Applied Epidemiology during COVID-19 in Vietnam

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A thesis submitted for the degree of Master of Philosophy in Applied Epidemiology of the Australian National University

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Statement of authorship

I declare that the work contained in this thesis is my own work. To the best of my knowledge and belief this thesis contains no material previously published by another person except where due acknowledgement has been made. This thesis contains no material that has been accepted for the award of any other degree or diploma in any university. Contributions made to the research by others have been acknowledged in the respective chapter preface.

Quach Ha-Linh
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Acknowledgement

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Abstract

This thesis presents projects I conducted between February 2020 to December 2021 to meet the competencies of the Master of Applied Epidemiology Program (MAE) of the Australian National University (ANU). During this period, I was employed at the Department of Communicable Disease Control of the National Institute of Hygiene and Epidemiology (NIHE) in Hanoi, Vietnam.

Chapter 1 – Introduction.

This chapter provides an overview of my field placement, describes how I met the different MAE requirements, and presents other side projects I have been involved in during my MAE that do not fall under the MAE competencies.

Chapter 2 – Investigate an outbreak: *In-flight transmission of SARS-CoV-2 in Vietnam: Results from an outbreak investigation and containment measures.*

This project covers the investigation of and response to an in-flight COVID-19 transmission event in Vietnam in March 2020. I took part in the investigations from the beginning which resulted in the publication of two journal articles: one on the in-depth investigation of the on-board transmission event (**Journal Article 1**), and another one describing the response activities to prevent community transmission (**Journal Article 2**). We found that one infectious passenger in business class very likely infected at least 12 other passengers during a 10-hour flight, many of whom were seated beyond the two-row/seat distance threshold that is usually used for contact tracing among airplane passengers. Timely, systematic and comprehensive contact tracing of all passengers and their close contacts was needed to prevent widespread community transmission.

Chapter 3 – Analyze a public health dataset: *Association of public health interventions and COVID-19 incidence in Vietnam, January to December 2020.*

In this project I analyzed the relation between public health interventions and COVID-19 incidence in Vietnam over the course of 2020, which culminated in the publication of **Journal Article 3**. This analysis, which was the first of its kind in Vietnam and the region, identified important associations between the timing of public health interventions and changes in the reproductive number of SARS-CoV-2.

Chapter 4 – Evaluate a surveillance system: *After action review of the COVID-19 surveillance system in Quang Ninh Province, Vietnam in 2020*.

For this project I conducted a **Literature Review** on the World Health Organization (WHO)'s After Action Review (AAR) toolkit, and used it to evaluate the effectiveness of the surveillance system in Quang Ninh province, Vietnam in preventing and controlling COVID-19. This evaluation, presented as

a **Final Report** in this chapter, was part of a WHO-funded initiative to learn lessons from the COVID-19 response in Vietnam. While central coordination and adaptive capacity during the emergency were identified as strengths, my evaluation also provides important recommendations on how to improve the surveillance system in Quang Ninh province, in particular through improved integration of different data systems and communication channels between health jurisdictions of Quang Ninh's healthcare system.

Chapter 5 – Design an epidemiological project: *User-generated online information in response to a COVID-19 outbreak in Vietnam in July – September 2020*.
In this project I investigated so-called 'infodemics' related to a COVID-19 outbreak in Da Nang province, Vietnam between July and September 2020 by applying content analysis and semantic network analysis to publicly available user-generated information from the internet. I conducted two separate analyses: one on 'infodemics' related to COVID-19 incidence and mortality, which resulted in **Submitted Article Manuscript 1**; and another on 'infodemics' in relation to public health interventions, which resulted in **Submitted Article Manuscript 2.** Findings showed that public awareness and perceptions were highly correlated with the evolution of COVID-19 incidence and mortality (at first) during the outbreak, while misinformation and unverified information related to public health interventions that were implemented in response to the outbreak were also prevalent.

Chapter 6 – Other MAE requirements.
In this chapter I report on other MAE requirements which I completed during my fellowship, namely the publication of a **Lay Audience Report**, the **Lesson From The Field**, and the **Teaching Experience**.

Table of Content

Chapter 1. Introduction

Table of Content – Chapter 1

List of Abbreviations – Chapter 1

ANU	Australian National University
BCG	Bacillus Calmette–Guérin
COVID-19	Coronavirus 2019
HISoc	Humanitarian Innovation Society
MAE	Master of Applied Epidemiology
NIHE	National Institute of Hygiene and Epidemiology
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
Td	Tetanus-diphtheria vaccine

Introduction to field placement

I commenced my Master of Philosophy in Applied Epidemiology (MAE) field work placement at National Institution of Hygiene and Epidemiology (NIHE) in Hanoi, Vietnam from 9th March 2020.

NIHE operates as a scientific research and public deployment agency under Vietnam Ministry of Health. NIHE's aims is to research on epidemiology, medical microbiology, immunology and molecular biology; to research and develop new vaccines for human use; to direct a number of national health programs; to advise Vietnam Ministry of Health on preventive medicine strategies and measures; and to provide postgraduate training and field placement for higher medical students across the country. NIHE is one of four major Pasteur institutes in Vietnam, and focus on public health program and research for 10 Northern provinces. I was located in Department of Communicable Disease Control at NIHE, under supervision of Dr Nguyen Cong Khanh. The department included two working office focusing on (i) Communicable disease control activities, and (ii) National Immunization Program for the Northern region in Vietnam. The department is the focal point for surveillance system of communicable disease in Northern region, and operates the Emergency Operation Center for Hanoi and six other provinces in the region.

Summary of field placement activities

My main responsibility in the department is to conduct data input for respiratory disease notifiable system for 6 focal hospitals in Northern area and COVID-19 dashboard for case monitoring. This is a routine activity by the department to provide updates and monitor confirmed and suspected infectious cases in six Northern provinces, Vietnam.

Another job I took on was deployment by National Steering Committee of COVID-19 Prevention and Control since March 2020 to support the General Department of Preventive Medicine and national Pasteur Institutes in contact tracing and surveillance. I and my cohort colleague – Ms. Ngoc-Anh Hoang were involved in building the database for COVID-19 epidemiological data and developing data entry and management protocols. This database has been used to generate COVID-19 situation report for the office of the Deputy Prime Minister and the Ministry of Health. This database is now also used for the national COVID-19 monitoring dashboard, managed by NIHE and we were in charge of its data input during our field placement also. My role was included case and contacts tracing, interviewing, and collaborate with local authorities and health agencies in detecting, tracing, and quarantining any risky contacts with potential COVID-19 exposure. My colleague and I also contributed in develop the protocol for contact tracing among passengers and close contacts of passengers on flights with COVID-19 confirmed case in Vietnam. This protocol is still being used by contact tracers and includes standardized forms to monitor contact tracing, and scripts for phone calls covering a variety of specific situations. During this time, we had been working collaboratively with colleagues from General Department of Preventive Medicine, the Ministry of Health, the Ministry of Science and Technology, Hanoi Medical University, Hanoi University of Public Health, Hanoi University of Science and Technology, and private companies. We also led groups of medical and public health students for remote contact tracing activities and case investigations. Until November 2021, we were both involved with four major community outbreaks, and conducted contact tracing for nearly all flight passengers on flights with COVID-19 confirmed cases in March 2020.

Summary of MAE requirements

A. Core requirements

1. **Investigate an acute public health problem or threat (Chapter 2)**
   - In-flight transmission of SARS-CoV-2 in Vietnam: Results from an outbreak investigation and containment measures.

2. **Analyze a public health dataset (Chapter 3)**
   - Association of public health interventions and COVID-19 incidence in Vietnam, January to December 2020.

3. **Evaluate a surveillance system (Chapter 4)**
   - After action review of the COVID-19 surveillance system in Quang Ninh Province, Vietnam in 2020.

4. **Design and conduct an epidemiological study (Chapter 5)**
   - User-generated online information in response to a COVID-19 outbreak in Vietnam in July – September 2020.

B. Other requirements

1. **Literature review (Chapter 4)**
   - After Action Reviews for emergency preparedness and responses to infectious disease outbreaks: a literature review.

2. **Report to a non-scientific audience (Chapter 6)**
   - Quach Ha Linh, Pham Quang Thai (2021) "*Equality in COVID-19 vaccination administration – a dilemma*" ("*Bình đẳng trong sử dụng vắc-xin COVID-19 – bài toán khó*"), Suc Khoe & Doi Song – Official press representatives of Vietnam Ministry of Health, Vol 4 (4973), 7 Jan 2021.

Available at: https://suckhoedoisong.vn/binh-dang-trong-su-dung-vac-xin-covid-19-bai-toan-kho-n185112.html.

3. Publication or advanced draft submission to an international peer-reviewed journal

Published:

- Hoang NA[#], Pham QT[#^], Quach HL[^], Nguyen CK, Colquhoun S, Lambert S, Duong HL, Tran QD, Phung CD, Tran ND, Ngu DN, Tran AT, Nguyen TBH, Dang DA[*], Vogt F[*]. **Re-positive testing, clinical evolution and clearance of infection: results from COVID-19 cases in isolation in Vietnam** (accepted for publication in *Western Pacific Surveillance and Response*).
- Quach HL[#], Nguyen CK[#^], Hoang NA[^], Pham QT, Tran ND, Le TQM, Do HT, Vien CC, Phan TL, Ngu DN, Tran AT, Phung CD, Tran DQ, Dang QT, Dang DA[*], Vogt F[*]. **Association of public health interventions and the COVID-19 incidence in Vietnam, January to December 2020**. *International Journal of Infectious Disease*. S1201-9712(21)00600-7. Published 2021 July 28. doi: 10.1016/j.ijid.2021.07.044.
- Quach HL[#], Hoang NA[#], Nguyen CK[^], Pham QT, Phung CD, Tran ND, Le QMT, Ngu DN, Tran AT, La NQ, Tran DQ, Nguyen TT, Vogt F[*], Dang DA[*]. **Successful containment of a flight-imported COVID-19 outbreak through extensive contact tracing, systematic testing and mandatory quarantine: Lessons from Vietnam**. *Travel Medicine and Infectious Disease*. 42:102084. Published 2021 May 26. doi: 10.1016/j.tmaid.2021.102084.
- Pham TQ[#^], Hoang NA[#], Quach HL[^], Nguyen KC, Colquhoun S, Lambert S, Duong LH, Dai Tran Q, Ha DA, Phung DC, Ngu ND, Tran AT, La NQ, Nguyen TT, Le TQM, Tran ND, Vogt F[*], Dang DA[*]. **Timeliness of contact tracing among flight passengers during the COVID-19 epidemic in Vietnam**. *BMC Infectious Diseases*. 21(1):1-9. Published 2021 Apr 28. doi: 10.1186/s12879-021-06067-x.
- Nguyen KC[#^], Pham TQ[#], Quach HL, Hoang NA, Phung CD, Tran ND, Le TQM, Ngu DN, Tran AT, La NQ, Tran DQ, Nguyen TT, Vogt F[*], Dang DA[*]. **Transmission of SARS-CoV 2 during long-haul flight**. *Emerging Infectious Diseases*. 26(11):2617. Published 2020 Sep 18. doi: 10.3201/eid2611.203299.

Submitted:

- Quach HL[#], Nguyen CK[^], Pham QT, Hoang NA, Do THH, Nguyen TD, Ninh VC, Field E, Dang DA, Tran ND, Pham TCH, Tran AT, Nguyen TH, Ngu DN[*], Vogt F[*]. **After action review of COVID-19 surveillance system in Quang Ninh Province, Vietnam in 2020**. Submitted to *Asia Pacific Journal of Public Health* in November 2021.
- Quach HL[#^], Pham QT, Hoang NA, Phung CD, Nguyen VC, Le HS, Le CT, Bui TMT, Le HD, Dang DA, Tran ND, Ngu DN, Vogt F[*], Nguyen CK[*]. **Using 'infodemics' to understand public awareness and perception of SARS-CoV-2: a longitudinal analysis of online

information about COVID-19 incidence and mortality during a major outbreak in Vietnam, July - September 2020. Submitted to *Journal of Medical Internet Research* in September 2021.

- Quach HL[#^], Pham QT, Hoang NA, Phung CD, Nguyen VC, Le HS, Le CT, Le HD, Dang DA, Tran ND, Ngu DN, Vogt F[*], Nguyen CK[*]. **Understanding COVID-19 'infodemics': An analysis of user-generated online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020**. Submitted to *Health Informatics Research* in September 2021.

[#] (shared) first authorship
[*] (shared) last authorship
[^] (shared) corresponding authorship

4. Conference presentation

- Quach HL, Hoang NA, Nguyen CK, Thai PQ, Vogt F, '**In-Flight Transmission of SARS-CoV-2 During a Long-Haul Flight: Results from an Outbreak Investigation in Vietnam and Implications for Future Air Travel**'. Oral presentation, Southeast Asia and Western Pacific Bi-Regional Field Epidemiology Training Program COVID-19 Online Conference (virtual conference), 09-12 November 2020. (*Awarded First Place Outstanding Presentation*).
- Quach HL, Hoang NA, Nguyen CK, Thai PQ, Vogt F, '**In-Flight Transmission of SARS-CoV-2 During a Long-Haul Flight**'. Video presentation, Special Edition - Australasian COVID-19 Virtual Conference (virtual conference), 9 December 2020.
- Quach HL**,** Hoang NA, Nguyen CK, Pham QT, Phung CD, Le HS, Le CT, Vogt F, '**Understanding COVID-19 'infodemics': An analysis of user-generated online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020'.** Oral presentation, 10th Southeast Asia and Western Pacific Bi-regional TEPHINET Scientific Conference (virtual conference), 01-05 November 2021.

5. Teaching (Chapter 6)

- Lessons from the field: **Introduction to MicrobeTrace** (May 2021)
- Teaching experience: **Introduction to MicrobeTrace** (June 2021)

6. Coursework

- POPH8915 (Outbreak Investigation): Semester 1, 2020
- POPH8917 (Public Health Surveillance): Semester 1, 2020
- POPH8913 (Analysis of Public Health Data): Semester 2, 2020
- POP8916 (Issues in Applied Epidemiology): Semester 1, 2021
- POPH8914 (Methods in Applied Epidemiology): Semester 1, 2021.

Other activities

During my time in MAE and NIHE, I also participated in several side projects.

Project 1: Assessment of immune response, implementation process and Tetanus – diphtheria (Td) vaccination response in 7-year-old children in Yen Bai province in 2020.

This was a research project undertaken by the Northern Region National Immunization Program at Department of Communicable Disease Control, NIHE. The project followed a Td-vaccination campaign for 7-year-old in Yen Bai province, Vietnam, focusing on assessing immune response, implementation process and post-Td post-vaccination response in vaccinated population. The project was implemented from October 2020 to March 2021, and both my colleague and I were involved from the beginning. My role included conducting literature review, grant proposal, dispatch preparation, budget finalization, translation, participating in interview for healthcare workers, parents and teachers in the province.

Project 2: Increase the coverage of tuberculosis vaccination through reorienting and restructuring hospitals' vaccination systems in six Northern provinces, Vietnam

This was also a research project undertaken by the Northern Region National Immunization Program at Department of Communicable Disease Control, NIHE. This project assessed the postpartum vaccination system for hepatitis B vaccine in several hospitals in Vietnam. To improve the adherence of Bacillus Calmette–Guérin vaccines (BCG) uptake, this project aimed to assess the vaccination coverage of BCG vaccines in 6 Northern provinces in Vietnam. The project was funded by World Health Organization and implemented from November 2020 to March 2021. and both my colleague and I were involved from the beginning. My role included conducting literature review, grant proposal, and report writing.

Project 3: Research Project at Australian National University

This was a collaborated project between Australian National University (ANU), Harvard University and National University of Singapore to examining the relationship between country preparedness and COVID-19 pandemic. The research was commenced in May 2020. The research team aimed to systematically compare the various assessments, indices and benchmarking tools, and the national rankings and scores yielded by these tools with actual country-level outcomes of the COVID-19 pandemic. I applied and was involved in the research project as a student assistant, and participated to compile a database of country-level COVID-19 outcomes data including COVID-19 incidence and related public health interventions. The project ended in July 2020, final result was an advanced manuscript named "*National pandemic preparedness indicators were associated with better early* *performance, but not in the largest countries*” (accepted for publication to *Health Policy and Planning* in September 2021) and all students participated were credited in acknowledgement.

Project 4: ANU HISoc X Nasio Trust Summer Internship Program

This is a virtual summer internship program between the ANU’s Humanitarian Innovation Society (ANU HISoc) and the United Kingdom-Kenya based NGO - The Nasio Trust, the Mumias West Technical and Vocational College, and ANU Humanitarian Engineering to establish local student-led initiatives in Mumias, Kenya through a 7-week virtual internship program running 7 December 2020 - 7 February 2021. I participated in the program from November 2020 to February 2021 in the Health Application Team. My team’s responsible included developing a data collection app for community health volunteers within the local network, and I was in charge of data collection engine development and user experience design. I worked closely with student volunteers in ANU and healthcare volunteers in Kenya to conduct stakeholder research, developing and prototyping the application, and pilot run the app in February 2021. The app was launched successfully in March 2021 for Kenyan community volunteers.

Project 5: Online Crisis Simulation Workshop

This workshop was held by Global Health Innovation Policy Program on March 18 and 19, 2021. Four groups of graduate students and professionals from diverse backgrounds in regional affairs, international relations and health participated. I was assigned in “China” group and discussed global development and decisions in light of the ongoing COVID-19 pandemic.

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Chapter 2. Investigate an acute public health problem

In-flight transmission of SARS-CoV-2 in Vietnam:

Results from an outbreak investigation and containment measures

Table of Content – Chapter 2

List of Abbreviations – Chapter 2

COVID-19	Coronavirus 2019
CI	Confidence Interval
IQR	Interquartile Range
MAE	Master of Applied Epidemiology
NIHE	National Institute of Hygiene and Epidemiology
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2

Prologue

Background

Early into 2020, when the world was introduced to the magnitude and public health threats of COVID-19, Vietnam was one of the first countries to report COVID-19 cases outside of China. With close proximity and shared border with the then COVID-19 epicenter, Vietnam was particularly vulnerable with the importation of new cases and potential spillover to community transmission. The first three COVID-19 outbreaks reported in Vietnam were composed of eight imported cases with epidemiological links to Wuhan, China, and eight secondary cases in community. At the end of February 2020, most border control was focused on China inbound and outgoing travel, some was imposed on South Korea, Iran, and Northern Italy due to these countries' escalating COVID-19 situation. Into March 2020, as international travel was still operating, the first COVID-19 imported case from a novel source – London, United Kingdom was reported in Hanoi, Vietnam after a long-haul international flight.

My role

Since January, National Institute of Hygiene and Epidemiology (NIHE) was responsible to conduct surveillance and SARS-CoV-2 confirmation test for all suspected cases reporting in Northern Vietnam. NIHE was also a member of National Steering Committee of COVID-19 Prevention and Control, along with Ministry of Health, acting as expert advisers on public health interventions. The institute provided training and technical facilities for SARS-CoV-2 testing to all regional Center of Disease Control and some regional hospitals. In NIHE, Department of Communicable Disease Control was in charge of monitoring the COVID-19 sentinel surveillance system under the national sentinel disease surveillance. My field supervisor, in particular, was in charge of COVID-19 contact tracing system, and was a member of Rapid Information Response Team, National Steering Committee of COVID-19 Prevention and Control.

After my first course block in Canberra, I landed to Vietnam on the same day that the index case of the long-haul flight was confirmed, and contact tracing was already in progress. I was introduced right away to the Rapid Information Response Team by my field supervisor along with my cohort colleague – Ms. Hoang Thi Ngoc-Anh. Quickly we undertook the investigation of the flight as co-investigators. This involved conducting contact tracing for all passengers on the flight following possible COVID-19 exposure to the index case, and managing surveillance data for all confirmed and suspected cases (including close contacts of the index case and the passengers in Vietnam). Data management at that time was rather rapid and simple, we developed a shared Google Drive account where all data was compiled from local Center of Disease Control, COVID-19 designated hospitals and laboratories. Manual data input was required, and situation reports were sent in by hours. Meanwhile, contact tracing was done through phone call from the Rapid Information Response Team to all contacts we gathered from the flight manifest and close contact's lists by the index case. As soon as we located a person, a rapid protocol was followed to instruct the person to stay isolated, contact the local health staffs (often at commune/district health stations) to identify, quarantine the person as soon as possible. We conducted follow-up investigation to ensure the person in question was in quarantined. Some passengers were particularly hard to trace down, especially foreign tourists. as at that time, flight manifest only contained as far as names and passport number. Contact details were scarce, and we had to require assistance from embassy, tourism company, and local authorities. Language barriers and remote distance would hinder the timeliness of investigation, however, all passengers were understanding and cooperate with the process. The investigation took place during seven days after the contact tracing started (from 6 March – 13 March), where all traceable passengers, crew members who were still in the country at that time, and their close contacts were traced, quarantined and tested for SARS-CoV-2. The outbreak from the flight resulted in 15 additional cases with epidemiological link to the in-flight index case, and five community cases among close contacts. This outbreak was remarked as the first, and the biggest flight-related COVID-19 outbreak in Vietnam. The outbreak required national-scale investigation and resource, and was the topic of this chapter. In this investigation, Ngoc-Anh and I were both working on contact investigation and data compilation. Further into the process of writing the report, I was solely in charge of data analysis, report writing and manuscript preparation and submission. During submission, I had received guidance and support from my supervisors (Dr. Florian and Dr. Khanh), as well as a colleague from US Center of Disease Control in Vietnam – Dr. Matt Moore.

After the outbreak, I was an official member of the team, and was in charge of contact tracing and COVID-19 surveillance data system. We were frequently deployed by the team for all major inter-province outbreak in Vietnam, and at some point, we were staying with the team as the job required intensive hour commitment. This was a continued title for me until the end of the Master program, which I cherished as a valuable journey as the starting point of every field epidemiologist.

Achievements

This chapter consists of two papers I wrote during my time as a Master of Applied Epidemiology (MAE) scholar. The first paper was published on *Emerging Infectious Disease* in November 2020 (*Appendix 1*), reporting on the investigation of in-flight transmission of SARS-CoV-2 during the flight's course. The main hypothesis was that the index case - who were symptomatic on the flight - infected 11 other passengers on the same business class and three others in the economy class. I was involved since the conceptualization of the article until the end of submission (including journal submission, reviewers' responses, and proof-reading). Both my academic supervisor and field supervisor were involved in the process, and guided me throughout the submission. The second paper was published on *Travel Medicine and Infectious Disease* in May 2021 (*Appendix 2*), reporting on the containment effort of Vietnam Ministry of Health and National Steering Committee of COVID-19 Prevention and Control to contact trace, test, and quarantine all possible passengers on the flight and their close contacts.

I gave oral presentations of the first paper at two international conferences in 2020 (presentations are included in *Appendix 3*), and was awarded Outstanding Presentation at the 9th Bi-regional Training Programs in Epidemiology and Public Health Interventions Network Conference 2020 (Pictured below).

Abstract 1

Background

Importation of SARS-CoV-2 through infected air travelers contributed substantially to the global spread of COVID-19. However, evidence about the risk of in-flight transmission is scarce. In early March 2020, we observed a cluster of COVID-19 cases from suspected in-flight transmission among passengers and crew on an overnight flight of 10-hour duration from London, UK to Hanoi, Vietnam. We aimed to assess the risk of infection due to in-flight exposure to SARS-CoV-2 in order to understand the role of long-hail travel in potential super-spreader events.

Method

We conducted an in-depth epidemiological investigation to the response of the flight outbreak that involved contact tracing, systematic testing and strict quarantine to all traced passengers, crew members, and their close contacts in community. Logistic regression was used to identify factors associated with SARS-CoV-2 infection.

Result

We identified the index case as a 27-year-old woman with COVID-19 symptoms during the entire duration of the flight, who was PCR-confirmed with SARS-CoV-2 infection three days after arriving in Hanoi. We detected 14 additional cases among passengers and one among crew members, and five community cases. Twelve (80.0%) of the additional passenger cases were seated in business class together with the index case. Within business class, the attack rate was 62%, seating proximity to the index case was strongly associated with increased risk of infection (Risk Ratio: 7.33; 95% Confidence Intervals (95%CI) 1.16 – 46.23). Epidemiological investigations did not provide evidence of transmission before or after the flight for any of the additional cases.

Conclusion

Our findings strongly suggest that in-flight transmission originating from one symptomatic passenger caused a large COVID-19 cluster among flight passengers and close contacts in community. The cluster was successfully contained through timely, systematic and comprehensive public health responses thanks to multiagency collaboration despite delayed index case identification. This is the first in-depth analysis providing substantive evidence that air travel can facilitate SARS-CoV-2 super-spreader events. This study has significant implications for the safe resumption of air travel as long as COVID-19 presents a global pandemic threat.

Abstract 2

Background

The importation of SARS-CoV-2 through air travel poses substantial risks to generate new COVID-19 outbreaks. Timely contact tracing is particularly crucial to limit onwards transmission in settings without established community transmission.

Method

We conducted an in-depth analysis of the response to a big flight-associated COVID-19 outbreak in Vietnam in March 2020 that involved contact tracing, systematic testing and strict quarantine up to third generation contacts.

Result

183 primary contacts from the flight as well as 1,000 secondary and 311 third generation contacts[1] were traced, tested, and quarantined across 15 provinces across Vietnam. The protracted confirmation of the index case at 3 days and 19 hours after arrival resulted in isolation/quarantine delays of 6.8 days (Interquartile Range (IQR) 6.3–6.8) and 5.8 days (IQR 5.8–7.0) for primary and secondary cases, respectively, which generated 84.0 and 26.4 person-days of community exposure from primary and secondary cases, respectively. Nevertheless, only 5 secondary cases occurred.

Conclusion

A large flight-related COVID-19 cluster was successfully contained through timely, systematic and comprehensive public health responses despite delayed index case identification. Multiagency collaboration and pre-established mechanisms are crucial for low and middle income countries like Vietnam to limit community transmission after COVID-19 importation through air travel.

[1] Disclaimer: Third generation contacts were defined as either (i) non-close contacts (>2 m apart/in an open space during the incubation period) with a primary and/or a secondary contact or (ii) close contacts (≤ 2 m apart/in a closed space during the incubation period) with a secondary contact, between arrival of flight VN54 to Vietnam and start of isolation or quarantine.

Lessons learned

I was completely new to field epidemiology before the MAE commencement, outbreak investigation, field visit, contact tracing was all new concept to me. Stepping into the National Steering Committee of COVID-19 Prevention and Control, even after the POPH8316 Outbreak Investigation course from Dr. Philippa Binns in Canberra, I was overwhelmed. The seriousness, the rapidness, the constant phone calls and emails and reports in and out, all was to show how COVID-19 has reshaped communicable disease surveillance system in Vietnam. During the course of investigating the outbreak, I learned to step down, take in information once at a time, and build myself an understanding of how the system in place operated.

I also learned that the basic of filed epidemiology is to rapidly react and proactively act to contain outbreak, which means you have to utilize raw data and basic software to response to an outbreak in real time. As I mentioned, this was the very first stage of COVID-19 in Vietnam, especially at the magnitude of international flight with hundreds of passengers dispersing across the country without sufficient contact information. What I saw during the first few hours of investigation, not R studio or Stata, not fancy visualization software or stage-of-the-art call centers, personal phone was used to conduct contact tracing, and data was compiled on all networks, scanned picture, email, online message, to a simple Excel spreadsheet.

Of course, as new as the system was in place, many data were lost during the process. We could not get data on how many passengers were found at what date, and where, as all contact tracers got lost in the urgency to contact as many as possible and produce a close contact list before a suspected case report. After the outbreak, as I was in charge of writing the chapter and preparing publications, I had to scrape data from many unofficial sources as passengers on the flight were found in 15 provinces across Vietnam, and local health agencies were already too busy with COVID-19 situation at their region. I learned that while field epidemiology required rapid action and reaction to data, we need to be more careful and articulate with database that we have, to help answer the questions after every outbreak: what went right, what went wrong, and what was missing. The importance of data availability can make or break the investigation, and therefore the publication possibility afterward.

Public health impact

Our findings have several implications for international air travel, in particular since several countries have resumed air travel despite ongoing transmission. While thermal imaging and self-declaration of symptoms did not detect the probable index case who boarded the flight with symptoms, the study pointed out that more intensive screening is required. In addition, long-haul flights can lead not only to importation of COVID-19 cases but can provide conditions for super-spreader events. The number of probable secondary cases detected on the flight itself is on the higher estimation of SARS-CoV-2 infection on airplanes in the absence of face masks, while the role of personal movement, air conditions on the flights, and different vehicles such as meal trays and toilet were not discussed at length (1).

In many studies of flight-associated outbreak of COVID-19, contact tracing was only limited to passengers within two rows of the index cases (2–5), which could explain limited/absence of secondary flight-related transmission reported. The latest guidance from the international air travel industry classifies the in-flight transmission risk as very low and recommends only the use of face masks without additional measures to increase physical distance on board (6–8). Our findings challenge these recommendations since observed transmission was clustered and spread much further than the existing "two-row" (9) or "two meters" (10) rule recommended for COVID-19 prevention on aircrafts and other public transport would have captured. In Vietnam, national policy was changed as a result of this investigation towards mandatory testing upon arrival irrespective of departure location and pre-emptive 14-day quarantine irrespective of test result or clinical symptoms (11). This practice was carried on to 2021, and Vietnam was one of the first to conduct the measures along with considerable reduction of number of inbound flights, and saw very limited number of flight-associated COVID-19 clusters in community.

Recommendation

This investigation calls for tightened screening and infection prevention measures by public health authorities, regulators and airlines industry. Systematic screening and quarantine policies for in-bound passengers upon arrival should be considered justified for countries with low community transmission, high risk of case importation, and limited contact tracing capacity. Even though strict screening and quarantine for all inbound flights might be paramount in resources requirement for arrival countries, these measures proved successful in capitating any imported risks and effective alternatives until vaccination and treatment for COVID-19 reached global scale.

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Appendix 1. Journal Article 1.

Nguyen KC[#^], Pham TQ[#], Quach HL, Hoang NA, Phung CD, Tran ND, Le TQM, Ngu DN, Tran AT, La NQ, Tran DQ, Nguyen TT, Vogt F[*], Dang DA[*]. **Transmission of SARS-CoV 2 during long-haul flight**. *Emerging Infectious Diseases*. 26(11):2617. Published 2020 Sep 18. doi: 10.3201/eid2611.203299.

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Transmission of SARS-CoV-2 During Long-Haul Flight

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To assess the role of in-flight transmission of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), we investigated a cluster of cases among passengers on a 10-hour commercial flight. Affected persons were passengers, crew, and their close contacts. We traced 217 passengers and crew to their final destinations and interviewed, tested, and quarantined them. Among the 16 persons in whom SARS-CoV-2 infection was detected, 12 (75%) were passengers seated in business class along with the only symptomatic person (attack rate 62%). Seating proximity was strongly associated with increased infection risk (risk ratio 7.3, 95% CI 1.2–46.2). We found no strong evidence supporting alternative transmission scenarios. In-flight transmission that probably originated from 1 symptomatic passenger caused a large cluster of cases during a long flight. Guidelines for preventing SARS-CoV-2 infection among air passengers should consider individual passengers' risk for infection, the number of passengers traveling, and flight duration.

