Associations between wearing masks, washing hands, and social distancing practices, and risk of COVID-19 infection in public: a cohort-based case-control study in Thailand

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Abstract

Objective. To investigate whether wearing masks, washing hands and social distancing practices are associated with lower risk of COVID-19 infection.

Design. A retrospective cohort-based case-control study. All participants were retrospectively interviewed by phone about their preventive measures against COVID-19 infection.

Setting. Thailand, using the data from contact tracing of COVID-19 patients associated with nightclub, boxing stadium and state enterprise office clusters from the Surveillance Rapid Response Team, Department of Disease Control, Ministry of Public Health. Contacts were tested for COVID-19 using PCR assays per national contact tracing guidelines.

Participants. A cohort of 1,050 asymptomatic contacts of COVID-19 patients between 1 and 31 March 2020.

Main outcome measures. Diagnosis of COVID-19 by 21 April 2020. Odds ratios for COVID-19 infection and population attributable fraction were calculated.

Exposure. The study team retrospectively asked about wearing masks, washing hands, and social distancing practices during the contact period through telephone interviews.

Results. Overall, 211 (20%) were diagnosed with COVID-19 by 21 Apr 2020 (case group) while 839 (80%) were not (control group). Fourteen percent of cases (29/210) and 24% of controls (198/823) reported wearing either non-medical or medical masks all the time during the contact period. Wearing masks all the time (adjusted odds ratio [aOR] 0.23; 95%CI 0.09-0.60) was associated with lower risk of COVID-19 infections compared to not wearing masks, while wearing masks sometimes (aOR 0.87; 95%CI 0.41-1.84) was not. Shortest distance of contact >1 meter (aOR 0.15; 95%CI 0.04-0.63), duration of close contact ≤15 minutes (aOR 0.24; 95%CI 0.07-0.90) and washing hands often (aOR 0.33; 95%CI 0.13-0.87) were significantly associated with
lower risk of infection. Sharing a cigarette (aOR 3.47; 95% CI 1.09-11.02) was associated with higher risk of infection. Type of mask was not independently associated with risk of infection. Those who wore masks all the time were more likely to wash hands and practice social distancing. We estimated that if everyone wore a mask all the time, washed hands often, did not share a dish, cup or cigarette, had shortest distance of contact >1 meter and had duration of close contact \( \leq 15 \) minutes, cases would have been reduced by 84%.

Conclusions. Our findings support consistently wearing non-medical masks, washing hands, and social distancing in public to prevent COVID-19 infections.
Introduction

There is an urgent need to evaluate the effectiveness of wearing masks by healthy persons in the general public against COVID-19 infections. During the early stages of the outbreak of COVID-19, the World Health Organization (WHO) announced on 27 February 2020 that, “For asymptomatic individuals, wearing a mask of any type is not recommended”. The rationale, at that time, was to avoid unnecessary cost, procurement burden, and a false sense of security. A number of systematic reviews also found no conclusive evidence to support the widespread use of masks in public against respiratory infectious diseases such as influenza, SARS and COVID-19.

However, China and many countries in Asia including South Korea, Japan and Thailand have recommended the use of face mask among the general public since early in the outbreak. There is also increasing evidence that COVID-19 patients can have a “pre-symptomatic” period, during which infected persons can be contagious and, therefore, transmit the virus to others before symptoms develop. This led to the change of the recommendation of the US Centers for Disease Control and Prevention, updated on 4 April 2020, from warning the public against wearing face masks to advising everyone to wear a cloth face covering when in public. On 6 April and 5 June 2020, WHO updated their advice on the use of masks for the general public, and encouraged countries that issue the recommendations to conduct research on this topic.

Thailand has been implementing multiple measures against transmission of COVID-19 since the beginning of the outbreak. The country has established thermal screening at airports since 3 January 2020, and detected the first case of COVID-19 outside China, a traveler from Wuhan arriving at Bangkok Suvarnabhumi airport, on 8 January 2020. The country utilized the Surveillance and Rapid Response Team (SRRT), together with Village Health Volunteers, to...
perform contact tracing, educate the public about the disease and monitor the close contacts of COVID-19 patients in quarantine. The SRRT is an epidemiologic investigation team trained to conduct surveillance, investigations and initial controls of communicable diseases; including H5N1, SARS and MERS. Currently, there are more than 1,000 SRRTs established at district, provincial and regional levels in the country, working on contact tracing for COVID-19. In February 2020, public pressure to wear masks was high, medical masks were difficult to procure by the public, and the government categorized medical masks as price-controlled goods and announced COVID-19 as a dangerous communicable disease according to the Communicable Disease Act 2015 in order to empower officials to quarantine contacts and close venues. On 3 March, the Ministry of Public Health (MoPH) announced the recommendation of cloth mask for the public. On 18 March, schools, universities, bars, nightclubs and entertainment venues were closed. On 26 March, while the country was reporting approximately 100-150 new COVID-19 patients per day, the government declared a national state of emergency, prohibited public gatherings, and enforced everyone to wear a face mask on public transport. On 21 April, 19 new PCR-confirmed COVID-19 patients were announced by the Ministry of Public Health (MoPH), Thailand, bringing the total number of patients to 2,811 patients. Given the lack of currently available evidence, we evaluated the effectiveness of mask wearing, hand washing, social distancing and other preventive measures against COVID-19 infection in public in Thailand.
Methods

Study design.

