travelers were guided to a quarantine station (i.e., hotel facilities or hospitals) to self-isolate. In Japan, movement restrictions were enforced on passengers seated on the same plane within two rows in front of and two rows behind the positive passenger, regardless of the laboratory testing results.

In this study, we used the aforementioned entry screening results in Japan that were reported by the Ministry of Health, Labour and Welfare for the period from October 4, 2020 to April 23, 2022 [19]. The total number of tests and number of positive tests were recorded weekly by nationality (i.e., for Japanese and other passengers). However, in the entry screening results for flights from the UK to Japan, detailed information regarding flight connections and the specific nationality of each traveler beyond Japanese nationals was unavailable. Therefore, we had to impose an assumption that “other” travelers mostly included people who held a UK passport.

In addition to examining airport screening data, we investigated the prevalence of SARS-CoV-2 infection in the UK. The estimated prevalence data were retrieved from the Coronavirus (COVID-19) Infection Survey, which is openly available on the ONS website [20]. Weekly prevalence in England was used to represent the proportion positive among both Japanese and English visitors flying to Japan because the dataset for Northern Ireland and Scotland was available only as aggregated

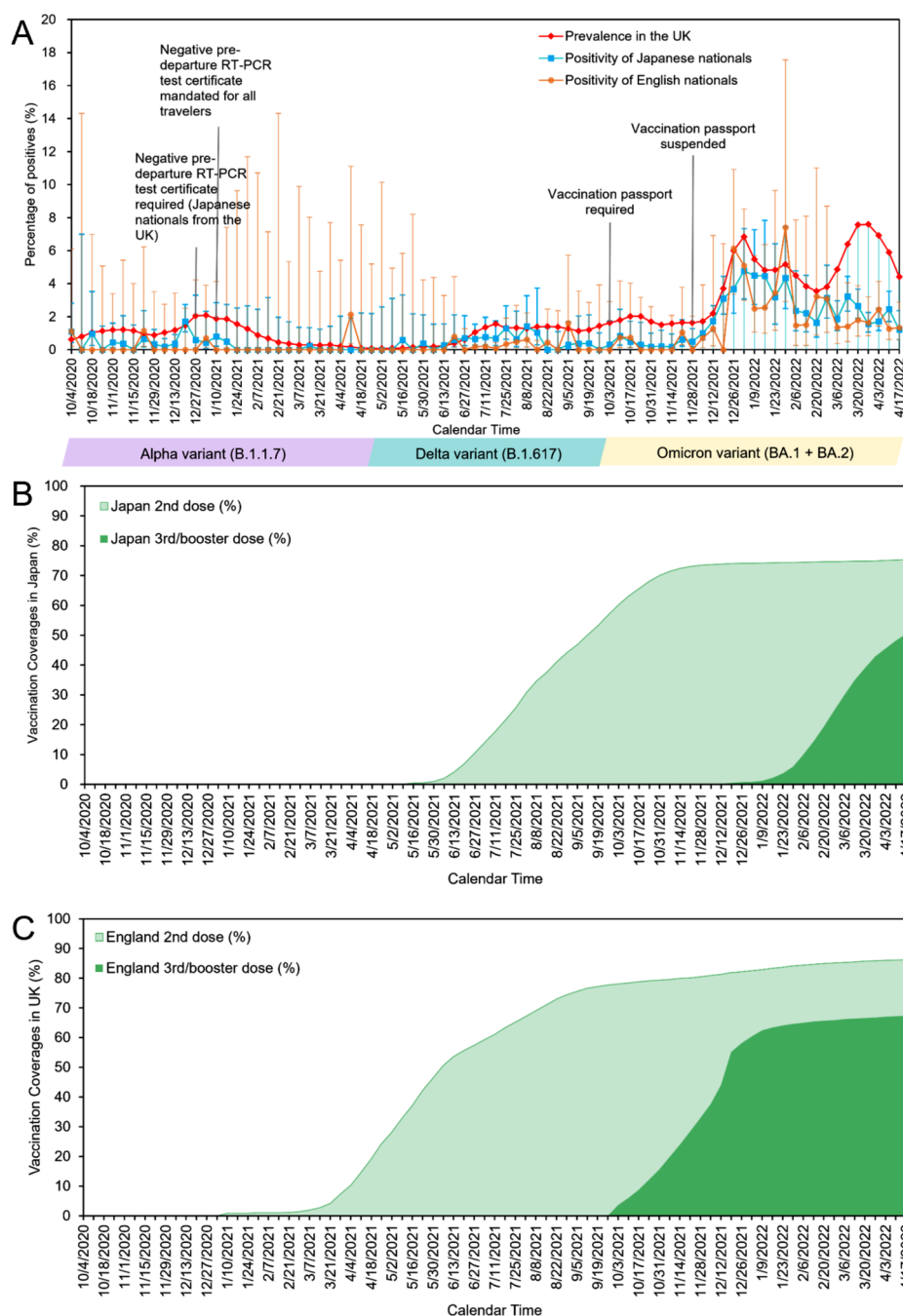


Fig. 1 Entry screening data for English and Japanese passengers at the Japanese border overlaid with the estimated prevalence of SARS-CoV-2 in the United Kingdom from the Office of National Statistics infection survey, 2020–2022. **(A)** The orange line represents weekly positivity based on real-time reverse transcription-polymerase chain reaction testing of all incoming English passengers entering Japan from the UK. The blue line represents the positivity of Japanese passengers arriving from the UK, whereas the red line indicates the weekly estimated prevalence of coronavirus disease 2019 from the ONS infection survey. Whiskers denote the 95% CI computed using the Wilson score method for each observation point, with corresponding colors for clarity. Travel policies in Japan are indicated on the chart. The three-color bar at the bottom represents the level of dominance of the Alpha, Delta, and Omicron variants of the severe acute respiratory syndrome coronavirus in the UK. **(B)** Weekly COVID-19 vaccination coverage in Japan for the second and third (booster) doses. Light green indicates the second-dose coverage from May 2021 and dark green represents the third-dose coverage, which began in December 2021. **(C)** Weekly COVID-19 vaccination coverage in the UK for the second dose and the third (booster) dose. Light green reflects the second-dose coverage from January 2021 and dark green represents the third-dose coverage, which began in September 2021

biweekly data in October 2020. Information on vaccination coverage for Japan and the UK was derived from the Japanese vaccination record system [23] and the UK Health Security Agency [24], respectively.

Statistical estimation of exit screening effectiveness

The epidemiological dataset contained weekly records of administered RT-PCR tests and the number of confirmed SARS-CoV-2-positive cases on arrival. These records allowed the calculation of the positivity rates for both English and Japanese passengers traveling from the UK. To derive the prevalence of SARS-CoV-2 infection in the UK, we divided the weekly ONS estimates of the average number of individuals who tested positive for SARS-CoV-2 in England by the total population of England estimated by the ONS for the year 2021. As the number of healthy samples in the ONS survey was maintained in the UK, we assumed that the testing frequency in England remained sufficiently high over the course of time. We regarded the observed traveler population at airports as if it were a random sample from the general population; hence, travel took place statistically independent of infection. This allowed us to impose the essential assumption that the observed positivity rate in Japan's airports was proportional to the prevalence of SARS-CoV-2 infection in the UK, $x(t)$ in week t , where t represents the number of weeks that elapsed from October 4, 2020 (thus, Week 13 contained December 27, 2020, when Japanese travelers from the UK were mandated for exit screening). Moreover, we introduced a constant scaling factor α , which corresponds to the proportionality of airport positivity in Japan to the ONS prevalence data, and another relative positivity parameter σ for Japanese travelers compared with English travelers. We modeled positivity $p(t)$ in week t among Japanese travelers arriving from the UK as

$$p(t) = \begin{cases} \alpha\sigma x(t), & (t \leq 12; 4Oct - 26Dec2020) \\ (1 - \epsilon)\alpha\sigma x(t), & (13 \leq t \leq 30; 27Dec2020 - 1May2021) \\ (1 - \epsilon)\alpha\sigma\delta(1 - \beta y_{j2}(t))x(t), & (31 \leq t \leq 61; 2May - 4Dec2021) \\ (1 - \epsilon)\alpha\sigma\delta\omega \\ \{1 - \beta_3[y_{j2}(t) + y_{j3}(t)(1 - \beta_3)]\} & (62 \leq t \leq 81; 5Dec2021 - 23Apr2022) \\ x(t), & \end{cases} \quad (1)$$