During the first 6 months of 2020, severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) spread to almost all countries and infected ≈4 million persons worldwide (*1*). Air travel is contributing to the extent and speed of the pandemic spread through the movement of infected persons (*2–4*); consequently, in March, many countries either completely halted or substantially reduced air travel.

Spread of SARS-CoV-2 across international borders by infected travelers has been well documented (*5,6*); however, evidence and in-depth assessment of the risk for transmission from infected passengers to other passengers or crew members during the course of a flight (in-flight transmission) are limited. Although the international flight industry has judged the risk for in-flight transmission to be very low (*7*), long flights in particular have become a matter of increasing concern as many countries have started lifting flight restrictions despite ongoing SARS-CoV-2 transmission (*8*).

The first case of coronavirus disease (COVID-19) in Vietnam was recorded on January 23, 2020; the patient was a visitor from Wuhan, China (*9*). On January 24, Vietnam suspended air travel from mainland China, Hong Kong, and Taiwan and, as the epidemic spread worldwide, gradually expanded travel bans, mandatory quarantine, and testing measures to incoming passengers from other countries (*10*).

In early March, when much of the global community was just beginning to recognize the severity of the pandemic, we detected a cluster of COVID-19 cases among passengers arriving on the same flight from London, UK, to Hanoi, Vietnam, on March 2 (Vietnam Airlines flight 54 [VN54]). At that time, importation of COVID-19 had been documented in association with 3 flights to Vietnam, including a cluster of 6 persons who had index cases and were evacuated from Wuhan; 6 secondary cases and resulted from virus transmission in Vietnam (*11*). No in-depth investigations among passengers on those flights were conducted, and no evidence indicated that transmission had occurred during the flights themselves.

Initial investigations of flight VN54 led us to hypothesize potential in-flight transmission originating from 1 symptomatic passenger in business class (the

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probable index case). We subsequently launched an extensive epidemiologic investigation that involved testing and isolation/quarantine of all traceable passengers and crew members of the identified flight. Our objectives were to estimate the probability that transmission of SARS-CoV-2 occurred on the flight in question and to identify risk factors associated with transmission.

Methods

We defined cases of SARS-CoV-2 infection according to Vietnam Ministry of Health guidelines in place at the time of our investigation (*12*). Specifically, we suspected defined suspected flight-associated COVID-19 cases as passengers or crew members on board flight VN54 landing in Hanoi on March 2 who reported fever and cough, with or without shortness of breath, during March 1–16. We defined confirmed flight-associated COVID-19 cases as passengers or crew members on flight VN54, regardless whether signs or symptoms developed, who had positive SARS-CoV-2 real-time reverse transcription PCR results from nasopharyngeal swab samples (*13*). Flight-associated cases were considered to have very likely acquired infection on board VN54 and were hence classified as probable secondary cases in this analysis if the following 3 criteria were met: 1) they experienced signs/symptoms 2–14 days after arrival or if they were SARS-CoV-2 positive by PCR 2–14 days after arrival in the absence of signs/symptoms; 2) in-depth investigation did not reveal any potential exposure to SARS-CoV-2 before or after the flight during their incubation period; and 3) they had shared cabin space with the probable index case during the flight (*14–17*).

At the time of flight VN54 arrival, all passengers from COVID-19–infected areas, including the United Kingdom, had their body temperature screened by thermal imaging and were required to declare any COVID-19 symptoms; only passengers arriving from China, South Korea, Iran, or Italy were required to undergo SARS-CoV-2 testing and 14-day quarantine. At that time, the use of face masks was not mandatory on airplanes or at airports (*18*).

As soon as the travel history of the probable index case became evident, the passenger list and flight manifest for flight VN54 was obtained from the Bureau of Immigration and the Civil Aviation Administration and sent to all provincial Centers for Disease Control with instructions for local health staff to trace all passengers and crew members of flight VN54. All successfully traced passengers and crew members were interviewed by use of a standard questionnaire, tested for SARS-CoV-2, and quarantined in designated facilities or at home. Any symptomatic person was isolated immediately until the test result was received. In-depth interviews were conducted with all persons with suspected or confirmed flight-associated cases; the specific focus was detecting any potential SARS-CoV-2 transmission events before and after the flight to investigate potential alternative scenarios for transmission other than during the flight. Furthermore, all persons with suspected or confirmed flight-associated cases were asked to identify persons with whom they had had close contact (<2 meter distance for >15 minutes) between arriving in Vietnam and the start of quarantine/isolation. These close contacts were also contacted, tested, and quarantined for 14 days. All persons in quarantine were checked twice daily for clinical signs/symptoms and fever; oropharyngeal swabs were collected on the day of admission, after 3–5 days, and on day 13, unless signs/symptoms developed, in which instance a specimen was collected immediately and the person was isolated and monitored until receipt of the test result.

Initial investigations of the probable index case generated our working hypothesis of in-flight transmission and guided further investigations. In particular, we investigated all possible exposures of all persons with flight-associated cases during their incubation period in relation to the timing of the flight, including locations where flight-associated cases may have crossed paths before and after the flight. To identify factors associated with in-flight infection risks, we calculated risk ratios and 95% CIs.

Results

Setting

Flight VN54 departed London at 11:10 AM local time on March 1, 2020, and arrived in Hanoi at 5:20 AM local time on March 2; the nonstop flight lasted about 10 hours. A total of 16 crew members and 201 passengers were on board. The 274 seats on the airplane were divided into business class (28 seats), premium economy class (35 seats), and economy class (211 seats); there were 4 toilets for business and premium economy classes and 5 for economy. The business class was exclusively reserved and separated from the premium economy and economy classes by a service/toilet area (Figure 1). Of the 201 passengers, 21 occupied business (75% seats occupied), 35 premium economy (100%), and 145 economy (67%) seats (Figure 1). Two meals were served, and flight attendants

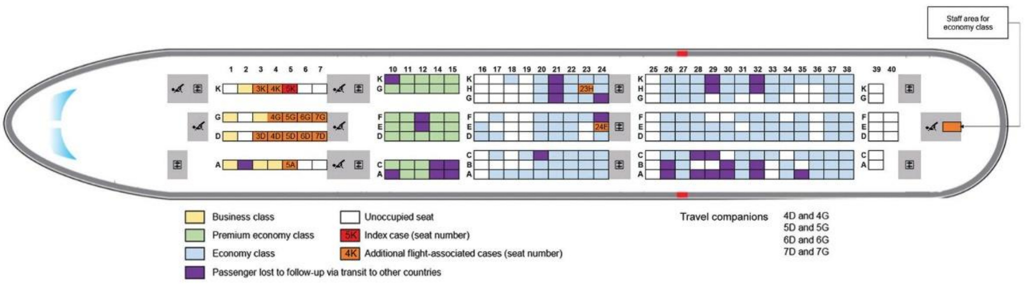

Figure 1. Seating location of passengers on Vietnam Airlines flight 54 from London, UK, to Hanoi, Vietnam, on March 2, 2020, for whom severe acute respiratory syndrome coronavirus 2 infection was later confirmed.

worked in 2 teams, 1 for the business and premium economy sections and 1 for the economy section.

Investigation of Probable Index Case

A 27-year-old businesswoman from Vietnam, whom we identified as the probable index case (hereafter case 1), had been based in London since early February. Our case investigations supplemented by information obtained from media reports indicated that she had traveled to Italy on February 18 with her sister, who was later confirmed to be SARS-CoV-2–positive in London, and back to London on February 20 to stay with her sister for another 2 nights. On February 22, case 1 and her sister returned to Milan, Italy, and subsequently traveled to Paris, France, for the yearly Fashion Week before returning back to London on February 25. They continued to reside in London until February 29, when case 1 started to experience a sore throat and cough while attending meetings and visiting entertainment hubs with friends. On March 1, she boarded flight VN54. She was seated in business class and continued to experience the sore throat and cough throughout the flight. Her signs and symptoms (fever, sore throat, fatigue, and shortness of breath) progressed further after arrival, and she self-isolated at her private residence in Hanoi and had contact with household personnel only. On March 5, she sought care at a local hospital in Hanoi, where an oropharyngeal swab sample was taken and tested; SARS-CoV-2 infection was confirmed by real-time reverse transcription PCR on March 6. On March 7, three of her household personnel received positive SARS-CoV-2 results, as did a friend of hers, whom she had visited in London on February 29, on March 10.

Case Finding and Epidemiologic Investigations

By March 10, all 16 (100%) of the flight crew and 168 (84%) of the passengers who remained in Vietnam had been traced; 33 (16%) passengers had already transited to other countries. We were able to quarantine, interview, and collect swab specimens for PCR testing from all passengers and crew members who remained in Vietnam. Passengers and crew had traveled on to 15 provinces in Vietnam, ranging from Lao Cai and Cao Bang in the north to Kien Giang in the south.

Through these efforts, we identified an additional 15 PCR-confirmed COVID-19 cases, 14 among passengers and 1 among crew members, resulting in a total of 16 confirmed flight-associated cases. Ages of affected persons ranged from 30 to 74 years (median 63.5 years); 9 (>50%) were male, and 12 (75%) were of British nationality (Table 1). Of the 15 persons with flight-associated cases, 12 (80%) had traveled in business class with case 1, and 2 travelers (cases 14 and 15) and 1 flight attendant (case 16) had been in economy class (Figure 1). Among persons in business class, the attack rate was 62% (13/21). Among passengers seated within 2 meters from case 1, which we approximated in business class to be ≤2 seats away, 11 (92%) were SARS-CoV-2–positive compared with 1 (13%) located >2 seats away (risk ratio 7.3, 95% CI 1.2–46.2) (Table 2). Of the 12 additional cases in business class, symptoms subsequently developed in 8 (67%); median symptom onset was 8.8 days (interquartile range 5.8–13.5) after arrival (Figure 2). None of the additional cases showed COVID-19 symptoms while on board VN54. All 12 additional cases in business class met the definition of probable secondary cases.

Our investigation did not reveal strong evidence supporting potential SARS-CoV-2 exposure either before or after the flight for any of the additional persons with flight-associated cases other than having traveled on the same flight as case 1 (Appendix, https://wwwnc.cdc.gov/EID/article/26/11/20-3299-App1.pdf). There were 4 traveling companion couples on board, and individuals within each couple

Table 1. Descriptive epidemiology for 217 passengers and crew on Vietnam Airlines flight 54 from London, UK, to Hanoi, Vietnam, March 2, 2020*

Passenger/crew information	Positive for SARS-CoV-2 by PCR, no. (%)†	Negative for SARS-CoV-2 by PCR, no. (%)
Total	16 (7.4)	201 (92.6)
Age, y		
<18	0	3 (2)
18-49	3 (19)	89 (44)
50-64	4 (25)	80 (40)
>65	9 (56)	29 (14)
Sex		
M	9 (56)	98 (49)
F	7 (44)	103 (51)
Nationality		
British	12 (75)	133 (66)
Vietnamese	3 (19)	31 (15)
Other	1 (6)	37 (18)
Seating location		
Business class	13 (81)	8 (4)
Premium economy class	0	35 (17)
Economy class	2 (13)	143 (71)
Crew members	1 (6)	15 (8)

*Median age, y (interquartile range) was 63.5 (56.0–67.5) for those who were SARS-CoV-2 positive and 51.5 (32.0–60.0) for those who were SARS-CoV-2 negative. SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.
†including the probable index case.

sat next to each other in business class. None of the couples or individual cases traveled or stayed with another couple or individual case before the flight or after arrival in Vietnam. Of these case-pairs, 3 (6 persons) were positive for SARS-CoV-2 on the same date: 6 days after arrival in Vietnam.

Among >1,300 close contacts of VN54 passengers and crew members, 5 confirmed cases were identified, 3 of whom were household personnel linked to case 1. The timing of last contact of the remaining 2 confirmed close contacts with their respective flight-associated cases suggests that infection of the flight-associated cases occurred at the same time and that time of infection coincided with the time of the flight (Appendix).

Discussion

Among the 217 passengers and crew members on a direct flight from London to Hanoi in early March 2020, we identified a cluster of 16 laboratory-confirmed COVID-19 cases. In-depth epidemiologic investigations strongly suggest that 1 symptomatic passenger (case 1) transmitted SARS-CoV-2 infection during the flight to at least 12 other passengers in business class (probable secondary cases).

Case 1 was the only symptomatic person on board and was the only person with a flight-associated case who had established contact with a person with a confirmed case (her sister) during her incubation period. The incubation periods for all persons with confirmed flight-associated cases overlapped with the timing of the flight (Figure 2). Our interviews did not reveal that any of the additional persons with flight-associated cases had been exposed to SARS-CoV-2 before or after the flight during their incubation periods other than having taken the same flight as case 1, nor did they suggest exposure for any of the 4 travel companion couples after the flight (Appendix). Similar intervals between arrival and positive SARS-CoV-2 test results among 3 case-pairs suggest a common exposure event rather than subsequent infection from one partner to the other. Last, we found a clear association between sitting in close proximity to case 1 and risk for infection (Table 2).

In the absence of genomic analysis, we were unable to completely rule out alternative transmission routes. However, all persons with flight-associated cases departed from the United Kingdom (none transited from other countries); and until the departure date of flight VN54, only 23 COVID-19 cases had

Table 2. Risk for SARS-CoV-2 infection by seating location among business class passengers on Vietnam Airlines flight 54 from London, UK, to Hanoi, Vietnam, March 2, 2020*

Seating location in relation to index case	Positive for SARS-CoV-2 by PCR, no. (%)†	Negative for SARS-CoV-2 by PCR, no. (%)	Relative risk	Risk ratio (95% CI)
≤2 seats away	11 (92)	1 (13)	0.9	7.3 (1.2–46.2)
≥2 seats away	1 (8)	7 (88)	0.1	

*SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.
†Excluding the index case.

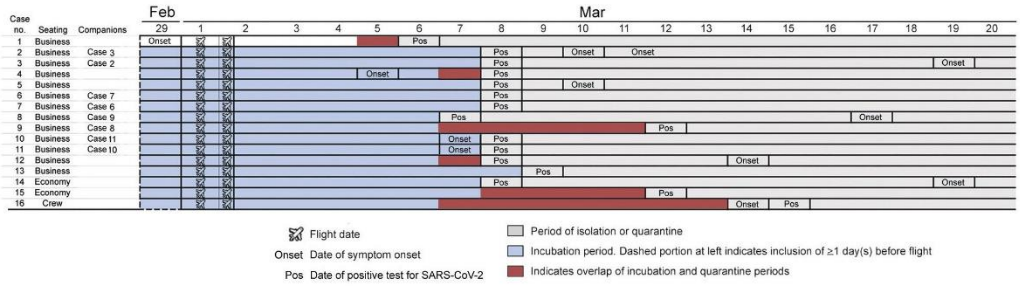

Figure 2. Epidemiologic and clinical timeline for passengers on Vietnam Airlines flight 54, from London, UK, to Hanoi, Vietnam, March 2, 2020, for whom SARS-CoV-2 infection was later confirmed. Because the flight arrived quite early in the morning (5:20 AM), we considered the remainder of the day (19 h) to be the day of arrival. Case 14 traveled with a companion who was tested but negative for SARS-CoV-2 infection. SARS-CoV-2, severe acute respiratory syndrome coronavirus 2.

been recorded in the United Kingdom. Although testing had not been implemented on a large scale nationwide at that time (*19*), community transmission in the United Kingdom was not yet widely established (*20*), making the presence of multiple persons on board incubating the illness unlikely. Similarly, for case 4, who reported having visited India before the United Kingdom during his incubation period, the possibility of preflight transmission remains slim because by March 1, only 3 cases of COVID-19 had been reported in India, although testing in India was still limited (*20–22*). Furthermore, none of the 30 colleagues of case 4, who shared the same preflight travel history but were all seated in economy class, were infected (Appendix).

We consider local transmission after arrival in Vietnam unlikely. As of March 1, 2020, only 16 cases of COVID-19 had been reported in Vietnam, and 17 days had passed since the last reported case (case 1 reported here became Vietnam case no. 17) (*18*). At that time, 1,593 persons had tested negative for SARS-CoV-2 infection in Vietnam, and according to official policy at that time, another 10,089 contacts and travelers returning from COVID-19–affected areas overseas were under preemptive quarantine directly at the time of arrival. In early March 2020, there was no evidence of community transmission of SARS-CoV-2 in Vietnam (*18*). We also note that cases 3 and 14 experienced symptom onset 17 days after flight VN54. Whether these cases reflect unusually long incubation periods or symptoms caused by conditions other than COVID-19 is unknown.

The most likely route of transmission during the flight is aerosol or droplet transmission from case 1, particularly for persons seated in business class (*23*). Contact with case 1 might also have occurred outside the airplane at the airport, in particular among business class passengers in the predeparture lounge area or during boarding. Although Vietnam Airlines keeps business class passengers separated from economy class passengers during most procedures before and during the flight, contact with the 2 economy class cases might have occurred after arrival during immigration or at baggage claim. We also note that 2 passengers, in the seats between the 2 cases in economy class, were lost to follow-up. Whether either of these passengers could represent a separate index case in economy class is unknown.

The role of fomites and on-board surfaces such as tray tables and surfaces in toilets remains unknown. For example, airline crew often use business class toilets while on board, which might explain the case among the crew serving in economy class, for whom no other potential source of infection could be established. Of note, the temporal sequence of symptom onset among cases in economy class and the crew member serving in economy class also allows for the possibility of a second in-flight transmission event, independent of the cluster in buisness class (Figure 2).

Our study has several limitations. First, we did not have genomic sequencing data available to support our hypothesis of in-flight transmission. However, the conclusiveness and unambiguity of our in-depth epidemiologic upstream and downstream investigations coupled with extensive laboratory testing make us confident of our main findings. Second, we lacked detailed data on activities of the cases while on board (e.g., movements or seat changes, use of toilets, or sharing meals), which might have enabled us to pinpoint the precise route of transmission. Third, our assessment of passengers' preflight exposure to other confirmed cases relied on interviews only. Fourth, we had no data available on individual passenger use of face masks while on board, which would have enabled a more refined risk analysis. Face masks were neither recommended nor widely used on airplanes in early March, in particular not among travelers from Europe (*24–26*), who constituted the majority of passengers on flight VN54. Last, given the delay between arrival and confirmation of the probable index case, no environmental samples could be collected from the airplane.

Our findings have several implications for international air travel, especially because several countries have resumed air travel despite ongoing SARS-CoV-2 transmission. First, thermal imaging and self-declaration of symptoms have clear limitations, as demonstrated by case 1, who boarded the flight with symptoms and did not declare them before or after the flight. Second, long flights not only can lead to importation of COVID-19 cases but also can provide conditions for superspreader events. It has been hypothesized that a combination of environmental factors on airplanes (humidity, temperature, air flow) can prolong the presence of SARS-CoV-2 in flight cabins (*27*). No evidence indicated that the regular air conditioning and exchange system on flight VN54 were malfunctioning. The number of probable secondary cases detected in our study is on the upper end of hypothesized estimations for SARS-CoV-2 transmission on airplanes in the absence of face mask use, although the movement of aerosols and droplets in the specific conditions of a flight cabin remains poorly understood (*27*). A study of a COVID-19 cluster with 16 infected flight passengers from Singapore in February 2020 identified only 1 instance of potential in-flight transmission (*28*). In-flight transmission has been hypothesized but not substantiated sufficiently in a non–peer-reviewed report of a cluster of 10 flight-associated cases in China in February (N. Yang et al., unpub. data, https://www.medrxiv.org/content/10.1101/2020.03.28.20040097v1.full.pdf). In January 2020, no secondary cases were detected after a 15-hour flight to Canada with a symptomatic person with COVID-19 on board (*29*), although contact tracing and monitoring were limited (*30*). Similar results with similar limitations have been reported from flights arriving in France (*31,32*) and Thailand (*33*) in January and February. All of these studies limited contact tracing to passengers within 2 rows of the index cases, which could explain why secondary flight-related transmission was not detected by those studies.

The latest guidance from the international air travel industry classifies the in-flight transmission risk as very low (*34*) and recommends only the use of face masks without additional measures to increase physical distance on board, such as blocking the middle seats (*7,35*). Our findings challenge these recommendations. Transmission on flight VN54 was clustered in business class, where seats are already more widely spaced than in economy class, and infection spread much further than the existing 2-row (*36*) or 2 meters (*37*) rule recommended for COVID-19 prevention on airplanes and other public transport would have captured. Similar conclusions were reached for SARS-CoV superspreader events on a flight in 2003, in which a high risk for infection was observed for passengers seated farther than 3 rows from the index case (*4*). This finding also concurs with transmission patterns observed for influenza virus (*38*) and is generally in line with the mounting evidence that airborne transmission of SARS-CoV-2 is a major yet underrecognized transmission route (*39,40*).

Our findings call for tightened screening and infection prevention measures by public health authorities, regulators, and the airline industry, especially in countries where substantial transmission is ongoing (*37*). Making mask wearing obligatory and making hand hygiene and cough etiquette standard practice while on board and at airports seems an obvious and relatively simple measure (*27*). Blocking middle seats, currently recommended by the airline industry (*7,35*), may in theory prevent some in-flight transmission events but seems to be insufficient to prevent superspreading events. Also, systematic testing, quarantine policies, or both, for inbound passengers at arrival might be justified for countries with low levels of community transmission, high risk for case importation, and limited contact tracing capacity (*5*). In Vietnam, for example, as a result of this investigation, national policy was changed toward mandatory testing at arrival irrespective of departure location and 14-day quarantine irrespective of test result or clinical signs/symptoms (*41*). This policy change eliminated the need for resource-intensive contact tracing of flight passengers altogether and enabled detection of another 106 cases among ≈5,000 passengers on 44 flights until all international flights were halted on March 28. However, given the logistic and economic implications of such policies, developing a quick and reliable point-of-care test that covers the entire infectious period remains paramount.

We conclude that the risk for on-board transmission of SARS-CoV-2 during long flights is real and has the potential to cause COVID-19 clusters of substantial size, even in business class–like settings with spacious seating arrangements well beyond the established distance used to define close contact on airplanes. As long as COVID-19 presents a global pandemic threat in the absence of a good point-of-care test, better on-board infection prevention measures and arrival screening procedures are needed to make flying safe.

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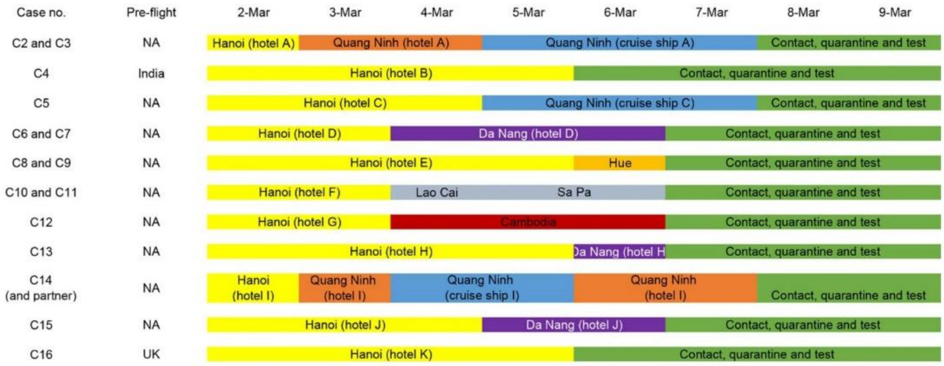
Transmission of Severe Acute Respiratory Syndrome Coronavirus 2 During Long Flight

Appendix

Appendix Table. Summary of epidemiological investigation of additional flight-related cases of flight VN54.

Case no.	Travel history
2 & 3	Case no. 2 (Female, 67) and no. 3 (Male, 74) were life partners from England. After arrival, they stayed in Hanoi for two days. On 4 March, they took a taxi to Quang Ninh – a Northern coast province about 122 miles from Hanoi that is popular for sightseeing. On 5-7 March, case no. 2 and 3 took a sightseeing ship around the island (separate with other cases). On 8 March, they were located, transferred to a local hotel for quarantine and tested positive for SARS-CoV-2 on the same day. None of them was presenting any symptoms of COVID-19 at that time.
4	Case no. 4 (Male, 51) was a Vietnamese government official who had been travelling with a group of 30 other officials on a business trip to India and England since mid-February. He did not experience any COVID-19 symptoms while abroad. On flight VN54 he was sitting in seat 5A, in same row with case no. 1, with no companion. After arrival, he travelled to and from work within Hanoi, and attended several meetings and gatherings. On March 5, he felt fatigue and joint pain in the morning, and became feverish in the evening. On 6 March, after being contacted following the confirmation of case no. 1, he was transferred to a designated hospital for quarantine and monitoring, where he was tested positive for SARS-CoV-2 the next day. None of his work colleagues, who had travelled with him in India and UK but were seated in the economy class of the same flight, tested positive for SARS-CoV-2.
5	Case no. 5 (Male, 58) was a single lone traveler from the UK who stayed for 3 days in Hanoi until 4 March, when he took a day tour to a nearby province with a tour guide (who was later confirmed positive with SARS-CoV-2 with symptoms onset on 7 March). He travelled further to Quang Ninh to take a cruise ship (separate with other cases) from 5-7 March. On 8 March, he was located, transferred to a local hotel for quarantine and tested positive for SARS-CoV-2 on the same day. He was asymptomatic at that time.
6 & 7	Case no. 6 (Male, 66) and case no.7 (Male, 60) were friends from UK and travelled together to Da Nang, a large coastal city in Southern Middle area of Vietnam, by flight on 4 March, after a one-day stay in Hanoi, where they had close contact with a saleswoman (who were later confirmed positive with COVID-19 with symptoms onset on 6 March) on the same day during a 15-minute conversation. Since then, the cases travelled together nearby Da Nang. On 7 March, after all hotels in Vietnam were alerted about unfolding outbreak, they were instructed to self-isolate in their hotel rooms. At the time of testing on 8 March, none of them were symptomatic.
8 & 9	Case no. 8 (Female, 66) and case no. 9 (Male, 71) were life partners from the UK. After arrival, they stayed in Hanoi until 6 March, when they travelled together by flight to Hue, a city in central Vietnam, where they were directly asked to self-quarantine in their room by alerted hotel staffs. On 7 March, samples were collected and later that day returned positive for case no. 8, while no. 9 tested negative initially. Both cases remained quarantined/isolated, and on 12 March, case no. 9 was confirmed positive as well.
10 & 11	Case no. 10 (Female, 70) and case no. 11 (Male, 69) were life partners from the UK, they stayed in Hanoi for two days after arrival. On 4 March, they took a night train to Lao Cai, a Northwest mountainous province of Vietnam bordering China. After checking into a local hotel on 5 March, they took a tour bus to Sa Pa, a nearby small mountainous town where they stayed in a hotel until 7 March, when local health staffs managed to locate and isolate them. They started experiencing cough and fever, and tested positive on the same day.
12	Case no. 12 (Female, 66) was a single traveler from the UK. She had already transited to Cambodia on 4 March after a two-day stay in Hanoi. She was identified by the Cambodian health authorities and tested for SARS-CoV-2 on 7 March. Her testing status and findings from epidemiological investigation was obtained from the Cambodia Center of Disease Control.
13	Case no. 13 (Male, 49) was a single traveler from the UK travelling to Da Nang on 6 March after his four-day stay in Hanoi. A day later, he was instructed to self-isolate in his hotel rooms after all hotels in Vietnam were alerted with the folding outbreak. At the time of testing, he was asymptomatic.
14	Case no. 14 (Female, 50) and her partner (who remained negative throughout) were both UK nationals and travelled in economy class. They travelled to Quang Ninh after arrival to Hanoi on 2 March. They took a cruise ship tour on 4-5 March (separate with other cases), and subsequently stayed in their hotel from 5-8 March. On 8 March, they were located, transferred to a local hotel for quarantine and case no. 14 tested positive for SARS-CoV-2 on the same day. At the time of testing, she was asymptomatic.
15	Case no. 15 (Male, 58) traveler from the UK in economy class. He travelled by flight to Da Nang on 5 March from Hanoi. In Da Nang, he travelled to surrounding cities until being contacted by his hotel staff on 7 March and was instructed to self-isolate in his hotel. At the time of testing, he was asymptomatic.
16	Case no. 16 (Female, 30) was a flight crew member serving in economy class. She remained in a common dormitory for Vietnam Airline crew member near Noi Bai Airport, Hanoi since arrival to 6 March. Before VN54 flight, she had served as an attendant on Vietnam Airline international flights on a daily basis to France, UK, Japan and South Korea since January 2020. She was asymptomatic when tested and put into quarantine on 7 March. On 13 March, when experiencing cough and fever, she was confirmed positive for SARS-CoV-2 the next day.



Appendix Figure. Summary of epidemiological investigation of additional flight-related cases of flight VN54.

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Appendix 2. Journal Article 2.

Quach HL[#], Hoang NA[#], Nguyen CK[^], Pham QT, Phung CD, Tran ND, Le QMT, Ngu DN, Tran AT, La NQ, Tran DQ, Nguyen TT, Vogt F[*], Dang DA[*]. **Successful containment of a flight-imported COVID-19 outbreak through extensive contact tracing, systematic testing and mandatory quarantine: Lessons from Vietnam**. *Travel Medicine and Infectious Disease*. 42:102084. Published 2021 May 26. doi: 10.1016/j.tmaid.2021.102084.

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Original article

Successful containment of a flight-imported COVID-19 outbreak through extensive contact tracing, systematic testing and mandatory quarantine: Lessons from Vietnam

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A R T I C L E I N F O

Keywords:
COVID-19
Case importation
Contact tracing
Cluster containment
Air travel
Vietnam

A B S T R A C T

Background: The importation of SARS-CoV-2 through air travel poses substantial risks to generate new COVID-19 outbreaks. Timely contact tracing is particularly crucial to limit onwards transmission in settings without established community transmission.

Methods: We conducted an in-depth analysis of the response to a big flight-associated COVID-19 outbreak in Vietnam in March 2020 that involved contact tracing, systematic testing and strict quarantine up to third generation contacts.

Results: 183 primary contacts from the flight as well as 1000 secondary and 311 third generation contacts were traced, tested, and quarantined across 15 provinces across Vietnam. The protracted confirmation of the index case at 3 days and 19 h after arrival resulted in isolation/quarantine delays of 6.8 days (IQR 6.3–6.8) and 5.8 days (IQR 5.8–7.0) for primary and secondary cases, respectively, which generated 84.0 and 26.4 person-days of community exposure from primary and secondary cases, respectively. Nevertheless, only 5 secondary cases occurred.

Conclusions: A large flight-related COVID-19 cluster was successfully contained through timely, systematic and comprehensive public health responses despite delayed index case identification. Multiagency collaboration and pre-established mechanisms are crucial for low and middle income countries like Vietnam to limit community transmission after COVID-19 importation through air travel.

1. Introduction

In March 2020, as the world began to experience the global spread of COVID-19, we detected a large cluster of COVID-19 cases arising from a flight arriving from London, UK to Hanoi, Vietnam at 5.20am on March 2 (flight VN54). A 27-year-old business class passenger who was

Abbreviations: NSCPC, National Steering Committee of COVID-19 Prevention and Control; rt-PCR, Reverse transcriptase Polymerase chain reaction.