We conducted a retrospective case-control study in which both cases and controls were drawn from a cohort of contact tracing records of the central SRRT team, Department of Disease Control (DDC), MoPH, Thailand (Figure 1). Contacts were defined by the DDC MoPH as individuals who had activities together with or were in the same location(s) as a COVID-19 patient. Contacts were classified by MoPH as high-risk contacts if they were family members or lived in the same household as a COVID-19 patient, if they were within 1-meter distance longer than 5 minutes of a COVID-19 patient, if they were exposed to cough, sneeze or secretions of a COVID-19 patient and were not wearing a protective gear, such as mask, or if they were in the same closed environment (e.g. room, nightclub, stadium, vehicle) within 1-meter distance longer than 15 minutes of a COVID-19 patient and they were not wearing a protective gear, such as mask. Contacts were classified as low-risk contacts if they had activities together with or were in the same locations as a COVID-19 patient, but did not fulfil the criteria of a high-risk contact. All high-risk contacts with any symptoms were tested with a PCR assay and quarantined in a hospital or a quarantine site. All high-risk contacts without any symptoms were self-quarantined at home. Before 23 March 2020, all high-risk contacts without any symptoms were tested using PCR assays on day 5 after the last date of exposure to a case. As of 23 March 2020, all household contacts were tested using PCR assays regardless of their symptoms. Other high-risk contacts were tested only if they developed any COVID-19 symptoms. All low-risk contacts were recommended to perform self-monitoring for 14 days, and visit healthcare facilities immediately for PCR-assays if they develop any symptoms of COVID-19. Hence, the main aim of the contact tracing was to identify and evaluate contacts, perform PCR diagnostic tests, and quarantine
high-risk contacts. All PCR tests were performed at laboratories certified for COVID-19 testing by the National Institute of Health of Thailand. Data of risk factors associated with COVID-19 infection, such as type of contact and use of mask, were recorded during the contact investigation, but not complete.

The central SRRT team was tasked to perform contact investigations for any cluster with at least five PCR-confirmed COVID-19 patients from the same location(s) within a one-week period. We primarily used these data to identify asymptomatic contacts of COVID-19 patients between 1 and 31 March 2020. To reduce the bias of the selection of asymptomatic contacts, all contact tracing records of the central SRRT team were used in the study.

We then conducted telephone calls and asked details about their contacts with COVID-19 patients (e.g. date, location, duration and distance of contacts), whether they wore masks, washed their hands and performed social distancing during the contact period, and whether the COVID-19 patient, if known, wore a mask. We also asked, and checked using records of the DDC, whether and when they were sick and diagnosed with COVID-19. To include only asymptomatic contacts in the study, we excluded people from the analysis who already had any symptoms of COVID-19; including cough, fever, fatigue, diarrhoea, abdominal pain, loss of appetite, and loss of smell and taste, on the first day of contact. We also excluded contacts whose contact locations were healthcare facilities because this study aimed to focus on infection in the public.
Asymptomatic contacts, cases, controls, index patients, primary index patients and COVID-19 patients were defined as described in Table 1. The reporting of this study follows the STROBE guidelines.

Selection of cases and controls

We defined asymptomatic contacts who were later diagnosed as COVID-19 patients using PCR assays by 21 Apr 2020 as cases (Table 1). All asymptomatic contacts who were not diagnosed as COVID-19 patients using PCR assays by 21 Apr 2020 were controls. We arbitrarily used 21 days after 31 March as the cutoff based on the evidence that most COVID-19 patients would likely develop symptoms within 14 days and it should take less than another 7 days for symptomatic patients, under contact investigations, to present at healthcare facilities and be tested for COVID-19 with PCR assays.

Statistical analysis

Odds ratios and 95% confidence intervals were estimated for associations between development of COVID-19 and baseline covariates, such as wearing masks, washing hands and social distancing using logistic regression with a random effect for location and a random effect for index patient nested within the same location. The interviewer identified the index patient, the symptomatic COVID-19 patient who had the closet contact, if an asymptomatic contact contacted more than one symptomatic COVID-19 patient. The percentage of missing values in the variable whether the COVID-19 patients wore a mask was 27%, and the variable was not included in the analyses. We assumed that missing values were missing at random and used imputation by chained equations. We created 10 imputed datasets and the imputation model included all listed confounders and the
case-control indicator. We developed the final multilevel mixed-effect logistic regression models on the basis of previous knowledge and a purposeful selection method.\textsuperscript{26}

We also estimated odds ratios and 95% confidence intervals for associations between compliance of mask wearing and other practices; including washing hands and social distancing using multinomial logistic regression models and the imputed data set. Logistic regression was also used to estimate p value for pairwise comparisons. Bonferroni correction was not performed. We estimated secondary attack rate using definitions as described in Table 1, to allow for comparison with other studies.

\textbf{Sensitivity analyses}

We conducted a sensitivity analysis by including type of mask in the multilevel mixed-effects logistic regression model for COVID-19 infection. We also tested a pre-defined interaction between type of mask and compliance of wearing masks.

\textbf{Additional analyses}

To respond to the national policy, we estimated population attributable fraction (PAF) using the imputed dataset and a direct method based on logistic regression as described previously (details in Supplementary Text).\textsuperscript{27, 28} In short, the final multivariable model was modified by considering each risk factor dichotomously, and PAF was calculated by subtraction of the total number of predicted cases from total number of observed cases, divided by the total number of observed cases. STATA version 14.2 and R version 4.0.0 were used for all analyses.
Participants and public involvement

No participants were involved in setting the research question or the outcome measures, nor were they involved in developing plans for design or implementation of the study. However, the study, as part of the outbreak investigation of the DDC, MoPH, was developed to respond to concerns by the public about risks and effectiveness of preventive measures of COVID-19 in different settings, and which preventive measures should be implemented when public gathering places, including restaurants, nightclubs, stadiums, workplaces, etc., were re-opening. No participants were asked to aid in interpreting or disseminated the results. There are plans to disseminate the results of the research to the public.

