Association of public health interventions and COVID-19 incidence in Vietnam, January to December 2020

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A R T I C L E   I N F O

A B S T R A C T

Background: Vietnam implemented various public health interventions such as contact tracing and testing, mandatory quarantine, and lockdowns in response to coronavirus disease 2019 (COVID-19). However, the effects of these measures on the epidemic remain unclear.

Methods: This article describes the public health interventions in relation to COVID-19 incidence. Maximum likelihood estimations were used to assess containment delays (time between symptom onset and start of isolation) and multivariable regression was employed to identify associated factors between interventions and COVID-19 incidence. The effective reproductive numbers (R_t) were calculated based on transmission pairs.

Results: Interventions were introduced periodically in response to the epidemic. Overall, 817 (55.4%) among 1474 COVID-19 cases were imported. Based on a serial interval of 8.72 ± 5.65 days, it was estimated that R_t decreased to below 1 (lowest at 0.02, 95% CI 0–0.12) during periods of strict border control and contact tracing, and increased ahead of new clusters. The main method to detect cases shifted over time from passive notification to active case-finding at immigration or in lockdown areas, with containment delays showing significant differences between modes of case detection.

Conclusions: A combination of early, strict, and consistently implemented interventions is crucial to control COVID-19. Low-middle income countries with limited capacity can contain COVID-19 successfully using non-pharmaceutical interventions.

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1. Introduction

As of June 2021, more than 182 million coronavirus disease 2019 (COVID-19) cases and nearly 3.9 million deaths related to COVID-19 had been reported globally (World Health Organization, 2021). Various public health measures were implemented at different stages across the world, with varying success (Liu et al., 2021; Flaxman et al., 2020; Li et al., 2021). China successfully contained the outbreak through strict lockdown measures (Pan et al., 1915; Tu et al., 2020). High-income countries like New Zealand, Australia, and Taiwan came close to elimination of community transmission for several months during 2020, through strict border control and extensive contact tracing (Summers et al., 2020). A number of low-middle income countries, including Vietnam, successfully applied a mixture of non-pharmaceutical interventions (NPIs) (Tu et al., 2020; Summers et al., 2020; Verhagen et al., 2020; Abdullahi et al., 2020). Vietnam implemented a large variety of interventions throughout 2020, including travel restrictions, mandatory testing and quarantine at international entry points, social distancing, and regional lockdowns.

Despite recent advances in vaccine development, NPIs will remain paramount until the very end of the pandemic (Liu et al., 2021; Duhon et al., 2021). It is therefore crucial to identify the most effective public health interventions for different stages of the epidemic (Peng Chua et al., 2021). However, evidence regarding the impacts of different public health measures on the epidemic is scarce, in particular for low-middle income countries.

This study was performed to assess the association between NPIs and COVID-19 incidence during different epidemic periods in Vietnam during 2020 in order to better understand how disease spread and response measures relate to one another and to provide public health guidance for the ongoing epidemic. The fact that Vietnam was affected by COVID-19 early on but did not experience widespread community transmission nationwide provides opportune conditions for this research.

2. Methods

2.1. Data source

Data of new daily confirmed COVID-19 cases were provided by the Vietnam Ministry of Health. All COVID-19 cases recorded between January and December 2020 were included in the analyses.

2.2. Definitions

Cases were defined according to the COVID-19 case definition of the Vietnam Ministry of Health (Vietnam Ministry of Health, 2020; Vietnam Ministry of Health, 2020). A laboratory-confirmed case was defined as a person who received a positive severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) test result by real-time reverse transcriptase PCR (rt-PCR). A suspected case was defined as any person either experiencing fever, cough, or shortness of breath with or without a travel history to COVID-19 affected areas during the 14 days before symptom onset, and/or being in close contact with a suspected or confirmed COVID-19 case during the case's infectious period. The source of infection was classified as imported (infection acquired most likely outside of Vietnam) or domestic (infection acquired most likely in Vietnam). The mode of case detection was categorized as (1) self-presentation at health facilities; (2) testing and quarantine at immigration points; (3) contact tracing following exposure with a confirmed case; and (4) enhanced mass testing in lockdown areas. All confirmed cases of COVID-19 were required to isolate at designated hospitals immediately after confirmation for monitoring and/or treatment (if needed). Clinical conditions of confirmed cases during isolation

and/or treatment were categorized as stable or critical. Cases were defined as free of infection, and thus discharged, if they tested negative for SARS-CoV-2 in three consecutive tests, with a sampling interval of 1 day between each test.

To describe the dynamics of the COVID-19 epidemic, six time periods were distinguished according to important milestones of interventions and virus transmission in Vietnam during 2020 (detailed epidemic characteristics of each period can be found in **Supplementary Material** File 1). Period 1 spanned from January 23 to March 20, 2020, when only imported cases and importation-related domestic cases were reported. During period 2 (March 21–31, 2020), the first two community outbreaks were reported and extensive testing and contact tracing strategies were enforced. During period 3 (April 1–30, 2020), nationwide social distancing measures were implemented, while the third community outbreak was detected. By period 4 (May 1 to July 24), after social distancing was lifted, international border control was a focus due to an influx of international travelers. During period 5 (July 25 to September 15), two outbreaks were detected and controlled. In period 6 (September 16 to December 31), Vietnam reported another two outbreaks due to unauthorized entry and quarantine violation, which in turn led to strengthened international border policies.

Public health interventions were grouped into three categories: (1) travel-related measures; (2) active case-finding measures; and (3) other NPIs. Travel-related measures included travel restriction, arrival screening and quarantine, and border closure to high-risk countries. Active case finding measures included contact tracing, testing, quarantine of contacts, and confirmation of cases. The remaining NPIs included regional lockdowns, school closure, cancellation of mass gatherings and non-essential activities, and personal protective measures (i.e., mask-wearing, hand hygiene, etc.).

2.3. Outcome measurements

The effective reproduction number (Rt) was defined as the average number of secondary infections generated by a single case in a population at time t (Nishiura & Chowell, 2009; Linka et al., 2020). The serial interval, a key parameter for Rt (Du et al., 2020; Nishiura et al., 2020), was defined as the time interval between symptom onset of transmission pairs, which was calculated as the interval from the date of symptom onset in the primary case to the date of symptom onset in the secondary case (Svensson, 2007) (see **Supplementary Material** File 2 for details about how transmission pairs were established). Containment delay of a case was defined as the time interval between the date of symptom onset and the date of isolation. For cases who were not symptomatic at testing, the date of positive test confirmation was used. Imported cases who were quarantined directly at immigration points were excluded from the containment delay, serial interval, and Rt analysis.

2.4. Statistical analysis

An epidemic curve by date of onset was plotted along with implemented interventions, with a detailed description of the three aforementioned intervention groups during each period. Epidemiological and socio-demographic characteristics of all confirmed cases were compared across the six epidemic periods using the Chi-square test and Fisher's exact test. Multinomial logistic regression was used to compare case characteristics by mode of detection, and risk ratios (RR) and 95% confidence intervals (95% CI) were calculated. Logistic regression was used to identify factors associated with clinical conditions, based on odd ratios (OR) with 95% CI. Estimations for containment delays stratified by case characteristics were summarized using the mean and standard deviation (SD). R package "fitdistrplus" (Delignett-Muller & Dutang,

2015) was used for maximum likelihood estimations to fit distributions of containment delays, and to compare by goodness-of-fit test for Akaike Information criterion (AIC). Multivariable linear regression was used to explore associated factors of containment delay using the regression coefficient (RC) with 95% CI. The threshold for statistical significance was set at a *P*-value of less than 0.05. The R package "EpiEstim" (Cori, 2021) was used to estimate serial interval distributions, and these estimations were then used to calculate median Rt with 95% CI based on the daily number of cases via a 7-day moving average using the method developed by Cori et al. (Cori et al., 2013).