where ϵ represents the effectiveness of the exit screening. Hence, we multiplied the relative reduction $((1 - \epsilon))$ by the observed positivity from Week 13. We assumed that the proportion positive on entry was elevated by a constant factor δ when the Delta variant (B.1.617.2) began to spread in the UK in early May 2021 (Week 31). At approximately the same time, Japan started its vaccination campaign for the second dose. $y_{j2}(t)$ and $y_{j3}(t)$ represent the time-dependent fractions of the second-dose and third-dose (booster) vaccination coverage, respectively, among the Japanese, as shown in Fig. 1B, and β represents the effect of vaccination on positivity

among travelers, which is not identical to the biological concept of “vaccine efficacy” or the epidemiological term “vaccine effectiveness,” which are unique causal impacts. Our vaccine effect represents the vaccine-induced relative changes in positivity among travelers, which is prone to various biases (e.g., vaccinated people are more likely to be mobile and have a greater number of contacts than unvaccinated people). We measured the vaccination effect during the Delta variant dominant period by multiplying β by the time-dependent coverage of the second dose. The Omicron variant (B.1.1.529) began to spread in December 2021 (Week 62) [25] and passengers became more likely to be positive than before on entry. We described the elevated relative proportion by a constant factor ω . As the vaccination effect is considered to have been altered by entry into the Omicron variant dominant period, we introduced another parameter β_3 and multiplied it by the third-dose (booster) vaccination coverage. We modeled positivity $b(t)$ among English passengers arriving at the airport from the UK as

$$b(t) = \begin{cases} (1 - \epsilon)\alpha x(t), & (t \leq 14; 4Oct2020 - 9Jan2021) \\ (1 - \epsilon)\alpha(1 - \beta y_{e2}(t))x(t), & (15 \leq t \leq 30; 10Jan - 1May2021) \\ (1 - \epsilon)\alpha\delta(1 - \beta y_{e2}(t))x(t), & (31 \leq t \leq 52; 2May - 2Oct2021) \\ (1 - \epsilon)\alpha\delta\{1 - \beta[y_{e2}(t) + y_{e3}(t)(1 - \beta)]\}x(t), & (53 \leq t \leq 61; 3Oct - 4Dec2021) \\ (1 - \epsilon)\alpha\delta\omega\tau\{1 - \beta_3[y_{e2}(t) + y_{e3}(t)(1 - \beta_3)]\}x(t), & (62 \leq t \leq 81; 5Dec2021 - 23Apr2022) \end{cases} \quad (2)$$

Exit screening among non-Japanese travelers began on September 1, 2020, which was earlier than the obtainable data period. Given that exit testing occurred in the same country (the UK), we also represented the effectiveness of exit screening among English passengers by ϵ . The time-dependent second-dose vaccination coverage $y_{e2}(t)$ in the UK began to increase from the week of January 10, 2021, as shown in Fig. 1C, which reflects the national vaccination program that began in December 2020, approximately 3–4 months earlier than in Japan. The third-dose vaccination rollout in the UK $y_{e3}(t)$ started in September 2021 (Fig. 1C), approximately 2–3 months earlier than in Japan [26–28]. Equations (1) and (2) did not account for the leaky or partial effect of vaccination. Additionally, although the vaccination effect of our model does not purely measure the causal impact of vaccination, the formulation of beta with the third dose is in line with the all-or-nothing assumption. When the Omicron variant became widespread, the UK government decided not to impose population-wide restrictions to suppress transmission [29], and on February 21, 2022, the UK government explicitly announced the relaxation of its suppression policy [30]. Rapidly growing risk was recognized in Japan, and the Japanese government decided to prohibit new entry again from December 2021 (new entry was temporarily allowed for a few months prior to the closure). Because of this change, the characteristics

of foreign passengers arriving in Japan during the Omicron variant period may have changed, whereas Japanese passengers remained unchanged, and we assumed that the change was captured by a constant factor τ . During the pandemic, Japanese passengers were primarily business travelers who had brief stays in the UK. Thus, we assumed that vaccination coverage in Japan captured coverage among Japanese travelers.

We assumed that a positive entry screening result was a binomial sampling process for each week and used the maximum likelihood method to obtain parameter estimates that governed Eqs. (1) and (2). We considered the likelihood that used Eq. (1) and the likelihood that used Eq. (2) to be conditionally independent, and obtained the total log-likelihood as the summation of these likelihoods. We determined the 95% confidence intervals (CIs) of the parameters using the profile likelihood and calculated the 95% CI of the passenger positivity rate using the Wilson score method. We calculated the 95% CIs of the model prediction using the bootstrap method.

The final models are presented as Eqs. (1) and (2). We compared Akaike's information criterion with those of other models to identify the best-fit explanatory model. Specifically, we modeled prevalence in an alternative manner by considering the impact of the vaccination passport policy on both Japanese and English travelers (i.e., we multiplied the risk by an additional constant parameter c during week $53 \leq t \leq 61$, i.e., October 3 to December 4, 2021).

Results

Figure 1A shows COVID-19 positivity over time among English and Japanese passengers overlaid with data for the prevalence of SARS-CoV-2 infection in England that we obtained from the ONS infection survey data. From October 4, 2020 to April 23, 2022, 36,484 Japanese nationals and 14,298 English nationals who departed from the UK underwent entry screening. Of these, 449 Japanese and 114 English nationals tested positive on entry screening. The overall positivity was 1.23% (95% CI: 1.12, 1.35) among Japanese nationals and 0.80% (95% CI: 0.66, 0.96) among English nationals.

Exit screening became mandatory for Japanese travelers on December 27, 2020. The average proportion positive among Japanese passengers during the month before mandatory screening was 0.67% (95% CI: 0.45, 0.98), whereas the proportion decreased to 0.49% (95% CI: 0.21, 1.15) in the first month of exit screening, which yielded a crude absolute risk reduction of 0.18% points and risk ratio of 0.74 (95% CI: 0.29, 1.92). The data we obtained only covered the period after English nationals underwent exit screening, which made it impossible to estimate a similar risk ratio among English nationals.

Figure 2 illustrates the predicted and observed positivity on entry screening using Eqs. (1) and (2). Japanese and English travelers had a similar time-related pattern of positivity. The ONS data indicated that airport screening results among English travelers demonstrated prevalence that was 0.38 times (95% CI: 0.20, 0.71) the ONS prevalence; and positivity among Japanese travelers was 1.43 times (95% CI: 0.84, 2.49) that among English travelers. However, when the Delta variant emerged, overall positivity among both Japanese and English was 3.46 times (95% CI: 1.72, 7.50) that during the pre-Delta variant period. Positivity during the Omicron variant period was 1.46 (95% CI: 0.93, 2.30) times that during the pre-Delta variant period. When the Omicron variant was widespread and new foreign entrants were refused entry into Japan again, positivity among English passengers became 1.93 times (95% CI: 1.07, 3.55) that among Japanese travelers. The estimated effectiveness of exit screening was 59.3% (95% CI: 19.6, 81.3) for the entire study period. The results showed that vaccination contributed to reducing infections. The estimated coefficient for the vaccine effect, which we multiplied by vaccination coverage, was 1.00 (95% CI: 0.69, 1.16) before the circulation of the Omicron variant. We considered that the primary series did not significantly contribute to lowering risk among passengers arriving in Japan. When Omicron emerged and was widespread, the estimated coefficient was 0.72 (95% CI: 0.52, 0.87). The effect of the vaccine was more efficient during the Delta variant period than the Omicron variant period.

Table 2 compares the results of the main model and another model using Akaike's information criterion. The best-fit model is described above. Model No. 2 indicated that the vaccination passport policy did not have a significant risk-reducing effect on positivity and the estimated coefficient was 1.18 (95% CI: 0.53, 2.48). As indicated by the best-fit model (Model No. 1), relying solely on the vaccination effect during the Delta and Omicron variant periods, along with exit screening and changes associated with the variant, was sufficient for describing the time-varying proportion positive among passengers arriving in Japan. Supplementary Table S1 shows the parameter estimates.

Model 1 is the baseline model described as Eqs. (1) and (2). Parameter c represents the effectiveness of the vaccination passport policy (i.e., an additional parameter was multiplied for week $53 \leq t \leq 61$).

Discussion

In this study, we evaluated the effectiveness of the exit screening policy in the UK using entry screening data in Japan. We demonstrated a consistent time-dependent pattern between the entry screening data and the ONS data from the infection survey conducted in the UK.