RESULTS

Characteristics of the cohort data

The contact tracing of the central SRRT team consisted of 1,716 individuals who had contact with or were in the same location as a COVID-19 patient who were associated with three large clusters in nightclubs, boxing stadiums and a state enterprise office in Thailand (Figure 1). Overall, we considered 18 individuals as primary index patients because they were the first who had symptoms at those places, had had symptoms since the first day of visiting those places, or were considered to be the origin of infection of cases based on the contact investigations; 11 from the nightclub cluster, 5 from the boxing stadium cluster and 2 from the state enterprise office cluster. Timelines of primary index patients from nightclub, boxing stadium and state enterprise clusters are
described in details in Supplementary Text and Supplementary Figure 1-3. All 18 primary index patients were excluded from the analysis of the case-control study.

Selection of cases and controls

After retrospectively interviewing each contact by phone and applying the exclusion criteria (Figure 1), we included 1,050 asymptomatic contacts who had contact with or were in the same location as a symptomatic COVID-19 patient between 1 and 31 March 2020 in the analysis. The median age of individuals was 38 years (IQR 28-51) and 55% were male (Table 1). Most asymptomatic contacts included in the study were associated with the boxing stadium cluster (61%, n=645), with 36% (n=374) with the nightclub cluster, and 3% (n=31) with the state enterprise office cluster.

Overall, 211 (20%) asymptomatic contacts were later diagnosed with COVID-19 by 21 Apr 2020 (case group) and 839 (80%) were not (control group). Of the 211 cases, 150 (71%) had symptoms prior to the diagnosis of COVID-19 using PCR assays. The last date that a COVID-19 case diagnosed was 9 April 2020. Of 839 controls, 719 (86%) were tested with PCR assays at least once.

Figure 2 illustrates contacts (and possible transmission of COVID-19 infections) between index patients to asymptomatic contacts included in the study. A total of 228, 144 and 20 asymptomatic contacts contacted with index patients at nightclubs, boxing stadiums and the state enterprise office, respectively. For simplicity, Figure 2 is shown as all of them were contacted with the primary index patients in the clusters. The others then contacted with cases associated with nightclubs,
boxing stadiums and the state enterprise office at workplaces (n=277), households (n=230) and other places (n=151).

**Primary analysis**

Table 2 shows that there was a negative association between risk of COVID-19 infection and shortest distance of contact >1 meter (adjusted odds ratio [aOR] 0.15, 95% confidence interval [CI] 0.04-0.63), duration of contact within 1 meter ≤15 minutes (aOR 0.24, 95%CI 0.07-0.90), washing hands often (aOR 0.33, 95%CI 0.13-0.87) and wearing masks all the time (aOR 0.23, 95%CI 0.09-0.60). Wearing masks sometimes was not significantly associated with lower risk of infection (aOR 0.87, 95%CI 0.41-1.84). Sharing cigarettes was associated with higher risk of COVID-19 infection (aOR 3.47, 1.09-11.02). Type of masks was not independently associated with the risk of infection, and was not included in the final multivariable model.

**Association between compliance of mask wearing and other social distancing practices.**

Since wearing masks all the time was found to be negatively associated with COVID-19 infection, we wanted to explore characteristics of those patients because of a potential false sense of security caused by wearing masks. We found that those who wore masks all the time were more likely to have shortest distance of contact >1 meter (25% vs. 18%, pairwise p=0.03), have duration of contact within 1 meter ≤15 minutes (26% vs 13%, pairwise p<0.001) and wash their hands often (79% vs. 26%, pairwise p<0.001) compared with those who did not wear masks (Table 3). We found that those who wore masks sometimes were more likely to wash their hands often (43% vs. 26%, pairwise p<0.001) compared with those who did not wear masks. However, they were more
likely to had physical contact (50% vs. 42%, pairwise p=0.03) and duration of contact within 1
meter >60 minutes (75% vs. 67%, pairwise p=0.04) compared with those who did not wear masks.

Secondary attack rate
Overall, 982 (94%) were contacts with high-risk exposure. All 68 asymptomatic contacts without
high-risk exposure were controls. Among asymptomatic contacts with high-risk exposure included
in the study, the nightclub secondary attack rate was 16% (35/213), the boxing stadium secondary
attack rate was 87% (125/144), the workplace secondary attack rate was 4% (11/250), the
household secondary attack rate was 17% (38/230), and the secondary attack rate at other places
was 1% (2/145).

Sensitivity analyses
Since aOR of type of mask could be useful for future studies, we modified the final multivariable
model and presented those aOR in the Supplementary Table 1. Interaction between type of mask
and compliance of mask wearing was not observed.

Population attributable fraction (PAF)
Using the direct method to calculate PAF, we estimated that the proportional reduction in cases
that would occur if everyone wore a mask all the time during contact with index patients (PAF of
not wearing masks all the time) was 0.28 (Table 4). Among modifiable risk factors evaluated, PAF
of shortest distance of contact <1 meter was highest at 0.40. If everyone wore a mask all the time,
ashed hands often, did not share a dish, cup or cigarette, had shortest distance of contact >1 meter
and had duration of close contact ≤15 min, cases would have been reduced by 84%.
DISCUSSIONS

Statement of principal findings

This cohort-based case-control study provides a supporting evidence that wearing masks, washing hands and social distancing are independently associated with lower risk of COVID-19 infection in the general public. We observed that wearing masks all the time when expose to someone with COVID-19 was associated with lower risk of infection, while wearing masks sometimes was not. This supports the recommendation that people should be wearing their masks correctly at all times in public and at home when there is an increased risk.²⁴⁹¹⁰

We also quantified the effectiveness of different measures that could be implemented to prevent transmission in nightclubs, stadiums, workplaces and other public gathering places. We found that those who wore masks all the time were also more likely to wash hands and perform social distancing. We estimated that adopting all recommendations (wear masks all the time, wash hands often, not sharing dishes, cups or cigarettes, maintain a distance of <1 meter and, if needed, have less than 15 minutes contact) could result in controlling 86% of the burden of COVID-19 infections in our setting during the study period. We recommend that all public gathering places consider multiple measures to prevent transmission of COVID-19 and new pandemic diseases in the future.