2.5. Ethics

This research was reviewed and approved by The National Human Research Ethics Committee, of the Australian National University (Protocol 2020/769), and was waived by the Vietnam National Institute of Hygiene and Epidemiology as this work was considered part of routinely collected disease investigation.

3. Results

Table 1 shows the characteristics of the 1474 confirmed COVID-19 cases in Vietnam during 2020. More than half were male (*n* = 784, 53.19% male; *n* = 690, 46.81% female) and more than half were imported cases (*n* = 817, 55.43%). The majority of domestic cases were reported in period 5 (*n* = 51, 87.32%), and there were zero (0%) and three (0.7%) domestic cases detected in Vietnam during period 4 and period 6, respectively. Cases were predominantly in the 26–40 years age group and were lowest in the elderly across all periods. The number of COVID-19 cases peaked in period 5 (*n* = 631, 42.81% of all cases).

There were significant differences in most of the case characteristics (sex, age groups, source of infection, symptom status at testing, mode of case detection, clinical condition, and discharge conditions) detected across the six periods (*P* < 0.001), except for length of hospital stay. While only 201 (13.64%) cases reported symptom onset before or on the date of SARS-CoV-2 testing, the majority of cases (*n* = 1273, 86.36%) were asymptomatic at the time of testing. Cases were identified through self-presentation of a suspected case at health facilities (*n* = 165, 11.19%), actively detected at immigration points (*n* = 761, 51.36%), through contact tracing (*n* = 277, 18.79%), or through community testing in lockdown areas (*n* = 271, 18.39%). The percentages of cases detected by the different modes varied over time (Figure 1A), with an increasing percentage being picked up either at immigration points or through testing in lockdown areas.

Table 2 shows the comparison of case characteristics between the different modes of case detection while controlling for sex and age. As compared to cases detected at immigration points, cases were more likely to be symptomatic if detected through self-presentation at hospitals and in lockdown areas: RR 6.35 (95% CI 3.75–10.79) and RR 2.21 (95% CI 1.35–3.62), respectively. When stratified by epidemic periods, enhanced testing in lockdown areas detected more cases in most periods than immigration point testing.

Table 3 reports the univariate and multivariable analyses of the association between clinical conditions and case characteristics. Fifty-nine cases (4%) were classified as being in a critical clinical condition at some point during isolation and treatment, of which most clustered in period 5 (50 cases) (Table 1). No critically ill cases were recorded in period 4 or in the below 25 years age group. After controlling for sex and age, cases who acquired the infection domestically and who were symptomatic at the time of testing were more likely to develop a critical clinical condition during their course of illness compared to imported cases and

asymptomatic/pre-symptomatic cases: OR 4.99 (95% CI 1.06–23.49) and 2.73 (95% CI 1.48–5.05), respectively. No significant differences in clinical conditions were seen across periods.

By the end of 2020, 89.96% of all confirmed cases had been discharged from isolation. Thirty-five fatalities due to COVID-19 were recorded in Vietnam during 2020 (case fatality ratio, 0.07%); all were in period 5. More than 90% of cases were discharged during period 1, the latter half of period 4, and in period 6 (Figure 1B). The highest number of active cases at that time (499 cases) and the highest number of new cases per day (51 cases) were both recorded in period 5.

Table 4 and Figure 2A describe the public health interventions implemented across the six epidemic periods of COVID-19 in Vietnam during 2020. Border control and NPIs were imposed before the first case was reported, and were expanded in scope throughout the analysis period. The cancellation of mass gatherings and school closures were implemented in late January and continued periodically as soon as a community cluster was detected, when mask-wearing and personal hygiene practices were already encouraged. From period 1 onwards, regional lockdowns were enforced frequently during flare-ups of clusters, along with extensive contact tracing, testing, and quarantine for close contacts of suspected and confirmed cases. After local transmission was first reported in period 2, national-level social distancing recommendations and international and domestic mobility restrictions were introduced swiftly in period 3. These measures were subsequently relaxed in period 4 and mostly aimed to limit case importation. Period 5 saw the biggest clusters recorded (**Supplementary Material** File 1), and regional lockdowns were extended to city-wide lockdowns, with the utilization of community surveillance teams and universal testing. The number of cases soon declined and returned to predominantly imported cases in period 6, when measures were again used to focus on border control. During this period, Vietnam reported two instances of imported cases among illegal trespassers and one community cluster due to quarantine violation (**Supplementary Material** File 1).

A total of 182 transmission pairs were recorded in the database, resulting in a gamma distributed serial interval with a mean of 8.72 ± 5.65 days (**Supplementary Material** Figure S1). Figure 2B shows the variation in reproduction number over time using a moving average of 7 days, with two observed peaks at the end of period 4 and the end of period 6 (median Rt 12.59 (95% CI 2.91–34.01) and 13.88 (95% CI 4.82–30.42), respectively), and lowest at the end of period 5 (median Rt 0.02 (95% CI 0–0.12)) (**Supplementary Material** Table S1). Sensitivity analyses were also conducted to examine the distribution of serial intervals excluding outlier intervals longer than 21 days (**Supplementary Material** Figure S2) and 14 days (**Supplementary Material** Figure S3), which provided slightly smaller mean values of 8.36 ± 5.20 and 7.09 ± 4.07, respectively. Yet, this resulted in similar distributions of Rt over time, with slightly higher or lower Rt estimation for serial intervals excluding intervals longer than 21 days and 14 days, respectively (**Supplementary Material** Figures S4 and S5).

During the early weeks of period 1, which coincided with the national Lunar New Year celebrations, Vietnam recorded two local outbreaks (Van Cuong et al., 2020; Le et al., 2020; Phan et al., 2020), which resulted in Rt of 1.76 (95% CI 0.79–3.32). Following stringent containment measures including a regional lockdown, Rt decreased to below 1, before increasing to reach 6.98 (95% CI 2.71–14.35) on February 28, coinciding with the rise in inbound international flights. During March, the number of imported in-flight transmission outbreaks (Khanh et al., 2020) kept the level of Rt stable before it started to decline gradually to 1.66 (95% CI 1.21–2.22) at the end of period 1. Into period 2, two unlinked community clusters were reported; the gradual reduction of Rt from 1.94 (95% CI 1.46–2.53) to 0.25 (95% CI 0.12–0.46) con-

Table 1

Descriptive characteristics of 1474 confirmed COVID-19 cases reported in Vietnam across six periods of the COVID-19 epidemic in Vietnam from January to December 2020[a]