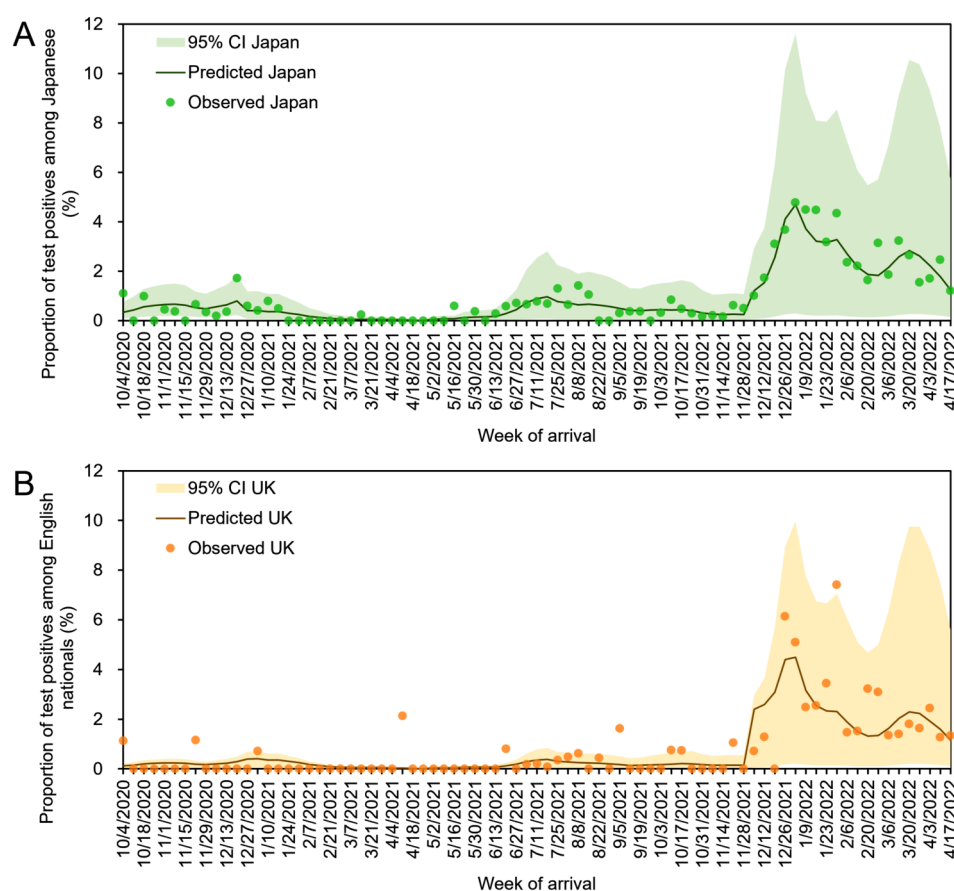


Fig. 2 Comparison of observed and predicted positivity of entry screening in Japan, 2020–2022. **A.** The line shows the predicted proportion of positive tests among Japanese passengers overlaid with dots representing the observed entry screening positivity over time. The shaded light green area represents the 95% CI (bootstrap method) of predicted positivity. **B.** Similarly, the line illustrates the predicted proportion of positive tests among English passengers overlaid with observed entry screening positivity over time. The shaded light yellow area represents the 95% CI (bootstrap method) of predicted positivity

Table 2 Comparison of models for positivity on entry screening among travelers to Japan

No.	Number of parameters	Model	Akaike's information criterion value
1	8	Main model	5758.9
2	9	Main model plus vaccination passport	5760.7

The smaller the values of AIC, the better the fit of the model to the observed data

Exit screening was underway when the prevalence of the ONS data considerably surpassed that observed in entry screening, which indicates a substantial risk reduction from exit screening. Given the inconsistent time patterns, we used a statistical model to describe prevalence at entry screening that accounted for the estimated 59.3% (95% CI: 19.6, 81.3) effectiveness of exit screening. Our model estimates captured the observed positivity pattern

from October 4, 2020 to April 23, 2022, which encompassed the period in which the Alpha, Delta, and Omicron variants were dominant.

This is not the first study in which researchers quantified the effectiveness of exit screening for COVID-19; however, it is the first in which researchers evaluated the effectiveness of such screening by focusing on the UK and exploiting the long-term dynamics of COVID-19 in both the origin country (using ONS infection survey data in the UK) and the destination country (using universal testing data gathered on entry to Japan). Using a simplistic model, we showed that exit screening contributed to reducing passenger positivity by 59.3%. Despite this, the Delta and Omicron variants elevated prevalence among travelers by 3.46 times and 1.46 times that during the pre-Delta variant period. The latter result may reflect the well-known capacity of the Omicron variant to escape existing immunity in the population [31–33] and its short mean generation time of 2–3 days [34]. Clearly, we ignored the small time gap for the replacement of the

variant and our model remained very simplistic, with instant replacement. Our model still successfully demonstrated that exit screening within 72 h before departure during the dominance of the Omicron variant was not very effective in reducing infection among travelers.

Positivity among passengers never exceeded the prevalence of infection in the ONS data over time. This finding may reflect the lower overall risk propensity of travelers compared with the general population. Kucharski et al. [35] showed that if testing was conducted both at departure and arrival, passengers arriving with infections represented only a subset of individuals who may have been infected and attempted to travel. In our study, we used a scaling factor α to adjust for the difference in the overall gap between the ONS prevalence data and positivity in Japan. Despite a lowered positivity for individual travelers, overall positivity was kept high as the number of travelers increased, as was the case during the period in which the Omicron variant was dominant.

Exit screening alone was the only factor in our model that explained a consistent reduction in the proportion positive throughout the study. Before our study, published findings explored the optimal timing for implementing RT-PCR or antigen testing as part of exit screening. According to a modeling study by Kiang et al. [14], the most effective approach for reducing onward transmission is to test within 3 days before departure, followed by a post-quarantine test on arrival. In another modeling study, Johansson et al. [15] showed that testing a day before arrival resulted in a 17–35% risk reduction, whereas testing 3 days before arrival yielded a 5–13% reduction in the risk of introduction. Using real-world data, Clifford et al. [18] found that testing a day before travel is more effective in reducing post-arrival transmission compared with testing 4–7 days before travel. Similarly, Chad et al. [17] observed that delays of up to 72 h in obtaining RT-PCR test results led to a high probability (39.2%) of onward transmission, with a modest 4.5% reduction in expected post-arrival transmission. Bart et al. [16] showed that post-arrival test results were 52% less likely to be positive when pre-departure COVID-19 testing occurred within a day. In this study, the recommended timing for testing was 72 h before the departure time; this policy was associated with a 59.3% reduced post-arrival proportion positive among passengers from the UK. The effectiveness was diminished with the Omicron variant and when society was about to be reopened in the UK [36–38]. However, if the time of testing was closer to departure (e.g., 24 h before departure), the published evidence suggests that the positive impact of exit screening may have been observed from 2022.

As a side finding, the vaccination passport policy—the confirmation of vaccination status that facilitated international business and travel—had a limited impact.

Despite the ongoing debate on the ethical and legal issues regarding this subject [39, 40], our analysis suggests that the impact of this policy was relatively restricted. Although vaccination passports can have an additional impact (e.g., enhancing vaccine acceptance [41, 42]), we focused our evaluation to the context of the proportion positive among travelers and examined the effectiveness of the passport policy in reducing the positivity during international travel. Given that the policy facilitated increased international travel, even among infected individuals, it is plausible that the estimated effectiveness in positivity reduction is small or absent. Future studies that evaluate this policy require a set of evaluations that rely on multidisciplinary views and approaches.

Five technical limitations of the study should be acknowledged. First, we did not consider the duration of travel, purpose of travel, flight connections, and passport types of Japanese and English passengers, potentially overlooking critical insights into travel patterns and risks associated with their travel. Second, we did not collect the vaccination history on an individual basis (i.e., we did not capture the vaccination history of negative test entry); thus, we were unable to fully address the link between vaccination and the risk of infection. Third, we solely relied on time-dependent patterns of positivity and ignored the individual heterogeneity of the risk of illness onset (e.g., age, obesity, and underlying comorbidities). Fourth, in addition to analyzing positivity, Japan conducted genome sequencing using samples that were detected at the airport. However, the sequencing results (e.g., in cases infected with variants of concern) were not tied with positivity data at the individual level. Fifth, we acknowledge that the age distributions of infections in the UK may differ from that of travelers, and our assumption of proportionality of entry screening data to ONS prevalence data may be biased. However, even though the overall positivity may be biased, we assumed that the proportionality of time-dependent changes between airport screening data and ONS data held over the course of time, which allowed an estimation of the exit screening impact.

Conclusions

Despite the aforementioned limitations, we believe that we successfully estimated the effectiveness of exit screening in the UK using a simplistic statistical model. Although the proportion positive later increased considerably and precluded preventing the introduction of imported cases, submitting a certificate of negative test result decidedly contributed to reducing positivity among travelers.