Public messaging on how to wear masks correctly needs to be consistently delivered, particularly among those who wear masks sometimes or incorrectly (e.g. not covering both nose and mouth).
This is because, based on our findings, those who wear masks intermittently could be a group that did not practice social distancing adequately.

Comparison with other studies

The effectiveness of wearing masks observed in this study is consistent with previous studies; including a randomized-controlled trial (RCT) showing that adherent use of a face mask reduce the risk of influenza-like illness\(^2^9\) and case-control studies which found that wearing masks is associated with lower risk of SARS infection\(^3^0\)-\(^3^2\) While previous studies found use of surgical masks or 12–16-layer cotton masks demonstrated protection against coronavirus infection in the community\(^3^0\)-\(^3^2\) we did not observe a difference between wearing non-medical and medical masks in the general population. Therefore, we strongly support wearing non-medical masks in public to prevent COVID-19 infections. Even though the risk perception of COVID-19 threat can increase the likelihood of wearing medical masks in other settings\(^3^3\) we maintain that medical masks should be reserved for healthcare workers.

This study found a negative association between risk of COVID-19 infection and social distancing (i.e. distance and duration of contact), which is consistent with previous studies which found that at least 1-meter physical distancing was strongly associated with a large protective effect, and distances of 2 meters could be more effective\(^3^2\) Effectiveness of hand hygiene is consistent with the previous studies\(^3^4\) Although sharing dishes or cups was not independently associated with the infection in our study, based on previous studies\(^3^5\) we still recommend not sharing dishes or cups.
The household secondary attack rate in our study (17%) is comparable with those reported ranging from 11% to 19%,\textsuperscript{35} \textsuperscript{36} and relatively high compared to workplaces and other places. While challenging and sometimes impractical, household members should immediately separate a person who develops any possible symptoms of COVID-19 from other household members (i.e. a sick person should stay in a specific room, use a separate bathroom, if possible, and do not share dishes, cups and other utensils in the households).\textsuperscript{37} All household members should be encouraged to wear masks, keep washing hands and perform social distancing to the extent possible.\textsuperscript{38}

The high number of COVID-19 patients associated with nightclubs in Bangkok is comparable to COVID-19 outbreak associated with Itaewon nightclub cluster in Seoul, Korea, in May 2020.\textsuperscript{39} Similarly, we also found individuals who visited several nightclubs in the same area during the short period of time. The high number of COVID-19 patient cluster associated with boxing stadiums in Bangkok is similar to COVID-19 case cluster probably associated with a football match in Italy in February 2020.\textsuperscript{40} The secondary attack rate of COVID-19 at a chore practice in the U.S. was reported to be as high as 53%,\textsuperscript{41} and the secondary attack rates in public gathering places with high density of people shouting and cheering, such as football and boxing stadiums, are still largely unknown.

It is likely that clear and consistent public messaging from policy makers prevents a false sense of security and promotes compliance with social distancing in Thailand. It is recommended that both mainstream and social media should support public health responses by teaming with government in providing consistent, simple and clear messages.\textsuperscript{42} Both positive and negative messages can influence the public.\textsuperscript{42} In Thailand, daily briefings of Thailand's Centre for COVID-19 Situation
Administration (CCSA) gave clear and consistent messages on social distancing every day, as well as how to put on a mask and wash hands. The situation reports and advices by CCSA on daily basis have greatly improved the confidence in the public and compliance with the recommendations. Those are shown by the official online surveys of the DDC,43 of which results are reported during the daily briefings regularly.

**Strength and limitations of the study**

To our knowledge,32 this is the first epidemiological study to quantitatively assess the protective effect of wearing masks against COVID-19 infections in the general population. Studying asymptomatic contacts covering the period when multiple measures (including wearing masks) were recommended but not compulsory, allowed us to evaluate the potential effectiveness of each measure.

There are several limitations of the study. First, our finding might not be generalizable to all settings, since findings were based on contacts associated with three major COVID-19 clusters in Thailand during March 2020. Second, the estimated odds ratios were based on a condition that the contact with index patients occurred. Our study did not evaluate or take into account the probability of contacting index patients in public. Third, our findings were based on PCR testing per national contact tracing guideline,21 22 and as such the estimated odds ratios might not take account of all asymptomatic infections. Fourth, it is impossible to identify every potential contact an individual has and some individuals may have been contacts to more than one COVID-19 patient. Hence, our estimated secondary attack rates among contacts with high-risk exposure could be over or under-estimated. Fifth, findings were subject to common biases of retrospective case-control studies;
including memory bias, observer bias and information bias. Nonetheless, we used structured interviews, whereby each participant was asked the same set of defined questions, to reduce potential biases.

**Considerations for further research**

Evaluating effectiveness of wearing masks, washing hands and social distancing during an outbreak of COVID-19 is difficult. Prospective RCTs could give the best estimate of the effectiveness of each measure; however, setting up an RCT in an area or a country where a measure of interest is strongly recommended or compulsory is probably impractical. Nonetheless, we suggest that RCT of wearing masks should be conducted when and where possible because findings of RCTs will give a higher level of evidence to the public and policy makers. Other types of studies; including natural experiment, cross-sectional, case-control and cohort studies should also be conducted to evaluate effectiveness of wearing masks against COVID-19 and other respiratory infections in different settings. In addition, social and behavioural studies are needed to understand how people could perceive and adopt the recommendations of wearing masks, washing hands and social distancing in different settings.

**Conclusions and future implications**

As measures against COVID-19 are being implemented or relaxed in many countries worldwide, it is important that we continue to expand our understanding about the effectiveness of each measure. Wearing masks, washing hands and social distancing are strongly associated with lower risk of COVID-19 infections. We strongly support wearing non-medical masks in public to prevent COVID-19 infections. We also suggest that medical masks should be reserved for healthcare
workers. Everyone should also wash their hands frequently and comply with recommendations of social distancing.