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symptomatic while on board and who tested positive for SARS-CoV-2 four days after arrival in Vietnam on 6 March was identified as index case. In-depth epidemiological investigations revealed in-flight transmission during the 10 h flight duration as the most likely route of transmission [1].

Until then, Vietnam had recorded three minor instances of COVID-19 importation through air travel but no intensive contact tracing for passengers and their contacts was performed. Flight VN54 resulted in the first extensive case finding and contact tracing operations to prevent further transmission in Vietnam. As contact tracing activities have been conducted to find potential exposed passengers on flight with cases of H1N1, SARS, MERS, Tb, and measles, COVID-19 is certainly not an exception for infectious disease on transportation. Mass transmission instances of COVID-19 on flights had been explored and described in

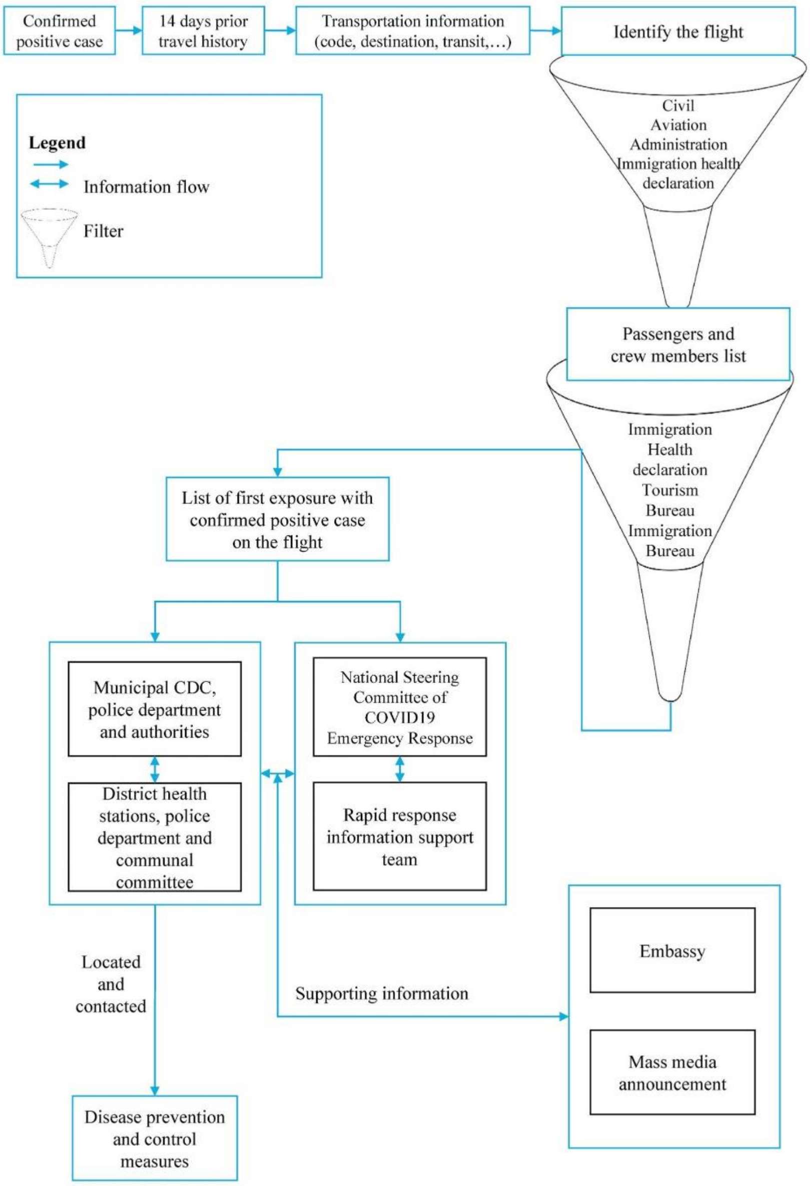

Fig. 1. Contact tracing strategy for primary contacts of VN54 flight in Vietnam.

previous publications, however, the focus is limited to transmission risk from infected individuals on the flight [2], with criteria of contact trace for 2 or lesser seats from index case. While an infectious person, with an unpredicted novel disease, can still transmit to larger scale of passengers on flight and also more contacts in local settings, contact tracing should not stop at the current boundary of proximity, but to be tested its containment capacity at large. Here we analyze epidemiological characteristics of the flight VN54 cluster and the subsequent containment efforts undertaken among passengers, crew and their contacts to prevent further transmission of SARS-CoV-2 in Vietnam. This work provides valuable information of how to contain COVID-19 importation through air-travel successfully in a low-middle income setting.

2. Methods

2.1. Contact and case definitions

A case of COVID-19 was defined according to the Vietnam Ministry of Health guidelines in place at the time of our investigation [3]. All passengers and crew members on board VN54 flight were considered as primary contacts of the index case. Secondary contacts were defined as persons who had close contacts ($\leq$2 m for $\geq$ 15 min/in the same closed space, e.g. house, workplace, public transport, during the incubation period) with a primary contact between arrival of flight VN54 to Vietnam and start of isolation or quarantine. Third generation contacts were defined as non-close contacts (>2 m apart/in an open space during the incubation period) with a primary and/or a secondary contact between arrival of flight VN54 to Vietnam and start of isolation or quarantine. Persons testing positive for SARS-CoV-2 using reverse transcriptase Polymerase chain reaction (rt-PCR) were considered primary cases if they arose among primary contacts, secondary cases if they arose among secondary contacts, and third generation cases if they arose among third generation contacts, all regardless of COVID-19 symptoms.

2.2. Case investigation, contact tracing, testing and quarantine

Contact tracing started on the early morning of 6 March, four days after the arrival of flight VN54 in Vietnam. The Ministry of Health and the National Steering Committee for COVID-19 Prevention and Control (NSCPC) were tasked with intensive contact tracing of all flight-related primary and secondary contacts. The flight manifest was obtained from the Immigration Bureau and the Vietnam Civil Aviation Administration on the same day. The passenger list was distributed to relevant provincial Center of Disease Control for contact tracing. At provincial levels, local health staffs cooperated with local government authorities, social security departments, and local volunteers in order to locate and contact passengers and identify their contacts. Since the majority of passengers were tourists and non-Vietnamese nationals, tourism companies and hotel administrations in all provinces were asked to report the presence of foreign tourists to local authorities and health authorities. Provincial health staff communicated contact tracing status back to NSCPC daily (Fig. 1).

All traced primary contacts who could be reached were interviewed using a standard questionnaire regarding their secondary and third generation contacts since arrival to Vietnam. In addition, they were tested for SARS-CoV-2 and transferred to mandatory 14-day quarantine immediately at centralized facilities, regardless of symptoms and test result. All flight passengers who had already transited out of Vietnam were contacted through border health control authorities at their last traceable destinations. Similar to primary contacts, secondary contacts were traced, tested for SARS-CoV-2, and systematically quarantined for 14 days in centralized facilities (at first). Third generation contacts were asked by local health staffs to quarantine at home for 14 days, with daily symptom monitoring by local health staffs. If their primary or secondary contact became a confirmed case, they would be treated as secondary contacts, i.e. tested and transferred to centralized quarantine immediately.

All persons in centralized quarantine had their symptoms and temperature checked twice daily, and in addition to testing at start of quarantine, they also had oropharyngeal swabs collected after 3–5 days and on day 13 before exiting quarantine. Accommodation, meals, and basic hygiene necessities were provided free of charge under the Ministry of Health's Mandatory Quarantine Scheme. Any person showing COVID-19 symptoms, either at time of being successfully traced by local health staffs or at any point during centralized or home quarantine, got immediately transferred to a reference hospital for isolation and monitoring, as did anyone who got tested positive. Details of contact tracing and testing strategy can be found in Fig. 2.

2.3. Laboratory and case management capacity

In response to the increased testing needs resulting from the response to flight VN54, SARS-CoV-2 RT-PCR laboratory testing capacity was quickly scaled up in Vietnam [4]. From relatively limited and centralized testing capacities, within 10 days, over thirty local CDCs and all tertiary level hospitals were enabled to handle up to 1500 tests per day. Similarly, ICU capacity and isolation wards were ramped up in all provincial health facilities, and military-run bases, dormitories, and hotels were repurposed as centralized quarantine facilities. At designated COVID-19 hospitals, infection control measures were strengthened, including strict visitor controls, triage of patients with pneumonia or other symptoms of respiratory infection, hand hygiene and mask wearing requirements, and maintenance of strict infection control practices with personal protective equipment. Healthcare workers at these designated hospitals were required to avoid non-essential travel outside of hospitals. All confirmed COVID-19 cases were isolated in designated COVID-19 hospitals, and received treatment free-of-charge until confirmation of SARS-CoV-2 clearance as per Vietnam Ministry of Health's criteria.

2.4. Border control measures

Since mid-January, the Government of Vietnam implemented temperature screening for all international passengers (air and land) arriving in Vietnam. At the time of flight VN54, all passengers with a history of travel to Mainland China, Hong Kong, Taiwan (from 1 February), South Korea (from 24 February), Iran and Italy (from 28 February) had to undergo compulsory SARS-CoV-2 testing and quarantine. There was no requirement to wear masks on board commercial flights at that time. Since VN54 departed in the UK, which was not covered by this policy at that time, none of its passengers got tested and/or quarantined upon arrival.

2.5. Non pharmaceutical measures

At time of arrival of flight VN54, targeted lock-downs around locations with confirmed COVID-19 cases, such as hospital wards, resident buildings, hotels, etc. Were the population-level method of choice in response to a newly confirmed cases. In addition, anonymized information about newly confirmed COVID-19 cases and newly identified clusters were shared publicly through mass media and official governmental websites by NSCPC. Once the index case on flight VN54 got confirmed, official messages calling for all passengers and crew members on that flight to seek medical services were broadcasted daily on mass media nationwide. Regular hand washing, mask wearing, and social distancing was encouraged. At the same time, the NSCPC monitored the media landscape for misinformation. Schools and universities in Vietnam were already closed since February, and mass gatherings were mostly canceled. At most workplaces, temperature screening, health and international travel history monitoring were already in place. Mask wearing policies were turned from mandatory for high-risk workers (healthcare workers, essential workers) into mandatory in public places

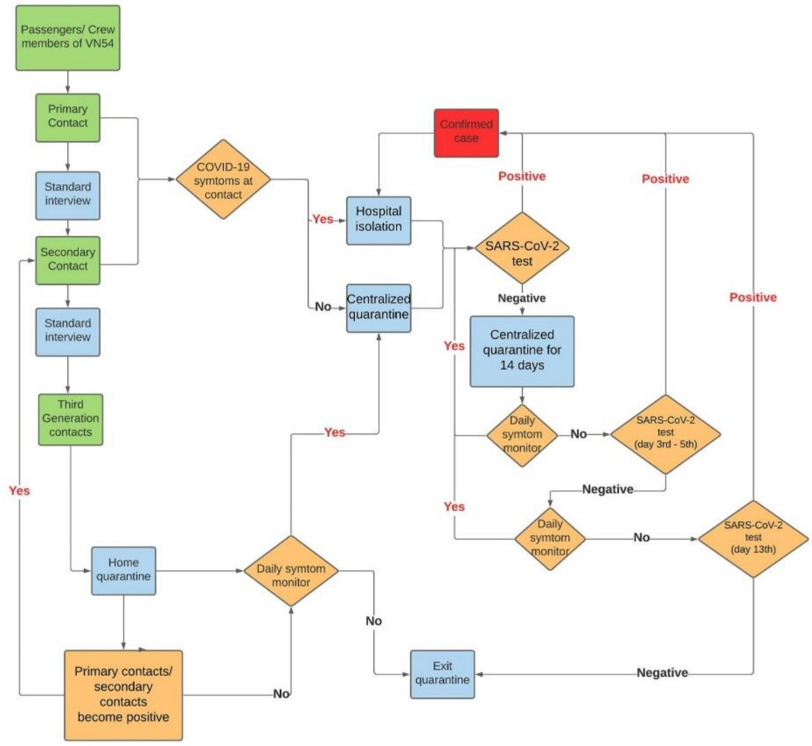

Fig. 2. Testing and quarantine strategy for traceable primary, secondary, and third generation contacts of VN54 flight in Vietnam.

[5].

2.6. *Ethics*

This analysis was approved and exempted for ethics by the National Institute of Hygiene as a part of national COVID-19 outbreak investigation and response activities.

3. Results

A total of 16 crew members and 201 passengers were on board flight VN54, with 71.6% (n = 144) of passengers being foreigners, while 93.7% (n = 15) of crew members were Vietnamese (Table 1). Contact tracing for primary contacts of the flight was completed on 10 March (eight days after the flight arrival; four days after contact tracing initiation). All of the 167 (83.1%) passengers and the 16 (100%) crew members who were still in the country at that time were successfully traced. The remaining 33 passengers transited to other countries (Table 1).

Table 1
Demographic information and tracing outcomes for passengers and crew members of flight VN54.

	Passengers (N = 201) (n, %)	Crew members (N = 16) (n, %)
Nationality		
Vietnamese	33 (16.4)	15 (93.7)
British	144 (71.6)	0 (0)
Other	24 (11.9)	1 (6.3)
Contact tracing status		
Traced	168 (83.6)	16 (100)
Transited	33 (16.4)	0 (0)

By 13 March (11 days after arrival; seven days after contact tracing initiation), we had identified a total of 1000 secondary contacts, who were all placed into centralized quarantine facilities, and 311 third generation contacts, who were asked to self-quarantine at their homes for 14 days.

Tracing activities for primary, secondary, and third generation contacts is illustrated in Fig. 3. The majority of primary and secondary contacts were traced and quarantined/isolated four to five days after the index case confirmation. For primary contacts, the median duration from flight arrival to start of quarantine was 5.8 days (Interquartile range - IQR 4.8–6.8), while the median time from index case confirmation to start of quarantine was 2.0 days (IQR 1.0–3.0) (Table 2). These data were not available for secondary and third generation contacts.

Among primary contacts, we identified 15 primary COVID-19 cases in addition to the index case, of which 14 were passengers and one was a crew member. One of the passenger cases had already transited to Cambodia, where she was identified, tested, and confirmed for SARS-CoV-2 infection by the Cambodia Center of Disease Control. On-board transmission during the 10-h flight duration was found to have been the most likely route of transmission for these primary cases [1]. Subsequently, five secondary cases emerged among secondary contacts of four primary cases. Of these, three were family members of primary cases, one was a local tourist operator and one was a saleswoman who

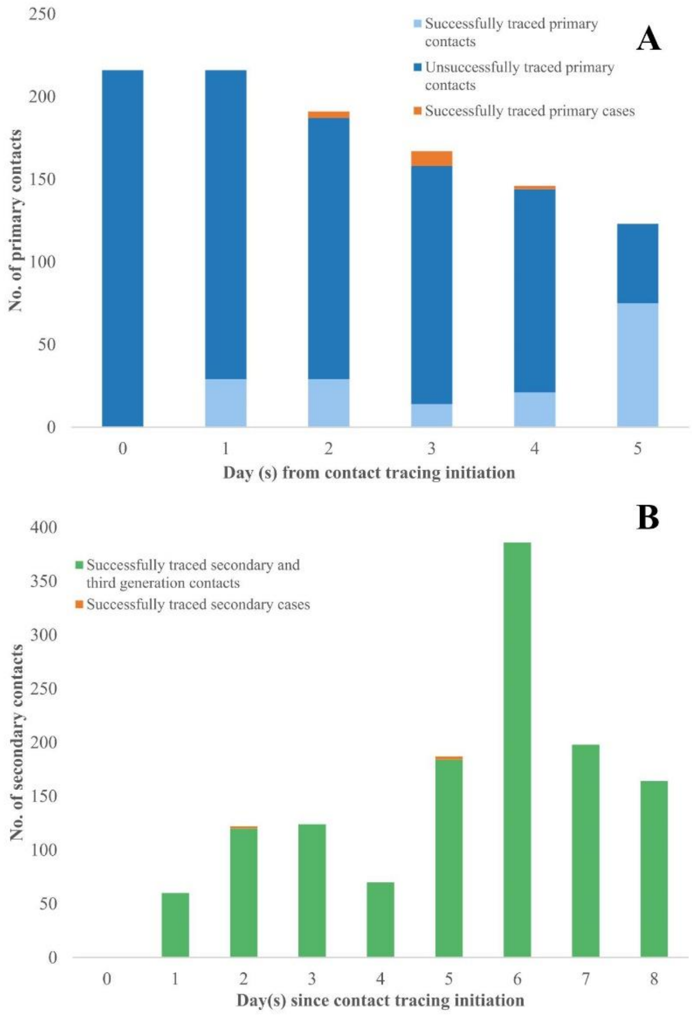

Fig. 3. Time course for contact tracing of primary, secondary, and third generation contacts of VN54 flight in Vietnam.

had contact with primary cases. No third generation cases were reported.

Fig. 4 and Table 2 shows the temporal sequence of exposure, symptom onset and isolation for primary and secondary cases. The index case, who was symptomatic during the flight, presented at a health facility in Hanoi on 5 March (three days after landing) and received a nasopharyngeal swab. The laboratory test result was reported positive at 11pm the same day (5 March), and the index case was immediately isolated (3 days and 19 h after arrival). Contact tracing was only started the following morning at 8 a.m. on 6 March (4 days and 3 h after arrival of the flight).

Consequently, for primary cases, the median duration between last exposure (arrival of the flight) and start of isolation/quarantine was 6.8 days (IQR 6.3–6.8), of which the delay from index case confirmation to isolation/quarantine was 3.0 days (IQR 2.5–3.0). The equivalent delays for secondary cases were 5.8 days (IQR 5.8–7.0) (from last exposure to their epi-linked primary cases) and 2.0 days (IQR 2.0–5.1), respectively (Table 2). Among the remaining 15 primary cases who got infected by the index case during the flight, 10 (67%) subsequently developed symptoms, of which three developed symptoms before being isolated. This resulted in a total of 84.0 person-days of community exposure, of which 4.0 person-days were symptomatic community exposure (6.8 days if the index case is included). The median time interval from last exposure to symptom onset was 10.8 days (IQR 6.6–15.1) for primary cases. Transmission occurred from three primary cases during symptomatic, pre-symptomatic, and asymptomatic stages of infection to three, one, and one secondary case, respectively (Fig. 4). All secondary cases developed symptoms after a median of 4.8 days (IQR 4.0–4.8) after last contact with the primary cases. Three secondary cases were symptomatic before or at start of quarantine, while two developed symptoms

Table 2
Containment delays and epidemiological profiles of primary contacts, primary cases and secondary cases resulting from the VN54 cluster.

Time interval	Primary contacts[a] (N = 183)	Primary cases (N = 15)	Secondary cases (N = 5)
Index case confirmation to isolation/quarantine (median, IQR) (days)	2.0 (1.0–3.0)	3.0 (2.5–3.0)	2.0 (2.0–5.1)
Last exposure to isolation/quarantine (median, IQR) (days)	5.8 (4.8–6.8)	6.8 (6.3–6.8)	5.8 (5.8–7.0)
Last exposure to symptom onset (median, IQR) (days)	–	10.8 (6.6–15.1)	4.8 (4.0–4.8)
Cumulative duration of community exposure (person days)	–	84.0	26.4
Cumulative duration of symptomatic community exposure (person-days)	–	4.0	7.0
Case categories (n, %)			
Symptomatic	–	3 (20)	4 (80)
Pre-symptomatic	–	7 (47)	1 (20)
Asymptomatic	–	5 (33)	0

Note: Data for secondary contacts were not available.
[a] All flight passengers and staff who were still in Vietnam at time of contact tracing initiation.

after isolation, resulting in 26.4 person-days of community exposure, of which 7.0 person-days were symptomatic community exposure (Table 2). The serial interval between transmission pairs was between −2 days and 10 days (average 3.4 days).

Fig. 5 illustrates the geographical distribution of primary cases and contacts (part A), and secondary cases and contacts (part B) in Vietnam. When contacted by local health authorities, primary and secondary contacts had already dispersed to 15 provinces and cities extending from the northernmost (Cao Bang) to the southernmost (Kien Giang) of Vietnam. Primary and secondary cases were identified in six and two provinces, respectively. On average, 7.1 secondary contacts were traced per primary contact, while 0.3 secondary cases were identified per primary case (Supplement 1). An average of 87.4 secondary contacts were traced for every primary case. The attack rate among secondary contacts was 0.3%.

4. Discussion

We report on the first commercial flight arriving in Vietnam with imported COVID-19 cases on board where exhaustive contact tracing and quarantine of all passengers and their contacts was undertaken. We successfully contained a large COVID-19 outbreak with unfolding community transmission through intensive identification, tracing, testing and quarantine measures among 217 flight passengers/crew and more than 1300 of their contacts. These rapid, nationwide efforts limited the outbreak to 16 primary cases among flight passengers/crew and 5 secondary cases within the community in Vietnam.

There were delays before contact tracing initiation. First, the index case was not detected directly upon arrival but only passively by self-presentation at a hospital in Hanoi on 5 March, three days after arrival despite being symptomatic on the flight. Three secondary infections resulted from this extended community exposure. Second, since the positive PCR result was confirmed positive in the late evening of 5 March, the contact tracing process for contacts beyond the index case was only initiated the next morning (9 h later). By this time, 4 days and 3 h after arrival of flight VN54, flight passengers had dispersed already all across Vietnam (Fig. 5) and had generated numerous secondary and third generation contacts, which complicated and delayed timely tracing further.

The case finding and contact tracing activities that followed occurred almost simultaneously, which required the close cooperation of local government authorities and health agencies from all provinces around the country. During the course of four days, contact tracing reached all passengers and crew members who remained in Vietnam at time of investigation (168 of passengers and 16 crew members). Concurrently, after seven days of intensive contact tracing, we had placed into quarantine over 1300 secondary and third degree contacts, among who we identified five additional secondary cases, which corresponds to seven secondary contacts per primary contact and about 87.4 contacts per case. This is higher than the contact-per-case ratios estimated in a study from Singapore (30.8 ratio) [6], Taiwan (27.6 ratio) [7], and several cities in Mainland China (20–40 ratios) [8] during the peak of the outbreak. However, similar estimations of secondary cases per primary cases and per secondary contacts (0.3%) of flight associated cases were

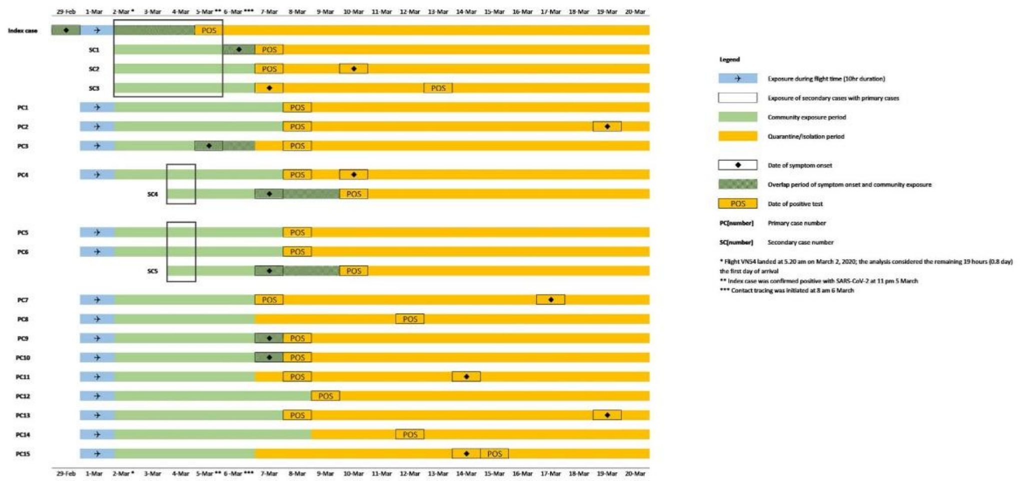

Fig. 4. Temporal sequence of exposure, symptom onset and isolation for all primary and secondary cases of VN54 flight in Vietnam.

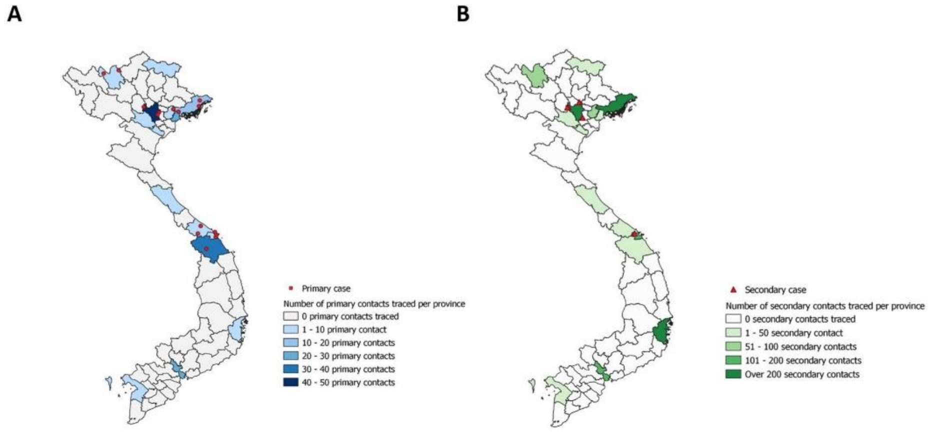

Fig. 5. A. Geographical distribution of primary cases and contacts of VN54 flight in Vietnam. B. Geographical distribution of secondary cases and contacts of VN54 flight in Vietnam.

observed in the US (0.4%) [9], Taiwan (0.8%) [7] and Singapore (0.5%) [10]. These could be explained by the testing and contact strategy in place at that time, as inclusion criteria for close contacts included both confirmed and suspected cases of COVID-19 [11]. Even though several general prevention measures were in place, in the absence of community cases for 23 consecutive days, no restrictions on in-country travel or on social distancing existed in Vietnam, which might explain the relatively high ratios observed in our study. Pung et al. hypothesized that for most primary cases detected after the arrival date, transmission might had ended early [10], since the viral load and viral viability decreased over time with risk of secondary transmission [12]. In comparison with several studies suggesting that transmission happens shortly before symptom onset [13,14], our findings of limited transmission between flight cases and community cases might be a result of the fact that many primary cases were isolated for a substantial amount of time before symptom onset. The timeliness of isolating/quarantine of all traceable passengers and crew members, indiscriminate of their seating location on the plane in relation to the index case or their time of symptoms onset surely mitigated the extend of community transmission in Vietnam.

Timeliness is of essence for effective contact tracing in infectious disease control. Both the timing of arrival/exposure in relation to the timing of symptom onset and isolation/quarantine are relevant for the control of COVID-19 associated with international air travel. In this cluster containment response, 15 additional cases were isolated/quarantined after four days of contact tracing initiation; seven of whom (47%) were quarantined before symptom onset. This was higher than the 24.5% of pre-symptomatic cases reported in Singapore's contact tracing efforts [15]. The relatively high percentage of 80% of case not showing symptoms at time of testing positive or at all during isolation observed in our study (Fig. 3) is consistent with the rate of asymptomatic carriage in another study of asymptomatic cases among flight passengers in Japan [16], and a flight-related COVID-19 investigation from Singapore to Hangzhou [17]. Notably, we also observed symptom onset among primary cases that was at the upper end of the incubation period described in previous epidemiological reports collated in a systematic review (95th percentile of patients at 11.7 (95% CI 9.7–14.2) days) [18], China (97th percentile at 11.5 (8.2–15.6) days) [19], Wuhan, China (95th percentile at 12.5 days) [20], estimating an average incubation period of 11 days, longer than secondary cases'. Although this was discussed in previous report by the unpredictable clinical characteristics of SARS-CoV-2 and possibly a second in-flight transmission [1], long incubation times and high proportions of asymptomatic infections certainly have public health implications for COVID-19 outbreak response. Importantly, transmission in this cluster was observed from symptomatic, pre-symptomatic and asymptomatic primary cases (Fig. 3), with observed incubation periods (4.8 days) and serial interval (3.4 days) among secondary cases at lower ends of previous estimate [19,21]. This is consistent with current literature on the variety of infection pathways by phase of illness. Given the mounting evidence of pre-symptomatic COVID-19 transmission, this certainly challenges containment effort as the effectiveness of contact tracing decreases if transmission occurs before symptom onset in the index case [22]. As a result, asymptomatic testing is increasingly recommended around the world to ensure the sensitivity and timeliness of case confirmation [23–25], and 14-day isolation is required in many countries for cases and high-risk contacts [26,27]. In Vietnam, rigorous contact tracing, frequent testing and systematic quarantine guaranteed a highly sensitive approach and allowed us to timely and effectively identify all case associated with flight VN54. However, as all cases were detected through contact-based surveillance, the average delay from exposure to isolation for primary cases in this study (6.8 days) was higher than those of similar mode of detection and similar to those of symptom-based surveillance [28]. Among those who were symptomatic before quarantine/isolation, the observed 6.3 days of delay in admission in our study were also higher than the delay from onset to admission observed in Mainland China (average 4.9 days for travelers) [28], and in Hong Kong (2.6–4.2 days for imported cases) [29]. This may be explained by the delay in the initial confirmation of the index case as explained above. Longer delays for successful contact tracing and isolation/quarantine were also observed for primary cases than for secondary cases, which in our study was due to the fact that three out of five secondary cases, who were direct epi-linked to the index case of the flight, were very quickly identified and isolated. The remaining two secondary cases were isolated only five days after exposure to their primary cases, and two days after their primary case confirmation. Both were detected by their own presentation at healthcare facilities (Fig. 4).

The analysis of our response efforts offers a number of lessons learnt for future outbreaks in similar settings: contact tracing and case findings activities require timeliness, equipped staffs and prepared facilities [30, 31]. Indeed, the organizational resources and structures needed for public health measures at national scale in response to the flight VN54 cluster were required and utilized for the first time in Vietnam. Required facilities, included quick available passenger's information, consistent and rapid communication means for internal uses and public uses, testing and quarantine facilities, were mobilized to help multi-agency staffs to conduct an effectively exhaustive contact tracing effort. Many studies showed the challenges to access data and mobilize resources in complex multi-jurisdictional contexts [31,32]. The flow of passenger data from airlines to public-health agencies can easily be delayed since many airlines do not share these data willingly, and many public health agencies do not have the authority to access such information on time [33,34]. In addition, a broken feedback loop of information across health jurisdictions for national-wide contact tracing can also quickly stagnant the contact tracing process. One study from the US CDC's airport quarantine stations showed incomplete information gathered from local health agencies during a Tboutbreak rendered it difficult to indicate whether potential contacts were found or tested [35]. Another study from Germany showed that completeness of information for passengers on board is crucial to improve a comprehensive international contact tracing process, coupled with health education for passengers about infectious disease transmission on public transport [36]. In Vietnam, even though the process was newly introduced and not yet tested in a simulation exercise, passenger information was obtained and distributed during the first day of the outbreak response, which greatly enhanced the process of subsequent contact tracing. Although complete information was not available for all passengers since passengers did not have to disclose their address in Vietnam upon arrival at that time, national cooperation and support from local authorities, tourism and police departments ensured effectively tracing of all passengers who remained in Vietnam at time of contact tracing was initiated. Additionally, clear and sensitive inclusion criteria for contact tracing are crucial. The fact that we applied a blanket definition of primary contacts to all passengers and crew members on flight VN54 was novel to traditional public health measures for COVID-19 at time of investigation. Before VN54, there was three instances of non-quarantined imported cases detected in Vietnam, however, investigation was scoped at close contacts in community, and to passengers within two seats away from index case. Following the country's approach of "To miss one case is to ignite two others", this cluster containment effort showed that it is possible to quickly contain a highly infectious pathogen such as SARS-CoV-2 through national collective efforts and multi-agency. The delays inherent to case finding measures such as testing, tracing and quarantine/isolation highlight the need for rapid adaptation of response mechanisms in public health emergencies. While the delay in the detection of the index case could have been shortened by systematic obligatory testing at arrival, contact tracing initiation could have been accelerated by pre-established and pre-tested standard operating procedures to trigger immediate activation of public health response following laboratory confirmation. Lessons were learnt quickly in Vietnam. For example, as a result of the difficulties experienced to trace highly-mobile tourists across the country, as soon as from 6 March 2020 onwards, all inbound passengers were required to fill out health declaration forms that included passengers' contact information in Vietnam. Soon thereafter, starting on 21 March 2020, mandatory SARS-CoV-2 testing and quarantine were implemented for all passengers arriving in Vietnam regardless of their place of departure, which in turn greatly reduced contact tracing efforts and resources for provincial health jurisdictions. To justify the need for the extensive contact tracing and testing regime as implemented in our study, appropriate resources and training as well as a good understanding of the local context of the COVID-19 situation are needed.