Abbreviations

COVID-19	Coronavirus disease 2019
RT-PCR	Reverse transcription-polymerase chain reaction

ONS Office for National Statistics
SARS-CoV-2 Severe acute respiratory syndrome coronavirus 2

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12879-024-09894-w>.

Supplementary Material 1

Supplementary Material 2

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Author contributions

HN conceived the study. LS, AA, and HN participated in the study design. LS and AA collected and analyzed the data. LS, AA, and HN drafted the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data availability

Airport entry screening data for non-Japanese passengers who arrive from the UK are publicly available on the website of the Ministry of Health, Labour and Welfare [19] and in the available supplementary data. We sourced the UK data used in this study from the ONS's Coronavirus (COVID-19) Infection Survey, which is openly accessible on the ONS website [20]. We obtained the vaccination coverage data used in this study for Japan and the UK from publicly available sources—specifically from the Japanese vaccination record system [23] and the UK Health Security Agency [24], respectively. The data sources are acknowledged for their contributions, and we adhered to their respective data-sharing policies and terms of use.

Declarations

Ethical approval and consent to participate

In this study, we used de-identified entry screening data that were provided publicly by the Ministry of Health, Labour and Welfare. Given that our research exclusively relied on publicly accessible data devoid of any personal identification, prior ethical assessment or permission to conduct the study was not required.

Consent for publication

Not applicable.

Competing interests

The authors declare no competing interests.

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RESEARCH

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Evaluation of the exit screening policy among travelers arriving from Asian and Pacific nations

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Abstract

Background The Japanese government has instituted border control measures against COVID-19, including entry and exit screening of people arriving from overseas. We sought to evaluate the effectiveness of the exit screening policy in Japan in reducing the risk of importing COVID-19 cases among travelers from Asian and Pacific countries.

Methods The study period was stratified based on the timing of exit screening: (i) the control period (the pre-exit screening period from 25 October 2020 to 16 January 2021), (ii) the time period with the Alpha variant from 17 January to 10 April 2021, and (iii) the time period with the Delta variant from 2 May to 2 October 2021. Incidence data in the countries of origin were used to adjust for the risk of infection among travelers. The positivity rate of entry screening in Japan was compared among the three different study periods, adjusting for the risk of infection in the country of origin.

Results The adjusted relative risk of positivity was greatly reduced and substantially below the value of 1 during the Alpha variant period compared with the control period. Although the relative risks increased when comparing the Delta variant period against control, the estimate remained below 1, except for among travelers from India and Myanmar. The relative risk reduction was greatest in high-income countries, with estimates of 100% and 96% risk reduction during the Alpha and Delta variant periods, respectively, followed by upper-middle-income countries with estimates of 90% and 76%, respectively.

Conclusions Even in the presence of the Alpha and Delta variants, exit screening clearly reduced the risk of infection among travelers arriving from Asian and Pacific nations. As the testing relies on the country of origin, the effectiveness varied greatly by the socioeconomic income status and epidemiological situation of those countries. Test standardization and quality assurance may be required in low- and middle-income countries.

Keywords Severe acute respiratory syndrome coronavirus 2, Border control, Quarantine, Travel, Statistical estimation, Effectiveness, Southeast Asia, Western Pacific

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Background

The COVID-19 pandemic has led to a substantial decrease in the volume of travel, marked by a significant reduction in airline transportation resulting from the closure of multiple country borders and cancellation of international flights for safety reasons. Simultaneously, various countermeasures for border control have been introduced, aiming to ensure the absence of infection among arriving passengers (as well as departing passengers), while satisfying the need for international travel [1–4].

From March 2020 to December 2022, Japan adopted border control measures; of these, entry screening was carried out primarily at designated international airports—Tokyo-Narita, Tokyo-Haneda, and Kansai, which were gradually increased including Chubu (from June 2020), Fukuoka (from November 2020), Okinawa (from August 2022), and Hokkaido-Chitose (from December 2022). All incoming passengers, including Japanese citizens, were required to undergo testing upon arrival, via real-time reverse transcription-polymerase chain reaction (RT-PCR) testing, and from late July 2020 also by

quantitative antigen testing of saliva specimens, as part of the entry screening process. Beginning in September 2020, Japan initiated a temporary removal of the prohibition on the re-entry of foreign nationals, and at the same time mandated exit screening, i.e., submission of a certificate of negative RT-PCR testing that had been conducted within 72 h of departure [5]. Except for tuberculosis for selected nations and for obtaining residence permit, COVID-19 was the first disease to which exit screening was legally imposed. On 20 December 2020, the detection of the Alpha variant (B.1.1.7) in a traveler arriving from the United Kingdom triggered the swift imposition of further measures, including from 27 December 2020 the requirement for Japanese nationals arriving from the United Kingdom (UK) being required to provide a negative pre-departure test certificate [6]. Given the further development of the epidemic, on 13 January 2021, all passengers, regardless of nationality and origin of departure, were mandated to provide a negative pre-departure test certificate when entering Japan [7]. Detailed time-dependent changes in entry and exit screening measures are described in Table 1.

Table 1 Description of airport screening policy and border control measures against COVID-19 from September 2020 to March 2022 in Japan

Calendar time (Date/ Month/Year)	Event description
1/9/2020	Issued temporary lifting of foreign national re-entry prohibition, but imposing mandatory pre-departure negative RT-PCR testing submission (i.e. exit screening)
1/10/2020	Issued temporary permission for foreign national new entry with mandatory pre-departure negative RT-PCR testing submission (exit screening)
1/12/2020	Detection of the first case infected with Alpha variant from the UK at an airport
2/12/2020	Health follow-up via questionnaires mandated for individuals who have at least a 14-day stay history in Hubei Province or Zhejiang Province, China
24/12/2020	Issued prohibition on new entries (non-visa entry) among UK nationals
26/12/2020	Started mandatory quarantine at a facility nearby airport with post-hoc testing at Day 3
27/12/2020	Issued pre-departure negative RT-PCR testing certificate requirement (exit screening) for returning Japanese from the UK
28/12/2020	Suspension of new entries for foreign nationals from all nations
13/1/2021	Compulsory pre-departure negative RT-PCR testing certificate requirement for all travelers (including Japanese), regardless the country of origin
28/3/2021	Detection of the first case infected with Delta variant from India at an airport
14/5/2021	Issued prohibition on re-entry travelers from India, Nepal, and Bangladesh
4/6/2021	Started six-day quarantine at a facility nearby airport with post-hoc testing at Day 3 and Day 6
20/9/2021	Permission granted for re-entry travelers from India, Nepal, and Bangladesh
1/10/2021	Mandatory vaccination passport (submission certificate of vaccination) requirement for all travelers (otherwise, entry screening followed by quarantine)
8/11/2021	Resumption of new entries for foreign nationals from all nations
30/11/2021	Suspension of new entries for foreign nationals from all nations
30/11/2021	Issued cancellation of vaccination passport policy (submission certificate of vaccination)
1/3/2022	Resumption of new entries among foreign nationals from all nations
26/9/2022	Cancellation of all entry screening testing with regard to COVID-19
27/12/2022	Resumption of COVID-19 entry screening for travelers arriving from China (excluding Hong Kong and Macau) or having the history of stay during the past 7 days
9/1/2023	Requirement of a 72-hour pre-departure certificate and entry screening for passengers from Macau
28/4/2023	Cancellation of pre-departure certificate and vaccination certificate for all incoming passengers. Entry screening for symptomatic individuals from China and other countries was carried out.

While many countries implemented mandatory exit screening [8], little research has been done to quantify the effectiveness of such screening measures. Few studies have employed epidemiological or simulation-based methods to assess exit screening performance. According to one simulation study, anterior nasal PCR testing within 3 days of departure resulted in a 36% reduction in the total number of infectious days (95% confidence interval [CI]: 29–41%) [9]. Another study suggested that testing 3 days before travel led to a 10–29% decrease in the risk of transmission, while testing on the day of travel resulted in a more substantial reduction, by 44–72% [10]. Additionally, rapid antigen testing immediately before departure was associated with a decrease in post-arrival transmission by 37.4–46.7% [11]. From 20 March to 3 September 2022, pre-departure testing ≤ 1 day was linked to a 52% reduction in post-arrival diagnosis of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) in the United States (US) [12]. A study in the UK indicated that pre-flight testing within 24 h reduced the entry of infectious travelers into the community, with a relative risk of 0.69 compared to scenarios with no testing before departure or after arrival [13]. However, few studies have drawn their conclusions from empirically observed exit screening data, and even with the same exit screening strategy (within 24 h), there are likely variations in the performance of exit screening. Also, many

relevant studies have focused on domestic travelers or those within the European Union (EU) or from the US, indicating the need for a comprehensive analysis that could potentially resolve the shortage of evidence from other parts of the globe.