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Contributors

PD, RS, CN and DL contributed to design of the study. PD, RS and DL contributed to setting up the database and quality control. AP, CJ, DR, ND, NE, NP, NS, OY, PaP, PiP, PK, PS, PW, SC, SK and TC contributed to data collection. DL carried out the main statistical analysis. PD and RS coordinated the study and contributed to the statistical analyses. PD, RS and DL contributed to interpretation of the results and drafted the manuscript. All authors commented on drafts and read and approved the final manuscript. The corresponding author attests that all listed authors meet authorship criteria and that no others meeting the criteria have been omitted. PD is the guarantor.

Competing interests:
The authors declare that they have no completing interests.

**Ethical approval**

As this study is part of the routine situation analysis and outbreak investigation of the DDC MoPH Thailand, it was not required to obtain ethics approval and no written informed consent was collected. However, the study team strictly followed ethical standards in research, that is, all individual information was strictly kept confidential and not reported in the paper. The DDC MoPH Thailand approved the analysis and reporting of data in aggregate.

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**Data sharing**

All data in aggregate are reported in the manuscript.
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### Table 1. Definitions used in the study

| Classification            | Definition                                                                                                                                 |
|---------------------------|-------------------------------------------------------------------------------------------------------------------------------------------|
| Asymptomatic contacts     | Individuals who had contact with or were in the same location as a symptomatic COVID-19 patient, and had no symptoms of COVID-19 on the first day of contact. |
| Cases                     | Asymptomatic contacts of COVID-19 patients who were later diagnosed and officially reported as COVID-19 patients by 21 Apr 2020.               |
| Controls                  | Asymptomatic contacts of COVID-19 patients who were never diagnosed as COVID-19 patients by 21 Apr 2020.                                      |
| Index patients            | The COVID-19 patients identified from the contract tracing data as the potential source of infection. Cases (as defined above) could also be included as index patients. |
| Primary index patients    | The earliest COVID-19 patients whose probable sources of infection were prior to the study period (1 to 31 March 2020), whom we were not able to identify the source of infection from, or whose probable sources of infection were outside the contract tracing data included in the study. |
| COVID-19 patients         | Individuals who had PCR positive for SARS-CoV-2, officially confirmed and reported by Department of Disease Control (DDC), Ministry of Public Health (MoPH), Thailand |
| Secondary attack rate     | The percentage of new cases among asymptomatic contacts with high-risk exposure.                                                             |
| High-risk exposure        | Individuals who lived in the same household as a COVID-19 patient, had a direct physical contact with a COVID-19 case, had face-to-face contact with a COVID-19 case within 1 meter and longer than 15 minutes, or were in a closed environment with a COVID-19 patient at a distance of within 1 meter and longer than 15 minutes. |
| Household contact         | Individuals who lived in the same household as a COVID-19 patient.                                                                        |
Table 2. Factors associated with COVID-19 infections