Our analysis had several limitations. The VN54 cluster was an early event during the COVID-19 epidemic in Vietnam after nearly a month of no new confirmed cases nationwide. Hence, a lot of information was missing due to the lack of standard data collection and reporting at that time. We lacked individual-level data about secondary and third generation contacts, including demographics, type and location of exposure, date of quarantine for each individual, number of secondary and third generation contacts per epi-linked primary contacts, and unsuccessfully traced contacts. Such data would have allowed an in-depth analysis of contact behaviors and to assess differences in risks of infection.

The longer the ongoing pandemic lasts, the less sustained border control measures such as total border closures or blanket quarantine policies are to remain practical and acceptable. Vietnam, as many countries, is now considering to resume commercial air travel despite considerable risk of disease importation and very low in-country transmission. Sustainable and flexible surveillance and contact tracing system is crucial to adapt to the ever-changing situation, and to achieve a balance between containing disease spread while reducing the overall health and socioeconomic impact due to COVID-19.

5. Conclusion

Intensive tracing, testing and quarantine of all flight passengers, crew and their contacts helped to contain an unfolding COVID-19 outbreak in Vietnam caused by in-flight transmission from one symptomatic passenger on board. Multi-agency collaboration, sensitive testing policy and strict quarantine mechanisms allow COVID-19 outbreaks to be managed with limited secondary cases in the community. Low and middle income countries need to establish a combination of appropriate measures in response to the risk of COVID-19 importation through air travel and subsequent community transmission.

CRediT authorship contribution statement

Ha-Linh Quach: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Ngoc-Anh Thi Hoang:** Data curation, Investigation, Visualization, Writing – review & editing. **Cong Khanh Nguyen:** Project administration, Investigation, Supervision, Writing – review & editing. **Quang Thai Pham:** Project administration, Investigation, Supervision, Writing – review & editing. **Cong Dinh Phung:** Resources, Software, Visualization. **Nhu Duong Tran:** Investigation, Methodology, Resources. **Quynh Mai Thi Le:** Investigation, Methodology, Resources. **Duy Nghia Ngu:** Formal analysis, Investigation, Resources. **Anh Tu Tran:** Formal analysis, Investigation, Resources. **Ngoc Quang La:** Data curation, Validation. **Dai Quang Tran:** Data curation, Validation. **Trong Tai Nguyen:** Data curation, Validation. **Florian Vogt:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing. **Duc Anh Dang:** Project administration, Supervision.

Declaration of competing interest

The authors declare no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.tmaid.2021.102084.

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Appendix 3. Conference presentation 1.

Presentation at:

- Quach HL, Hoang NA, Nguyen CK, Thai PQ, Vogt F, '**In-Flight Transmission of SARS-CoV-2 During a Long-Haul Flight: Results from an Outbreak Investigation in Vietnam and Implications for Future Air Travel**'. Oral presentation, Southeast Asia and Western Pacific Bi-Regional Field Epidemiology Training Program COVID-19 Online Conference (virtual conference), 09-12 November 2020. Oral presentation recording (2:37 – 21:24): https://youtu.be/1D0-U9yAgs8
- Quach HL, Hoang NA, Nguyen CK, Thai PQ, Vogt F, '**In-Flight Transmission of SARS-CoV-2 During a Long-Haul Flight**'. Video presentation, Special Edition - Australasian COVID-19 Virtual Conference (virtual conference), 9 December 2020.

In-flight transmission of SARS-CoV-2 during a long-haul flight

Results from an outbreak investigation in Vietnam and implications for future air travel

Quach Ha Linh
Master of Applied Epidemiology, ASEAN-Australian Health Security Scholar
Australian National University - National Institute of Hygiene and Epidemiology

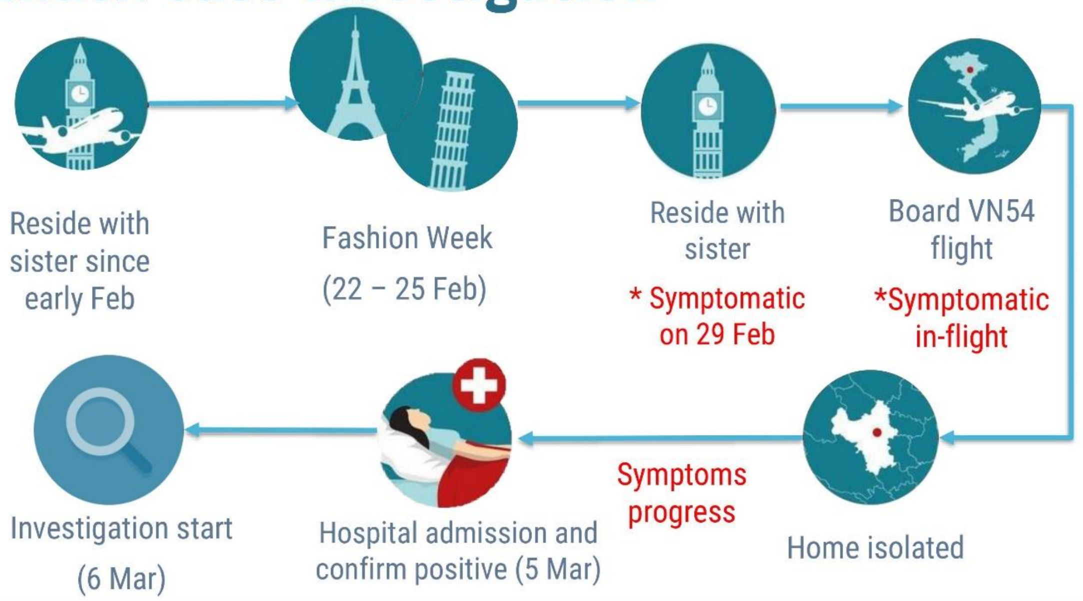
Background

- Air travel contributes to the spread of the pandemic.
- Limited evidence of transmission risk from infected passengers to other passengers or crew members.
- In early March, we detected a large cluster of COVID-19 among passengers arriving on the flight from London to Hanoi, Vietnam.

Settings

- VN54 direct flight
- Landed in Hanoi on 2 March – 10 hours flight duration.
- 16 crew members and 201 passengers on board.
- 21 (75%) in business, 35 (100%) premium economy, 145 (67%) in economy.

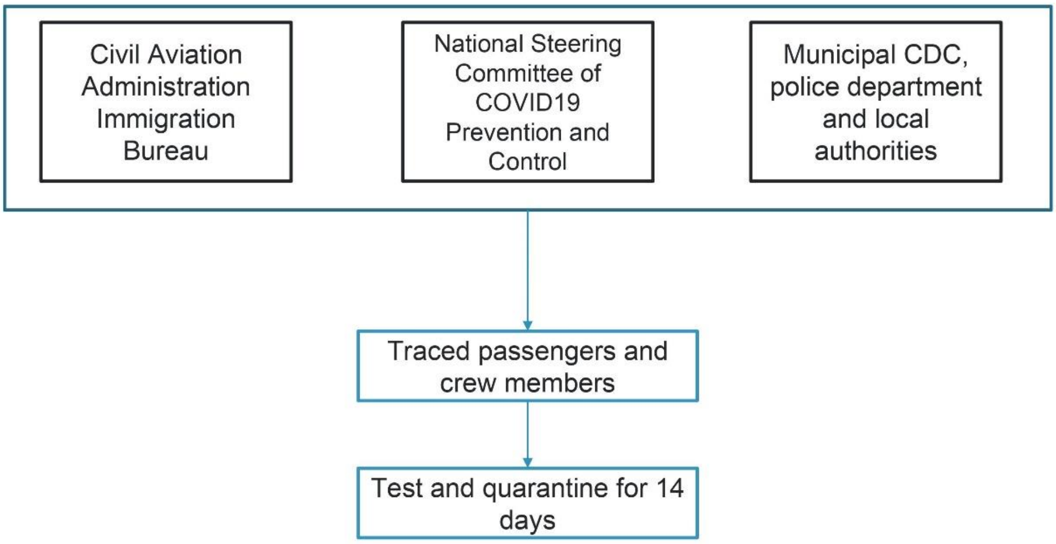
Index case investigation

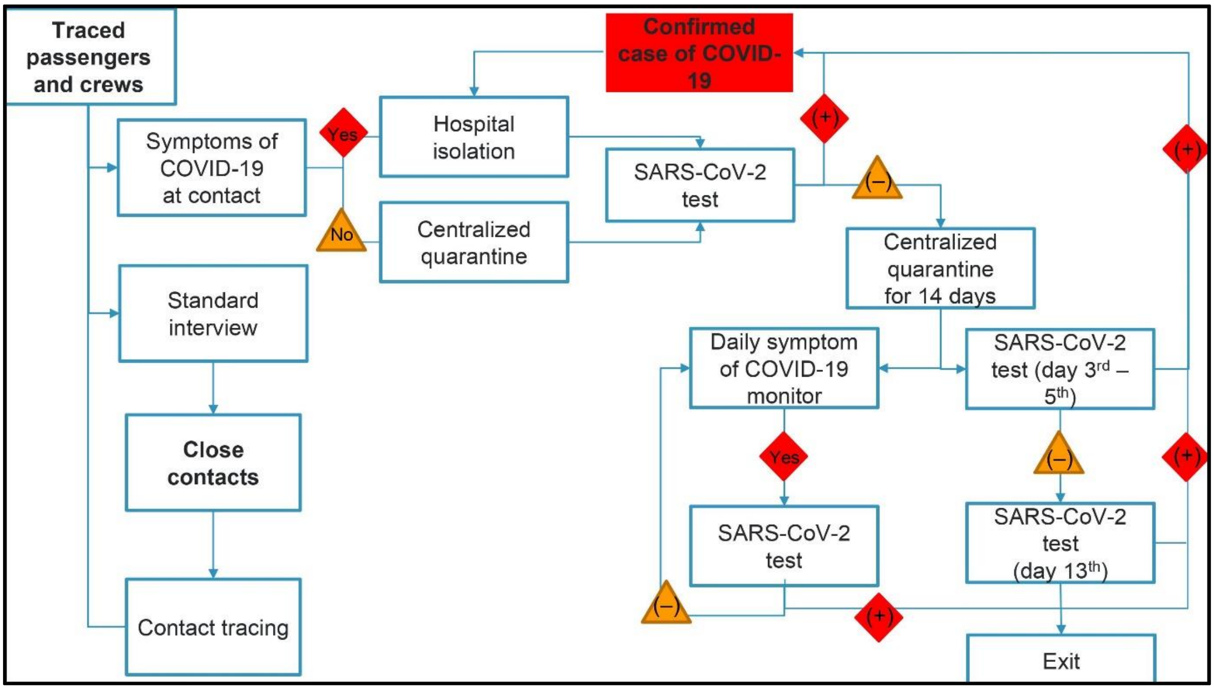


Objectives

- To estimate the probability that SARS-CoV-2 transmission occurred on the flight VN54.
- To identify associated risk factors.

Methods





Results

16 (100%) crews, 168 (84%) passengers

Contacted, tested, and quarantine

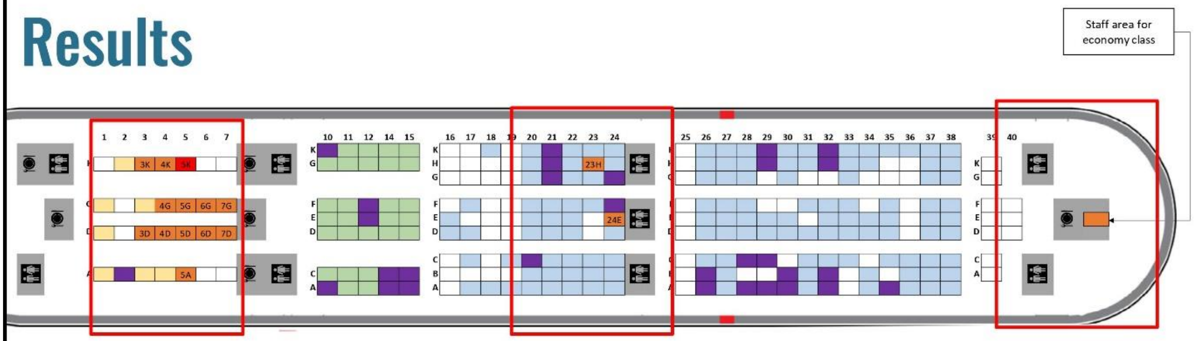
15 additional flight-associated cases

50% being male, 75% British

5 additional community cases

Among 1,311 close contacts traced and quarantined

Results



Business class

Premium economy class

Economy class

Transited passengers

Unoccupied seat

Confirmed COVID-19 case with seat number

Attack rate in business class was 62% (13/21)

Results

Seating location in business class related to index case	**PCR-positive* (n, %)**	**PCR-negative (n, %)**	**Relative Risk**	**RR (95%CI)**
≤2 seats away	11 (92%)	1 (13%)	0.9	7.3
>2 seats away	1 (8%)	7 (88%)	0.1	(1.2 – 46.2)

Results

Case no.	Seating	Companions	29-Feb	1-Mar	2-Mar	3-Mar	4-Mar	5-Mar	6-Mar	7-Mar	8-Mar	9-Mar	10-Mar	11-Mar	12-Mar	13-Mar	14-Mar	15-Mar
1	Business		Sx Onset	✈	✈				POS									
2	Business	Case 3		✈	✈						POS		Sx Onset					
3	Business	Case 2		✈	✈						POS							
4	Business			✈	✈			Sx Onset			POS							
5	Business			✈	✈						POS		Sx Onset					
6	Business	Case 7		✈	✈						POS							
7	Business	Case 6		✈	✈						POS							
8	Business	Case 9		✈	✈					POS								
9	Business	Case 8		✈	✈										POS			
10	Business	Case 11		✈	✈					Sx Onset	POS							
11	Business	Case 10		✈	✈					Sx Onset	POS							
12	Business			✈	✈						POS						Sx Onset	
13	Business			✈	✈							POS						
14	Economy	Life partner		✈	✈						POS							
15	Economy			✈	✈										POS			
16	Crew			✈	✈												Sx Onset	POS

- Sx Onset — Date of symptom onset
- POS — Date of positive test for SARS-CoV-2
- Period of isolation or quarantine
- Incubation period. Dashed portion at left indicates inclusion of ≥1 day(s) before flight
- Indicates overlap of incubation and quarantine periods

Discussion

In-flight transmission hypothesis

- Index case was **the only symptomatic person on board** and with **established contact to a confirmed case** during incubation period.
- The incubation periods of flight-associated cases **overlapped with flight time**.
- Community transmission in the departure nor arrival destination was **not widely established** at time of flight.

Possible routes of transmission:

- **Aerosol or droplet transmission** during the course of the flight
- **Contact outside the aircraft** at the airport before or after boarding

Limitations

- No **genomic sequencing data** available.
- No detailed data on the **cases' activities or prevention measures** while onboard.
- No **environmental samples** could be collected.

Implications

- Long-haul flights can lead to **super-spreader events** of COVID-19.
  - → **Systematic testing and/or quarantine policies** upon arrival (Vietnam in 21 March)
- In-flight transmission was beyond the "**2 rows / 2 seats**" distance for close contacts on airplanes.
  - → **Mask wearing, personal hygiene mandatory** on board. (Vietnam in 6 March)
  - → **Health declaration, social distancing** at airport. (Vietnam in 6 March)

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- Academic supervisor: Dr. Florian Vogt
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- Vietnam Ministry of Health, National Steering Committee of COVID-19 Prevention and Control
- Dr. Matt Moore, US Center of Disease Control in Vietnam
- Municipal Center of Disease Control in Vietnam, passengers on VN54 flight
- Research School of Population Health, ANU College of Health and Medicine, Australian National University
- Indo-Pacific Center for Health Security, Department of Foreign Affair and Trade

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Chapter 3. Analysis of a public health dataset

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

Table of Content – Chapter 3

List of Abbreviations – Chapter 3

COVID-19	Coronavirus 2019
NPIs	Non-Pharmaceutical Interventions
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2

Prologue

Background

After one year of COVID-19, Vietnam reported nearly 1500 confirmed cases and 35 fatalities related to COVID-19. Vietnam was one of the first countries to implement measures early on during the outbreak, including travel restrictions to many countries with high risk of COVID-19, mandatory testing and quarantine of international entry points, school closure, and regional lockdowns. During 2020, by constant implementation of non-pharmaceutical interventions (NPIs) throughout the year, Vietnam successfully contained COVID-19 epidemic, and avoided national-wide transmission. To assess the association between NPIs and COVID-19 incidence during different epidemic periods in Vietnam during 2020 is 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 never experience widespread community transmission nationwide provided opportune conditions for this study.

My role

During my time as a member of Rapid Information Team in National Steering Committee of COVID-19 Prevention and Control, I was in charge of data compilation and data management for COVID-19 epidemiological data in Vietnam. From the first few months of MAE program, I was inspired to evaluate the timeline of NPIs in Vietnam comparing to other countries in the world, namely United States, India, South Korea, South Africa, Italy, Australia, and China. From this initial idea, my academic supervisor advised me to focus on Vietnam for better data availability and accessibility. This project became my data analysis project, and I was planning to evaluate the association between NPIs and COVID-19 progression in Vietnam for the first 6 months of 2020. This was a great ending point, as Vietnam did experience national-wide social distancing during April after a few community outbreaks, and reported no new community cases from May to June. However, from July to September, new COVID-19 community outbreak was reported in Central Vietnam. This outbreak broke the record of new cases confirmed per day, and remarked the first COVID-19 deaths in Vietnam. After this outbreak, both my academic supervisor and I reconsidered the scope of the outbreak, and decided to redo the analysis till December. This would give the study a more wholesome scope of Vietnam's COVID-19 epidemic.

For this project, I was the primary investigator and data analysist. After conceptualize the research questions and objectives, I began to conduct data collection and cleaning. Case data was extracted from the COVID-19 epidemiological database that I was already in charge of. Despite of some data that were manually inputted and cleaned from case investigation reports, I was struggled to fill in missing case data by contacting provincial health staffs for retrospective collection, and even through internet resources. These were data collected during emergency period, when many data were lost in the process

and we only got case identified number for case count purpose. Date data (hospital discharge, quarantine started, isolation started) and case detection method data were particularly challenged as these were not regularly recorded, I had to scan through each case report. Similarly, for data input of case-pairs, I also re-read each case report to develop transmission network and connect data. I systematically collected NPIs implemented in Vietnam in the span of one year, methodologically and chronically divided them into periods of time. This was also challenging as there were no archive system for NPIs of COVID-19, so data was collected manually through official guidelines on Ministry of Health and provincial Department of Health, also supplemented by internet search. After three months of data collection and cleaning, and after consultation with my supervisor, by the beginning of 2021, I began to conduct data analysis on STATA and R. I managed to finish the analysis within three months and produced the final manuscript by March 2021 thanks to my academic supervisor's support and guidance.
The appendix of this chapter contains the paper I prepared for publication in the 'Field Epidemiology Special Edition' on *International Journal of Infectious Disease*. The paper was accepted and published online on 29 July 2021 (*Appendix 1*).

Abstract

Background

Vietnam implemented various public health interventions such as systematic testing and quarantine of arriving passengers, rigorous contact tracing, social distancing, and regional lockdowns in response to the COVID-19 pandemic. However, the impact of the different measures on COVID-19 incidence remains unclear, in Vietnam and elsewhere. The limited scale of the in-country epidemic in Vietnam during 2020 allowed us to investigate these effects during different epidemic periods.

Method

We analyzed the implementation of public health interventions alongside the evolution of the COVID-19 epidemic in Vietnam during 2020 and differentiated between distinct epidemic periods. Maximum likelihood estimations were used to fit distributions of containment delays, and multivariable regression was applied to identify associated factors. We also calculated effective reproductive numbers (Rt) based on transmission pairs' serial intervals.

Result

Various public health measures were introduced periodically in response to the changing epidemic. 817 (55.4%) among the total of 1,474 COVID-19 cases during the study period were imported cases. Based on an observed serial interval of 8.72 (±5.65) days, we estimated Rt to reduce below 1 during periods of aggressive border control and contact tracing measures, and to increase before periods of unexpected community clusters. Containment delays showed significant differences between modes of case

detection. Over time, the mode of case detection shifted from passive notification by hospitals to active case finding via contact tracing and immigration points testing.

Conclusions

Early, stringent and consistent implementation of non-pharmaceutical interventions is crucial to ensure maximum impact on the COVID-19 epidemic. We show that low- and middle-income countries with limited pandemic response capacity can contain COVID-19 successfully, both among imported cases and locally generated clusters, using traditional public health response measures.

Lesson learned

One of the biggest problems of preparing data analysis was the lack of focus. I struggled with what the project could be and should be in the early months of the program. In the heap of articles and research of COVID-19 and countries' responses to the epidemic, I was running from one idea to another, wanting to use every analysis and every models for my analysis. I was not confident enough in the first analysis plan that I had, and constantly on the hunt for the new flashy things that other researchers had done. However, a good manuscript should not be a shell of other previous manuscripts, but a stable home where you stay true to your objective with the data you have. This decision came to me late, after many, many analysis plans I sent to my supervisor, changing and adding new things, then dropping it because I set my target too high or too irrelevant. Many ideas were perfect on paper, on already-published articles, but not feasible in reality if I do not have that data accessible, or the statistical capacity to manufacture it. This also proved that even with a plan, preparation would not always guarantee success. The longing process of producing the project was also an attribute, as the scope moved from six months, to pending, to one year of COVID-19. For each stage, I had to redo data collection, cleaning and analysis, and especially, to re-focus the manuscript to the changing situation of COVID-19 in Vietnam. Luckily, with the constant support from Dr. Florian, I finally found the confidence in my own narrative, and focus the analysis on fixed goal, and finish this one-year-labor chapter. This is perhaps the hardest chapter in my thesis – mentally wise, and also my proudest achievement.

Limitation

In addition to limitations listed in Appendix 1, I acknowledge additional measurement bias. Due to high proportion of pre-symptomatic cases of COVID-19 recorded in 2020 in Vietnam (asymptomatic at time of confirmation) and lack of sufficient data for symptomatic data during isolation and treatment, I used date of positive test as a proxy for date of symptom onset for these cases in analysis. This would inevitably introduce less accurate estimations in the study, which might entail a shorter serial interval, discard negative value of serial interval, and an early estimation of Rt consequently. I also did not include imported cases in the analyses, which dismissed the possibility of imported cases infected local cases. These are inherently challenges in estimation of case-based reproductive number instead of instantaneous reproductive number (which used Bayesian estimation). Even though this was a retrospective analysis and the discussion showed my estimation of Rt was responsive in time with public health interventions and epidemic progression in Vietnam, I would encourage future estimation to take into account reporting delay, estimation biases, and the transmission mechanism of COVID-19 and other infectious disease to choose appropriate parameters and models for Rt.

Public health impact

The study showed that even in low-middle income countries with limited pandemic response capacities, public health preparedness and swift adaptations to the fast-changing COVID-19 situation proved effective in preventing SARS-CoV-2 to spread into community settings. The early implementation of mandatory quarantine at arrival, active case finding, and rigorous contact tracing proved particularly effective to prevent and contain community transmission throughout all phases of COVID-19 in the country. Enhanced testing in lockdown area as implemented in Vietnam as opposed to wider range national-wide lockdown in other countries showed to detect high number of cases and contain cluster successfully, while simultaneously challenged the need for large work force by utilizing community volunteers. This in cooperation with intensive contact tracing and mass testing proved the success of combination of public health measures to entail the growing epidemic. In addition, adaptive measures must be taken at sight of any changes in epidemiological movement of COVID-19 epidemic, as Vietnam was and continue doing into 2021 as more risk comes from unauthorized entries to avoid quarantine measures.

Recommendation

All countries should assess their range of public health measures to identify the most effective ones according to their current epidemic stage. The effectiveness of public health interventions should be evaluated on a continuous basis, and adapted accordingly. To face the future of COVID-19 being the new “normal”, countries should consider stringent and pro-active control of imported cases in combination with string national surveillance and response systems.

Acknowledgement

I thank my academic and field supervisors for their support and guidance through the production of the chapter. I acknowledge important contributions from the following institution and committee in Vietnam for COVID-19 cases data for this study: National Steering Committee for COVID-19 Prevention and Control, Ministry of Health, Ministry of Science and Technology, National Institute of Hygiene and Epidemiology, Nha Trang Pasteur Institute, Tay Nguyen Institute of Hygiene and Epidemiology, Ho Chi Minh Pasteur Institute.

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Appendix 1. Journal Article 3.

Quach HL[#], Nguyen CK[#^], Hoang NA[^], Pham QT, Tran ND, Le TQM, Do HT, Vien CC, Phan TL, Ngu DN, Tran AT, Phung CD, Tran DQ, Dang QT, Dang DA[*], Vogt F[*]. **Association of public health interventions and COVID-19 incidence in Vietnam, January to December 2020**. *International Journal of Infectious Disease*. S1201-9712(21)00600-7. Published 2021 July 28. doi: 10.1016/j.ijid.2021.07.044.

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

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ABSTRACT

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 (Rt) 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 Rt 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 characteristic of 1474 COVID-19 confirmed cases reported in Vietnam by six periods of pandemic progression[*] from January to December 2020.

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[†]
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															0.000[†]
0 - 25 y	22	25.88	40	32.79	15	23.81	20	13.79	80	12.68	93	21.73	270	18.32	
26 - 40 y	29	34.12	39	31.97	24	38.10	88	60.69	191	30.27	212	49.53	583	39.55	
41 - 60 y	20	23.53	36	29.51	18	28.57	35	24.14	213	33.76	100	23.36	422	28.63	
> 60 y	14	16.47	7	5.74	6	9.52	2	1.38	147	23.30	23	5.37	199	13.50	
Age (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[#]
Cases' source of infection															0.000[†]
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	
Symptomatic at testing															0.000[†]
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[†]
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 lock down areas	6	7.06	23	18.85	16	25.4	0	0	226	35.82	0	0	271	18.39	
Clinical conditions															0.000[†]
Stable	81	95.29	120	98.36	62	98.41	145	100	581	92.08	426	99.53	1415	96.00	
Critical conditions	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[†]
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[†]
Lengths of hospital stay (days) (mean, SD)[**]	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[#]

[*] Six periods were defined by key date of events and public health interventions implemented from 1 January to 31 December 2020. See methods for clarification.

[**]Excluded 35 deaths due to COVID-19, 3 deaths not due to COVID-19, and 110 COVID-19 patients not discharged at time of analysis.

[†]p-value was calculated by Chi-square test.

[#]p-value was calculated by Fisher's exact test.

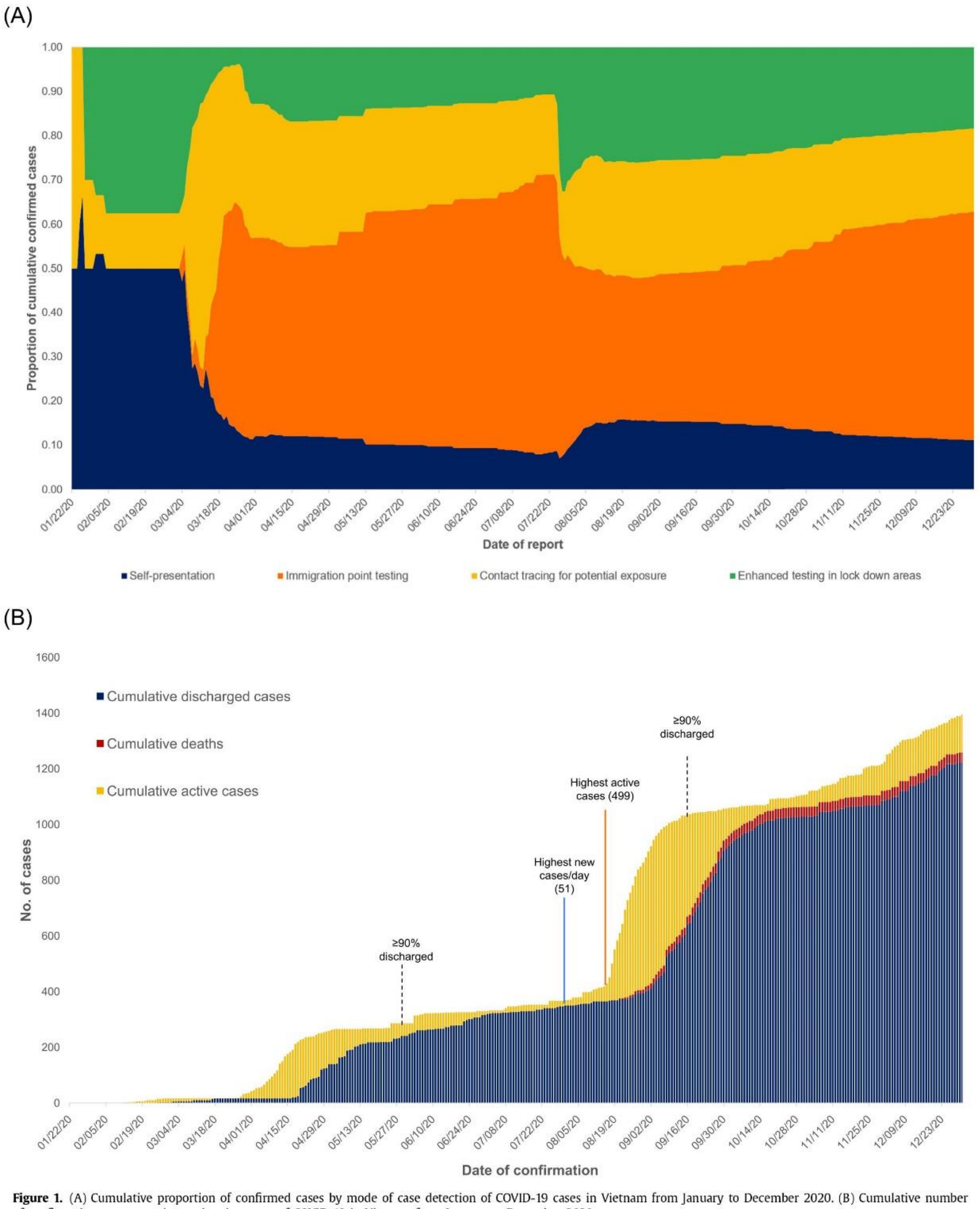

Figure 1. (A) Cumulative proportion of confirmed cases by mode of case detection of COVID-19 cases in Vietnam from January to December 2020. (B) Cumulative number of confirmed cases, recoveries, and active cases of COVID-19 in Vietnam from January to December 2020.