Japan is an East Asian country in the Western Pacific region with close connections and communications to neighboring nations in the Western Pacific and Southeast Asia. Using the entry screening dataset of passengers from Asia-Pacific countries and analyzing the local epidemiological dataset at the origin before and after the exit screening measure, we aimed to evaluate the effectiveness of the exit screening policy in Japan from October 2020 to October 2021.

Methods

Brief description of the border control policy in Japan

Initially, the exit screening policy was different between Japanese citizens and non-Japanese. Starting from 1 September 2020, foreign nationals entering Japan were required to undertake exit screening, presenting a certificate of negative RT-PCR or quantitative antigen testing result carried out within 72 h of departure. Japanese citizens were initially free from the exit screening requirement, but this same requirement later began to be enforced from 13 January 2021 (Fig. 1). In addition, genome sequencing of all positive samples was carried

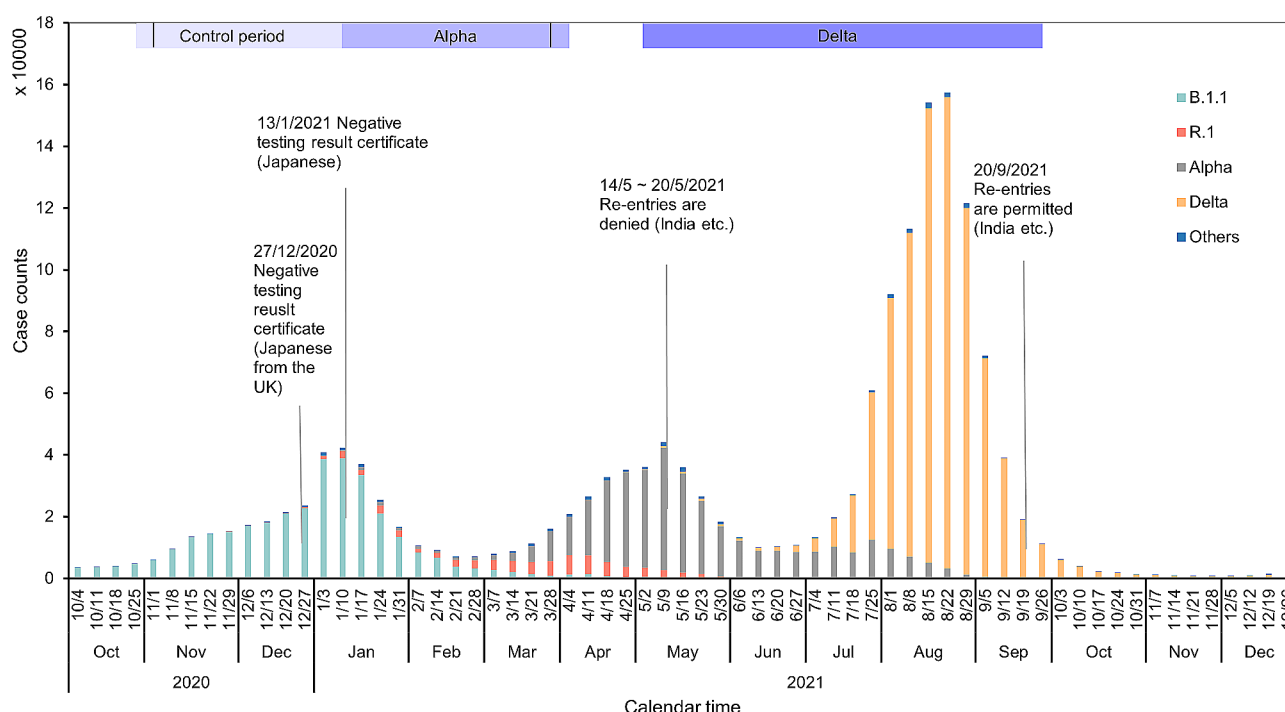


Fig. 1 Epidemic dynamics of COVID-19 in Japan, 2020–21. Border control policy changes were overlaid with variant-proportionated domestic weekly cases in Japan from October 2020 to December 2021. The purple gradient bar at the top represents, from left to right, the control period, the Alpha variant period, and the Delta variant period. The areas between the vertical lines indicate the study periods among foreign travelers. The different colors on the bar represent the proportions of cases attributed to different variants of concern owing to local transmission in Japan

out. The first diagnosis of the Alpha variant, in a traveler from the UK, was made at the airport on 1 December 2020 [14], while the initial diagnosis of the Delta variant (B.1.617.2), in a traveler from India, took place on 28 March 2021 [15] (Table 1).

While the general exit screening policy timeline has been outlined above and in Table 1, there were minor variations among foreign travelers from Asian and Pacific countries. Given the limited risk of infection compared with other countries, non-Japanese from Australia, China, and South Korea, among others, etc. were exempted from presenting pre-departure test result certificates for an 11-week period from 1 November 2020 until 13 January 2021. Because of their very limited number, foreign travelers from Myanmar were required to undergo exit screening only beginning 1 November 2020. For similar reasons, non-Japanese citizens from Cambodia, Fiji, Laos, Mongolia, and Sri Lanka were only required to provide the certificates starting from 13 January 2021 (Supplementary Figure S1).

Epidemiological dataset

All arriving passengers entering Japan, regardless of nationality and origin of departure, were required to undergo immediate RT-PCR or antigen testing upon arrival. The results of the entry screening tests conducted between 4 October 2020 and 23 April 2022 were publicly announced by the Ministry of Health, Labour, and Welfare. Because publicly available entry screening data starts from the time at which exit screening was already underway for non-Japanese travelers, we used entry screening results among Japanese nationals. This provided a control period with no exit screening requirement, i.e., between 4 October 2020 and 13 January 2021. The numbers of tests and positive test results were recorded weekly by nationality (i.e., for Japanese and other nationals) for air flights originating from a certain country [16].

In the present study, the selection of countries in the Western Pacific and Southeast Asian regions followed the World Health Organization classification [17], involving 11 countries in the Southeast Asia region and 37 countries and areas in the Western Pacific region. Of these, 19 countries with zero Japanese travelers and 20 countries with a limited number of travelers and without any positive cases at all were excluded from the analysis. In total, nine countries were subject for country-specific analysis, i.e., China, South Korea, Indonesia, Vietnam, Malaysia, the Philippines, Myanmar, India, and Bangladesh.

In addition to entry screening data, we examined the weekly incidence of COVID-19 in these nine countries, derived from national surveillance records. The daily number of confirmed cases were retrieved from the repository of the Center for Systems Science and Engineering at Johns Hopkins University [18]. The incidence

level at the origin country was regarded as reflecting the prior probability of infection among travelers.

Comparison across time periods

According to the timing of exit screening among Japanese travelers, we defined a control period spanning the 12 weeks from 25 October 2020 to 16 January 2021. The subsequent 12 weeks, from 17 January 2021 to 10 April 2021, were defined as the time period dominated by Alpha variant, coinciding with the enforcement of mandatory exit screening for all Japanese nationals from 13 January 2021 in response to the emergence in the UK [7]. Because exit screening became mandatory for Japanese from 13 January 2021, the week that contains 13–16 January might not strictly be regarded as control. Thus, we also examined the results using an alternative control period for 11 weeks, i.e., from 25 October 2020 to 9 January 2021. Except for India and Bangladesh, the time period dominated by the Delta variant was defined as lasting from 2 May to 2 October 2021 (Fig. 1). As the first Delta variant-infected traveler from India was diagnosed on 28 March 2021, the time period for India dominated by the Delta variant was assumed to have been already established earlier, and the predominant time period of Delta variant was defined as lasting from 11 April to 2 October 2021.

For this evaluation, we calculated unadjusted and adjusted prevalence ratio comparing positivity among travelers between two time periods, i.e., Alpha vs. control and Delta vs. control. As an adjustment factor, the prevalence at the origin country was calculated from the local incidence data obtained from the repository [18] for each period followed by its division by the population estimate in 2021. The prevalence was obtained as a convolution of the incidence and the survivorship function of virus positivity [19]. The relative risk of positive testing among those undertaking exit screening was calculated as the ratio of the adjusted positivity during the period dominated by the Alpha or Delta variant to the adjusted positivity during the control period. The adjusted positivity was defined as the unadjusted positivity (i.e., positivity from entry screening) divided by the cumulative incidence of the country of origin. The effectiveness of exit screening was derived from relative risk reduction, or the one minus adjusted prevalence ratio. The 95% CIs of positivity rates were determined using the Wilson score method. While depicting the relative risk and unadjusted prevalence ratio, their 95% CIs were calculated using the Wald confidence interval.