Characteristics	Period 1		Period 2		Period 3		Period 4		Period 5		Period 6		Grand total		P-value
	n	%	N	%	n	%	n	%	n	%	n	%	n	%	
All cases	85	5.77	122	8.28	63	4.27	145	9.84	631	42.81	428	29.04	1474	100	
Sex															0.000[c]
Male	43	50.59	50	40.98	27	42.86	110	75.86	278	44.06	276	64.49	784	53.19	
Female	42	49.91	72	59.02	36	57.14	35	24.14	353	55.94	152	35.51	690	46.81	
Age group (years)															0.000[c]
0–25	22	25.88	40	32.79	15	23.81	20	13.79	80	12.68	93	21.73	270	18.32	
26–40	29	34.12	39	31.97	24	38.10	88	60.69	191	30.27	212	49.53	583	39.55	
41–60	20	23.53	36	29.51	18	28.57	35	24.14	213	33.76	100	23.36	422	28.63	
>60	14	16.47	7	5.74	6	9.52	2	1.38	147	23.30	23	5.37	199	13.50	
Age (years), mean (SD)	38.19 (18.09)		35.59 (14.72)		37.35 (15.02)		34.49 (11.40)		45.46 (18.61)		35.14 (13.85)		39.80 (16.94)		0.000[d]
Source of case infection															0.000[c]
Imported cases	62	72.94	72	59.02	33	52.38	145	100	80	12.68	425	99.3	817	55.43	
Domestic cases	23	27.06	50	40.98	30	47.62	0	0	551	87.32	3	0.7	657	44.57	
Being symptomatic at testing															0.000[c]
No	55	64.71	101	82.79	55	87.30	145	100	489	77.50	428	100	1273	86.36	
Yes	30	35.29	21	17.21	8	12.70	0	0	142	22.50	0	0	201	13.64	
Mode of case detection															0.000[c]
Self-presentation at health facilities	15	17.65	12	9.84	5	7.94	1	0.69	130	20.6	2	0.47	165	11.19	
Immigration points testing and quarantine	22	25.88	63	51.64	32	50.79	144	99.31	79	12.52	421	98.36	761	51.36	
Contact tracing following exposure to COVID-19	42	49.41	24	19.67	10	15.87	0	0	196	31.06	5	1.17	277	18.79	
Enhanced testing in lockdown areas	6	7.06	23	18.85	16	25.4	0	0	226	35.82	0	0	271	18.39	
Clinical condition															0.000[c]
Stable	81	95.29	120	98.36	62	98.41	145	100	581	92.08	426	99.53	1415	96.00	
Critical	4	4.71	2	1.64	1	1.59	0	0	50	7.92	2	0.47	59	4.00	
Discharge from isolation	85	100	122	100	63	100	145	100	593	93.38	318	74.3	1326	89.96	0.000[c]
Number of fatalities due to COVID-19	0	0	0	0	0	0	0	0	35	5.55	0	0	35	0.07	0.000[c]
Length of hospital stay (days), mean (SD)[b]	21.8 (12.74)		23.09 (14.69)		22.89 (9.57)		21.30 (9.29)		23.97 (11.36)		23.31 (10.13)		23.24 (11.25)		0.141[d]

SD, standard deviation.

[a] The six periods were defined by key dates of events and public health interventions implemented from January 1 to December 31, 2020. See Methods for clarification.

[b] Excluded 35 deaths due to COVID-19, three deaths not due to COVID-19, and 110 COVID-19 patients not discharged at the time of the analysis.

[c] P-value calculated by Chi-square test.

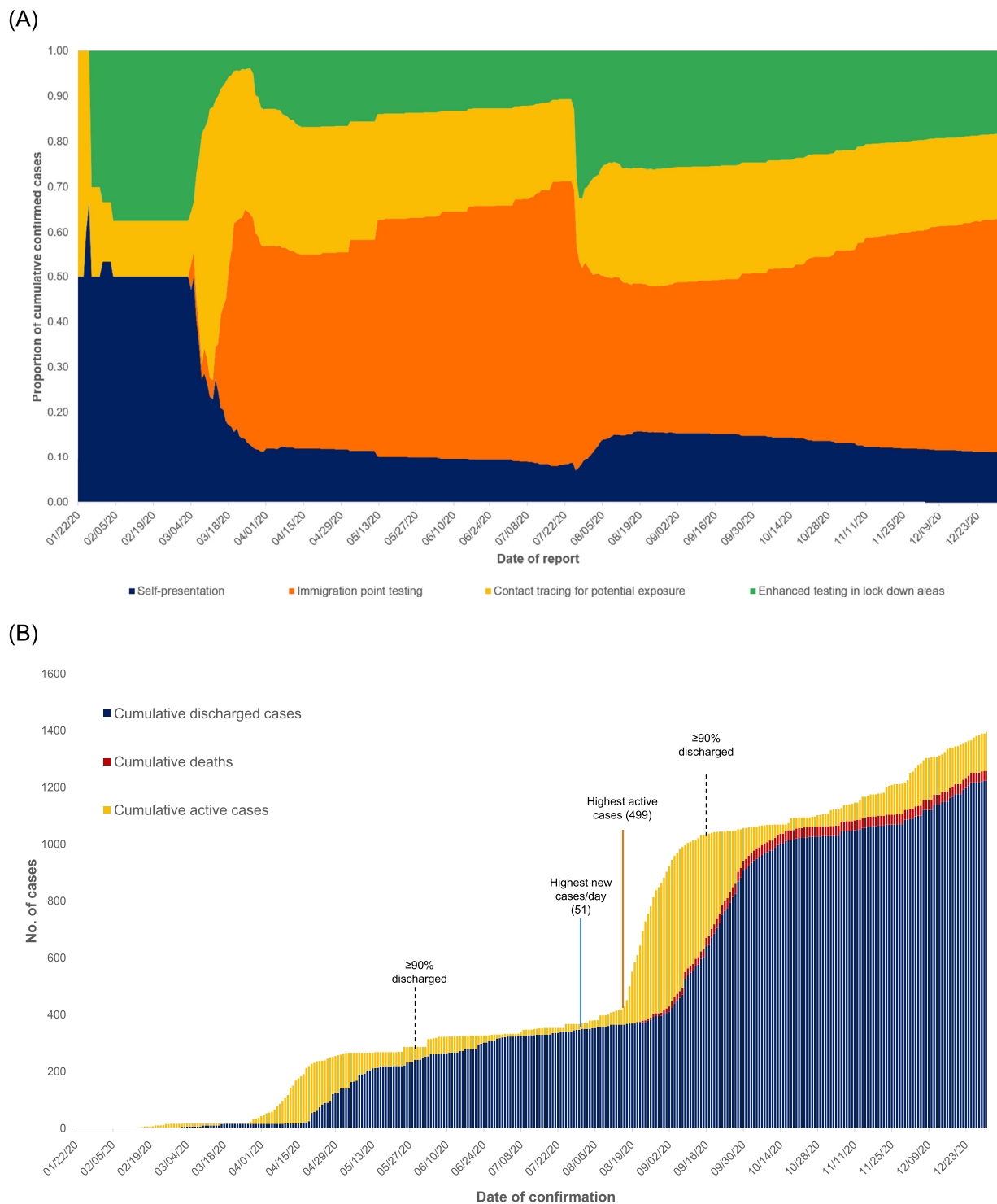[d] P-value calculated by Fisher's exact test.

(A)

(B)

Figure 1. (A) Cumulative proportion of confirmed cases by mode of case detection of COVID-19 cases in Vietnam from January to December 2020. (B) Cumulative number of confirmed cases, recoveries, and active cases of COVID-19 in Vietnam from January to December 2020.