| Factors                        | Cases (n=211)   | Controls (n=839) | Crude odds ratio (95% CI) | P   | Adjusted odds ratio (95% CI) | P   |
|-------------------------------|----------------|-----------------|---------------------------|-----|----------------------------|-----|
| **Male gender**               |                |                 |                           |     |                            |     |
|                               | 146/211 (69%)  | 434/838 (52%)   | 0.83 (0.47-1.46)          | 0.52| 0.76 (0.41-1.41)           | 0.38|
| **Age group**                 |                |                 |                           |     |                            |     |
| ≤15 years old                 | 6/211 (3%)     | 49/829 (6%)     | 0.65 (0.17-2.48)          | 0.28| 0.57 (0.15-2.21)           | 0.20|
| >15 – 40 years old            | 94/211 (45%)   | 435/829 (52%)   | 1.0                       | 1.0 |                            |     |
| >40 – 65 years old            | 98/211 (46%)   | 302/829 (36%)   | 1.66 (0.92-2.99)          | 1.77| 0.94-3.32                  |     |
| >65 years old                 | 13/211 (6%)    | 43/829 (5%)     | 1.27 (0.32-4.97)          | 0.97| 0.22-4.24                  |     |
| **Contact place** b           |                |                 |                           |     |                            |     |
| Nightclub                     | 35 (17%)       | 193 (23%)       | Not applicable c          | -   | Not applicable c           | -   |
| Boxing stadium                | 125 (59%)      | 19 (2%)         |                           |     |                            |     |
| Workplace                     | 11 (5%)        | 286 (34%)       |                           |     |                            |     |
| Household                     | 38 (18%)       | 192 (23%)       |                           |     |                            |     |
| Others                        | 2 (1%)         | 149 (18%)       |                           |     |                            |     |
| **Shortest distance of contact** |            |                 |                           |     |                            |     |
| Physical contact              | 132/197 (67%)  | 292/809 (36%)   | 1.0                       | 0.001| 1.0                        | 0.02|
| ≤1 meter without physical contact | 61/197 (31%)  | 335/809 (41%)   | 0.76 (0.43-1.36)          | 1.09| 0.58-2.07                  |     |
| >1 meter                      | 4/197 (2%)     | 182/809 (22%)   | 0.08 (0.02-0.30)          | 0.15| 0.04-0.63                  |     |
| **Duration of contact within 1 meter** |    |                 |                           |     |                            |     |
| >60 minutes                   | 180/199 (90%)  | 487/801 (61%)   | 1.0                       | 0.003| 1.0                        | 0.09|
| >15 – 60 minutes              | 14/199 (7%)    | 162/801 (20%)   | 0.52 (0.23-1.16)          | 0.67| 0.29-1.55                  |     |
| ≤15 minutes                   | 5/199 (3%)     | 152/801 (19%)   | 0.13 (0.04-0.46)          | 0.24| 0.07-0.90                  |     |
| **Sharing dishes or cups d,e** |            |                 |                           |     |                            |     |
| None                          | 125/210 (60%)  | 576/837 (69%)   | 1.0                       | 0.001| 1.0                        | 0.38|
| Yes                           | 85/210 (40%)   | 261/837 (31%)   | 2.72 (1.49-4.97)          | 1.33| 0.70-2.54                  |     |
| **Sharing cigarettes d,f**    |            |                 |                           |     |                            |     |
| None                          | 196/209 (94%)  | 824/836 (99%)   | 1.0                       | 0.001| 1.0                        | 0.04|
| Yes                           | 13/209 (6%)    | 12/836 (1%)     | 6.19 (2.13-17.95)         | 3.47| 1.09-11.02                 |     |
| **Washing hands d,g**         |            |                 |                           |     |                            |     |
| None                          | 44/210 (21%)   | 121/826 (15%)   | 1.0                       | <0.001| 1.0                        | 0.04|
| Sometimes                     | 114/210 (54%)  | 333/826 (40%)   | 0.40 (0.18-0.89)          | 0.34| 0.14-0.81                  |     |
| Often                         | 52/210 (25%)   | 372/826 (45%)   | 0.19 (0.08-0.44)          | 0.33| 0.13-0.87                  |     |
| **Wearing masks d,h**         |            |                 |                           |     |                            |     |
| Wearing methods                                      | Unadjusted | Adjusted  | OR     | 95% CI    | Adjusted  | 95% CI    | Adjusted  | 95% CI    |
|-----------------------------------------------------|------------|-----------|--------|-----------|-----------|-----------|-----------|-----------|
| Not wearing masks                                   | 102/211 (48%) | 500/834 (60%) | 1.0    | <0.001    | 1.0       | <0.001    | 1.0       | 0.007     |
| Wearing non-medical masks                           | 25/211 (12%) | 77/834 (9%) | 0.78   | (0.32-1.90) | 0.77      | (0.32-1.90) | 0.75      | (0.37-1.52) |
| Wearing non-medical and medical masks alternately   | 12/211 (6%) | 48/834 (6%) | 0.46   | (0.13-1.64) | 0.45      | (0.13-1.64) | 0.44      | (0.12-1.59) |
| Wearing medical masks                               | 72/211 (34%) | 209/834 (25%) | 0.25   | (0.12-0.53) | 0.26      | (0.12-0.54) | 0.24      | (0.11-0.53) |
| Compliance with mask wearing d,h                    |            |           |        |           |           |           |           |           |
| Not wearing a mask                                   | 102/210 (49%) | 500/823 (61%) | 1.0    | <0.001    | 1.0       | 0.87      | 0.87      | 0.007     |
| Sometimes                                           | 79/210 (38%) | 125/823 (15%) | 0.75   | (0.37-1.52) | 0.74      | (0.36-1.53) | 0.71      | (0.32-1.55) |
| All the time                                        | 29/210 (14%) | 198/823 (24%) | 0.15   | (0.07-0.36) | 0.16      | (0.08-0.36) | 0.14      | (0.07-0.31) |

Footnote of Table 2. a Both crude and adjusted odds ratios were estimated using logistic regression with a random effect for location and a random effect for index patient nested within the same location. b The state enterprise office was considered and included as a workplace. Others included restaurants, markets, malls, religious places, households of index patients or other people but not living together, etc. c Location was included in the model as a random effect variable. d During the contact period. e Sharing dishes but using communal spoons all the time was considered as not sharing dishes. f Included sharing electronic cigarettes and any vaping devices. g Included washing with soap and water, and with alcohol-based solutions. h Wearing masks incorrectly (i.e. not covering both nose and mouth) was considered as not wearing.
Table 3. Factors associated with compliance of mask wearing

| Factors                        | Not wearing masks (n=602) | Wearing masks sometimes (n=204) | Wearing masks all the time (n=227) | P       |
|--------------------------------|---------------------------|---------------------------------|-----------------------------------|---------|
| Male gender                    |                           |                                 |                                   | 0.03    |
| Age group                      |                           |                                 |                                   |         |
| ≤15 years old                  | 324/601 (54%)             | 129/204 (63%)                   | 115/227 (51%)                    | <0.001  |
| >15 – 40 years old             | 269/594 (45%)             | 117/204 (57%)                   | 132/225 (59%)                    |         |
| >40 – 65 years old             | 236/594 (40%)             | 76/204 (37%)                    | 84/225 (37%)                     |         |
| >65 years old                  | 44/594 (7%)               | 6/204 (3%)                      | 6/225 (3%)                       |         |
| Contact places                 |                           |                                 |                                   |         |
| Nightclub                      | 84 (14%)                  | 51 (25%)                        | 91 (40%)                         | <0.001  |
| Boxing stadium                 | 48 (8%)                   | 66 (32%)                        | 29 (13%)                         |         |
| Workplace a                     | 178 (30%)                 | 46 (23%)                        | 64 (28%)                         |         |
| Household                      | 167 (28%)                 | 27 (13%)                        | 33 (15%)                         |         |
| Others b                       | 125 (21%)                 | 14 (7%)                         | 10 (4%)                          |         |
| Shortest distance of contact   |                           |                                 |                                   | 0.005   |
| Physical contact               | 246/588 (42%)             | 96/191 (50%)                    | 76/212 (36%)                     |         |
| ≤1 meter without physical contact | 238/588 (40%)             | 70/191 (37%)                    | 83/212 (39%)                     |         |
| >1 meter                       | 104/588 (18%)             | 25/191 (13%)                    | 53/212 (25%)                     |         |
| Duration of contact within 1 meter |                   |                                 |                                   |         |
| >60 minutes                    | 396/590 (67%)             | 143/190 (75%)                   | 121/205 (59%)                    | <0.001  |
| >15 – 60 minutes               | 120/590 (20%)             | 23/190 (12%)                    | 30/205 (15%)                     |         |
| ≤15 minutes                    | 74/590 (13%)              | 24/190 (13%)                    | 54/205 (26%)                     |         |
| Sharing dishes or cups c,d     |                           |                                 |                                   | <0.001  |
| None                           | 361/601 (60%)             | 130/203 (64%)                   | 200/226 (88%)                    |         |
| Yes                            | 240/601 (40%)             | 73/203 (36%)                    | 26/226 (12%)                     |         |
| Sharing cigarettes c,e         |                           |                                 |                                   |         |
| None                           | 586/600 (98%)             | 194/202 (96%)                   | 223/226 (99%)                    | 0.26    |
| Yes                            | 14/600 (2%)               | 8/202 (4%)                      | 3/226 (1%)                       |         |
| Washing hands c,f              |                           |                                 |                                   |         |
| None                           | 142/594 (24%)             | 16/203 (8%)                     | 6/224 (3%)                       | <0.001  |
| Sometimes                      | 298/594 (50%)             | 99/203 (49%)                    | 42/224 (19%)                     |         |
| Often                          | 154/594 (26%)             | 88/203 (43%)                    | 176/224 (79%)                    |         |