* Corrected figure 1B is on page 77.

Corrected Figure 1B: Cumulative number of active cases, discharged, and deaths of COVID-19 in Vietnam from January to December 2020.

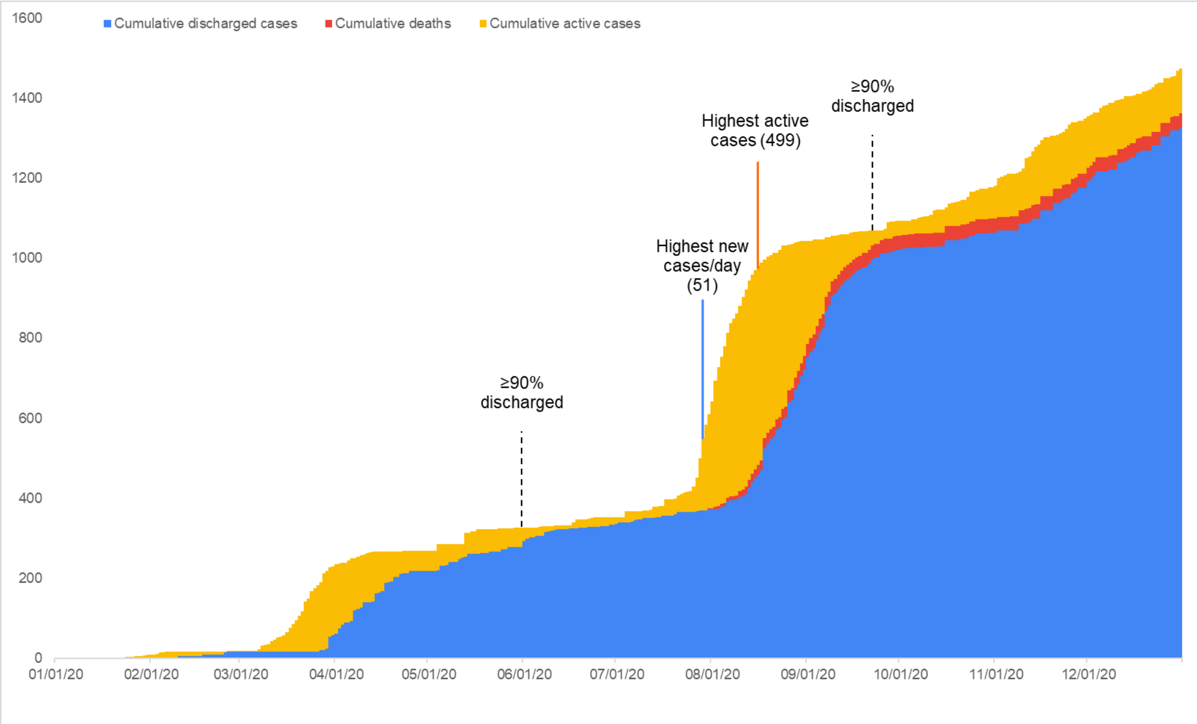

Table 2
Relationship between mode of case detection and characteristics of confirmed COVID-19 cases and epidemic periods of 1474 confirmed COVID-19 cases reported in Vietnam from January to December 2020

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 ageModel 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.

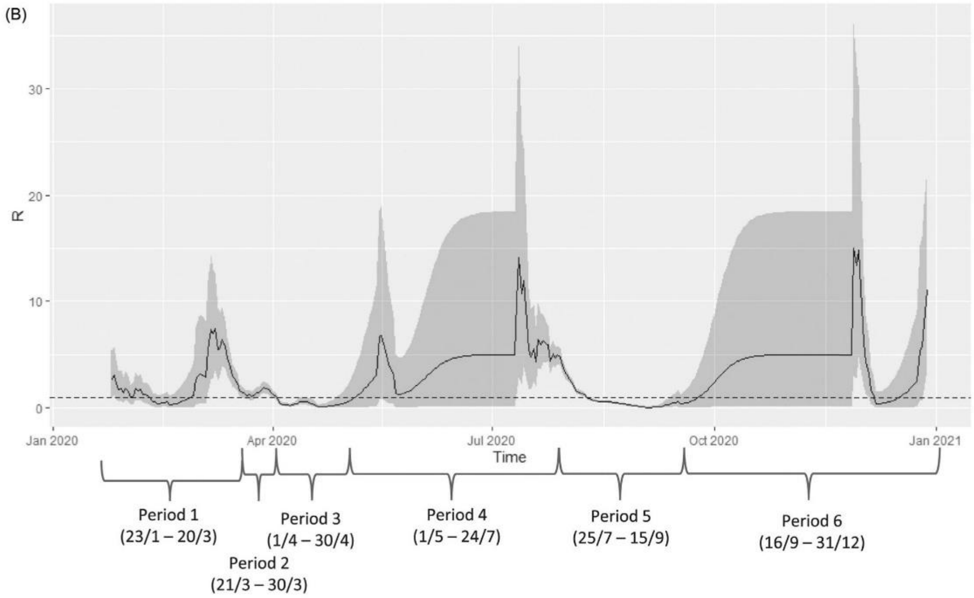

Figure 2. Continued

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 quarantined 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.

(continued on next page)

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.

(continued on next page)

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.

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CRediT authorship contribution statement

Ha-Linh Quach: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft, Writing – review & editing. **Khanh Cong Nguyen:** Project administration, Investigation, Supervision, Writing – review & editing. **Ngoc-Anh Hoang:** Data curation, Investigation, Visualization, Writing – review & editing. **Thai Quang Pham:** Project administration, Investigation, Supervision, Writing – review & editing. **Duong Nhu Tran:** Investigation, Methodology, Resources. **Mai Thi Quynh Le:** Methodology, Resources. **Hung Thai Do:** Data curation, Validation. **Chien Chinh Vien:** Data curation, Validation. **Lan Trong Phan:** Data curation, Validation. **Nghia Duy Ngu:** Formal analysis, Investigation, Resources. **Tu Anh Tran:** Formal analysis, Investigation, Resources. **Dinh Cong Phung:** Resources, Software, Visualization. **Quang Dai Tran:** Investigation, Resources. **Tan Quang Dang:** Investigation, Resources. **Florian Vogt:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

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Supplementary materials

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Supplement 1. Epidemiological descriptions of six periods of COVID-19 progression in Vietnam from January to December 2020.

Period 1 (22 January – 20 March)

The first four cases were reported during Lunar New Year – "Tet" celebration in Vietnam (January 2020) including two imported cases from Wuhan and two secondary cases. Into February, twelve cases of five repatriates from Wuhan and seven secondary cases were reported, 11 cases were located in the same location of Son Loi Commune, Vinh Phuc Province in Northern Vietnam[1-2]. Strict measures were initiated including a 20-day lockdown of the infected commune. All cases were isolated in healthcare facilities, whereas 10,000 citizens residing in the commune were tested for SARS-CoV-2 and monitored from 11 February (last case confirmation) to 4 March (20 days later)[3]. After the last case's confirmation (11 February), no more cases were recorded for 23 consecutive days. Early in March, a new wave of imported cases attributed by tourists and repatriates was reported, alongside their secondary cases in community.

Period 2 (21 March – 31 March)

Community transmission was officially confirmed as Vietnam recorded two cluster of cases without epi linked to prior cases during the last few weeks of March. One cluster included 19 confirmed cases linked to an entertainment hub. The index case was reportedly coming to a night club on 14 March in Ho Chi Minh city, which triggered extensive contact tracing, testing and quarantine to more than 300 persons identified in close contacts with either the index case or the night club in question. Another cluster was linked to a top-tier hospital in Hanoi in late March, which accounted for 50 cases of COVID-19 (the largest cluster reported in Vietnam so far), including hospital workers, service providers, in-patients and their household members. This event was subsequently led to contact tracing, test and quarantine of all out patients and their care-takers who were in the hospitals from 12 March, plus nearly 5000 persons who resided in Bach Mai at that time. Both of these clusters were populous community with frequent mobility and activities.

Period 3 (1 Apr – 30 Apr)

During this period, no secondary cases from imported source were seen. A new community cluster with indefinite source of transmission of 13 cases was reported in a small village in the North of Hanoi. After the index case tested positive for SARS-CoV-2, the 600 residents populated the village where he lived was under quarantine effective immediately. Contact tracing process included all residents in the first village, and extended to three nearby villages. In total, 1,000 residents were put under medical isolation for 21 days. No secondary cases nor local cases were reported since April 13 to the end of the period.

Period 4 (1 May – 24 July)

No community cases nor secondary cases were reported during this period. A total of 144 imported cases were detected by enhanced surveillance at immigration points, all were tested and quarantined at time of confirmation. One imported case who entered Vietnam illegally through trail path was detected in May. Vietnam remarked a total of 2.5 months of COVID-19 free from community transmission.

Period 5 (25 July – 15 September)

Two unlinked community clusters were reported. The first outbreak was spotted in three regional public hospitals in Da Nang – a municipal city in Central Vietnam. The outbreak spread among patients, caretakers, healthcare workers of the hospitals and their close contacts, and later in community and returnees from Da Nang to other provinces. The outbreak consisted of nearly 400 confirmed cases

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[1] Thanh HN, Van TN, Thu HNT, Van BN, Thanh BD, Thu HPT, et al. Outbreak investigation for COVID-19 in Northern Vietnam. Vol. 20, The Lancet Infectious Diseases. Lancet Publishing Group; 2020. p. 535–6.

[2] Van Cuong L, Giang HTN, Linh LK, Shah J, Van Sy L, Hung TH, et al. The first Vietnamese case of COVID-19 acquired from China. Vol. 20, The Lancet Infectious Diseases. Lancet Publishing Group; 2020. p. 408–9.

[3] Vietnam News. Vĩnh Phúc puts great efforts to cope with Covid-19 [Internet]. [cited 2021 March 2]. Available from: https://vietnamnews.vn/society/592194/vinh-phuc-puts-great-efforts-to-cope-with-covid-19.html

across Da Nang, neighbouring Quang Nam province, and in other provinces in Vietnam. This was also the first outbreak with 35 fatalities due to COVID-19 in Vietnam. The second outbreak was consisted of 13 cases among service staffs and visitors to a restaurant in Hai Duong city in Northern Vietnam, and later spread to one unlinked case in community.

Period 6 (16 September – 31 December)

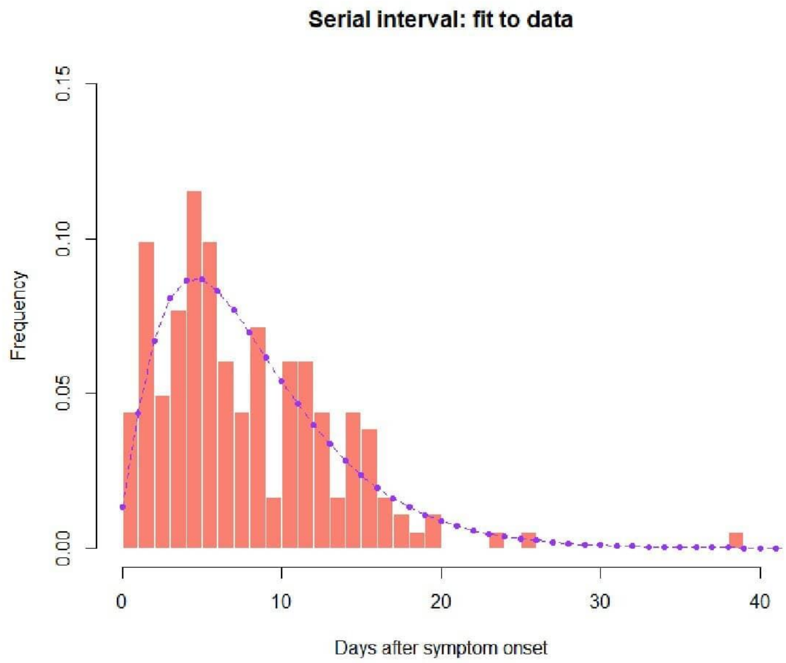
Two clusters were reported, both involving quarantine violation. The first outbreak was detected in late November, one imported case who violated quarantine measures successfully transmitted to three other community cases in Ho Chi Minh City. The second outbreak was involved four imported cases in Southern area of Vietnam, all entered Vietnam illegally in late December.

Supplement 2. Construction of transmission pairs.

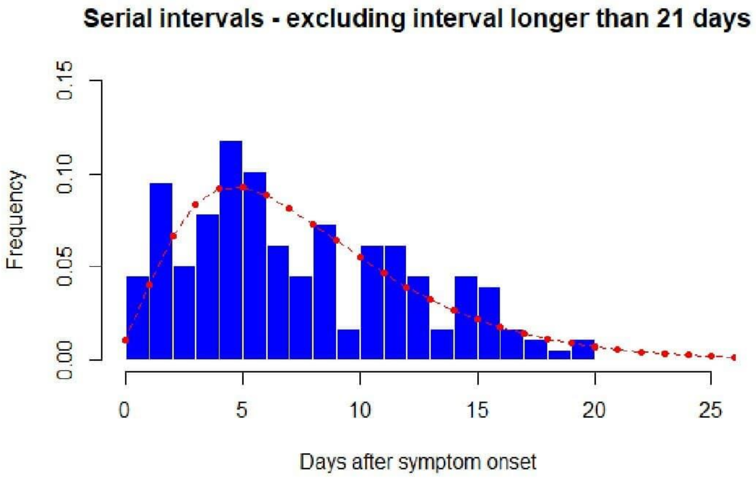
During 2020, results from contact tracing and epidemiological investigations about every new confirmed COVID-19 cases were reported. These reports included cases' travel histories as well as demographic and epidemiological information of their close contacts. We reviewed these case reports to construct the transmission pairs through the following steps:

- We first identified a pair or groups of confirmed cases that shared close contacts or travel histories. We then determined if two or more cases were transmission pairs by comparing name of each person on the other's epidemiological investigation forms, and investigating their relationship of exposure before one of each was confirmed SARS-CoV-2 positive. Relationships between transmission pairs included: family/household, work/study, vehicle sharing, hospital settings, neighbour/friend/less than 2-meter contacts.
- Due to the nature of contact tracing done in Vietnam at that time, whenever a confirmed case was notified, all their close contacts were identified, traced, tested for SARS-CoV-2, and quarantined for 14 days. Whenever a close contact tested positive for SARS-CoV-2, the same protocol was implemented for this person's close contacts. This process would limit potential untested cases among high-risk contacts as well as confirm possible transmission pathway. We determined the infector and infectee of each transmission pair according to time and location of exposures. If two cases shared a common epidemiological link, the infector was determined by the person who had a travel history to a defined COVID-19 clusters/areas prior to exposure with the other person – the infectee – who did not have any other epidemiological link. If more than two cases were involved in the transmission pathway, we evaluated their exposure history, and assumed that the infector was the first to developed symptoms, had previous travel history to COVID-19 clusters/ares and/or tested positive with COVID-19 in the group. As a result, no negative serial intervals were recorded in this study.

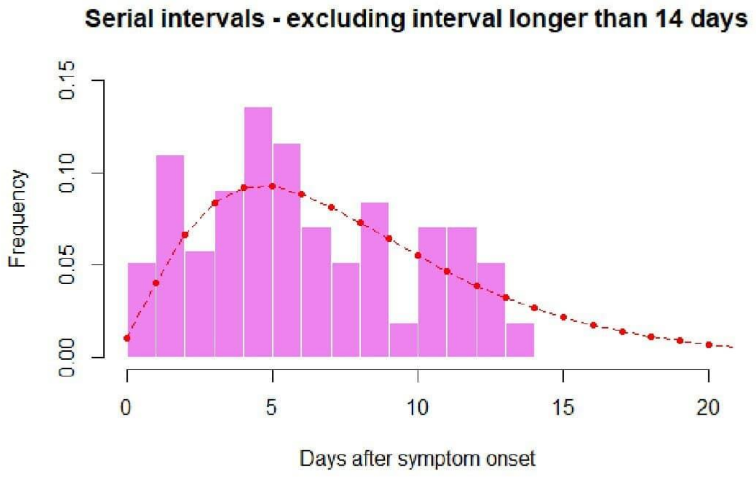
Supplement Figure 1. Distribution of serial interval of 182 transmission pairs of COVID-19 from 1474 confirmed cases of COVID-19 reported in Vietnam from January to December 2020. Dotted purple line represents Gamma distribution.



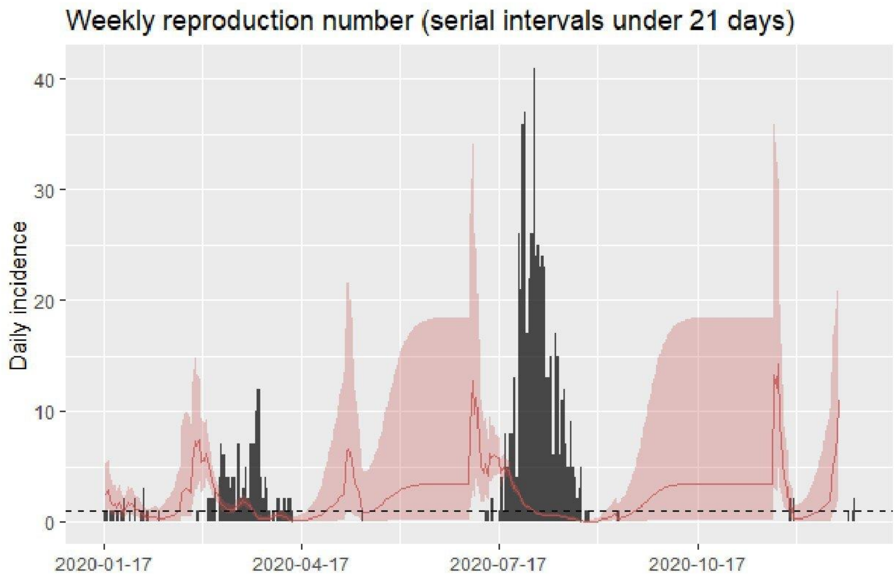
Supplement Figure 2. Distribution of serial interval of 178 transmission pairs of COVID-19 from 1474 confirmed cases of COVID-19 reported in Vietnam from January to December 2020 after excluding serial intervals longer than 21 days. Dotted red line represents Gamma distribution.



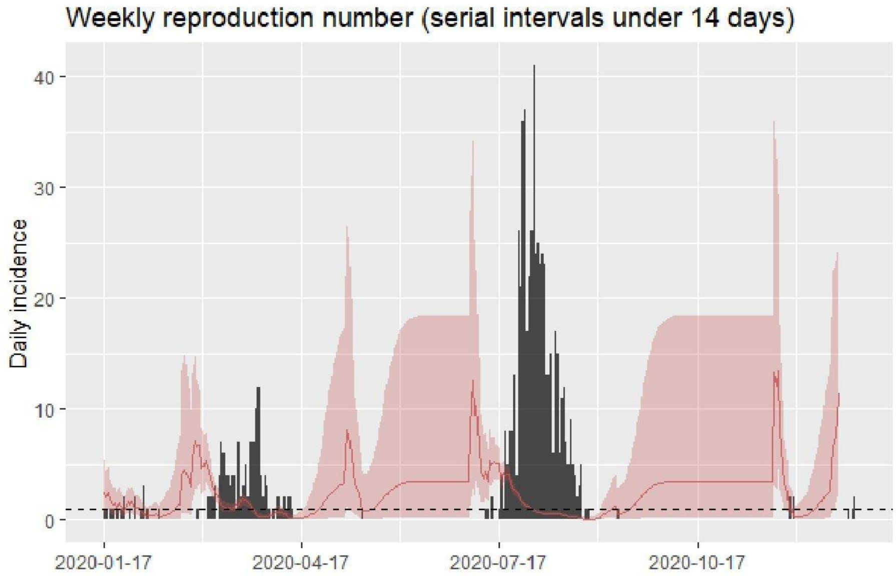
Supplement Figure 3. Distribution of serial interval of 155 transmission pairs of COVID-19 from 1474 confirmed cases of COVID-19 reported in Vietnam from January to December 2020 after excluding serial intervals longer than 14 days. Dotted red line represents Gamma distribution.



Supplement Figure 4. Distribution of daily estimated reproduction number across number of new daily cases of COVID-19 in Vietnam from January to December 2020, calculated from serial intervals excluding intervals longer than 21 days. Solid red line marks the effective reproduction number, dashed horizontal line represents the value "1" of effective reproduction number, and red areas represent the 95% confidence interval.



Supplement Figure 5. Distribution of daily estimated reproduction number across number of new daily cases of COVID-19 in Vietnam from January to December 2020, calculated from serial intervals excluding intervals longer than 14 days. Solid red line marks the effective reproduction number, dashed horizontal line represents the value "1" of effective reproduction number, and red areas represent the 95% confidence interval.



Supplement Table 1. Mean and 95%CI of reproduction number with moving average of 7 days, based on 693 non-quarantined imported cases and local cases.

Time	Median (95% CI)	Time	Median (95% CI)	Time	Median (95% CI)
2020-01-18	2.43 (0.84-5.32)	2020-05-10	5.04 (0.73-16.72)	2020-08-31	0.04 (0-0.24)
2020-01-19	2.93 (1.24-5.75)	2020-05-11	4.17 (0.6-13.83)	2020-09-01	0.05 (0-0.28)
2020-01-20	2.18 (0.85-4.49)	2020-05-12	3.46 (0.5-11.49)	2020-09-02	0.06 (0-0.34)
2020-01-21	1.58 (0.55-3.46)	2020-05-13	2.94 (0.42-9.77)	2020-09-03	0.19 (0.03-0.62)
2020-01-22	1.73 (0.67-3.55)	2020-05-14	2.57 (0.37-8.53)	2020-09-04	0.22 (0.03-0.75)
2020-01-23	1.32 (0.46-2.9)	2020-05-15	0.95 (0.03-5.06)	2020-09-05	0.27 (0.04-0.89)
2020-01-24	1.78 (0.75-3.48)	2020-05-16	0.88 (0.03-4.69)	2020-09-06	0.32 (0.05-1.06)
2020-01-25	1.44 (0.56-2.97)	2020-05-17	0.87 (0.03-4.65)	2020-09-07	0.38 (0.05-1.25)
2020-01-26	0.89 (0.26-2.12)	2020-05-18	0.91 (0.03-4.83)	2020-09-08	0.44 (0.06-1.46)
2020-01-27	1.09 (0.38-2.39)	2020-05-19	0.97 (0.04-5.14)	2020-09-09	0.51 (0.07-1.68)
2020-01-28	1.76 (0.79-3.32)	2020-05-20	1.04 (0.04-5.55)	2020-09-10	0.24 (0.01-1.27)
2020-01-29	1.52 (0.64-2.97)	2020-05-21	1.14 (0.04-6.06)	2020-09-11	0.27 (0.01-1.45)
2020-01-30	1.68 (0.76-3.16)	2020-05-22	1.25 (0.05-6.64)	2020-09-12	0.31 (0.01-1.66)
2020-01-31	1.19 (0.46-2.45)	2020-05-23	1.37 (0.05-7.3)	2020-09-13	0.36 (0.01-1.91)
2020-02-01	1.14 (0.44-2.35)	2020-05-24	1.51 (0.05-8.01)	2020-09-14	0.42 (0.02-2.22)
2020-02-02	1.11 (0.43-2.28)	2020-05-25	1.65 (0.06-8.77)	2020-09-15	0.49 (0.02-2.58)
2020-02-03	0.9 (0.31-1.97)	2020-05-26	1.8 (0.07-9.57)	2020-09-16	0.56 (0.02-3.01)
2020-02-04	0.51 (0.12-1.38)	2020-05-27	1.95 (0.07-10.38)	2020-09-17	0.66 (0.02-3.5)
2020-02-05	0.52 (0.12-1.39)	2020-05-28	2.1 (0.08-11.2)	2020-09-18	0.76 (0.03-4.06)
2020-02-06	0.34 (0.05-1.11)	2020-05-29	2.25 (0.08-12)	2020-09-19	0.88 (0.03-4.69)
2020-02-07	0.35 (0.05-1.18)	2020-05-30	2.4 (0.09-12.77)	2020-09-20	1.02 (0.04-5.4)
2020-02-08	0.38 (0.06-1.27)	2020-05-31	2.54 (0.09-13.5)	2020-09-21	1.16 (0.04-6.18)
2020-02-09	0.42 (0.06-1.38)	2020-06-01	2.66 (0.1-14.17)	2020-09-22	1.32 (0.05-7.02)
2020-02-10	0.46 (0.07-1.52)	2020-06-02	2.78 (0.1-14.79)	2020-09-23	1.49 (0.05-7.91)
2020-02-11	0.21 (0.01-1.11)	2020-06-03	2.88 (0.11-15.34)	2020-09-24	1.66 (0.06-8.84)
2020-02-12	0.23 (0.01-1.22)	2020-06-04	2.97 (0.11-15.82)	2020-09-25	1.84 (0.07-9.78)
2020-02-13	0.26 (0.01-1.38)	2020-06-05	3.05 (0.11-16.25)	2020-09-26	2.01 (0.07-10.72)
2020-02-14	0.29 (0.01-1.57)	2020-06-06	3.12 (0.11-16.61)	2020-09-27	2.19 (0.08-11.63)
2020-02-15	0.34 (0.01-1.8)	2020-06-07	3.18 (0.12-16.93)	2020-09-28	2.35 (0.09-12.5)
2020-02-16	0.39 (0.01-2.08)	2020-06-08	3.23 (0.12-17.19)	2020-09-29	2.5 (0.09-13.31)
2020-02-17	0.45 (0.02-2.41)	2020-06-09	3.27 (0.12-17.42)	2020-09-30	2.64 (0.1-14.06)

2020-02-18	0.53 (0.02-2.8)	2020-06-10	3.31 (0.12-17.6)	2020-10-01	2.77 (0.1-14.73)
2020-02-19	0.61 (0.02-3.25)	2020-06-11	3.34 (0.12-17.76)	2020-10-02	2.88 (0.11-15.32)
2020-02-20	0.71 (0.03-3.76)	2020-06-12	3.36 (0.12-17.88)	2020-10-03	2.98 (0.11-15.84)
2020-02-21	0.82 (0.03-4.36)	2020-06-13	3.38 (0.12-17.99)	2020-10-04	3.06 (0.11-16.28)
2020-02-22	2.28 (0.33-7.58)	2020-06-14	3.4 (0.12-18.08)	2020-10-05	3.13 (0.11-16.66)
2020-02-23	2.57 (0.37-8.53)	2020-06-15	3.41 (0.12-18.15)	2020-10-06	3.19 (0.12-16.98)
2020-02-24	2.66 (0.38-8.83)	2020-06-16	3.42 (0.12-18.2)	2020-10-07	3.24 (0.12-17.25)
2020-02-25	2.59 (0.37-8.6)	2020-06-17	3.43 (0.13-18.25)	2020-10-08	3.28 (0.12-17.47)
2020-02-26	2.44 (0.35-8.12)	2020-06-18	3.44 (0.13-18.29)	2020-10-09	3.32 (0.12-17.65)
2020-02-27	4.99 (1.48-11.92)	2020-06-19	3.44 (0.13-18.32)	2020-10-10	3.35 (0.12-17.8)
2020-02-28	6.98 (2.71-14.36)	2020-06-20	3.45 (0.13-18.34)	2020-10-11	3.37 (0.12-17.93)
2020-02-29	6.66 (2.81-13.04)	2020-06-21	3.45 (0.13-18.36)	2020-10-12	3.39 (0.12-18.03)
2020-03-01	7.22 (3.58-12.76)	2020-06-22	3.45 (0.13-18.38)	2020-10-13	3.4 (0.12-18.11)
2020-03-02	5.29 (2.63-9.35)	2020-06-23	3.46 (0.13-18.39)	2020-10-14	3.41 (0.12-18.17)
2020-03-03	5.49 (3.08-8.93)	2020-06-24	3.46 (0.13-18.4)	2020-10-15	3.42 (0.13-18.23)
2020-03-04	6.3 (3.97-9.42)	2020-06-25	3.46 (0.13-18.41)	2020-10-16	3.43 (0.13-18.27)
2020-03-05	5.69 (3.73-8.24)	2020-06-26	3.46 (0.13-18.42)	2020-10-17	3.44 (0.13-18.3)
2020-03-06	4.59 (3.06-6.56)	2020-06-27	3.46 (0.13-18.42)	2020-10-18	3.44 (0.13-18.33)
2020-03-07	3.74 (2.54-5.29)	2020-06-28	3.46 (0.13-18.43)	2020-10-19	3.45 (0.13-18.35)
2020-03-08	2.95 (2-4.16)	2020-06-29	3.46 (0.13-18.43)	2020-10-20	3.45 (0.13-18.37)
2020-03-09	2.75 (1.91-3.8)	2020-06-30	3.46 (0.13-18.43)	2020-10-21	3.45 (0.13-18.39)
2020-03-10	2.32 (1.61-3.21)	2020-07-01	3.46 (0.13-18.44)	2020-10-22	3.46 (0.13-18.4)
2020-03-11	1.64 (1.09-2.34)	2020-07-02	3.46 (0.13-18.44)	2020-10-23	3.46 (0.13-18.41)
2020-03-12	1.51 (1.02-2.14)	2020-07-03	3.46 (0.13-18.44)	2020-10-24	3.46 (0.13-18.42)
2020-03-13	1.29 (0.85-1.85)	2020-07-04	8.39 (1.21-27.85)	2020-10-25	3.46 (0.13-18.42)
2020-03-14	1.16 (0.76-1.68)	2020-07-05	12.59 (2.91-34.01)	2020-10-26	3.46 (0.13-18.43)
2020-03-15	1.2 (0.8-1.71)	2020-07-06	9.53 (2.2-25.74)	2020-10-27	3.46 (0.13-18.43)
2020-03-16	1.08 (0.71-1.56)	2020-07-07	11.15 (3.88-24.45)	2020-10-28	3.46 (0.13-18.43)
2020-03-17	1.18 (0.79-1.67)	2020-07-08	7.55 (2.63-16.56)	2020-10-29	3.46 (0.13-18.43)
2020-03-18	1.41 (0.99-1.94)	2020-07-09	5.1 (1.77-11.18)	2020-10-30	3.46 (0.13-18.44)
2020-03-19	1.38 (0.97-1.9)	2020-07-10	4.49 (1.74-9.24)	2020-10-31	3.46 (0.13-18.44)