Table 2

Relationship between mode of case detection and characteristics of confirmed COVID-19 cases and epidemic periods of 1474 confirmed COVID-19 cases reported in Vietnam from January to December 2020

Characteristics	Model 1					
	Self-presentation at health facilities		Contact tracing following potential exposure		Enhanced testing in lockdown areas	
	RR	95% CI	RR	95% CI	RR	95% CI
Sex						
Male	Ref.		Ref.		Ref.	
Female	2.42*	1.66–3.52	2.28*	1.70–3.06	3.09*	2.26–4.23
Age group (years)						
0–25	Ref.		Ref.		Ref.	
26–40	1.76	0.98–3.15	1.12	0.74–1.69	1.75***	1.03–2.98
41–60	3.80*	2.09–6.90	2.39*	1.55–3.68	5.75*	3.40–9.73
>60	13.40*	6.57–27.31	7.29*	4.13–12.86	24.25*	12.94–45.43
Being symptomatic at testing						
No	Ref.		Ref.		Ref.	
Yes	13.09*	8.69–19.72	4.49*	3.12–6.45	4.63*	3.15–6.79
Period						
1						
2						
3						
4						
5						
6						

Characteristics	Model 2					
	Self-presentation at health facilities		Contact tracing following potential exposure		Enhanced testing in lockdown areas	
	RR	95% CI	RR	95% CI	RR	95% CI
Sex						
Male	Ref.		Ref.		Ref.	
Female	2.40*	1.53–3.76	2.16*	1.45–3.21	2.80*	1.84–4.27
Age group (years)						
0–25	Ref.		Ref.		Ref.	
26–40	2.02***	1.07–3.81	1.51	0.91–2.52	2.20***	1.19–4.05
41–60	3.85*	1.98–7.51	2.96*	1.71–5.12	6.37*	3.39–11.95
>60	9.99*	4.07–24.51	6.53*	2.91–14.66	20.08*	8.49–47.52
Being symptomatic at testing						
No						
Yes						
Period						
1	Ref.		Ref.			
2	0.28**	0.11–0.70	0.20*	0.09–0.40	1.34	0.46–3.90
3	0.21**	0.06–0.67	0.15*	0.06–0.37	1.65	0.53–5.16
4	0.01*	0.00–0.09	NA	NA	NA	NA
5	2.12***	1.01–4.44	1.18	0.64–2.14	8.70*	3.30–22.92
6	0.01*	0.00–0.03	0.01*	0.00–0.02	NA	NA

Characteristics	Model 3					
	Self-presentation at health facilities		Contact tracing following potential exposure		Enhanced testing in lockdown areas	
	RR	95% CI	RR	95% CI	RR	95% CI
Sex						
Male	Ref.		Ref.		Ref.	
Female	2.30*	1.45–3.66	2.17*	1.46–3.24	2.79*	1.82–4.26
Age group (years)						
0–25	Ref.		Ref.		Ref.	
26–40	2.09***	1.09–4.04	1.51	0.91–2.52	2.22***	1.20–4.11
41–60	4.08*	2.05–8.13	2.93*	1.69–5.09	6.41*	3.40–12.09
>60	10.44*	4.17–26.16	6.58*	2.93–14.78	20.52*	8.63–48.76
Being symptomatic at testing						
No	Ref.		Ref.		Ref.	
Yes	6.35*	3.74–10.79	1.49	0.92–2.42	2.21**	1.35–3.62
Period						
1	Ref.		Ref.		Ref.	
2	0.48	0.18–1.26	0.23*	0.11–0.48	1.80	0.61–5.33
3	0.39	0.11–1.30	0.18*	0.07–0.45	2.26	0.71–7.22
4	0.04**	0.01–0.37	NA	NA	NA	NA
5	6.04*	2.67–13.65	1.50	0.76–2.94	14.13*	5.09–39.28
6	0.03*	0.01–0.14	0.01*	0.00–0.02	NA	NA

RR, risk ratio; CI, confidence interval.

* $P < 0.001$

** $P < 0.01$

*** $P < 0.05$. NA, not applicable; there were no cases detected by contact tracing following potential exposure or enhanced testing in lockdown areas in periods 4 and 6. Model 1 presents the results of multinomial regression analyses examining case symptomatic status at testing detected by different modes of case detection with 'immigration point testing and quarantine' as the reference, adjusted for sex and age. Model 2 presents the results of multinomial regression analyses examining cases in different epidemic periods detected by different modes of case detection with 'immigration point testing and quarantine' as the reference, adjusted for sex and age Model 3 presents the result of multinomial regression analyses examining case symptomatic status at testing and at different epidemic periods detected by different modes of case detection with 'immigration point testing and quarantine' as the reference, adjusted for sex and age.

tinued, which coincided with strict lockdown measures in high-risk areas, extensive case finding, and surveillance. Later in period 3, as nationwide social distancing recommendations were in place with only one ongoing active cluster under lockdown already, Rt remained below 1 on average until the end of April. In period 4, however, when international and domestic mobility resumed, a gradual increase in Rt to 5.75 (95% CI 0.83–19.03) was observed in early May. This coincided with one non-quarantined imported case detected after unauthorized entry. The gradual increase in Rt resumed in June, reaching a peak of Rt at nearly 13, pre-dating the biggest community outbreak in Vietnam in 2020 in period 5 (**Supplementary Material** File 1). Even though both outbreaks in period 5 (**Supplementary Material** File 1) were not detected in the early phases, the implementation of a rapid lockdown, nationwide contact tracing, testing and quarantine strategy for all returnees from high-risk regions, and universal testing in lockdown areas was correlated with a decrease in median

Rt from 3.02 (95% CI 2.61–3.47) to 0.48 (95% CI 0.02–2.58) after 2 months. In period 6, Rt peaked in late November and late December, which coincided with two instances arising from imported cases who had violated border control and COVID-19 quarantine measures.

Data of 713 cases were used to calculate containment delays, defined as the time between a case's symptom onset and start of quarantine, while 761 imported cases who immediately isolated upon arrival to Vietnam were excluded. Overall, the mean containment delay was 1.62 days (95% CI 1.38–1.86) with a standard deviation of 3.31 days (95% CI 3.15–3.50) (**Supplementary Material** Table S2). For the 201 cases who were symptomatic at testing, a longer mean containment delay was observed (5.04 days (95% CI 4.40–5.69)). There were significant differences in the mean containment delay for cases detected by different modes of detection. While all cases detected during periods 4 and 6 reported zero days of containment delay, there was a temporal fluctuation in the