Sensitivity analysis

In the baseline analysis, the length of the control period without exit screening was fixed as a 12-week long period. To address the uncertainty potentially associated

with this length, we also computed the effectiveness of exit screening, varying its length from 9 to 15 weeks.

Grouped analysis and analysis among foreign travelers

Among countries with non-zero data, we performed a grouped analysis by income level, i.e., the classification of subgroups following the World Bank country classification [20]. In the Southeast Asia and Western Pacific regions, most countries fall into the high-income, upper-middle-income, and lower-middle-income categories. Although there are 48 countries and areas in these regions, not every country was included in the analysis; countries with fewer than 10 weekly Japanese travelers or no Japanese travelers for consecutive weeks were excluded from the selection. Countries that were classified as high-income were Australia, South Korea, New Zealand, and Singapore. Similarly, upper-middle-income countries included China, Fiji, Indonesia, Malaysia, and Thailand. Lower-middle-income countries included Bangladesh, India, Cambodia, Lao PDR, Sri Lanka, Myanmar, Mongolia, Nepal, the Philippines, and Vietnam. Positivity and effectiveness of exit screening were computed for those three groups, using weighted positivity by travel volume.

We performed the same analysis among foreign travelers, focusing on countries that had no requirement for exit screening for non-Japanese citizens during the control period from 1 November 2020 to 13 January 2021. The time periods dominated by the Alpha and Delta variants are dealt with as the same as the analysis among Japanese travelers. This analysis was able to be conducted for China, South Korea and Sri Lanka.

Results

Figure 2 displays the relative risk of positivity during the Alpha and Delta variant dominated periods compared against the control period among the nine countries that were included. When the Alpha variant was dominant (Fig. 2A), the relative risk was generally below one except for India. Five countries, i.e., South Korea, Vietnam, Malaysia, Myanmar, and Bangladesh, showed the expected value of relative risks to be zero. When the Delta variant replaced others (Fig. 2B), the relative risk of infection among Japanese travelers from India and Myanmar exceeded one, although the 95% CI of Myanmar spans from 0.12 to 9.31, and thus, the statistical significance cannot be demonstrated. Conversely, the relative risks for South Korea and China were zero. Among the remaining countries, relative risks were elevated compared with the comparison between the Alpha variant and control period, and in fact, the unadjusted prevalence ratio when the Delta variant was dominant exceeded the value of one among travelers from Indonesia, Philippines, Myanmar, India and Bangladesh. Even when the length

of control period was varied from 9 to 15 weeks, our sensitivity analysis showed that these results remained unchanged (Supplementary Figure S2). The qualitative patterns of orders for relative risk reduction were maintained from Fig. 2. During the period in which the Delta variant was dominant, results consistent with Fig. 2 were again observed, and India showed an absence of reduced risk during the period when exit screening was mandated (Supplementary Figure S3). Even when we removed the week that contained 13–16 January 2021 from control period, our qualitative findings were not altered (Supplementary Figure S4).

Figure 3 illustrates the relative risk reduction via grouped analysis by income levels, comparing the Alpha and Delta variant periods against the control period. When the Alpha variant was dominant (Fig. 3A), the highest relative risk reduction was observed among high-income countries at 100% (95% CI 26.9–100), followed by upper-middle-income countries at 90.4% (95% CI 78.7–95.7). When the Delta variant replaced others (Fig. 3B), the relative risk reduction decreased among all three groups. The high-income group experienced a slightly decreased relative risk reduction at 95.9% (95% CI -112.8–100), followed by upper-middle-income countries at 76.1% (95% CI 61.9–85.0). Although the 95% CI of the high-income group crossed 0%, and thus, the statistical significance cannot be established, the expected values by income status were consistently ordered. The relative risk reduction of lower-middle-income countries was expected to be below 0%, implying that the risk of infection among travelers returning from those countries was not reduced by exit screening. For both periods, the volume of travelers was greatest among those returning from upper-middle-income countries, followed by those returning from high-income countries.

Figure 4 presents the relative risk reduction among foreign travelers arriving from China, South Korea, and Sri Lanka. Comparing the Alpha variant period against the control period (Fig. 4A), the relative risk reductions in China, South Korea and Sri Lanka were 86.9% (95% CI -37.8–98.8), 50.9% (95% CI -404.0–95.2), and 93.7% (95% CI 38.8–99.4), respectively. During the Delta variant period (Fig. 4B), the relative risk reductions in China, South Korea and Sri Lanka were 100% (95% CI 52.7–100), 82.0% (95% CI -105.3–98.4) and 93.1% (95% CI 66.0–98.6), respectively. During the Alpha variant period, the lower 95% CI for China crossed 0%, and for both periods, the lower 95% CI for South Korea also crossed 0%, and thus, the finding cannot be overexaggerated.

Discussion

The present study evaluated the effectiveness of the exit screening policies for COVID-19 among Japanese and non-Japanese travelers arriving from Asian and

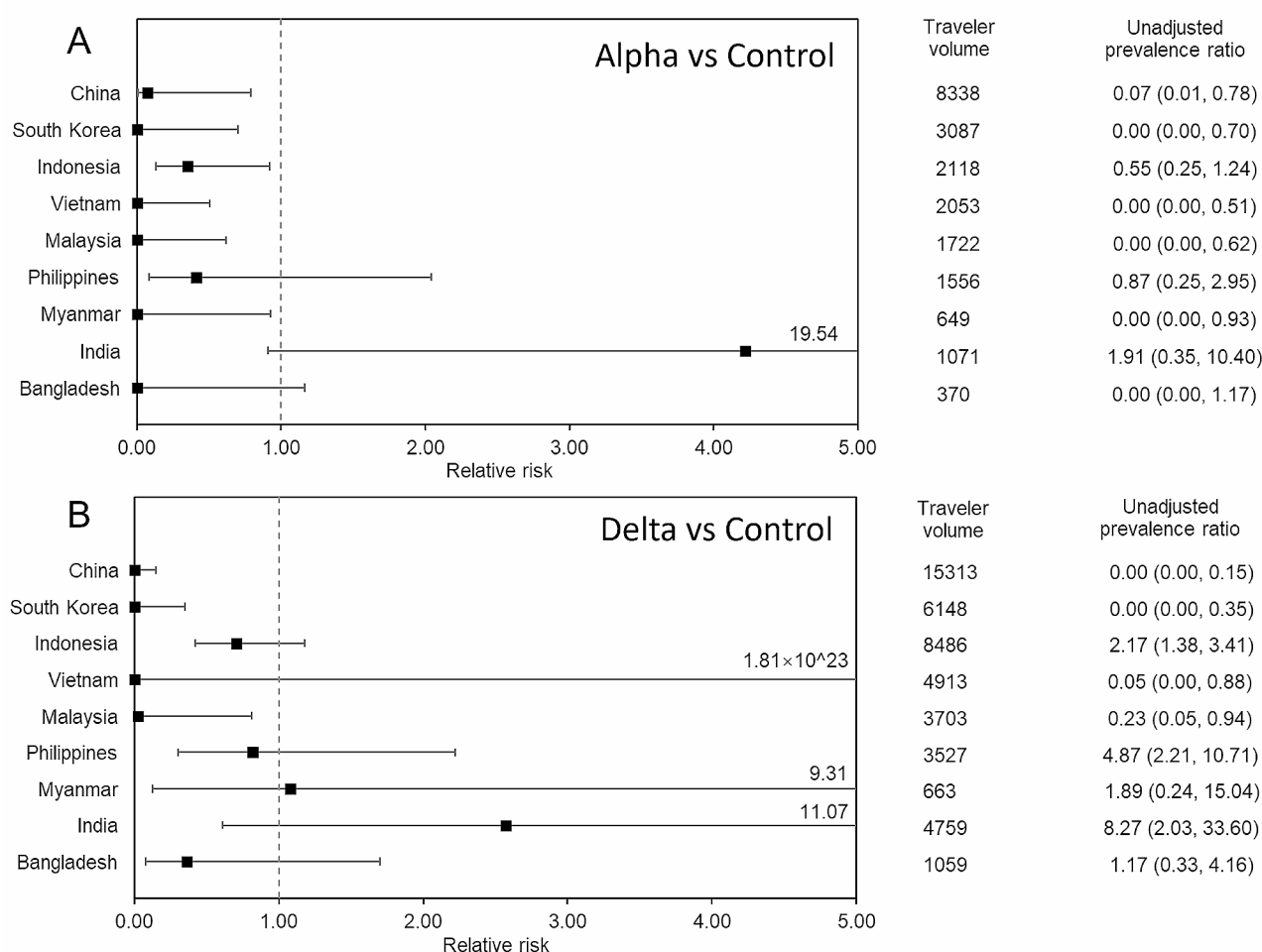


Fig. 2 Relative risks of COVID-19 among Japanese travelers returning from nine countries during the Alpha and Delta periods compared with the control period, 2020–21. Relative risks of nine countries during **(A)** the Alpha variant period and **(B)** the Delta variant period. The risk in these periods with exit screening was compared against the risk during the control period without exit screening practice among Japanese nationals. For both periods, the dashed line signifies a relative risk value of 1 (i.e., no indication of the effectiveness of exit screening). Upper bound values among certain countries are shown as numerical numbers on the whisker. In the unadjusted prevalence ratio columns, values inside parentheses represent the corresponding 95% confidence intervals derived from binomial distribution