2020-03-20	1.66 (1.21-2.22)	2020-07-11	5.31 (2.52-9.66)	2020-11-01	3.46 (0.13-18.44)
2020-03-21	1.94 (1.46-2.53)	2020-07-12	4.19 (1.99-7.62)	2020-11-02	3.47 (0.13-18.44)
2020-03-22	1.81 (1.35-2.36)	2020-07-13	6.32 (3.76-9.86)	2020-11-03	3.47 (0.13-18.44)
2020-03-23	1.68 (1.26-2.2)	2020-07-14	5.85 (3.64-8.83)	2020-11-04	3.47 (0.13-18.44)
2020-03-24	1.47 (1.09-1.94)	2020-07-15	6.19 (4.16-8.79)	2020-11-05	3.47 (0.13-18.44)
2020-03-25	1.26 (0.92-1.68)	2020-07-16	5.96 (4.21-8.14)	2020-11-06	3.47 (0.13-18.44)
2020-03-26	1.03 (0.73-1.39)	2020-07-17	5.92 (4.39-7.76)	2020-11-07	3.47 (0.13-18.44)
2020-03-27	0.72 (0.48-1.03)	2020-07-18	4.41 (3.27-5.78)	2020-11-08	3.47 (0.13-18.44)
2020-03-28	0.42 (0.24-0.66)	2020-07-19	5.08 (4-6.34)	2020-11-09	3.47 (0.13-18.44)
2020-03-29	0.31 (0.17-0.53)	2020-07-20	4.66 (3.74-5.72)	2020-11-10	3.47 (0.13-18.44)
2020-03-30	0.32 (0.17-0.55)	2020-07-21	4.93 (4.09-5.88)	2020-11-11	3.47 (0.13-18.44)
2020-03-31	0.26 (0.12-0.46)	2020-07-22	4.8 (4.06-5.62)	2020-11-12	3.47 (0.13-18.44)
2020-04-01	0.21 (0.09-0.41)	2020-07-23	3.97 (3.37-4.62)	2020-11-13	3.47 (0.13-18.44)
2020-04-02	0.27 (0.12-0.5)	2020-07-24	3.29 (2.82-3.83)	2020-11-14	3.47 (0.13-18.44)
2020-04-03	0.33 (0.16-0.6)	2020-07-25	3.02 (2.61-3.47)	2020-11-15	3.47 (0.13-18.44)
2020-04-04	0.41 (0.2-0.73)	2020-07-26	2.71 (2.35-3.11)	2020-11-16	3.47 (0.13-18.44)
2020-04-05	0.55 (0.29-0.93)	2020-07-27	2.34 (2.03-2.67)	2020-11-17	3.47 (0.13-18.44)
2020-04-06	0.55 (0.28-0.95)	2020-07-28	1.91 (1.65-2.19)	2020-11-18	3.47 (0.13-18.44)
2020-04-07	0.55 (0.27-0.96)	2020-07-29	1.57 (1.35-1.81)	2020-11-19	3.47 (0.13-18.44)
2020-04-08	0.53 (0.25-0.96)	2020-07-30	1.48 (1.27-1.7)	2020-11-20	3.47 (0.13-18.44)
2020-04-09	0.44 (0.18-0.86)	2020-07-31	1.38 (1.19-1.59)	2020-11-21	13.37 (3.09-36.12)
2020-04-10	0.4 (0.16-0.83)	2020-08-01	1.21 (1.04-1.4)	2020-11-22	11.9 (2.75-32.14)
2020-04-11	0.28 (0.08-0.67)	2020-08-02	0.97 (0.82-1.13)	2020-11-23	13.88 (4.82-30.42)
2020-04-12	0.14 (0.02-0.46)	2020-08-03	0.88 (0.74-1.03)	2020-11-24	8.88 (3.09-19.47)
2020-04-13	0.06 (0-0.34)	2020-08-04	0.75 (0.62-0.89)	2020-11-25	5.68 (1.97-12.45)
2020-04-14	0.07 (0-0.38)	2020-08-05	0.71 (0.58-0.85)	2020-11-26	3.98 (1.38-8.72)
2020-04-15	0.08 (0-0.43)	2020-08-06	0.66 (0.54-0.79)	2020-11-27	3.04 (1.06-6.66)
2020-04-16	0.09 (0-0.5)	2020-08-07	0.56 (0.45-0.69)	2020-11-28	1.42 (0.33-3.83)
2020-04-17	0.11 (0-0.58)	2020-08-08	0.57 (0.46-0.7)	2020-11-29	1.22 (0.28-3.3)
2020-04-18	0.13 (0-0.67)	2020-08-09	0.59 (0.47-0.72)	2020-11-30	0.29 (0.01-1.55)
2020-04-19	0.15 (0.01-0.79)	2020-08-10	0.55 (0.44-0.69)	2020-12-01	0.28 (0.01-1.51)
2020-04-20	0.18 (0.01-0.94)	2020-08-11	0.58 (0.45-0.72)	2020-12-02	0.29 (0.01-1.55)
2020-04-21	0.21 (0.01-1.11)	2020-08-12	0.54 (0.42-0.68)	2020-12-03	0.31 (0.01-1.66)
2020-04-22	0.25 (0.01-1.32)	2020-08-13	0.49 (0.37-0.62)	2020-12-04	0.34 (0.01-1.82)

2020-04-23	0.3 (0.01-1.57)	2020-08-14	0.5 (0.38-0.64)	2020-12-05	0.38 (0.01-2.03)
2020-04-24	0.35 (0.01-1.87)	2020-08-15	0.44 (0.32-0.58)	2020-12-06	0.43 (0.02-2.29)
2020-04-25	0.42 (0.02-2.22)	2020-08-16	0.38 (0.27-0.51)	2020-12-07	0.49 (0.02-2.6)
2020-04-26	0.49 (0.02-2.63)	2020-08-17	0.38 (0.27-0.52)	2020-12-08	0.56 (0.02-2.97)
2020-04-27	0.59 (0.02-3.11)	2020-08-18	0.35 (0.24-0.49)	2020-12-09	0.64 (0.02-3.41)
2020-04-28	0.69 (0.03-3.67)	2020-08-19	0.27 (0.17-0.41)	2020-12-10	0.73 (0.03-3.91)
2020-04-29	0.81 (0.03-4.3)	2020-08-20	0.24 (0.14-0.38)	2020-12-11	0.84 (0.03-4.48)
2020-04-30	0.94 (0.03-5.01)	2020-08-21	0.2 (0.11-0.33)	2020-12-12	0.96 (0.04-5.12)
2020-05-01	1.09 (0.04-5.8)	2020-08-22	0.19 (0.1-0.33)	2020-12-13	1.1 (0.04-5.83)
2020-05-02	1.25 (0.05-6.65)	2020-08-23	0.15 (0.07-0.29)	2020-12-14	1.24 (0.05-6.61)
2020-05-03	1.42 (0.05-7.56)	2020-08-24	0.06 (0.01-0.16)	2020-12-15	1.4 (0.05-7.44)
2020-05-04	1.6 (0.06-8.51)	2020-08-25	0.07 (0.02-0.18)	2020-12-16	1.56 (0.06-8.32)
2020-05-05	1.78 (0.07-9.48)	2020-08-26	0.05 (0.01-0.16)	2020-12-17	1.73 (0.06-9.22)
2020-05-06	1.96 (0.07-10.45)	2020-08-27	0.02 (0-0.12)	2020-12-18	4.61 (0.67-15.31)
2020-05-07	2.14 (0.08-11.4)	2020-08-28	0.03 (0-0.14)	2020-12-19	4.84 (0.7-16.08)
2020-05-08	5.6 (0.81-18.59)	2020-08-29	0.03 (0-0.17)	2020-12-20	7.08 (1.64-19.12)
2020-05-09	5.73 (0.83-19.03)	2020-08-30	0.04 (0-0.2)	2020-12-21	10.33 (3.59-22.65)

Supplement Table 2. Mean and standard deviation of containment delays by cases' characteristics and epidemic periods for 713 confirmed cases of COVID-19* in Vietnam from January to December 2020.

Characteristics	Containment delay				
	Mean	**95%CI**	**SD**	**95%CI**	**p-value**
All cases	1.62	1.38 – 1.86	3.31	3.15 – 3.50	
Cases with symptoms at first positive testing (N=201)	5.04	4.40 – 5.69	4.61	4.20 – 5.11	
Sex					
Male	1.46	1.10 – 1.82	3.11	2.88 – 3.39	0.2759#
Female	1.73	1.41 – 2.06	3.44	3.27 – 3.69	
Age group					
0 – 25 y	1.67	0.98 – 2.36	3.24	2.82 – 3.08	0.7672†
26 – 40 y	1.75	1.29 – 2.21	3.35	3.05 – 3.71	
41 – 60 y	1.44	1.07 – 1.82	3.04	2.79 – 3.33	
> 60 y	1.70	1.13 – 2.27	3.70	3.34 – 4.15	
Case categories					
Imported cases	0.96	0.50 – 1.42	1.72	1.44 – 2.11	0.1223#
Domestic cases	1.67	1.42 – 1.94	3.41	3.23 – 3.60	
*Mode of case detection**					
Self-presentation at hospitals	3.21	2.54 – 3.88	4.32	3.90 – 4.84	0.0000†
Contact tracing for potential exposure to COVID-19	1.10	0.79 – 1.40	2.57	2.37 – 2.80	
Enhanced testing in lock down areas	1.19	0.83 – 1.54	2.97	2.74 – 3.24	
*Period****					
1	1.05	0.56 – 1.53	1.92	1.63 – 2.33	0.2212†
2	1.10	0.58 – 1.62	2.00	1.69 – 2.44	
3	1.26	0.09 – 2.42	3.53	2.82 – 4.72	
4	0	--	0	--	
5	1.78	1.49 – 2.08	3.54	3.34 – 3.76	
6	0	--	0	--	

#p-value was calculated by t-test

†p-value was calculated by ANOVA test

*761 cases who were quarantined from immigration points were excluded because they did not contribute to the transmission in Vietnam.

**Mode of case detection by immigration point testing and quarantine obsoletes any observable containment delay.

***Only cases with none containment delay were observed in Period 4 and 6.

Supplement Table 3. Mean and standard deviation of containment delays for 713 confirmed cases of COVID-19* in Vietnam from January to December 2020.

Distribution	Containment delay		AIC
	Mean (95% CI)	**SD (95% CI)**	
Pareto	2.01 (1.83 – 2.53)	1.01 (1.00 – 1.43)	1217.47**
Normal	1.62 (1.38 – 1.84)	3.31 (3.12 – 3.49)	3734.98
Weibull	1.61 (1.44 – 1.81)	1.00 (0.92 – 1.10)	2119.10
Gamma	1.62 (1.50 – 1.75)	1.00 (0.94 – 1.06)	2119.10

*761 cases who were quarantined from immigration points were excluded because they did not contribute to the transmission in Vietnam.

**Maximum likelihood estimation calculated lowest AIC for Pareto distribution of containment delay.

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Chapter 4. Evaluate a surveillance system

After action review of the COVID-19 surveillance system
at Quang Ninh Province, Vietnam in 2020

Table of Content – Chapter 4

List of Abbreviations – Chapter 4

AAR	After Action Review
CDC	Center for Disease Control and Prevention
COVID-19	Coronavirus 2019
F1	First-degree contacts
F2	Second-degree contacts
F3	Third-degree contacts
EBS	Event-Based Surveillance
IAR	Intra-Action Review
ILI	Influenza-like infection
NIHE	National Institute of Hygiene and Epidemiology
POE	Points of Entry
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
SARI	severe acute respiratory infection
SVP	severe virus pneumonia
RRT	Rapid Response Teams
WHO	World Health Organization

Prologue

Background

In face of emerging COVID-19 imported threats in January 2020, Vietnam public health system had triggered the COVID-19 surveillance system across the country (1, 2). This system aims to detect case early, conduct continuous case surveillance and management at all healthcare facilities and immigration points to minimize onward community transmission. Thanks to constant operation of the surveillance system parallel at all provinces and cities across the country, early and swift interventions was proactively implemented and outbreaks were quickly under control. By the end of 2020, Vietnam was one of a few countries that had good control for COVID-19 with limited 1474 confirmed cases and 35 COVID-19-related fatalities (3). Quang Ninh is a coastal province in the Northeast region of Vietnam. The province has land and sea border with Mainland China and has one international airport. Quang Ninh owns many famous scenic spots welcoming about 10 million tourists annually. Despite of close proximity to Mainland China, there were only 22 cases of COVID-19 detected in the province in 2020. Quang Ninh province has shown strong surveillance capacity of the COVID-19 epidemic so far through strong demonstration of surveillance, contact tracing and case detection. Therefore, the province is an excellent example for surveillance system evaluation, which can facilitate improvements in the systems' performance and the overall public health response. The findings are very important to improve the infectious disease control system in Quang Ninh in particular and in Vietnam in general in the future.

My role

In April 2020, Vietnam World Health Organization (WHO) cooperated with National Institute of Hygiene and Epidemiology (NIHE) to perform an After Action Review (AAR) of COVID-19 surveillance and responses activities in Vietnam. Two locations were chosen for the evaluation, Quang Ninh Province and Me Linh Commune, Hanoi City. My field supervisor was the primary investigator for this project, and I was enlisted for project assistant. At first, my role in the project included literature review of global AARs experience, agenda and budget preparation, and report writing for Quang Ninh Province solely. Later on, as the project was delayed further to July, and then October 2020, my responsibility grew to include tool kit development, proposal writing, and stakeholder interview. Because of local COVID-19 situation, the project was delayed until November 2020 and focused to evaluate the whole system's performance in the year 2020. Our team went to Quang Ninh for stakeholder meeting in late November 2020, and began sending surveys in December 2020 (*Appendix 1*). We only received the surveys back in March 2021 because the province was experiencing a wide-scale community outbreak in January and February 2021. The interview was conducted in May 2021 by a guided questionnaire (*Appendix 2*). The final report was prepared by me in May 2021 and submitted to Vietnam WHO. In January 2022, the report was modified for publication and submitted to *Journal of Emergency Management.* This chapter included two parts. Part I is a literature review of AARs in response to infectious disease outbreaks. Part II is the final report of evaluation of COVID-19 surveillance system using AAR.

Retrospectively, this was a predefined commissioned project between my field placement and Vietnam WHO. Due to this, I do not have authority over the methodology or data collection method. The nature of the project and the prolonged pandemic condition did not allow me to choose a more appropriate method for surveillance system evaluation, instead, this was an evaluation of COVID-19 preparedness, surveillance and response systems in Quang Ninh Province. I acknowledged there were certainly many challenges in the process of this project that hindered data availability and analysis, including limited number of participants and very cut-down approach of survey and phone interview. The AAR is used to reflect on systematic responses after an emergency event, yet its approach could not reach and assess all aspects of a system under pressure of an emerging event such as COVID-19. Other than detailing the unfolding action from preparation (if any) to implementation, AAR did not collect evidence of the system's operation feature, especially attributes of a surveillance system as the US Center of Disease Control (CDC)'s guideline or other evaluation tool by WHO. AAR sure has its merits that I detailed in Part I of this chapter, and used in supplement with the US CDC guideline's attributes in Part II. However, I would not recommend AAR for a comprehensive evaluation of a public health system, but for a tool to engage stakeholders across administrative levels to learn and improve after an emerging event to strengthen the system's resilience and adaptability in future event.

Abstract 1

Background

After Action Reviews (AAR) are a qualitative evaluation methodology recommended by the World Health Organization (WHO) to analyze best practices and challenges in responding to a public health event. The extent to which WHO guidance on AAR methodology is followed to assess public health responses and public health systems responding to emerging infectious diseases remains unclear.

Method

We conducted a literature review on studies and reports that used WHO's AAR toolkit to evaluate responses to infectious disease outbreaks. PubMed and WHO's AAR repository were searched for studies and reports published between 2015 and 2020 in English language.

Result

Among 86 screened articles, we identified eight reports using WHO's AAR method to evaluate public health responses to an infectious disease outbreak. Four of them strictly followed the WHO's toolkit, implementation and reporting format, while the other four used the AAR method in combination with document reviews and questionnaire surveys. One study was implemented in an institutional setting.

The scope of four studies was at local level, and four studies focused on responses at national level. Three studies included evaluation of the AAR method, and all of them rated AARs positively to assess outbreak responses. However, only half of participants interviewed in those reports agreed that AARs contributed to strengthening the systems under evaluation.

Conclusion

Our findings suggested the WHO AAR toolkit is a suitable methodology to evaluate responses to infectious disease outbreaks. WHO's recommendations need to remain adaptive to cater for evaluation needs in particular settings.

Abstract 2

Background

Public health surveillance is crucial in the response to COVID-19 but formal performance evaluations of surveillance systems are lacking. We conducted an After Action Review (AAR) of the performance of the COVID-19 surveillance system in Quang Ninh Province, Vietnam during 2020.

Method

This was a retrospective evaluation using the COVID-19 specific AAR methodology developed by the World Health Organization in combination with guidance from the US Centers for Disease Control and Prevention for the performance assessment of surveillance systems. We conducted a stakeholder survey, reviewed documents, and performed key informant interviews with leading public health managers from the Quang Ninh Center for Disease Control and Prevention's COVID-19 surveillance system.

Result

The COVID-19 surveillance system was based on the pre-existing surveillance system as implemented across multiple administrative levels in the province. The system's strengths were: early preparation for emergency response; strong governance and central coordination; and multidisciplinary collaboration. Stakeholders agreed that the system proved useful and adaptive to the fast-evolving COVID-19 situation in general, but was weakened by overly complex data systems, redundant administrative processes, unclear communication channels, and lack of resources.

Conclusion

Overall, the surveillance systems in Quang Ninh province proved effective in the response to COVID-19 during 2020. Several recommendations for improvements were made based on identified areas of concern that are of relevance for COVID-19 surveillance systems elsewhere in Vietnam and similar settings elsewhere.

Lesson learned

As this was my first experience of surveillance system evaluation, I learnt the process of project implementation and management from protocol, funding, logistics preparation, interview, to report writing. This project enabled my ability to navigate and communicate with many stakeholders, and making decisive decisions for the project. I got to try on many roles: the project officer, the project writer, the interviewer, the scribe, and the assistant for logistics preparation. I also learnt that no system is perfect, as well as no project is, and managing your expectation is needed for all project. This evaluation was delayed three times during the course of one year, and finished within two months. There were times of frustration and disappointment, but thanks to my supervisor and my colleague – Ms Ngoc-Anh, I found the confidence and motivation to finish the project in time for both WHO deadline and my thesis chapter.

This was also my first time conducting semi-structured interview by myself, based on my own interpretation of question guide. The interview was such a valuable opportunity, not only for data collection purpose, but also to test my understanding of the system from its core to sustain the conversation. I also found a literature review was a very good preparation step in preparation of a report. Even if you have all the toolkits and guideline, previous experience of how the method was carried out and how to choose the appropriate method for a report proved to be extremely important.

Public health impact

This evaluation was reported to Vietnam WHO as a join-partnership project between Vietnam WHO and NIHE for one of the first AAR for COVID-19 Prevention and control activities. Even though the initial planning of a result-sharing workshop among stakeholders were not possible, an AAR report was shared among participating stakeholders and other provincial CDC in Vietnam. The report recommended a synchronized sharing database for COVID-19 at national scale, while complimenting the success of Quang Ninh CDC in its COVID-19 battle. The finding of the report will help served as a basis evaluation for capacity improvement of COVID-19 outbreak control and coordination across levels among relevant stakeholders in Vietnam.

Acknowledgement

I would like to acknowledge my academic supervisor, Dr. Florian Vogt for his constant support throughout the project to help me finished it, for his valuable feedback on my evaluation and report; and MAE supervisor – Dr. Emma Field, for her guidance of stakeholders' interview and qualitative data analysis. I would also like to acknowledge Dr. Nguyen Cong Khanh – my field supervisor, Ms. Hoang

Thi Ngoc-Anh – my MAE colleague, staffs at Department of Communicable Disease Control in NIHE and Vietnam WHO, and stakeholders from Quang Ninh CDC, for their contribution in this evaluation.

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Part I. Literature review

After Action Reviews for emergency preparedness and responses to infectious disease outbreaks: a literature review

Background

After Action Reviews (AAR) are a qualitative evaluation methodology to analyse the "what, how and why" after the occurrence of an event or project (1). It aims to identify best practices and challenges in responding to the event, propose mid- and long-term actions to be taken to ensure better preparation for future events.

It was first formally developed by the US Army and has now extended into many other domains (2). The AAR methodology developed by the World Health Organization (WHO) was designed to evaluate the responses to any public health event taken by different types of entities and organizations involved in the review process (1). The success of an AAR depends on the ability to bring together stakeholders to analyse retrospectively the actions taken during the response to the event, and to identify areas for improvement. AARs are not intended to review the performance or capacity of individuals or units, but to identify structural difficulties and challenges that need to be addressed, and document best practices to be maintained. AARs provide an opportunity for participants to translate real-life experiences during the event into lessons for the future and to develop action plans, such as national disaster response plans. AAR helps ensure critical thinking around the event using root cause analysis of the problem (1).

WHO identifies four formats of AAR: debrief, working group, key informant interviews and mixed-methods (1). The structure of conducting and reporting an AAR follows three steps: including (i) Objective observation: a structured review of responses activities; (ii) Analysis of gaps, best practices and contributing factors; (iii) Identification of areas for improvement and propose follow-up actions. The basic content of AAR consists of five evaluation pillars: (i) Monitoring; (ii) Test system; (iii) Coordination and implementation; (iv) Risk communication; and (v) Case management, where each pillars were assessed on best practice, challenges, and lesson learnt (1). Depending on the context, AARs can cover different areas for evaluations. WHO also encourages evaluation to be compared against International Health Regulation (IHR) core competencies for performance (1). There is also a post-evaluation section for participants of the AAR to evaluate the methodology's effectiveness in achieving its goal of response evaluation, and a follow-up action plan detailed concrete measures, accounted stakeholders, and agenda for deadline.

AARs have been regularly adopted in Europe to assess responses to major outbreaks such as national and EU-level responses to Ebola in 2014-2015 (3) and to the H1N1 epidemic in 2013 (4,5). AARs were also conducted for the responses to natural disasters such as the 2017 fires in Portugal (6), and the hurricanes Ike (2008), Gustav (2008), and Katrina (2005) in US (7).

In Vietnam, an AAR was held for the response to a drought and salt water intrusion in three provinces in 2017 (8). The assessment, which involved a large number and range of actors at national, provincial and local levels, identified the lack of a legal framework to support disaster management as one of the main causes for the slow response. This review provided important evidence for policy makers and governments in Vietnam to decide on future methods for disaster response implementation. In 2019, with the support of WHO and the US Center for Disease Control and Prevention, Vietnam conducted another AAR, this time of the diphtheria epidemic response in Dak Lak Province (9). Final lessons learned after the response include recommendations how to restructure the local surveillance system, to improve the national vaccination system for diphtheria, and proactively organization of epidemic response assessment activities.

The extent to which AARs are being used to assess public health responses to emerging infectious diseases, and in particular how closely these AAR toolkits developed by WHO, is not known. This prevents us from developing recommendations how to improve the WHO AAR toolkit. We therefore undertook a review to understand how AAR methodology is being used as compared to its official guideline proposed by WHO and how suitable it is to evaluate public health responses to such events.

Method

Selection criteria

We included peer-reviewed journal articles and published non-peer reviewed reports of AARs that used WHO's AAR toolkit to evaluate responses to outbreaks of infectious diseases and were published from 2015 to 2020 in English language. We chose 2015 as cut-off point because it was the earliest year that WHO's repository stored AAR reports (10). Exclusion criteria were un-finished reports or publications, reports not included WHO's AAR toolkit as method, not published in English, and not on infectious disease outbreaks.

Search strategy

First, we search the PubMed database with the different combinations of the following search terms: "after action review", "infectious disease", "world health organization", "epidemic", "outbreak", "emergency". Table 1 shows the search statements used and resulting number of studies found at each query. We also searched WHO's main repository for AARs, the WHO After Action Review Strategic Partnership for Health Security and Emergency Preparedness database (10) to retrieve all reports on completed AARs. Results were merged, removed for duplications, screened for inclusion, and reasons for exclusion were documented. We then extracted key characteristics on AAR methodology from each included study for descriptive analysis. We also assessed how closely included AARs followed the WHO AAR toolkit and how effective AAR methodology was to assessed the response in focus.

Table 1. Search terms and search results on PubMed

Search	Search Field	Query (*Filter: English*)	Results
#1	All Field	"After Action Review"	49
#2	All Field	infectious disease	677,493

#3	All Field	epidemic OR outbreak OR emergency	549,053
#4	All Field	“World Health Organization”	98,489
#5	All Field	#2 OR #3	1,176,137
#6	All Field	#1 AND #5	20
#7	All Field	#1 AND #4	4
#8	All Field	#6 OR #7	22
#9	Date publication	("2015"[Date - Publication]: "2020"[Date - Publication])	8,222,679
#10	All Field	#8 AND #9	16

Data extraction

The following data were extracted from each study or report: (i) General Information: Author and year of publication; setting; scope of evaluation (national level, regional level, agency level, etc.), event under evaluation and year of event; (ii) Comparison to WHO’s guideline (Details in Table 2).

Table 2. Variables for data extraction.

Data extracted	Variables
Format	- WHO guideline: Debriefing, working group, key informant interviews, mixed-methods - Other
Pillar of evaluation	- WHO guideline: (i) Monitoring; (ii) Test system; (iii) Coordination and implementation; (iv) Risk communication; and (v) Case management. - Other
Phases of evaluation	- WHO guideline: design, preparation, and implementation. - Other
Comparison to IHR	- WHO guideline: Yes - No
Final evaluation by participants	- WHO guideline: Yes - No
Reporting format	- WHO guideline: qualitative format with 3 parts structure: (i) Objective observation: a structured review of responses activities; (ii) Analysis of gaps, best practices and contributing factors; (iii) Identification of areas for improvement and propose follow-up actions. - Other
Follow-up plan for improvement	- WHO guideline: Yes - No

Result

A total of 86 studies (70 reports from the WHO database and 16 articles from PubMed) were obtained from the initial search. After screening and comparison against exclusion criteria, eight studies were included into final results.

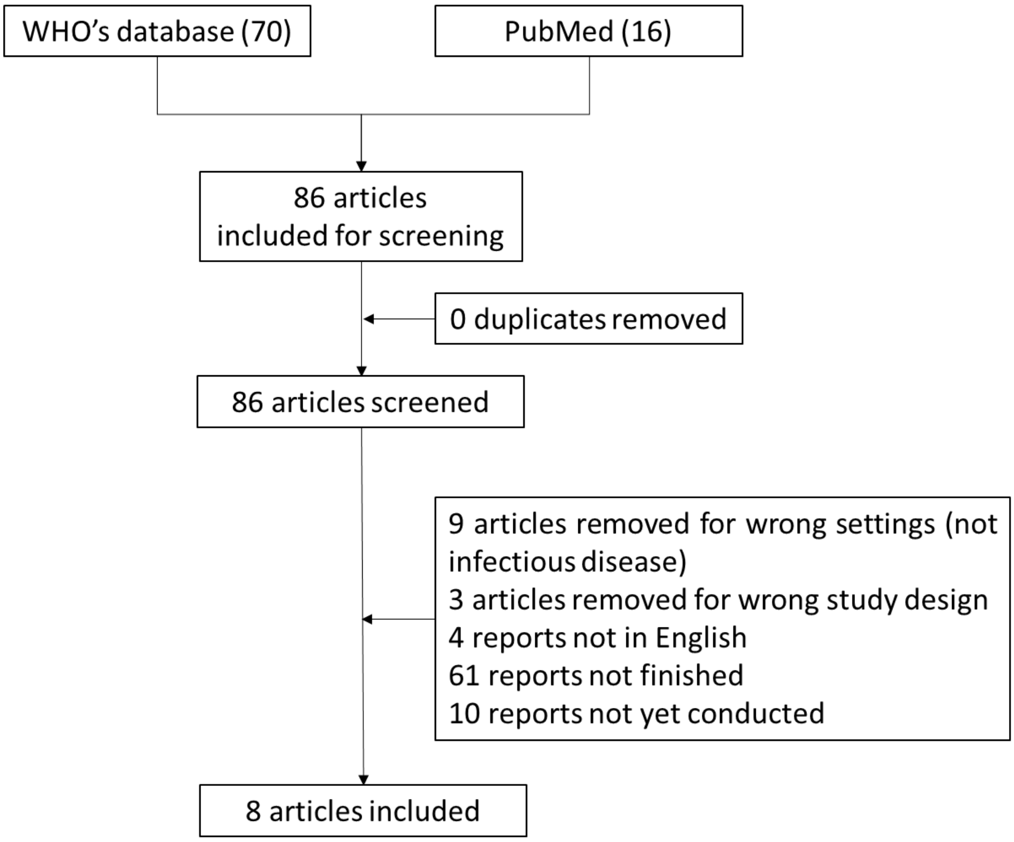

Figure 1. Flow chart of article screening results

A summary of all study characteristics can be found in Table 3. There were three studies published in 2017, three studies published on 2018, and two published on 2021. Four studies were conducted in Nigeria – two focused on Lassa fever (13, 15), one on cerebrospinal meningitis outbreak (11), and one on cholera outbreak (12). Two studies were performed during the COVID-19 outbreak in Italy (2) and Vanuatu (16), one was implemented in response to H1N1 in the US (14), and one evaluation was done after the Ebola outbreak in Sierra Leone (17). Among the eight included studies, four (50%) used AAR methods in combination with other evaluation tools such as document reviews or questionnaire surveys in combination with quantitative assessments. Four studies strictly followed WHO's three-phase AAR methodology and the five evaluation pillars, conducting in conference settings with stakeholders presented. Four studies used group discussion as their main method, three used debriefings, and one used key informant interviews. Public health systems were a common scope for evaluations, appearing in 7 studies, while one study was situated in a hospitals' setting (2). Half of the included studies were conducted in response to outbreaks at local levels, and the other half at national levels. Four studies included a follow-up section detailing stakeholders' action plan for system improvement in future events.

Table 3. Summary of included articles.