Footnote of Table 3. P values were estimated using univariable multinomial logistic regression models. Missing values were imputed using the imputation model. Wearing masks incorrectly (i.e. not covering both nose and mouth) was considered as not wearing. a The state enterprise office was considered and included as a workplace. b Included restaurants, markets, malls, religious places, public places, households of index patients or other people but not living together, etc. c During the contact period. d Sharing dishes but using communal spoons all the time was considered as not sharing dishes. e Included sharing electronic cigarettes and any vaping devices. f Included washing with soap and water, and with alcohol-based solutions.
Table 4. Population attributable fraction (PAF) of risk factors for COVID-19 infection

| Risk factors                                | Nightclub | Boxing stadium | Workplace | Household | Other places | Overall |
|---------------------------------------------|-----------|----------------|-----------|-----------|--------------|---------|
|                                             | Prev a    | PAF b          | Prev a    | PAF b     | Prev b       | PAF b   | Prev a | PAF b |
| Non-modifiable                              |           |                |           |           |              |         |        |       |
| Female gender                               | 0.51      | 0.08           | 0.13      | 0.002     | 0.40         | 0.03    | 0.68   | 0.09 |
| Age group >15 years old                     | 1.00      | 0.32           | 0.98      | 0.05      | 0.99         | 0.37    | 0.82   | 0.26 |
| Modifiable                                  |           |                |           |           |              |         |        |       |
| Distance of contact <1 m c                   | 0.88      | 0.71           | 0.98      | 0.19      | 0.65         | 0.72    | 0.87   | 0.68 |
| Duration of contact within 1 m >15 min c     | 0.86      | 0.55           | 0.99      | 0.11      | 0.70         | 0.57    | 0.91   | 0.53 |
| Sharing dishes or a cups c, d               | 0.34      | 0.10           | 0.30      | 0.01      | 0.19         | 0.06    | 0.57   | 0.11 |
| Sharing cigarettes c, e                      | 0.08      | 0.13           | 0.02      | 0.001     | 0.01         | 0.07    | 0      | 0    |
| Not washing hands c, f                      | 0.05      | 0.06           | 0.21      | 0.01      | 0.20         | 0.17    | 0.10   | 0.08 |
| Not wearing masks all the time c, g         | 0.60      | 0.52           | 0.80      | 0.08      | 0.78         | 0.65    | 0.86   | 0.55 |
| Sum of all modifiable risk factors i         | 0.98      | 0.75           | 0.98      | 0.97      | 0.99         | 0.97    |        |      |

Footnote of Table 4. a Prevalence (Prev) was estimated using the imputed data set. b PAF was estimated using the direct method (Supplementary Text). c During the contact period. d Sharing a dish but using communal spoons all the time was considered as not sharing a dish. e Included sharing an electronic cigarette and any vaping device. f Washing hands included washing with soap and water, and with alcohol-based solutions. g Wearing masks incorrectly (i.e. not covering both nose and mouth) was considered as not wearing. i Age and gender were considered as non-modifiable risk factors, while other risk factors were considered as modifiable. Total PAF was directly estimated using logistic regression in the form of natural logarithm; therefore, total PAF was not equal to the direct summation of PAF of each risk factor.
Figure 1. Study flow diagram

1,716 individuals who had contacted with or were in the same location as a COVID-19 patient, and traced by the central SRRT team in Thailand

666 excluded
18 were primary index patients
583 could not be contacted and interviewed by the study team
54 did not contact or were not in the same place with a symptomatic COVID-19 patient between 1 and 31 March 2020
6 contacted in a healthcare facility
5 had symptoms on the first date of contact

1,050 asymptomatic contacts included in the study

211 people were later diagnosed COVID-19 by 21 Apr 2020 (case group)

839 people were not diagnosed COVID-19 by 21 Apr 2020 (control group)

Footnote of Figure 1. SRRT= Surveillance and Rapid Response Team (SRRT), Ministry of Public Health (MoPH), Thailand
Figure 2. Development and transmission of COVID-19 among asymptomatic contacts included in the study
Footnote of Figure 2. A, B and C represent the nightclub cluster, boxing stadium cluster and state enterprise office cluster, respectively. Black nodes represent primary index patients, red dots represent cases, and green dots represent controls. Orange dots represent index patients (confirmed COVID-19 patients) who could not be contacted by the study team. Black lines represent household contacts, purple lines represent contacts at workplaces and gray lines represent contacts at other locations. Definition of index patients, cases and controls are listed in Table 1.
Supplementary Text