Pacific countries using entry screening data in Japan. We defined three time periods, (i) a control period without exit screening, (ii) the Alpha variant dominated period in the presence of exit screening, and (iii) the Delta variant dominated period in the presence of exit screening, comparing origin-incidence adjusted relative risks of the Alpha and Delta variant periods against the control period. The adjusted relative risk decreased well below the value of one during the Alpha variant period, and that during Delta variant period was also generally below one, except for travelers from India and Myanmar. Via exit screening, the greatest relative risk reduction was seen in high-income countries during both the Alpha and Delta variant periods. Upper-middle-income countries also experienced substantial risk reduction, but lower-middle-income countries were not associated with a positive impact of exit screening during the Delta variant period.

To our knowledge, the present study is the first to evaluate the effectiveness of exit screening that is carried out in origin countries, using entry screening results in Japan as the outcome measure. The relative risk reduction of more than 50% for both high-income and upper-middle-income countries is consistent with our foregoing evaluation that focused on the United Kingdom (Liu et al., submitted); using not only entry screening data but also Office for National Statistics COVID-19 infection survey data, the exit screening in the UK was estimated to have reduced the risk of positivity in Japan by 59%. What is notable is that (i) risk reduction via exit screening became more challenging during the Delta variant period than the Alpha variant period, and (ii) depending on the origin country where exit screening was conducted, the risk reduction would be highly variable. As for (i), an elevated transmissibility (and perhaps also a

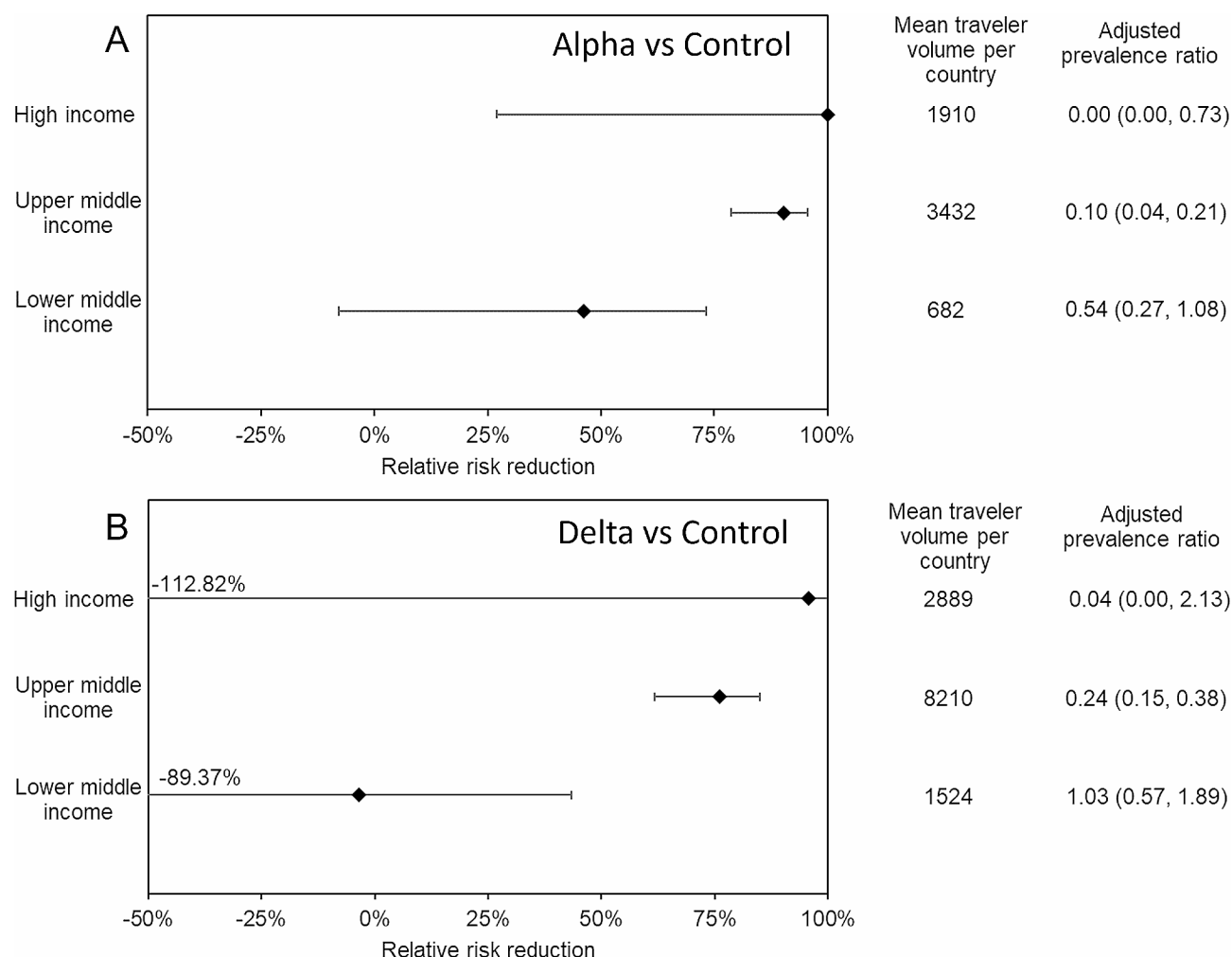


Fig. 3 Relative risk reductions of COVID-19 among returning Japanese by country income level category. Relative risk reductions during (A) the Alpha variant period and (B) the Delta variant period among Japanese travelers returning from high-income, upper-middle-income, and lower-middle-income countries are shown. Extremely small lower bound values for certain countries are shown on the whisker. Within the adjusted prevalence ratio column, values in parentheses indicate the corresponding 95% confidence intervals derived from binomial distribution

shorter incubation period) of the Delta variant compared with the Alpha variant [21–24] may partly explain this difficulty. With respect to (ii), the South Asian countries experienced the largest-ever epidemic caused by the Delta variant [25–27], most notably in India [19, 28–30], and there were substantial number of passengers presenting pre-departure negative test certificates that did not meet testing quality standards; moreover, there were even reports of falsification of pre-departure certificates [31, 32]. Countries with high prevalence tended to yield increased relative risks (i.e. lower effectiveness of exit screening), while countries with low prevalence tended to yield lower relative risks.

How are our estimates of exit screening effectiveness compared against other published evidence? The present study used empirically observed entry screening data collected at airports in Japan, and from January 2021, the country required all travelers to undertake

exit screening via RT-PCR testing conducted within 72 h prior to departure. Preceding simulation or epidemiological studies have investigated the optimal timing for exit screening using RT-PCR or antigen testing. Kiang et al. [9] suggested PCR testing within 3 days of departure, coupled with a post-quarantine test upon arrival, as the most effective strategy for reducing onward transmission. Via a modelling approach, Johansson et al. [10] found that testing a day before arrival resulted in a risk reduction of 17–35%, while testing 3 days before arrival yielded a 5–13% reduction in the risk of introduction. Chad et al. [11] showed that delays up to 72 h in obtaining RT-PCR test results led to a high probability (39.2%) of onward transmission, with a modest 4.5% reduction in expected post-arrival transmission. Bart et al. [12] demonstrated a 52% lower likelihood of positive post-arrival test results when pre-departure COVID-19 testing occurred within a day. Additionally, Clifford et al. [13] reported that