Author Year	Setting	Scope of evaluation	Event under evaluation	Format	Pillars under evaluation	Comparison to WHO's guideline of AAR methodology
Mase et al (2017) (14)	Ohio, US	Public health departments, Ohio State	H1N1 influenza mass vaccination (2017)	Document review Debriefing Questionnaire survey	(1) Mass vaccination; (2) Volunteer management; (3) Community mitigation; (4) Interoperable communications; (5) Risk communications; and (6) Epidemiologic surveillance and investigation	• Not followed three phases of AAR (no reporting of objective observations of the responses or follow-up action) • Followed AAR's pillars for evaluation (with modification: focusing on vaccination) • No comparison to IHR • Followed the AAR qualitative reporting format • No final evaluation from participants • No follow-up plan
Nigeria CDC and WHO (2018) (11)	Nigeria	National public health system, Nigeria	National cerebrospinal meningitis outbreak (2017 – 2018)	Working group	(1) Coordination; (2) Surveillance; (3) Case management; (4) Risk communication and Social Mobilization; (5) Laboratory; and (6) Logistics and Vaccination.	• Followed three phases of AAR • Followed AAR's pillars for evaluation • No comparison to IHR • Followed the AAR qualitative reporting format • Included follow-up plan
Nigeria CDC and WHO (2018) (12)	Maiduguri Borno State, Nigeria	Public health system, Maiduguri Borno State, Nigeria	Cholera outbreak following displacement camp (2017)	Working group	(1) Coordination and logistics; (2) Surveillance and laboratory; (3) Case management and Infection prevention and control; (4) Risk communication and community engagement; (5) Water, Sanitation and	• Followed three phases of AAR • Followed AAR's pillars for evaluation • No comparison to IHR • Followed the AAR qualitative reporting format • Included follow-up plan

					Hygiene; and (6) Oral cholera vaccination.	
Sorbello et al (2020) (2)	Milan, Italy	Hospital of San Raffaele Scientific Institute, Milan, Italy	COVID-19 epidemic (2020)	Key informant interview	(1) Staff management; (2) Logistics and supplies; (3) COVID-19 diagnosis and clinical management; and (4) Communication.	• Followed three phases of AAR • Modified AAR's pillars for evaluation to quantitative ranking of effectiveness • No comparison to IHR • Not followed AAR qualitative reporting format (quantitative report) • No follow-up plan
Nigeria CDC and WHO (2018) (13)	Nigeria	National public health system, Nigeria	Lassa fever outbreak (2018)	Working group	(1) Coordination and logistics; (2) Case management, Safe burial, Infection Prevention and Control; (3) Risk communication and social mobilization; (4) Laboratory; and (5) Surveillance	• Followed three phases of AAR • Followed AAR's pillars for evaluation • No comparison to IHR • Followed the AAR qualitative reporting format • Included follow-up plan
Nigeria CDC and WHO (2017) (15)	Nigeria	National public health system, Nigeria	Lassa fever outbreak (2017)	Working group	(1) Coordination; (2) Surveillance; (3) Case management and infection prevention and control; (4) Laboratory; (5) Logistics; and (6) Communication.	• Followed three phases of AAR • Followed AAR's pillars for evaluation • No comparison to IHR • Followed the AAR qualitative reporting format • No final evaluation from participants • Included follow-up plan
Tapo et al (2020) (16)	Vanuatu	International health center, Vanuatu	COVID-19 epidemic (2020)	Document review Debriefing	(1) Coordination and staffing; (2) Pre-arrival preparations; (3) Before departure from origin; (4) Upon arrival at the airport in	• Not followed three phases of AAR (not reporting of improvements and follow-up actions) • Not followed AAR's pillars for evaluation (focusing on point-of-entry only)

					Vanuatu; (5) Check-in to quarantine facilities; (6) During quarantine; and (7) Quarantine discharge.	• No comparison to IHR • Followed the AAR qualitative reporting format • No final evaluation from participants • No follow-up plan
Boland et al (2017) (17)	Sierra Leone	District health system, Port Loko and Kambia district, Sierra Leone	Ebola outbreak (2014 - 2017)	Document review Debriefing Questionnaire survey	(1) Environmental and infrastructural; (2) Sociocultural; and (3) Political and organizational.	• Not followed three phases of AAR (not reporting of objective observations of the responses) • Not followed AAR's pillars for evaluation (focusing on local context) • No comparison to IHR • Followed the AAR qualitative reporting format (in combination with quantitative ranking of challenges) • No final evaluation from participants • No follow-up plan

There were three studies that included participants evaluations of the AAR methodology applied in the report (11–13). Although the overall assessment of the AAR's suitability to connect stakeholders and provide platforms for ideas and pooled experience were positive (from more than 80% of participants in all studies with evaluation recommended AAR methodology), only half of participants agreed that AARs actually achieved its objectives. Especially in terms of strengthening interdisciplinary collaboration and coordination, less than 20% of participants agreed with that capacity of AAR (11,12). Meanwhile, the four studies not following directly WHO's AAR steps highlighting the need to adjust the AAR methodology for smaller level analyses, for example a unit, regional or individual institution's performance (14). Modification for a focused system rather than an integrated system were also encouraged to improve follow-up actions within local contexts and enhance multi-disciplinary cooperation (2).

Discussion and Conclusion

From the analysis of eight studies, we found that the WHO AAR methodology was not always strictly followed but often in combination with other qualitative and quantitative measures. While the qualitative element of the WHO AAR method was easier to follow in a conference setting with available stakeholders, many evaluations required methodological modifications (i.e. survey, document review) and also incorporate quantitative methods, depending on local context.

AARs were more of use in the evaluation of district or national level systems rather than a specific system (e.g. surveillance, laboratory, or point-of-entry), as the WHO AAR evaluation pillars are rather general and aim at higher-level evaluations. Similarly, even though WHO recommends to implement AARs within IHR's core competencies, which are more suitable for national-level systems, none of the included studies used IHR as a comparator.

This review is subject to several limitations. First, the number of articles included is small, which could limit the generalizability of this review. Second, less than half of included studies reported participant evaluations of AAR effectiveness, which also hindered us to obtain sufficient coverage of participant's reflections about the suitability of the AAR method to achieve its objectives. Follow-up plan for future actions were only included in four reports, which was a crucial aspect of a system evaluation. This accompanied with the lack of participants' evaluation hindered the extent of this review to assess the AAR method.

Despite these limitations, this review generally suggests that the AAR methodology is suitable to evaluate public health responses to infectious disease events, and to learn lessons and identify areas of improvements needed for future public health threats. The need to evaluate public health responses is particularly important in the current COVID-19 pandemic due to its ever-changing nature and prolonged duration. Modifications to the WHO AAR guidance is necessary to collect relevant information from a large range of data source and use approaches with more stakeholder involvement in consideration of local contexts and the scope of the evaluations.

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Part II. Final report

After Action Review of the COVID-19 surveillance system in Quang Ninh Province, Vietnam in 2020

Introduction

COVID-19 has been detected in virtually all countries around the world by the end of 2020. Vietnam was one of the first few countries reporting COVID-19 confirmed cases outside of China, as early as January 23, 2020. After one year, Vietnam reported nearly 1,500 cases of COVID-19 with 35 related fatalities (1). With relatively low reported number of cases and deaths in the world, Vietnam has managed to avoid nation-wide community transmission, while improving epidemic response capacity in all aspects around the country. An active surveillance system for COVID-19 was established in Vietnam in 18 January 2020, which required participations from all healthcare facilities, local authorities and other jurisdictions at commune, district, province, and regional level across Vietnam. Thanks to this early, extensive surveillance system before any cases were detected, Vietnam has successfully adapted with the changing epidemic (2–4). After one year of COVID-19, evaluation of the COVID-19 surveillance system to prepare for long-term COVID-19 pandemic is needed, especially in low-middle income country as Vietnam.

After Action Reviews (AAR) are a tool developed by WHO in 2015 to review actions undertaken during the response to an event of public health concern (5). In 2020, the European Centre for Disease Prevention and Control (CDC) recommended AAR for public health responses to COVID-19 (6) and WHO published guidance on Intra-Action Reviews (IAR) – a modification of the AAR specifically for COVID-19 (7). However, there is a scarcity of published AARs of surveillance systems, particularly from Asia-Pacific region and on COVID-19 (8). The majority of AARs were performed in the African region (8,9), and on regional outbreaks such as H1N1 and West Nile virus (10,11). A small number of AARs on COVID-19 preparedness and response were done in hospital (12) and public health settings (13,14), but none focused on surveillance systems.

This report performed AAR of the COVID-19 epidemic's preparedness and response by the COVID-19 surveillance system in Quang Ninh Province, Vietnam during 2020. We aimed to evaluate how surveillance system prepared and responded to the epidemic, and thus systematically identify lesson learned and follow-up practical actions for improvement opportunities.

Method

Study design

We evaluated the performance of the COVID-19 surveillance system at Quang Ninh CDC between 1 January and 31 December 2020 in Quang Ninh province, Vietnam. The framework for this evaluation followed the WHO AAR Guidelines (5), with minor adjustments to the local context. In addition, the surveillance system was assessed against four attributes developed by the US CDC's guidelines for public health surveillance system evaluations (15) (Table 1).

Table 1. Surveillance system attributes and definition.

Attribute	**Definition**
Usefulness	The capacity to achieve defined objects of the system: detect COVID-19 cases and outbreaks in the region/ decision makings on outbreak responses/ collaborate with other systems and jurisdictions in the region.
Simplicity	The ease of the systems to be operated and integrated with other systems.
Flexibility	The ability of the system to timely adapt to change data needs and/or operating conditions without significant changes in system resources.
Acceptability	The willingness of persons and organizations to participate in the surveillance system.

Setting

Quang Ninh is a coastal province in the northeastern region of Vietnam. Quang Ninh has both land border (approx. 200,000 km) and sea border (approx. 200 km) with Mainland China, and one international airport - Van Don. Quang Ninh is one of the leading tourist centers in Vietnam, welcoming nearly 10 million visitors annually, amongst which, 4.3 million are international visitors. Quang Ninh has four municipal cities, nine districts, and one commune. There is at least one public health station per ward per cities/districts, along with Department of Health approved public and private clinics. Quang Ninh's health system includes four regional hospitals, three regional clinics, 10 provincial health centers, 12 district health centers, and 186 commune health stations. Despite its close proximity to China, the province only reported 22 cases of COVID-19 (five imported cases were detected in the community and 17 were imported cases who were quarantined immediately after arrival to Vietnam at Van Don International Airport) during 2020. Until the end of 2020, Quang Ninh did not record any community cases. Quang Ninh Center for Disease Control and Prevention (CDC) is the prime health agency for COVID-19 surveillance system in the province, who monitors all COVID-19 surveillance activities conducted by other health agencies in Quang Ninh.

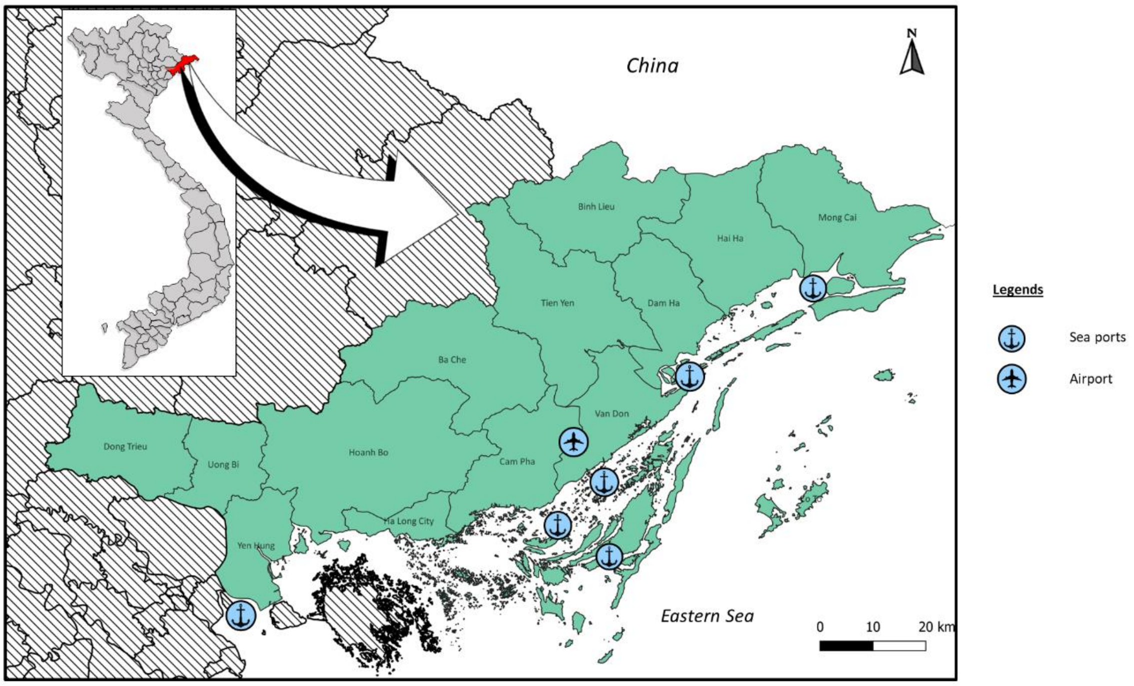

Figure 1. Geographical map of Quang Ninh Province in Vietnam

Data collection

Data were collected using a structured survey (*Appendix1*) and in-depth interviews based on interview guideline (*Appendix 2*).

A structured survey about COVID-19 surveillance, case detection and contact tracing was translated into Vietnamese and developed based on the IAR questionnaire for COVID-19 by WHO (7). The survey was divided into three sets of question on the COVID-19 surveillance system, including: (i) Document existing systems in place; (ii) Identify and analyze what happened so far during the COVID-19 outbreak response; and (iii) Improve existing COVID-19 outbreak response strategy. The survey was sent to Quang Ninh CDC's Department of Communicable Disease Control whose staff were responsible for the surveillance system's operations. The department head distributed the survey in parts to staff in charge of subjects covered in the survey. Staff filled in the questions together under the guidance of the survey and returned the completed survey. Staff were also asked to provide relevant supporting documents (official guidelines, situation reports, etc.).

An in-depth interview guideline was developed based on the AAR key informant interview questions (5) and four system attributes by US CDC (15). We conducted the interviews with Quang Ninh CDC staff through phone. Respondents were asked to assess surveillance system by attributes, share best practice and challenges of the system, and recommendations. Interview script was scribed down per the respondents' verbal consent. Respondents to the survey and interview were informed of study purpose, which was to evaluate system's performance and not individual's.

Participant selection

Staff of Department of Communicable Disease Control Department at Quang Ninh CDC was purposively included in the study. For the qualitative interviews, we selected five staff who took part in the COVID-19 surveillance system. The selection was purposively based on staff's experience and involvement with the system during the study period.

Data analysis

Survey responses and relevant documents were summarized to describe the following system operation areas: reporting system; availability of surveillance guidelines, documents, and reports; case detection and investigation; emergency preparedness, resources and supply chain; data analysis and interpretation. Interview notes were manually transcribed to Microsoft Word, and summarized according to the following system attributes: Usefulness; Simplicity; Flexibility; Acceptability. Opinions and suggestions during the interviews was also collected.

Ethics

Ethics review of this report was waived by the Australian National University Human Research Ethics Committee under the waiver number HREC/17/ANU/909.

Results

System operation

<u>Communication and reporting system</u>

Figure 1 depicts the COVID-19 surveillance system in Quang Ninh Province (adapted from the surveillance system before COVID-19 in Supplement Figure 1). Quang Ninh CDC was the focal point to receive and disseminate COVID-19 daily surveillance report in the province. Quang Ninh CDC received daily COVID-19 situation updates from seven databases operating within the province:

(I) Normal surveillance system:

(1) Sentinel surveillance system (42 nationally notifiable diseases, including and prioritizing influenza, dengue, diarrhea, and hand-foot-mouth disease) at district health centers, regional hospitals, and registered private clinics.

(2) Event-based surveillance system (EBS) included media scanning and omits collection of information from other sources, such as pharmacies, animal and agricultural sectors, community, workplaces, the private sector, and schools at: (i) Quang Ninh's district health centers, commune health stations, district-level clinics/hospitals; (ii) national/regional health agencies (Mandated by Decision 134/QD-DP, issued in 2014 by Vietnam's Ministry of Health's General Department of Preventive Medicine).

(3) Incidence-based surveillance system (IBS) for severe acute respiratory infections, influenza-like illness, severe pneumonia at Quang Ninh's district and provincial hospitals (private and public). Since July 2020, a separated COVID-19 IBS managed by Quang Ninh General Hospital was established (Mandated by Circular 54 in 2015 by Ministry of Health).

(II) Enhanced surveillance system

(4) COVID-19 hotline and COVID-19 community feedbacks.

(5) SARS-CoV-2 laboratory system at seven laboratories in Quang Ninh.

(6) COVID-19 contact tracing data systems from Quang Ninh CDC's contact tracing teams, supplemented by three national databases: (i) "Bluezone" – Vietnam's proximity-tracking mobile apps; (ii) "Antoancovid" –National COVID-19 hot spots dashboard by Ministry of Science and Technology; and (iii) Online health declaration form – Vietnam's health declaration database by International Health Quarantine Centers.

(7) COVID-19 surveillance reports from International Health Quarantine Centers at several points of entry in Quang Ninh, which managed inbound passengers arrived at Quang Ninh.

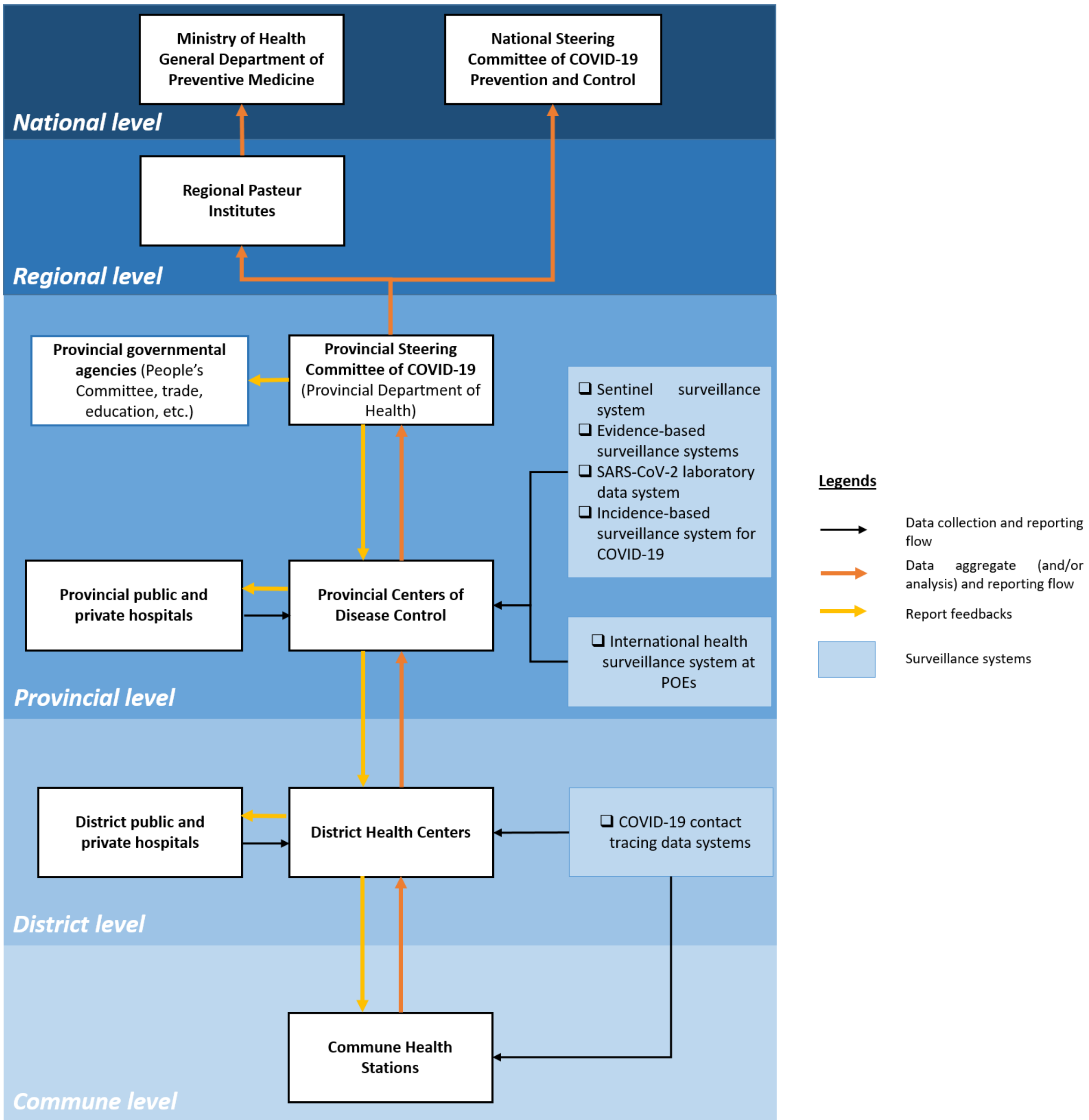

Figure 1: Quang Ninh's COVID-19 surveillance system

In turn, the CDC aggregated and sent the data they received to Quang Ninh Steering Committee of COVID-19 Prevention and Control – situated at Quang Ninh Department of Health. The CDC was responsible to send three COVID-19 surveillance reports/day by post and electronic mail to the Steering Committee. After modification and approval by Quang Ninh Steering Committee, final COVID-19 situation report was sent back to all health facilities by electronic mail by 6 pm every day. In addition, final report was disseminated weekly to other government agencies in the province by post and/or electronic mail, including: Quang Ninh People's Committee, Quang Ninh Department of Police and Social Security, Quang Ninh Department of Culture, Tourism, and Sport, Quang Ninh Department of Education, Quang Ninh Department of Trade, and Quang Ninh International Border Control. Representatives of these agencies are members of the Steering Committee. COVID-19 weekly situation report was produced by the CDC and disseminate to all district health stations and healthcare facilities by Friday every week. In case of active COVID-19 cluster in the province, reporting frequency was increased to once every three hours from hospitals and district health stations where the cluster was located, and similar frequency was required for the CDC to report to the Steering Committee.

Availability of surveillance guidelines, documents, registers and formats

All healthcare facilities, including hospitals, provincial and district health offices, and POEs, were equipped with up-to-date official guideline of COVID-19 surveillance, management, and responded by Vietnam Ministry of Health. Guideline for sentinel surveillance of COVID-19 was required for Quang Ninh General Hospital, and enhanced sentinel SARI, ILI, and SVP surveillance for all healthcare facilities. SARS-CoV-2 testing technical procedure, data collection and reporting, and biosafety guideline was required for 6/6 approved laboratories in Quang Ninh (including five provincial hospitals and one private hospital). Reporting formats like weekly reporting form, line list, case investigation form, testing data form, daily situation reporting form, case-based reporting form, and EBS report form were distributed to all health centers in paper and/or electronic form, and they are using the guidelines properly. The CDC kept a hard copy of daily and weekly surveillance reports in a file cabinet.

Case/ outbreak detection and investigation

COVID-19 case definition was frequently updated by Ministry of Health's requirement. In 2020, only one COVID-19 community outbreak was detected and notified in Quang Ninh. This outbreak was detected in March 2020 through the EBS system alerted by Ministry of Health and National Steering Committee, where passengers from international flight with COVID-19 confirmed case might travel to Quang Ninh. From flight manifest from Aviation Administrative Organization and foreign accommodation registration from Quang Ninh Tourism Department, supported by EBS data from social media and community reports, the CDC had successfully detected four first COVID-19 cases.

For imported cases of COVID-19 arrived to the province, the CDC detected through the COVID-19 surveillance system at all international POEs. All inbound passengers must go through triage, SARS-CoV-2 testing and transferring incoming passengers from arrival point to appropriate quarantine facilities During quarantine, the CDC provided SARS-CoV-2 testing to all quarantined passengers, and transferred confirmed cases to designated hospitals for isolation and/or treatment. The CDC also cooperated with Quang Ninh Tourism Department and Police Department to contact tracing and manage all foreigners working and travelling internationally to the province.

For all suspected/confirmed cases of COVID-19 detected in the province, and/or in other provinces but had travel history in Quang Ninh, and/or persons returning from COVID-19 cluster areas in Vietnam, the CDC was alerted through the EBS systems across the province. For any alert, contact tracing was conducted by both provincial health staffs and CDC staffs, with assistance from provincial/commune authorities and local police if needed for hotel registration and residential registration. Contact tracing was required to three degrees of contacts (9): (i) all close contacts of COVID-19 confirmed cases (first-degree contacts – F1); (ii) close contacts of F1 and non-close contacts of COVID-19 confirmed cases (second degree contacts – F2); and (iii) non close contacts of F1 and close contacts of F2 (third degree contacts – F3). While F1s are required to test for SARS-CoV-2 and quarantine at designated facilities, F2 and F3 are required to home quarantine and monitored closely by local healthcare staffs. For cases with inter-provincial travel history, contact tracers had to contact with case reporting provinces for case investigation data and close contacts lists. However, there were no common sharing databases for case reports or national case tally between provinces, and between provinces and national level. Communication and updates were still on unofficial platforms including email, phone calls, or group chats between provincial CDCs and national health agencies.

Emergency preparedness, resources and supply chain

Quang Ninh CDC had Emergency Preparedness and Response Plan for COVID-19 before any COVID-19 cases were detected in the province, accompanied with budget, logistic and supplies plans. The plan including outbreak investigation, SARS-CoV-2 testing capacity enhancement, and COVID-19 case management in different outbreak scenarios. The CDC and all district health stations also had an emergency management committee and the CDC established a multi-sectorial Public Health Emergency Management task force.

For COVID-19 emergency preparation, Quang Ninh CDC adopted the national motto "3 first" (first proactive prevention, first detection, first response) and “4 local” (local forces, local command, local logistics). Under CDC’s guideline, 15 COVID-19 rapid response teams (RRT) including two in provincial level and 13 working in district level was established before any cases were detected in Quang Ninh. CDC organized 3 training courses for provincial level RRTs and separated training courses for 13 district level RRTs and commune health staffs for monitoring COVID-19 cases in community. Per emergency plan, 100% of CDC staffs were trained to conduct contact tracing and investigation, and at least 30% of CDC staffs were trained to perform epidemiological data analysis and reporting in case of staff shortage. All training was also provided before the first case of COVID-19 in the province, and updated per every requirement by Ministry of Health. In case of community outbreak in any communes, CDC would provide enhanced local human resources (including additional workforce from police, military, teachers, and local security) and local facilities (military buildings, hotels, schools, etc. for quarantine, private and community clinics for testing and treatment) for the local RRT.

However, all respondents reported instances of facilities shortage, especially with bio samples and facilities for SARS-CoV-2 testing, and emergency facilities for RRT operation, and skilled human resource shortage for outbreak investigation and contact tracing in commune at further locations (islands or mountainous areas). Even in CDC, there were instances of human resource shortages for surveillance, contact tracing, and data analysis activities, that staffs from other departments were mobilized for assistance and support. In case of long-term community cluster in the province, many stakeholders evaluated that there would definitely be shortage for human resources in all aspects. Stakeholders also emphasized that with limited budget and timing, organized simulation training or advanced training for data management and analysis were not conducted, especially for healthcare staffs at lower level.

Case management

All COVID-19 cases in Quang Ninh (including imported cases who were quarantined at arrival and any cases detected in community) were transferred to one designated hospital in the region. All cases were isolated and treated for any COVID-19 compatible symptoms, and only released from isolation/hospitals if met with COVID-19 discharge criteria by Ministry of Health. Cases' data was communicated from designated hospitals to Quang Ninh CDC and Quang Ninh Department of Health daily for updates, and SARS-CoV-2 samples were sent to the CDC for confirmation weekly. By the end of 2020, no active outbreak and COVID-19 active cases were reported in Quang Ninh.

Data analysis and interpretation

Quang Ninh CDC and all district health stations did not use one standardized COVID-19 reporting format for surveillance data entry and analysis purposes. All district health stations are equipped with one working email, one wired phone, and at least one internet-connected computer for reporting purpose to the CDC. The CDC also had connected database to all regional hospitals, private clinics, district and commune health stations through EBS and sentinel surveillance system. All data were compiled and communicated to CDC in various means and formats (Excel spreadsheets, email, text message, Google forms, word documents). These data were and inputted and cleaned by CDC staffs manually or digitally for epidemiological analysis purposes. These data were submitted to Quang Ninh Steering Committee for decision-making purpose, including cluster containment, response policy, expansion and/or halt of certain public health measures in the province.

Surveillance system attributes

Usefulness

The system was found to be helpful to evaluate the magnitude of morbidity and vulnerability to COVID-19 of Quang Ninh as well as to assess the effectiveness of prevention and control measures in the province in the past year. For all stakeholders, the system helped to detect outbreaks early, and advanced laboratory system in the province was able to confirm any suspected cases quickly for swift and effective interventions to prevent further transmission. Stakeholders noted that they saw a surge effectiveness in the EBS system and its interconnection to the bigger system of response to COVID-19 in the province. Any alert would trigger quickly responses from not only healthcare system, but also in local authorities, multiple jurisdictions in the province, and especially among community through risk communication. In term of short-term capacity to prevent and control COVID-19 outbreaks in the province, all respondents responded positively. However, in face of a prolonged outbreak, respondents expressed that the system may be overburdened and under-staffed, thus not effective to control the situation in long term. Especially if COVID-19 situation was to happen in national scope, the system would be challenged to response timely and effectively.

Recommendations:

- To liaise with local authorities a detailed plan for surge capacity and different COVID-19 case scenarios, especially in preparation of human resources, logistic and supply chain.
- To utilize the strong multidisciplinary cooperation with local authorities to deploy future enhanced surveillance systems not only in provincial level but also district and commune levels.

Simplicity

Since there was no exclusive system for COVID-19, CDC staffs had to navigate through different systems, connected to a variety of health levels and agencies, to receive sufficient COVID-19 data. All stakeholders responded that even though each system alone was not difficult to execute, its complexity required a high degree of manual labor and high person-time contribution from all health agencies. These systems were not synchronized or connected in format or platform, thus creating challenges for data compilation, analysis, and management.

"When there are too much systems to navigate, we must call in staffs from other departments in CDC just to do reports, especially with a variety of reports and questions we must answer every day."

Recommendations:

- To systematically summarize and integrate different reports/data output to reduce redundancy/replication, mobilize sufficient staffs/facilities and appropriate data input requirements.
- To consider merging and/or adapting any repeating requirements for reports to different outlets, and pre-formatting the reporting templates, for time and resource saving.
- Reporting format should be synchronized and/or integrated (at least per one data output requirement) to reduce manual data handling in the system, limit data transfer errors, and rapid automatic data analysis capacity.

Flexibility

One of the most common responses from stakeholders is that the system had to adapt very quickly (sometimes under pressure) to meet many more demands from upper-level agencies such as local authorities or Quang Ninh's Department of Health. Under the conditions that no pre-existing systems were established for new data demands for COVID-19 (such as contact tracing progress, surveillance at immigration points, screening and quarantine), the staffs must update data through mostly spontaneous method (such as Google Sheet, Excel, Word documents). Especially in the changing landscape of COVID-19 progression, more demands were required, more data and creative method that CDC staffs and other health agencies must improvise to collect and compile.

"As you can see, all of current COVID-19 guidance now from Ministry of Health are temporary. Guidelines sometimes change too quick, and demand often increases in magnitude and scale, which requires system to change drastically. Sometimes, upper-level managements even require at much higher capacities and scope than the guidelines. Many times, CDC had to adapt to the changing demands before any guidelines, and then adapt back when the guidelines were official."

Not only in method, staffs also utilized social media and messenger applications for data update. For almost all CDC staffs in charge of COVID-19 surveillance, monitoring, and data analysis, a group chat with healthcare workers from commune or district health stations were most useful to receive reports, sometimes even informal orders or confirmation. Another group chat with local authorities and CDC Board of Director were also in use, mostly for emergency communication and rapid information updates. Another highlights that stakeholders emphasized is that EBS systems were able to adapt timely and effectively in response to COVID-19. Before COVID-19, EBS systems were not of use as often as common IBS systems at hospitals and district health stations. Since the epidemic, healthcare systems mostly depended on EBS for COVID-19 surveillance, and EBS capacity were heightened and sharpened through trials and efforts with Quang Ninh's experience with COVID-19.

Recommendations:

- To liaise with local authorities to detail stakeholders' need from the surveillance system and modify the logistical and administrative requirement for the system for future pandemic development plan.