Supplementary Methods

To respond to the national policy, we estimated direct population attributable fraction (PAF) using the imputed dataset and the direct method as previously described.\textsuperscript{27,28} Direct PAF can be obtained by calculating PAFs directly from individuals’ data using logistic regression.\textsuperscript{27,28} First, we had to modify our final logistic regression model by considering each risk factor dichotomously. Then, irrespective of exposure to each risk factor for each individual, that factor was removed from the population by calculating probability based on all observations as unexposed. The predicted probability of developing COVID-19 infection for each asymptomatic contact, with the assumption that there was no exposure to a certain risk factor, is:

\[
P_{ki} = \frac{1}{1 + \exp[-(\beta_0 + \sum_{j \neq i} \beta_j x_j)]}
\]

Where \(P_{ki}\) is representative of predicted probability of COVID-19 infection in individual asymptomatic contact \(k\), assuming no exposure to a specific risk factor \((x_i)\); \(\beta_j\) indicates the regression coefficient of risk factor \((x_j)\), except risk factor number \(i\) \((x_i)\). Subsequently, the sum of all predicted probabilities for all individuals in the study would be equal to adjusted estimate of total cases, which is anticipated in the absence of that specific risk factor \((x_i)\).

Then, PAF was estimated by subtraction of the total number of predicted cases from total number of observed cases, divided by the total number of observed cases:
PAF = \frac{\text{Total number of observed cases} - \text{Total number of predicted cases}}{\text{Total number of overserved cases}}

**Supplementary Results**

For the pub cluster, we identified 11 primary index patients who started having symptoms from 4 to 8 March and were diagnosed (and isolated) from 3 to 10 March (Supplementary Figure 1). Those primary index patients visited multiple nightclubs included in the analysis during the study period, and 35 of 228 (15%) asymptomatic contacts at nightclubs had PCR-confirmed COVID-19 infections after the contact (Figure 2, Cluster A).

For the boxing stadium cluster, we identified 5 primary index patients who started having symptoms from 6 to 12 March and were diagnosed (and isolated) from 11 to 21 March (Supplementary Figure 2). Those primary index patients visited multiple boxing stadiums included in the analysis during the study period, and 125 of 144 (87%) asymptomatic contacts at the boxing stadiums had PCR-confirmed COVID-19 infections after the contact (Figure 2, Cluster B).

Of the two primary index patients for the office cluster; one had had symptoms since 15 March 2020 (Primary index patient C1 in Supplementary Figure 3) and was considered as the source of infection to one new case in the office during the study period. The other primary index patient (Primary index patient C2 in Supplementary Figure 3) was a household member of a staff at the office, and was considered as the source of infection to that staff via household contact.
### Supplementary Table 1. Factors associated with COVID-19 infections in a multivariable model including type of mask

| Factors                          | Adjusted odds ratio (95% CI) | P    |
|----------------------------------|-------------------------------|------|
| **Male gender**                  |                               |      |
| Male                             | 0.75 (0.40-1.38)              | 0.35 |
| **Age group**                    |                               |      |
| ≤15 years old                    | 0.55 (0.14-2.15)              |      |
| >15 – 40 years old               | 1.0                           |      |
| >40 – 65 years old               | 1.76 (0.93-3.31)              |      |
| >65 years old                    | 1.00 (0.23-4.34)              |      |
| **Contact place**                |                               |      |
| Nightclub                        | Not applicable                | -    |
| Boxing stadium                   |                               |      |
| Workplace                         |                               |      |
| Household                         |                               |      |
| Others                            |                               |      |
| **Shortest distance of contact** |                               |      |
| Physical contact                 | 1.0                           | 0.02 |
| ≤1 meter without physical contact| 1.07 (0.56-2.01)              |      |
| >1 meter                          | 0.15 (0.04-0.63)              |      |
| **Duration of contact within 1 meter** |                       |      |
| >60 minutes                       | 1.0                           | 0.09 |
| >15 – 60 minutes                  | 0.66 (0.28-1.52)              |      |
| ≤15 minutes                       | 0.24 (0.06-0.91)              |      |
| **Sharing dishes or a cups**     |                               |      |
| None                             | 1.0                           | 0.39 |
| Yes                              | 1.32 (0.69-2.52)              |      |
| **Sharing cigarettes**           |                               |      |
| None                             | 1.0                           | 0.03 |
| Yes                              | 3.46 (1.09-10.98)             |      |
| **Washing hands**                |                               |      |
| None                             | 1.0                           | 0.04 |
| Sometimes                        | 0.33 (0.14-0.79)              |      |
| Often                            | 0.33 (0.13-0.88)              |      |
| **Wearing masks**                |                               |      |
| Not wearing masks                | 1.0                           | 0.55 |
| Wearing Non-medical masks        | 1.30 (0.48-3.47)              |      |
| Wearing Non-medical and medical mask alternately | 1.04 (0.26-4.14) |      |
| Wearing Medical masks            | 0.62 (0.25-1.52)              |      |
| **Wearing masks all the time**   |                               |      |
| No                               | 1.0                           | 0.006|
| Yes                              | 0.31 (0.12-0.80)              |      |
Footnote of Supplementary Table 1. a Both crude and adjusted odds ratios were estimated using logistic regression with a random effect for location and a random effect for index patient nested within the same location. Missing values were imputed using the imputation model. b The state enterprise office was considered and included as workplaces. Others included restaurants, markets, malls, religious places, households of index patients or other people but not living together, etc. c Location was included in the model as a random effect variable. d During the contact period. e Sharing dishes but using communal spoons all the time was considered as not sharing dishes. f Included sharing electronic cigarettes and any vaping devices. g Included washing with soap and water, and with alcohol-based solutions. h Wearing masks incorrectly (i.e. not covering both nose and mouth) was considered as not wearing.
Supplementary Figure 1. Timeline and possible transmission of primary index patients of the pub cluster.
Supplementary Figure 2. Timeline and possible transmission of primary index patients of the boxing stadium cluster
Supplementary Figure 3. Timeline and possible transmission of primary index patients of the state enterprise office cluster