Figure 2. (A) Epidemic curve by date of confirmation and public health interventions across the six periods from January to December 2020. Confirmed cases of COVID-19 are represented by (i) imported cases (infection most likely acquired outside of Vietnam) (blue) and (ii) domestic cases (infection most likely acquired inside of Vietnam) (orange). Public health interventions are represented by three groups: (1) travel-related measures (teal); (2) active case-finding measures (yellow); and (3) other non-pharmaceutical interventions (green). (B) Distribution of the daily estimated reproduction number of COVID-19 transmission in Vietnam from January to December 2020. The solid black line marks the median of effective reproduction number, the dashed horizontal line represents the value '1' of the effective reproduction number, and the grey areas represent the 95% confidence interval.
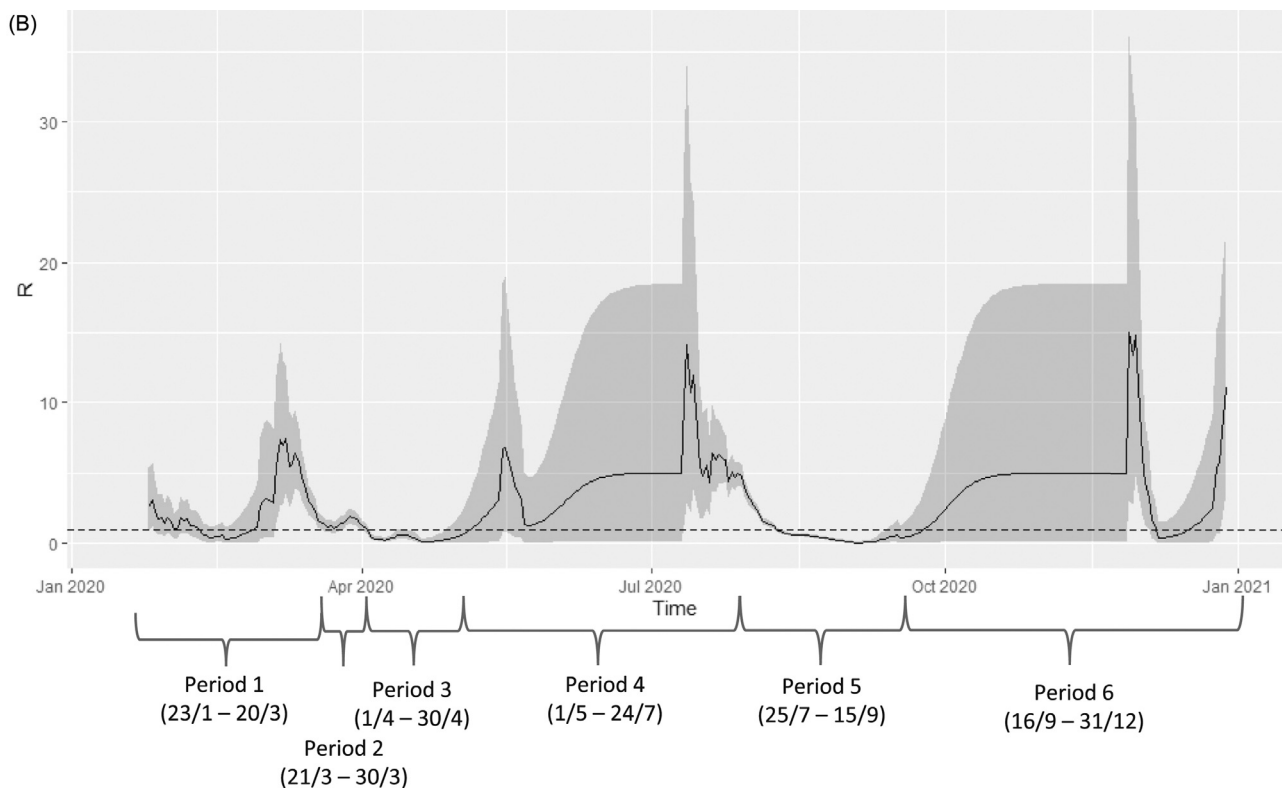
(B)

Figure 2. Continued

Table 3
Relationship between clinical conditions and characteristics of confirmed COVID-19 cases and epidemic periods of 1474 confirmed COVID-19 cases reported in Vietnam from January to December 2020

Characteristics	n (%)	Univariate association		Model 1		Model 2		Model 3		Model 4	
		OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Sex											
Male	33 (55.93)	Ref.		Ref.		Ref.		Ref.		Ref.	
Female	26 (44.07)	0.89	0.53–1.51	0.43**	0.24–0.77	0.49***	0.28–0.87	0.55***	0.31–0.97	0.40**	0.22–0.73
Age group (years)[a]											
26–40	17 (28.81)	Ref.		Ref.		Ref.		Ref.		Ref.	
41–60	4 (6.78)	6.08**	2.03–18.19	4.45**	1.47–13.53	4.78**	1.58–14.46	6.15**	2.04–18.52	4.65**	1.52–14.22
>60	38 (64.41)	34.16*	12.02–97.14	19.72*	6.77–57.47	20.66*	7.14–59.78	33.89*	11.78–97.49	19.74*	6.72–57.92
Source of case infection											
Imported cases	5 (8.47)	Ref.		Ref.						Ref.	
Domestic cases	54 (91.53)	14.54*	5.78–36.58	8.07*	3.07–21.19					4.99***	1.06–23.49
Period[b]											
1	4 (6.78)	Ref.				Ref.				Ref.	
2	2 (3.39)	0.34	0.06–1.88			0.64	0.11–3.85			0.4	0.06–2.70
3	1 (1.69)	0.33	0.04–3.00			0.42	0.04–4.18			0.26	0.02–3.05
5	50 (84.75)	1.74	9.61–4.95			1.46	0.48–4.44			0.85	0.20–3.56
6	2 (3.39)	0.10**	0.02–0.53			0.15***	0.03–0.86			0.53	0.08–3.73
Symptomatic at testing											
No	38 (64.41)	Ref.						Ref.		Ref.	
Yes	21 (35.59)	3.67*	2.17–6.21					3.34*	1.89–5.90	2.73**	1.48–5.05

OR, odds ratio; CI, confidence interval. *P < 0.001; **P < 0.01; ***P < 0.05.
[a] No critical cases younger than 26 years old were recorded.
[b] No critical cases in period 4 were recorded.Model 1 presents the results of logistic regression analyses examining associations between case sources of infection and case clinical conditions, adjusted for sex and age.Model 2 presents the results of logistic regression analyses examining associations between epidemic periods and case clinical conditions, adjusted for sex and age.Model 3 presents the results of logistic regression analyses examining associations between case symptomatic status at testing and case clinical conditions, adjusted for sex and age.Model 4 presents the results of logistic regression analyses examining associations between case sources of infection, epidemic periods, and case symptomatic status at testing and case clinical conditions, adjusted for sex and age.

mean containment delay during the other periods: period 1, 1.05 days (95% CI 0.56–1.53); period 2, 1.10 days (95% CI 0.58–1.62); period 3, 1.26 days (95% CI 0.09–2.42); period 5, 1.78 days (95% CI 1.49–2.08). Containment delay then was fitted using a Pareto distribution, resulting in a mean containment delay of 2.01 ± 1.01 days (**Supplementary Material** Table S3).

Table 5 shows the results of the univariate and multivariable regression analyses of containment delays with case characteristics and epidemic periods after adjusting for age and sex. The containment delay was significantly longer for cases who were symptomatic at testing than for cases who were not: RC 4.79 days (95% CI 4.36–5.22). Cases detected by active contact tracing and en-

Table 4

Descriptions of public health interventions implemented during the six periods of COVID-19 epidemics in Vietnam from January to December 2020.