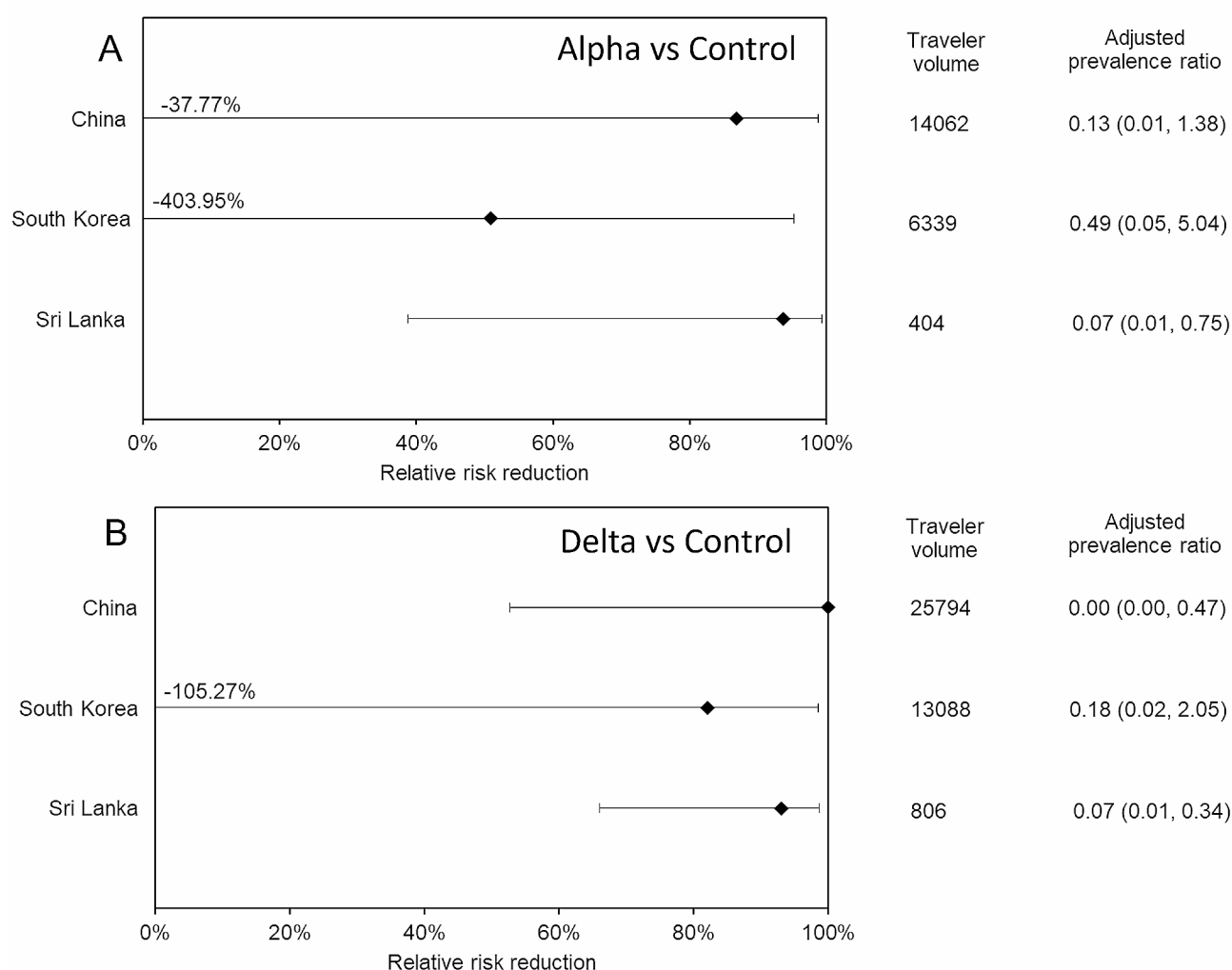


Fig. 4 Relative risk reductions of COVID-19 among non-Japanese travelers arriving from Asian countries, 2020–21. Relative risk reductions during (A) the Alpha variant period and (B) the Delta variant period among non-Japanese travelers arriving from China, South Korea and Sri Lanka are shown. Numeric lower bounds are provided for specific countries with extremely small values, and the adjusted prevalence ratio column includes values within parentheses denoting the corresponding 95% confidence intervals derived from binomial distribution

testing a day before travel was more effective in reducing post-arrival transmission. These findings underscore the importance of tailored testing approaches based on real-world dynamics and transmission probabilities, offering insights for public health strategies. The present study, revealing decreased effectiveness in the Delta period, suggests that for the Japanese government and other public health agencies, the timing for travelers undergoing exit screening may need to be shortened when a more transmissible variant emerges, e.g., within 48 h. Moreover, the method of testing may also be flexible, allowing for the adoption of antigen testing.

The relative risk reduction that we estimated demonstrated the performance of exit screening, but that finding was positively associated with income levels. A critical shortcoming of this finding is that the quality

assurance of exit screening must be made to ensure the effectiveness via a validated testing procedure; this key issue may be deemed problematic when the testing situation in the country of origin is complicated by local factors. For instance, one of the lower-middle-income countries, India, experienced an extremely large increase in the epidemic dominated by the Delta variant, and both the testing capacity and healthcare system itself were likely overwhelmed by massive number of severe cases [33, 34]. Of course, other explanations cannot be excluded. Although high-income countries yielded the greatest relative risk reduction, these countries included Australia, New Zealand and Singapore which had zero-COVID policies during the time period of our analysis, and the lowered risk during the Alpha and Delta variant periods could be explained by the heightened level of

control in those countries [35–37]. The same applies to non-Japanese arriving from China and South Korea with substantial travel volume. They showed a decreased risk of infection, but the control program was strengthened as the variant of concern began to be widespread, and their success in controlling the outbreak with substantial surveillance capabilities at the origin could explain the observed risk reduction [38–41]. Of course, low effectiveness of exit screening among low income countries could also be explained by other factors, e.g. limited capacity of surveillance and low ascertainment rate.

Three technical limitations of the present study should be discussed. First, our primary results were derived among Japanese travelers returning to Japan. This group was selected because of data availability and also the absence of exit screening policy during the control period. If Japanese people tended to strictly undertake exit screening compared with other nations, we may have overestimated the effectiveness of exit screening. Second, individuals who are likely to travel are predominantly healthy, suggesting the lower risk propensity of severity among travelers compared to the general population. This may elevate the risk of infection when free travel is allowed, but under the suppression policies that greatly reduced incidence, healthy travelers may have been less likely to be infected compared with others. In fact, Kucharski et al. [42] demonstrated that positivity at entry screening is likely to be lower than the prevalence at the origin. Thus, using entry screening data as the outcome may have already been relying on a substantially reduced risk of infection, and moreover, our estimate may be quite biased (perhaps overestimated) compared with the policy applied to the entire population. Third, the study did not handle the time period in which the Omicron variant was predominant. Changing characteristics of the epidemiology due to variant replacement and overwhelming pressure of case load demand can alter the ascertainment and also the effectiveness of exit screening. Our results were restricted to 2020–21, and additional insights must be gained by exploring datasets that cover the period after the emergence of Omicron variant.

Conclusions

Despite these limitations, we believe that the present study was successful in evaluating the effectiveness of exit screening policy among travelers arriving from Asian and Pacific countries using entry screening data in Japan. The adjusted relative risk decreased well below the value of one during the Alpha variant period, and that during the Delta variant period was also mostly below one except for India and Myanmar. Via exit screening, the greatest relative risk reduction was seen in high-income countries during both the Alpha and Delta variant periods. Upper-middle-income countries also experienced substantial

reductions, but lower-middle-income countries did not reveal a positive impact of exit screening during Delta variant period.

Abbreviations

CI	Confidence interval
COVID-19	coronavirus disease 2019
RT-PCR	real-time reverse transcription-polymerase chain reaction

Supplementary Information

The online version contains supplementary material available at <https://doi.org/10.1186/s12879-024-09327-8>.

Supplementary Material 1

Supplementary Material 2

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Author contributions

HN conceived the study. LS, AA, and HN participated in the study design. LS and AA collected and analyzed the data. LS, AA, and HN drafted the manuscript. All authors have read and agreed to the published version of the manuscript.

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Data availability

Airport entry screening data for Japanese and non-Japanese passengers are publicly available on the website of the Ministry of Health, Labour and Welfare [16] and are presented in the Additional Data file. The data sources are acknowledged for their contributions, and we adhered to their respective data-sharing policies and terms of use.

Declarations

Competing interests

The authors declare no competing interests.

Ethical approval and consent to participate

In this study, we utilized de-identified entry screening data that were publicly provided by the Ministry of Health, Labour, and Welfare. Given that our research exclusively relied on publicly accessible data devoid of any personal identification, prior ethical assessment or permission to conduct the study were not required.

Consent for publication

Not applicable.

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