Epidemic period	Public health interventions		
	Travel-related measures	Active case finding	Other NPIs
Period 0 (January 1–22)	Jan 1: Thermal screening and medical checkpoints at all immigration ports (land, air, sea). Travel advisory for limited travel to and from Wuhan, China. All inbound passengers with a travel history to Wuhan, China and displaying COVID-19 compatible symptoms at immigration points were mandatory quarantined and tested for SARS-CoV-2 (Vietnam Ministry of Health, 2020).	All suspected cases of COVID-19 with COVID-19 compatible symptoms and travel history to Wuhan, China were tested for SARS-CoV-2 and mandatory quarantine for 14 days at designated facilities (Vietnam Ministry of Health, 2020).	A COVID-19 health advisory was broadcasted across the mass media and official government outlet. No specific mask-wearing requirement.
Period 1 (January 23–March 20)	Jan 25: All flights from and to Wuhan, China were halted indefinitely. Feb 28: Temporary ban visa exemption and travel restriction for travelers from South Korea . Mandatory health declaration, SARS-CoV-2 testing, 14-day centralized quarantine required for travelers from South Korea at immigration points. March 1: Similar measures for travelers from Iran. March 2: Similar measures for travelers from Northern Italy. March 7: Mandatory health declaration for all travelers on international flights at immigration points. All passengers must wear masks on airplanes and at the airport. March 12: Temporary ban visa exemption and travel restriction for travelers from eight European countries. March 14: SARS-CoV-2 testing and 14-day centralized quarantine required for travelers from European countries at immigration points. Temporary ban visa exemption and travel restriction for travelers from Schengen countries, United Kingdom, and Northern Ireland. March 15: All passengers on international flights who had arrived in Vietnam from March 8 onwards were required to contact the local health authorities for health monitoring. March 18: SARS-CoV-2 testing and 14-day centralized quarantine required for travelers from the United States, Southeast Asian countries, and Russia at immigration points.	The suspected case definition was expanded to close contacts of confirmed cases or travellers with a travel history to countries with high-risk of COVID-19, regardless of symtom onset . All suspected cases of COVID-19 were tested for SARS-CoV-2 and mandatory quarantined for 14 days at designated facilities as soon as being identified, regardless of symptom onset. During quarantine, suspected cases were tested at least three times, on the first day of quarantine, day 3, and day 13 of quarantine, and whenever displaying COVID-19 compatible symptoms. Contact tracing was required for close contacts of confirmed cases (including those sharing the same vehicle, i.e., flights, or residing in the same lockdown areas), close contacts of close contacts of confirmed cases, and all international passengers arriving from March 8 onwards (from March 15) (Van Cuong et al., 2020). Close contacts of confirmed cases were tested and quarantined as a suspected case. Close contacts of close contacts of confirmed cases were tested for SARS-CoV-2, self-quarantined at home for 14 days, and underwent a basic daily check-up by local health staff. All passengers on the same international flights with confirmed cases of COVID-19 were tested and quarantined as a suspected case. The remaining passengers on international flights were tested and quarantined similar to close contacts of close contacts of confirmed cases.	Regional lockdown was enforced for highly affected regions including personal houses, residential buildings, workplaces, and residential streets where confirmed cases had visited or been accommodated during 14 days before symptom onset or confirmation of SARS-CoV-2. Lockdown was enforced for 14 days from the date of index case confirmation. During lockdown, a door-to-door community surveillance system was set up by the local health staff, which included daily symptom monitoring and SARS-CoV-2 specimen collection for residents inside lockdown areas. Environmental disinfection was performed regularly, and basic amenities and healthcare services were provided for residents free of charge by the government. A daily broadcast of new cases of COVID-19 was made across the mass media and official government sites. Anonymous details of characteristics of cases, along with past travel history were also made available to alert the population of potential exposure, and also help aid the contact tracing process. Face mask-wearing and personal hygiene practices were encouraged. Public events, mass gatherings, social and religious events were cancelled. Schools and universities across the country were closed until further notice. Remote working and studying arrangements were encouraged. Shops, restaurants, and businesses remained open but were obliged to implement thermal screening and hand sanitization. March 16: Mask-wearing and social distancing in public areas were required (Ha et al., 2020).
Period 2 (March 21–31)	March 21: SARS-CoV-2 testing and 14-day centralized quarantine required for all travelers from international flights at immigration points. March 22: Temporary ban visa exemption for all travelers from international flights. March 28: All international flights from and to Vietnam were halted.	Contact tracing and the suspected case definition were extended to all identified persons epi-linked to COVID-19 clusters (i.e., contact with COVID-19 confirmed cases and/or visit to COVID-19 infected areas during the 14 days before the first cases in the cluster were identified). Traced persons were tested and quarantined as a suspected case. SARS-CoV-2 testing was required for any patients admitted into hospitals across the country with symptoms of respiratory infection.	Regional lockdown was extended to 21 days after the last confirmed cases were confirmed in the cluster. No persons inside lockdown areas were allowed to leave until the lockdown period had ended. March 27: Entertainment activities, non-essential businesses and services in cities/provinces with confirmed cases were closed. March 31: 15-day national social distancing was implemented from April 1 across the country (Vietnam News, 2020). Inter-city transportation and non-necessary outdoor activities were prohibited.

Table 4 (continued)

Epidemic period	Public health interventions		
	Travel-related measures	Active case finding	Other NPIs
Period 3 (April 1–30)	Limited charter flights and cargo flights were allowed. All travelers who crossed land borders were required to provide a special travel license and were tested for SARS-CoV-2 every 2 weeks.	Serology and SARS-CoV-2 testing was implemented for vulnerable groups with high-risk exposure to SARS-CoV-2. This included street vendors and deliveryman in two large wet markets in Hanoi and frequent club-goers in a popular clubbing district in Ho Chi Minh City.	April 10: The regional lockdown was extended to a larger scale, to cover all residents living in the surrounding areas (i.e., villages, districts) near where confirmed cases had visited/been accommodated during 14 days before symptom onset or confirmation of SARS-CoV-2. April 15: National social distancing was extended until April 30. Limited inter-city transportation was allowed, based on risk assessment ranking (high, medium, and low risk).
Period 4 (May 1–July 24)	May 29: All domestic flights resumed to normal operation. June 30: Limited international flights from selected countries were allowed for diplomats, experts, and Vietnamese repatriates with official approval from the Vietnam government (Pollack et al., 2020). July 1: Visa services were resumed for the nationals of 80 countries. Returnees were given the option of 14-day self-paid quarantine in selected secluded hotels in Vietnam instead of centralized quarantine, with similar testing and quarantine requirements (Pollack et al., 2020).	No new updates since previous period.	May 1: National social distancing measures were lifted except for domestic flights. May 4: Universities and schools were re-opened nationwide.
Period 5 (July 25–September 15)	August 15: All international flights were halted. Extensive measures to detect, manage, test, and quarantine all border crossers were enforced by the provincial police departments and local authorities across the country. Detected border crossers were tested and quarantined as suspected cases of COVID-19. Legal punishment for illegal trespassing and infectious disease spreading act charge was issued to all detected border crossers and accomplices who were involved in transportation, accommodation, and guidance for unauthorized entry through international borders (Nguyen, 2021).	Contact tracing was extended to all persons residing in cities/provinces with confirmed cases of COVID-19 during 14 days before the first case was symptomatic and/or confirmed positive with SARS-CoV-2 who then traveled to other provinces and cities in Vietnam. Traced persons were required to test for SARS-CoV-2 and self-quarantine at home facilities for 14 days while undergoing a basic daily check-up by local health staff. August 1: Serology and SARS-CoV-2 testing were required for all foreigners residing in cities/provinces with infections. August 4: Community testing was extended for all people residing in cities/provinces with confirmed cases of COVID-19 (not only in lockdown areas); family representative sampling and pooled testing were performed.	For cities/provinces with confirmed cases of COVID-19, mass gatherings, religious events, school and universities were closed as soon as the first case was confirmed. Health declaration was mandatory for all residents, and inbound and outbound travelling were limited and monitored by checkup points at cities/provinces' bound. Outpatient healthcare services were discontinued, with the exception for SARS-CoV-2 testing for walk-ins . A COVID-19 community surveillance team was established in all districts to manage and detect any suspected cases in the community with compatible COVID-19 symptoms and to implement prevention measures. Enhanced surveillance was set up in all local pharmacies to document purchases of flu or fever medicine. SARS-CoV-2 testing was conducted for all examiners and students participating in the national high school examination in cities/provinces with confirmed cases of COVID-19, and separated examination was required for students who were suspected or confirmed cases of COVID-19. Eventually, a 28-day city-wide lockdown, restriction of inter-city transportation, and closure of all non-essential services were imposed for these cites/provinces. In cities/provinces without COVID-19 infections, non-essential services including outdoor dining, bars, clubs, and entertainment venues were required to close from August 19–31. All healthcare facilities were required to limit the intake of caretakers to one per patient per day, and no caretakers visited the emergency wards.

Table 4 (*continued*)

Epidemic period	Public health interventions		
	Travel-related measures	Active case finding	Other NPIs
Period 6 (September 16–December 31)	September 23: International flights resumed, allowing limited commercial international flights. December 1: All international flights were halted until the end of December (The Business Times, 2020). All travelers after finishing 14-day centralized quarantine had to self-quarantine at home for another 14 days, with daily health check-ups by local health staff. Extensive measures to detect, manage, test, and quarantine all unauthorized entry through the open path trail border were enforced by border patrols. Stricter legal punishment was given to border crossers who were confirmed positive with SARS-CoV-2 and/or infected other members in the community.	From December 1: All public hospitals were required to conduct periodical SARS-CoV-2 testing for all patients, caretakers, and staff whenever a community outbreak occurred in the region.	No new update from previous period.

NPIs, non-pharmaceutical interventions.

Table 5

Relationship between containment delay and characteristics of confirmed COVID-19 cases and epidemic periods for 713 confirmed cases of COVID-19 reported in Vietnam from January to December 2020[a]

Characteristics	Univariate association		Model 1		Model 2	
	RC	95% CI	RC	95% CI	RC	95% CI
Sex						
Male	Ref.		Ref.		Ref.	
Female	0.26 days	−0.22 to 0.77	0.24 days	−0.26 to 0.74	0.14 days	−0.24 to 0.53
Age group (years)						
0–25	Ref.		Ref.		Ref.	
26–40	0.08 days	−0.75 to 0.91	0.08 days	−0.75 to 0.91	0.10 days	−0.53 to 0.73
41–60	−0.23 days	−1.03 to 0.58	−0.28 days	−1.09 to 0.53	0.00 days	−0.61 to 0.62
>60	0.03 days	−0.83 to 0.89	0.00 days	−0.86 to 0.86	0.15 days	−0.51 to 0.80
Source of case infection						
Imported cases	Ref.		Ref.			
Domestic cases	0.71 days	−0.19 to 1.62	0.69 days	−0.23 to 1.61		
Being symptomatic at testing						
No	Ref.				Ref.	
Yes	4.77 days*	4.35 to 5.18			4.76 days*	4.34 to 5.17
Mode of case detection[b]						
Self-presentation at health facilities	Ref.					
Contact tracing following potential exposure to COVID-19	−2.11 days*	−2.73 to −1.50				
Enhanced testing in lockdown areas	−2.02 days*	−2.64 to −1.40				
Period						
1	Ref.					
2	0.05 days	−1.12 to 1.23				
3	0.21 days	−1.21 to 1.64				
4	−1.05 days	−7.60 to 5.50				
5	0.74 days	−0.12 to 1.60				
6	−1.05 days	−3.64 to 1.54				

Characteristics	Model 3		Model 4		Model 5	
	RC	95% CI	RC	95% CI	RC	95% CI
Sex						
Male	Ref.		Ref.		Ref.	
Female	0.31 days	−0.17 to 0.79	0.25 days	−0.25 to 0.75	0.07 days	−0.31 to 0.44
Age group (years)						
0–25	Ref.		Ref.		Ref.	
26–40	0.01 days	−0.80 to 0.81	0.10 days	−0.73 to 0.93	0.16 days	−0.46 to 0.78
41–60	−0.25 days	−1.04 to 0.53	−0.30 days	−1.11 to 0.51	0.03 days	−0.58 to 0.64
>60	0.02 days	−0.81 to 0.86	−0.09 days	−0.95 to 0.77	0.12 days	−0.53 to 0.77
Source of case infection						
Imported cases					Ref.	
Domestic cases					0.52 days	−0.45 to 1.50
Being symptomatic at testing						
No					Ref.	
Yes					4.79 days*	4.36 to 5.22
Mode of case detection[b]						
Self-presentation at health facilities	Ref.				Ref.	
Contact tracing following potential exposure to COVID-19	−2.11 days*	−2.73 to −1.49			−0.45 days	−0.96 to 0.06
Enhanced testing in lockdown areas	−2.03 days*	−2.65 to −1.40			−0.77 days **	−1.28 to −0.26
Period						
1			Ref.		Ref.	
2			0.07 days	−1.11 to 1.26	0.49 days	−0.51 to 1.49
3			0.22 days	−1.21 to 1.65	1.11 days	−0.11 to 2.33
4			−1.09 days	−7.65 to 5.48	1.02 days	−3.90 to 5.93
5			0.75 days	−0.12 to 1.62	1.56 days*	0.66 to 2.46
6			−1.11 days	−3.72 to 1.49	1.16 days	−0.79 to 3.11

RC, regression coefficient; CI, confidence interval. *$P < 0.001$; **$P < 0.01$.

[a] A total of 761 cases who were quarantined at immigration points were excluded because they did not contribute to the transmission in Vietnam.

[b] Mode of case detection by immigration point testing and quarantine obsoletes any observed containment delay. Model 1 represents linear regression analyses on the association between containment delay and case sources of infection, adjusted for sex and age. Model 2 represents linear regression analyses on the association between containment delay and case symptom onset at testing, adjusted for sex and age. Model 3 represents linear regression analyses on the association between containment delay and the modes of case detection, adjusted for sex and age. Model 4 represents linear regression analyses on the association between containment delay and epidemic periods, adjusted for sex and age. Model 5 represents linear regression analyses on the association between containment delay and case sources of infection, case symptom onset at testing, the modes of case detection, and epidemic periods, adjusted for sex and age.

hanced testing in lockdown areas had significantly shorter containment delays than cases who self-presented at health facilities: RC 2.11 days (95% CI 2.73–1.49) and RC 2.03 days (95% CI 2.65–1.40), respectively. Cases detected during period 1 had shorter containment delays than cases detected in all other periods, which was only statistically significant compared to period 5 (RC 1.56 days (95% CI 0.66–2.46)).

4. Discussion

This study provides evidence of the effectiveness of public health interventions in response to the COVID-19 incidence in Vietnam. While the main mode of case detection shifted from self-presentation to pre-emptive testing and quarantine at immigration points and lockdown areas, there were significant positive impacts

on containment delays through active case-finding measures compared to passive notification. The reproduction number decreased with the swift and strict implementation of NPIs.

Given the close proximity to China – the initial epicenter of COVID-19, Vietnam was particularly vulnerable to COVID-19 importation from international travel. However, limited domestic cases were seen even during times of a high load of imported cases during the first epidemic period, and again in periods 4 and 6, which was a direct result of testing and quarantine for all inbound passengers upon arrival (Khanh et al., 2020). As evidence grew about the infectivity and prevalence of asymptomatic cases (Kronbichler et al., 2020; Gao et al., 2020; Ren et al., 2021), Vietnam rolled out testing irrespective of symptoms very early into the epidemic. This was first done at immigration points for international inbound passengers, and later for all persons with epidemiological links to confirmed cases. This policy was implemented in early March, and following that, we saw the majority of cases in all periods being detected before any symptoms emerged. This also explains the longer containment delays for domestic cases than imported cases (Wong et al., 2020), with shorter delays among cases without symptoms at the time of testing.

A high number of cases were detected through enhanced testing in lockdown areas. Several countries, including China and Italy, implemented severe lockdowns of large geographical areas during the beginning of the pandemic, and succeeded in containing widespread transmission (Karnon, 2020). Meanwhile, Vietnam opted for targeted lockdowns of clearly defined areas, where mass testing was done of all persons living in these areas, irrespective of symptoms, with the help of community surveillance teams, who detected any symptomatic persons at the household level. Smaller-scale lockdowns were preferred due to the limited response capacity and also to utilize volunteers from within the community more efficiently, with the aim of increasing social responsibility among the population (Tran et al., 2020).

Similar to the scientific literature encouraging an adaptive combination of quarantine and other public health measures (Karnon, 2020; Johanna et al., 2011; Nussbaumer-Streit et al., 2020), Vietnam's extensive tracing and mandatory quarantine of all contacts in combination with social distancing measures helped to contain further spread. Increased active case-finding, contact tracing, and regional lockdowns had significant impacts on shortening containment delays in this study. When comparing periods of small-scale lockdown (period 1 to period 3, period 6) and wide-scale lockdown (period 5), quarantine measures focusing on close contacts of suspected and confirmed cases led to a significantly shorter containment delay. This might be explained by the small size of the lockdown areas, where contacts with confirmed cases were most apparent, and thus easier and quicker to test and identify.

In this study, the effective reproduction number varied over time, especially under the implementation and subsequent relaxation of NPIs. After the first two unlinked community outbreaks in period 2, which quickly unfolded into period 3 when regional lockdowns and national social distancing were implemented, a clear reduction in Rt was observed. This strongly suggests that timely implementation of active case-finding with prompt quarantine and social distancing, even without general lockdowns, can quickly curtail an ongoing outbreak (Kissler et al., 2020; Wilasang et al., 2020). These findings confirm the results from a modelling study involving 11 European countries, which showed how Rt began to decrease after school closures and other NPIs, even before a complete national lockdown (Flaxman et al., 2020). In Vietnam, after social distancing was lifted in period 4, a peak of Rt was observed, which eventually led to the biggest outbreak in period 5, which can be explained by the reintroduction of imported cases into high-risk areas (Yeoh et al., 2021) and/or the resumption of previous social mixing patterns, as observed in several countries

following lockdowns (Santamaría & Hortal, 2021; Marziano et al., 2021). In period 5, a wide-scale lockdown of two affected cities (Da Nang and Hai Duong), coupled with extensive testing and quarantine policies (see **Supplementary Material** File 1), resulted in a substantial reduction in Rt after only 2 weeks, and in the containment of outbreaks 2 months later. This aligns with previous research on the timeliness and effectiveness of combined public health practices (Linka et al., 2020; Nussbaumer-Streit et al., 2020; Bo et al., 2021), as applied in Singapore (Lee et al., 2020; Koo et al., 2020), Taiwan (Chen & Fang, 2021), and Hong Kong (Cowling et al., 2020).

From period 1 to period 3, the Rt estimations in our study approximated those from previous research on the first 100 COVID-19 cases in Vietnam (PQ et al., 2021), and one study during the same period from Taiwan (Ng et al., 2021), where the COVID-19 situation was similar to that of Vietnam at the time. However, to our knowledge, there is no other long-term observation of Rt beyond 6 months, making the comparison of our estimations difficult. We also observed a higher estimation of the serial interval compared to previous reviews (Griffin et al., 2020; Alene et al., 2021; Rai et al., 2021). The high percentage of asymptomatic cases at testing reported in Vietnam (Table 1) could have hindered the detection and accuracy of recalled symptom onset for both infectors and infectees, and lengthened the observed serial interval.

Towards the latter half of 2020, Vietnam experienced an increasing risk through unauthorized entry into the country without quarantine upon arrival. It has been suggested that the biggest cluster in Da Nang City in July (period 5) was due to undetected imported cases through unauthorized entry, since the city is a focal point for foreign companies and industries in Vietnam (Le et al., 2021; Pham et al., 2021). During this time, several instances of illegal trespassing were detected across the country, some of which were detected in the epicenter of the cluster itself (Nguyen, 2020; Thien Nhan, 2021). At the end of the year, another three instances of imported cases without quarantine, one resulting in community transmission, shows that strict testing and quarantine on arrival and border control can only limit but not eliminate the introduction of cases. As shown in this study, even with the exclusion of imported cases by border control, transmission chains could not be disrupted fast enough once there was an instance of new non-quarantined case importation. Even in countries with limited in-country transmission such as Vietnam, relying on border control measures has proven unsustainable in the long term, especially the longer the COVID-19 pandemic progressed (Pham et al., 2021). In 2021, Vietnam continues to initiate more active measures to detect illegal entries along all borders, not only official points of entry, where illegal trespassers are quarantined and tested at point of detection. However, it must be recognized that quarantine requirements for international inbound travelers still pose significant financial and social problems for many immigrants and repatriates, as well as a logistic burden for border patrols. Given the global movement to the new 'normal', Vietnam might come under pressure to keep its border open. This should only be considered with stringent and pro-active control of imported cases in combination with strong national surveillance and response systems.

This study has several limitations. As an observational study, a direct cause–effect relationship between public health interventions and the evolution of the epidemic cannot be established easily. While providing a description of public health interventions in scope and across epidemic periods, we acknowledge that compliance and adaptation of the public health measures surely varies across individuals and communities. Furthermore, we did not have data on individual-level protective behaviors (e.g. face mask-wearing, personal hygiene, etc.), which could have helped to assess more accurately the impact of interventions on transmission dynamics. Meanwhile, several publications in Vietnam have

shown good adherence to and perceptions towards personal protective measures among the Vietnamese population (Nguyen et al., 2020; Nguyen et al., 2020; Hoang et al., 2021), both during and after lockdown restrictions in April (Nguyen et al., 2020; Hoang et al., 2021). This would, in combination with the serial NPIs imposed by Vietnamese authorities, ensure success in limiting the impact of COVID-19. We also lacked detailed clinical information, including on the co-morbidities and clinical progression of cases during isolation and/or treatment. In addition, the relationship between serial intervals over time and public health interventions was not explored in detailed, which would be another powerful indicator for successful COVID-19 containment (Ali et al., 2020). Future research should focus on the impact of containment delays on Rt, especially in model with implemented NPIs. Lastly, the total number of tests performed and the total number of people in quarantine during the different time periods of this analysis were not available, which could have highlighted changes in the capacity and burden on Vietnam's healthcare system at that time.

In conclusion, the combination of stringently and consistently applied mandatory quarantine on arrival, active case-finding and contact testing, and small-scale regional lockdowns proved particularly effective in reducing COVID-19 transmission in Vietnam during 2020. Swift adaptation to the fast-changing COVID-19 situation is crucial in low-middle income countries with limited pandemic response capacities.

Declarations

CRediT authorship contribution statement

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Transparency declaration

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.ijid.2021.07.044.

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