Acceptability

All respondents viewed the system as acceptable in the response process to COVID-19 in the province. They reported that data received from the system were sufficient in quantity and timely with minimal errors. On the other hand, respondents also expressed that the variety of reporting formats, systems, and requirements were considered challenges for the timeliness of data reporting, especially during time of active COVID-19 clusters in the country. Stakeholders agreed that surveillance and contact tracing data from the system did meet the system's objectives, especially for navigating follow-up public health interventions and measures. However, respondents also expressed concerns of the lack of COVID-19 data (or the poor quality of any) received from other provinces or national health agencies. Since many

COVID-19 cases had complicated inter-provinces travel history, the need for timely reports and communication from reporting agencies of epidemiological investigation results. However, all respondents stated that there were no shared national COVID-19 database. CDC staffs had to create a database for themselves to keep update of COVID-19 progression in the country, while conducting appropriate and timely responses to any emerging threat within the province.

"One time, we only received informal news from neighboring province (from text messenger) about a confirmed COVID-19 case that travelled to many crowded destinations in our province. We had to mobilize quickly our resource for contact tracing all relevant contacts, communicate to public of high risk areas, and connect to the whole healthcare system in the province before any news. By the time the final case report reached us, all close contacts in Quang Ninh were already in quarantined."

Recommendations:

- To consider a shared secured database for COVID-19 cases at national scale for COVID-19 surveillance and monitoring
- To consider establishing an official communication platform for inter-provincial Centers of Disease Control to trigger timely alert for inter-provincial epidemiological investigation and securing data transferring process.

Discussion

In this study, we were able to identify a number of strengths and weaknesses of the COVID-19 surveillance system in Quang Ninh in response to the COVID-19 pandemic in 2020, and distill several recommendations with relevance for COVID-19 surveillance systems elsewhere in Vietnam and the region more generally for future pandemic development.

Three prominent components which contributed most to the effectiveness of the system included: (i) early preparation and governance coherently across the province; (ii) the readiness and adaptive abilities of the system throughout the year; and (iii) dedicated and innovative staff who constantly improve the system on its surge capacity. The system was well-prepared and ready in terms of emergency preparedness, training, and resource mobilization before any cases of COVID-19 was detected in the province. Central coordination was a distinctive feature of Vietnam's public healthcare system (22), and clearly showed in the distribution of responsibility across Quang Ninh healthcare system. This combined with strong governance and early preparation for COVID-19, which was also a prominent factor that Vietnam successfully employed for COVID-19 (23–25), helped Quang Ninh plan and apply an effective emergency response. Quang Ninh's preparation proved success to prompt rapid response to upcoming COVID-19 situation, both locally and nationally, with no widespread outbreak throughout 2020. While Quang Ninh CDC had efficiently followed and implemented national guideline, the system showed its willingness to adapt under any instances that innovation needed. This success is noteworthy from perspective of stakeholders who run the system and coordinate the changes in resource mobilization and multidisciplinary communication channels. The EBS system was one highlighted aspect of Quang Ninh's surveillance system. Of note, this EBS system was not only fueled by healthcare staff or existing surveillance, but by the people of Quang Ninh also. EBS at all healthcare facilities helped ensure the quick response to any development of this then-novel epidemic, and continue its robustness into the ongoing epidemic.

There were three key limitations to the systems in place. Firstly, it was noted that the systems were understaffed and overwhelmed under heavy administrative tasks. At time of evaluation, there was still no shared system or database of COVID-19 at regional or national extent, which could hinder timeliness and effectiveness of surveillance system in Quang Ninh and other provinces as well. A similar problem was encountered in the enhanced surveillance system for COVID-19 in Thailand, where individual patient data was not linked to testing or epidemiologic information (26,27). At the same time, within the province, data compilation activities were assessed complicated as staff must navigate through different database and inconsistent reporting format. In addition, high quantity and variety of report requirements from the system was remarked as the system's administrative challenge. While the implementation of multiple database and surveillance methodologies for COVID-19 were practiced in many countries and even encouraged (28,29), timely and accurate surveillance data remain the important output of surveillance, and would not be possible without an integrated system. To address the challenge, integration COVID-19 surveillance system into one-portal is recommended to strengthen information flow and improve efficiency (30). Similarly, there was also no official communication channel within healthcare systems within or outbound of the province to regional or national level. While social media and messenger apps might be utilized for surveillance purpose at time of emergency as practiced in Taiwan (31) and Thailand (27), a secured platform is still needed to facilitate timely communication, especially in case of wide-spread outbreak (32,33). Lastly, effectiveness of the surveillance systems was constrained by resources and training inaccessibility. While operating challenges for financial, training, and resources were common obstacles to COVID-19 surveillance (28), long-term preparedness plan would provide appropriate and timely resource mobilization in time of emergency (34,35).

The recommendations of this report should be considered to improve the usefulness of this system in COVID-19 case detection and management. Summary of key recommendations is listed in Table 2.

Table 2. Summary of key recommendations.

No.	Key recommendations
1	To explore opportunities to synchronize, integrate, or systematically restructure the systems in place (in formats and output) to reduce manual work, data management errors, and resource wastes.

2	To utilize current multidisciplinary cooperation with local authorities to develop an enhanced COVID-19 communication channel.
3	To develop a detailed plan for system's long-term capacity of COVID-19 prevention and control, with focus on human and logistics preparation.
4	To encourage the establishment of a national shared database for COVID-19 epidemiological data.

Since AAR had not been specifically designed for system evaluations, in 2020, WHO published additional guidance to apply AARs to infectious diseases (7) and other health emergencies (8). Previously, AARs were often used for outbreak response evaluations at national scale (8). Only recently during COVID-19, AARs were used at regional or institutional levels, and have proven its effectiveness (36,37). In this study, the AAR methodology was able to provide an ad hoc structure to evaluate the performance of the COVID-19 surveillance system in Quang Ninh CDC, in the grander scheme of the surveillance system in Quang Ninh Province. AAR helped identify bottlenecks in the system, and provided practical steps to direct resources into challenges that would have otherwise be neglected due to the constant requirement of the system to COVID-19. Our recommendation aimed to assist the system to cope with ongoing COVID-19 epidemic in a more organized and effective way. Following our study, Quang Ninh CDC conducted a discussion session designed to follow-up actions. Findings were disseminated to other CDCs in Vietnam to provide an introspective reflection after one year of COVID-19, and provide an open opportunity for future improvement. We expect that our findings provide operational improvements to enhance surveillance system in the province, thus strengthen the province's preparation and response capacity. Given the prolonged nature of the COVID-19 epidemic in Vietnam, periodic assessment of surveillance systems should be considered critical and widely implemented at agency level.

Due to the limited number of stakeholders participating in the survey and interview, some critical attributes of the surveillance system (such as timeliness, acceptability data quality, sensitivity, representativeness and stability) could not be addressed in detailed and discussed. The evaluation also did not account for stakeholders across the system, namely healthcare workers at lower level of the system at district and commune level, and in different health agencies in the province. These stakeholders developed and worked with the system, and ensured its success to control and prevent a wide-spread transmission of SARS-CoV-2 in the province. In addition, data inaccessibility hindered the evaluation to assess the input and output of the system. For example, even though the EBS system was evaluated highly effective, we did not have access to the report of data collected from the system and evaluate its quality in representativeness and timeliness to the pandemic evolution in the province. Overall, we highlight the need for a more comprehensive evaluations following the US CDC Guidelines to assess all possible attributes of a surveillance system, including assessing qualitative data of the system, and the logistical command chain across administrative levels. With heavy administration as a challenge stated above, it is crucial to evaluate the timeliness and sensitivity of reports collected across levels, and summarize it in a qualitative manner. Similarly, it would be interesting to assess staff's acceptability with the current "complex" systems that require a variety of format documents and reporting channels. The need for an integrate system should be accessed through qualitative research with staff across the system. Some stakeholders in the interviews did raise concerns about districts and communes located in mountainous or island area, citing difficulties to provide facilities or emergency resource timely and sufficiently. This can be addressed clearly in a conference format under the AAR method to have representatives in the system to evaluate the performance of the system in the past event, and addressing their challenges in accessibility and timeliness of the system. Clearly face-to-face conferences would not be ideal in COVID-19 times, hence we suggest focus groups divided by geographical area would improve accessibility for all healthcare levels, and at the same time provide a comprehensive learning and sharing platform.

There were some other limitations to the evaluation. The evaluation was performed after one year of COVID-19 response, which may have impacted stakeholders' perception. At time of study, the system was also under emergency mode as community outbreaks were detected in Vietnam (not in Quang Ninh). During interview, even though stakeholders were briefed about the purpose and focus of evaluation, respondents' assessment might still be reflective of a specific time point rather than the whole year. A limited number of interviewed stakeholders was acknowledged, which did not provide quantitative data for evaluation. Finally, this evaluation represents a discrete time point in one province in Vietnam, thus may not be extrapolated to the system's functionality under surge pressure. It is important to conduct another assessment of COVID-19 surveillance system at bigger scale for more comprehensive depiction.

Conclusion

The surveillance system in Quang Ninh Province, Vietnam contributed effectively to the COVID-19 response in 2020 thanks to early preparation for emergency response, strong governance and central coordination, and multidisciplinary collaboration. Certain areas of concern such as overly complex data systems, redundant administrative processes, unclear communication channels, and lack of resources compromised its performance. Several recommendations for improvement were made based on that are of relevance for COVID-19 surveillance systems elsewhere in Vietnam and similar settings elsewhere.

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Appendix 1. Structured survey questions

Structured survey questions
After Action Review of COVID-19 surveillance system at CDC Quang Ninh

Please answer the following questions in details and provide relevant documents if applicable.

Document existing systems in place

No.	Questions	Answer	Relevant document
1.1	What types of surveillance data and surveillance/early warning systems were in place to detect outbreaks, especially those originated from respiratory pathogens?		
1.2	What were the guidelines, SOPs and protocols in place to guide surveillance and response?		
1.3	What was the process for data analysis and transmission of public health information for decision making?		
1.4	What was the legal framework for rapid response teams (RRTs) and how was its role defined during a health emergency?		
1.5	What was the activation process for the RRT?		
1.6	How was the surveillance data linked to the laboratory data (e.g., inter-operable electronic information management system)? How did this differ for surveillance of notifiable disease and surveillance for an outbreak of novel pathogen?		
1.7	What types of training have been received for surveillance officers and RRT members prior to the detection of the first case of COVID-19 in the country?		
1.8	What guidelines, SOPs and protocol have been developed to detect cases, conduct contact tracing and monitor contacts prior to the detection of the first case of COVID-19 in the country?		
1.9	How were surveillance data linked to possible existing health system indicators (e.g., ICU bed availability, excess mortality, number of laboratory tests conducted) before the first case of COVID-19 was identified in the country?		

Identify and analyze what happened so far during the COVID-19 outbreak response

No.	Questions	Answer	Relevant document
2.1	How did surveillance and/or alert systems detect the first COVID-19 case and clusters in the province?		
2.2	What type of surveillance data or other information were useful or missing to guide response decisions (e.g., adjusting the social and public health measures, imposing and lifting travel restrictions)?		
2.3	What existing systems were adapted for detecting COVID-19 cases, conducting contact tracing and monitoring contacts and what new systems were instituted ad-hoc? How well did these work?		
2.4	How were COVID-19 suspected cases investigated and contact tracing conducted? What were the key roles that were essential for these activities (e.g., contact tracing central focal point for coordination)?		
2.5	Were there sufficient resources (human/financial/material) to undertake surveillance and early warning during the COVID-19 outbreak?		
2.6	Which COVID-19 surveillance guidance was used to build the case definitions during the COVID-19 outbreak and were they revised? And if so, when and why?		
2.7	What were all the efforts made to ensure contact tracing and monitoring of high-risk contacts were well-conducted? What were the new technologies used in combination with traditional boot-leather epidemiology (i.e., deploying contact tracers to the field to conduct contact tracing and active case-finding)?		
2.8	Were other types of surveillance systems (e.g., non-sentinel, sentinel or event-based surveillance systems) used to monitor trends or detect cases and clusters (e.g., ILI/SARI surveillance, ARI surveillance systems such as GISRS or other platforms, community-based and hospital-based event-based surveillance)?		
2.9	During the COVID-19 outbreak, how was epidemiological data managed, analyzed (e.g., weekly cases, hospitalization, and death, case fatality, cases in healthcare workers, disaggregated by sex and age), shared, and used to inform government officials to guide response? Were regular updates (e.g., situation reports) prepared and shared?		

2.10	How did partners or other sectors contribute to surveillance and early warning? How were information shared with partners and other sectors?		
2.11	Was the RRT adequately trained and equipped for undertaking COVID-19 response activities?		
2.12	Did any RRT members become COVID-19 cases or contacts? If yes, what happened?		
2.13	How were the findings of the RRT used for decision making regarding COVID-19 response?		
2.14	Were other mechanisms (EMTs, retired healthcare workers, school teachers, army officers…etc.) besides RRTs used in the COVID-19 response?		
2.15	Are all policies, plans and measures put in place during the COVID-19 response taking gender, equity and human rights into consideration?		
2.16	What policies or measures have been put in place during the COVID-19 response for disadvantaged subpopulations? (e.g., people with disabilities, persons with low socioeconomic status, ethnic minorities, rural poor, migrants and others experiencing exclusion and discrimination)?		
2.17	How populations at risks for COVID-19 (e.g., pregnant women, elderly) have been considered during the COVID-19 response?		
2.18	How were measures to protect disadvantaged and vulnerable population been enforced and monitored during the COVID-19 response?		
2.19	How are surveillance data linked to health care delivery and the health system as a whole during the COVID-19 response?		
2.20	How the "4-local" motto (local command; local spot, local materials, local logistics) was implemented in surveillance, case detection, and contact tracing of COVID-19 cases?		

Improve existing COVID-19 outbreak response strategy

No	Questions	Answers	Relevant document
3.1	What actions taken enabled an efficient and timely detection of COVID-19 cases and clusters?		
3.2	What new technologies or innovations were implemented to efficiently test, trace, and track all COVID-19 suspected cases and their contacts to control the COVID-19 outbreak?		
3.3	What challenges were encountered in detecting COVID-19 cases and clusters?		
3.4	What have been the challenges for conducting contact tracing, including timeliness of contact tracing, monitoring information on contacts, and measuring the performance of contact tracing?		
3.5	What actions were taken during the event that allowed for a better than expected performance of the RRT and the overall COVID-19 response?		
3.6	What challenges were encountered in the operations of the RRT?		
3.7	What challenges were encountered during investigating of rumors?		
3.8	What were the overall strengths and weaknesses of the surveillance, case investigation and contact tracing during the COVID-19 response?		
3.9	What were the overall strengths and weaknesses of the implementation of the "4-local" motto in the surveillance, case investigation and contact tracing during the COVID-19 response?		

Appendix 2. Semi-structured interview guide

Key Informants Interview Questions Guide
After Action Review of COVID-19 surveillance system at CDC Quang Ninh

Thank you for participating in the project "After Action Review of COVID-19 surveillance and response activities in Quang Ninh Province". We would like to conduct an in-depth interview in order to compliment the WHO AAR questionnaire that we received, with focus on surveillance, case detection, and contact tracing activity of the COVID-19 surveillance system.

Content of this interview:

Through interview sessions with key informants from COVID-19 surveillance system at CDC Quang Ninh, we aim to gather qualitative data on:

- Discuss the current status of the COVID-19 surveillance system in the province and its operation during 2020.
- Assess the operation of the surveillance system on some attributes: usefulness, flexibility, timeliness, data quality, representativeness, simplicity.
- Discuss successes, challenges, and the impacting factors that affect the system operation process during 2020 COVID-19 outbreak.
- Discuss recommendations for capacity enhancement of the COVID-19 surveillance system operation in future.

Interview process:

- Interviewer will conduct interview with key informants through phone. Each interview session will last 15 to 20 minutes. Interviewer will take note of interview session.

Expected interview participants:

- Health officers who directly worked with COVID-19 surveillance system during 2020 COVID-19 outbreak, preferably in different sectors including surveillance team, case detection team, and contact tracing.

Note:

- All questions will be asked out loud and explained in detailed. Please ask the interviewer whenever any questions are not clear to you.
- This interview will be transcribed for research purpose only and assessed by research team, no personal data will be collected. The result would not be published and only used to supplement the AAR WHO questionnaire.

Question Guide during the interview:

1. Please share your roles in the COVID-19 surveillance system at CDC Quang Ninh. Please discuss the operation of the system throughout the outbreak.

2. In the AAR questionnaire, when was the system put in place, and how CDC Quang Ninh adapted the system with existing sentinel surveillance system?
3. Please comment on the operation process of the COVID-19 surveillance system at CDC Quang Ninh over the past year. Think in terms of usefulness, timeliness, flexibility, data quality, representativeness, simplicity.
4. What successes and challenges the system had throughout the outbreak?
5. In your opinion, in order to well implement the task of monitoring and management, what area does the current monitoring system need to improve first?

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Chapter 5. Design and conduct an epidemiological study

User-generated online information in response to a COVID-19 outbreak in Vietnam in July – September 2020

Table of Content – Chapter 5

List of Abbreviations – Chapter 5

ANU	Australian National University
COVID-19	Coronavirus 2019
CI	Confidence Interval
IRR	Incidence Rate Ratio
MAE	Master of Applied Epidemiology
NIHE	National Institute of Hygiene and Epidemiology
OR	Odd Ratio
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2

Prologue

Background

"Infodemics" – a combination of "information" and "epidemic" - refers to "a rapid and far-reaching spread of both accurate and inaccurate information about something, such as a disease" (1). The abundancy of news, albeit facts or rumors, available to us by the widespread of smart devices and internet, it becomes more difficult to obtain true information without sufficient expertise or certain critical thinking skills. Infodemics recently emerged after a decade of seemingly epidemic-less from 2003 during the COVID-19 pandemic 2020 (1). "We're not just fighting an epidemic; we're fighting an infodemics," said Director-General of World Health Organization in February 2020, referring to fake news that "spreads faster and more easily than this virus" (2). Infodemics can create ambiguity and distrust between population and government officials, thus mitigate effectiveness public health policy to prevent the ongoing pandemic.

On 25 July 2020, after nearly 99-day streak of no community transmission, a surge of local cases of COVID-19 was spotted in Da Nang – a municipal city in Central Vietnam, mostly famous for foreign trade activities and tourism. The outbreak was consisted of cases linked to hospital clusters in Da Nang, and sporadic cases of tourists coming back from Da Nang and community cases, all with no sufficient epidemiological exposure to confirmed cases of COVID-19 or oversea travel (3,4). Nearly 400 cases with epidemiological links to Da Nang City were reported, highest in Da Nang and surrounding cities, and also in 10 other provinces and cities in Vietnam. A total of 35 fatalities was confirmed, remarked as first COVID-19 deaths in Vietnam. By late August – September 2020, the Da Nang outbreak was declared under control with no case detected and all remaining COVID-19 case discharged from isolation. During this period of outbreak, a series of public health measures were implemented by Vietnam government to limit and prevent further spread of diseases. To keep the public informed, health communication about these policies were frequently made by both governmental agencies and concerned online outlets. Public attention and responses were also paramount as concern was growing high with new cases of COVID-19 detected in community as well as new fatalities in COVID-19 cases.

My role

In July 2020, I was working closely with the Rapid Information Response Team, National Steering Committee of COVID-19 for the newest outbreak in Da Nang, Vietnam. One of the team member is the manager of the software for social media data listening and analysis, and was in charge of COVID-19 social data report for Prime Minister and Ministry of Health briefing. They collected data weekly and in response to any major online discussion or progression of COVID-19 situation in the country, but the data was not analyzed but only reported descriptively as cross-sectional data collection. My field supervisor and I suggested to use the software to monitor the public response to the ongoing outbreak online for an academic research.

I was assigned the co-lead of this study with my field supervisor. In August 2020, we conducted several meeting with the team to acquaint with the software and its function, and to discuss the possible topics for analysis. Since the ongoing outbreak at that time was the first provincial-level outbreak in Vietnam, and also the first to record any COVID-19-related deaths, and the government also implemented several interventions to combat the growing epidemic, I decided to focus on two topics: (i) COVID-19 progression in terms of incidence and mortality, and (ii) COVID-19 public health interventions during the outbreak. The team agreed to supply us the database and support for data collection, and I would be the one to conduct the study further and prepare the manuscript. I spent the next two months to conceptualize the data characteristics, and conduct literature review on content and textual analysis for online information. After finalizing the concept note, my academic supervisor and I prepared for two ethics applications to Australian National University (ANU)'s Research Ethics Committee and National Institute of Hygiene and Epidemiology (NIHE)'s Internal Review Board. I submitted and presented the ethics proposal and project proposal at NIHE in December 2020, and got accepted in January 2021. In February 2021, my ANU ethics application was finally approved. In March – April 2021, I conducted data collection and data cleaning with support from the team. For data processing and data analyses, I performed multiple analyses on Stata, R, and Python, including descriptive epidemiology, regressions, content analysis, sentiment analysis and semantics social network analyses in May – June 2021. Final manuscript writing was produced in July 2021 with the support from Dr. Florian Vogt – my academic supervisor.

This chapter consists of two papers I wrote for two topics of online information during the outbreak. The first paper titled "**Using 'infodemics' to understand public awareness and perception of SARS-CoV-2: a analysis of online information about COVID-19 incidence and mortality during a major outbreak in Vietnam, July - September 2020**" reported on the public attention and responses to online information of COVID-19 progression during the outbreak, which included descriptive and explorative analysis of online information's characteristics associated with time before, after, and during the outbreak, as well as textual analysis of word frequency and text network analysis (*Appendix 1).* The second paper titled "**Understanding COVID-19 'infodemics': An analysis of online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020**" reported on misinformation and unverified information distribution of public health interventions implemented during the outbreak in July. I conducted the data categorization for 500 online posts to misinformation and unverified information concerning different COVID-19 prevention measures, and analyzed the association between the information categories and time period of before, after, and during the outbreak (*Appendix 2)*. This paper was accepted for oral presentation at at the 10th Southeast Asia and Western Pacific Bi-regional TEPHINET Scientific Conference in November 2021 (*Appendix 3*).

Abstract 1

Background

Trends in the public perception and awareness of COVID-19 over time are poorly understood, in particular in contexts with low SARS-CoV-2 transmission and in low and middle income countries. We aimed to analyze characteristics and trends of online information during a major COVID-19 outbreak in Da Nang province, Vietnam in July-August 2020 in order to understand public awareness and perceptions during an unfolding epidemic.

Method

We collected online information on COVID-19 incidence and mortality from popular online platforms in Vietnam between 1 July and 15 September, 2020, and assessed their trends over time against the epidemic curve during that period. We explored the associations between engagement levels, sentiment polarity[2], and other characteristics of information posted online with the different phases of the outbreak using Poisson regression and multinomial logistic regression analysis. We also assessed the frequency of keywords over time, and conducted a semantic analysis of keywords using word segmentation.

Result

We found a close association between public awareness and perception levels based on user-generated online information for incidence and mortality, and the evolution of the actual COVID-19 situation in Vietnam. Online information generated higher engagement levels during the outbreak compared to before the outbreak. There was a close relationship between sentiment polarity and posts' topics: the emotional tendencies about COVID-19 mortality were significantly more negative, and more neutral or positive about COVID-19 incidence. Online newspaper reported significantly more information in

[2] Sentiment polarity is determined by Artificial Intelligence's scanning and dissecting of content, using Natural Language Processing technique. The software would scan the content of the content of each posts, subtract any nonsense words and special symbols, can segment the sentence into bracket of token (each token is a word or group of words that have meaning in Vietnamese language). Next, the software would compare token to Vietnamese Language Sentiment Lexicon, which divides Vietnamese language into positive-signal tokens and negative-signal tokens, and categorize tokens into each category (positive and negative). Each positive token equal + 1 value, and negative token equal – 1 value. Summary of number of positive token's value and number of negative token's value, divided by total number of words per the content, would result a figure within the range of -1 to +1. Value larger than +0.1 would be categorized as positive, smaller than -0.1 would be categorized as negative, and others neutral.

negative or positive sentiment than posts on online forums or social media. Keyword analysis showed that most topics of public concern followed closely the progression of the COVID-19 situation during the outbreak: the situation regarding imported cases before the outbreak; development of the global pandemic and vaccination; the epidemiological characteristics of the unfolding outbreak in Vietnam (including the first COVID-19 related fatalities in Vietnam); prevention and control measures; and the subsiding of the outbreak after two months.

Conclusion

This study shows how online information can reflect the development of a public health threat in real time, and provides important insights about changes in the levels and topics of public awareness and perception during different outbreak phases. Our findings can help public health decision makers in Vietnam and other low and middle income countries with high internet penetration rates to design more effective communication strategies during critical phases of an epidemic.

Abstract 2

Background

Online information about COVID-19 has been spreading widely since the beginning of the pandemic. A better understanding of these ‘online infodemics’ is crucial to improve outbreak response and public health communication.

Method

We analyzed user-generated online information about five public health interventions that were implemented during a large COVID-19 outbreak in Vietnam, July-August 2020. We compared the volume, source, sentiment polarity, and engagements of online posts before, during and after the outbreak using negative binominal and logistic regression, and assessed the content validity of the 500 most influential posts.

Result

Most of the 54,528 online posts included were generated during the outbreak (46,035; 84.42%) and by online newspapers (32,034; 58.75%). Among the 500 most influential posts, 316 (63.20%) contained genuine information, 10 (2.00%) contained misinformation, 152 (30.40%) were non-factual opinions, and 22 (4.40%) contained unverifiable information. All misinformation posts were made during the outbreak, mostly on social media, and were predominantly negative. Higher levels of engagement were observed for information that was unverifiable (IRR 2.83, 95%CI 1.33-0.62), posted during the outbreak (IRR before: 0.15, 95%CI 0.07-0.35; IRR after: 0.46, 95%CI 0.34-0.63), and with negative sentiment

(IRR 1.84, 95%CI 1.23-2.75). Negatively-toned posts were more likely to be misinformation (OR 9.59, 95%CI 1.20-76.70) or unverified (OR 5.03, 95%CI 1.66-15.24).

Conclusion

The overall volume of misinformation and unverified information was low and clustered during the outbreak, with social media being particularly affected. This in-depth assessment demonstrates the value of analyzing 'online infodemics' during a COVD-19 outbreak to inform public health response.

Lessons learned

This study was the first time I was introduced and practiced content analysis – a possibly novel statistical subject for field epidemiology. During time of preparation for data analysis, I was struggled to find appropriate way to analyze qualitative data, but under online posts format. Although social media analysis and infodemics are not new to public health, I was not well-versed at all to any of this concept. The collected data was also expected to be paramount (more than 30,000 entries), filled with slang and internet language, and working with heavy dataset would not be ideal on basic statistical software. I found that we can certainly do textual analysis on R, but Vietnamese data was not compatible. This required extensive learning of new analytical method, and I decided to take introductory courses on Python and Gephi to conduct the analysis suitable for Vietnamese language. Through many and many trials and errors, and at time my laptop crashed because the heavy workload, I managed to perform automatic English translation, sentiment and semantics analysis on my dataset. Even though my analysis is very basic in compared to how advanced natural language processing is, I am still very proud of its outcome.

Master of Applied Epidemiology (MAE) scholar is expected to lead and perform epidemiological study from beginning to end, and this is certainly a new challenging project for me. While there are many aspects for me to grow professionally and personally, I was able to conduct the study from conceptualization to final manuscript. My field supervisor was only assisted in the beginning stage for discussion facilitation, and the team was of help during the software introduction and first stage of data collection only. During the project, I learnt how to effectively manage time and resource without any assisting team. Although I felt missing out on the experience of working and leading a bigger team for this project, I am still grateful that the project was finished and done on time, by my own responsibility and contribution.

Limitations

In addition to limitations listed in Appendix 1 and Appendix 2, I acknowledge generalizability limitation of the study. The concept of online information collectively excluded people with no or poor access to internet, especially young children, elderly, and people with lower socioeconomic status. These are people who are statistically more vulnerable to COVID-19 infection. With prolonged pandemic and lockdown measures, these people are also in need of sufficient access to Internet for personal and professional use (5). Even though more than 73% of population in Vietnam have access to Internet in 2021 (6), the population with poor or no access would be disproportionately impacted by lack of updated information. It would be encouraged for further studies of their source of information regarding the unfolding epidemic. While our study could not capture the general population, extrapolation should not be made lightly to general perceptions of the COVID-19 situation in Vietnam.

Public health impact

This is the first research on online information of COVID-19 in Vietnam's public health context. In term of public health, the study explored multiple data analysis skills include social network analysis for keyword and topic. The findings can be used as indicators for evaluating impacts of online information, and an up-to-date demonstration of infodemics importance in public health research. The results can inform relevant stakeholders including Vietnam Ministry of Health, NIHE, and Ministry of Science and Technology to review and implement the appropriate health communication strategy.

Recommendation

Online platforms had an important role in our lives, supplying rapid information to our every needs on a convenient widely-accessible device. Public health education and promotion soon realized the importance of communication through social media, but to monitor public attention and engagement with those information is also essential to decide the message impact. During COVID-19, online information spread wider, and faster than ever; thus the impact of online information to public adherence and perceptions of the ongoing outbreak grows. Public health agencies should consider more technological advanced method as event-based surveillance for COVID-19 to monitor online health information.

Acknowledgement

I would like to thank my academic supervisor, Dr. Florian Vogt, for supporting me throughout the study, especially your great guidance during the ethics application. I would also like to acknowledge Dr. Nguyen Cong Khanh – my field supervisor, and members of the Rapid Response Team for their contributions for this study design and data collection. I acknowledge my MAE colleague – Ms. Hoang Thi Ngoc-Anh's support throughout the difficult navigation of this epi study.

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Appendix 1. Submitted Article Manuscript 1.

Quach HL[#^], Pham QT, Hoang NA, Phung CD, Nguyen VC, Le HS, Le CT, Bui TMT, Le HD, Dang DA, Tran ND, Ngu DN, Vogt F[*], Nguyen CK[*]. **Using 'infodemics' to understand public awareness and perception of SARS-CoV-2: a longitudinal analysis of online information about COVID-19 incidence and mortality during a major outbreak in Vietnam, July - September 2020**. Submitted to *Journal of Medical Internet Research* in September 2021.

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Using 'infodemics' to understand public awareness and perception of SARS-CoV-2: a longitudinal analysis of online information about COVID-19 incidence and mortality during a major outbreak in Vietnam, July - September 2020

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Abstract

Background

Trends in the public perception and awareness of COVID-19 over time are poorly understood, in particular in contexts with low SARS-CoV-2 transmission and in low and middle income countries. We aimed to analyze characteristics and trends of online information during a major COVID-19 outbreak in Da Nang province, Vietnam in July-August 2020 in order to understand public awareness and perceptions during an unfolding epidemic.

Method

We collected online information on COVID-19 incidence and mortality from popular online platforms in Vietnam between 1 July and 15 September, 2020, and assessed their trends over time against the epidemic curve during that period. We explored the associations between engagement levels, sentiment polarity, and other characteristics of information posted online with the different phases of the outbreak using Poisson regression and multinomial logistic regression analysis. We also assessed the frequency of keywords over time, and conducted a semantic analysis of keywords using word segmentation.

Result

We found a close association between public awareness and perception levels based on online information for incidence and mortality, and the evolution of the actual COVID-19 situation in Vietnam. Online information generated higher engagement levels during the outbreak compared to before the outbreak. There was a close relationship between sentiment polarity and posts' topics: the emotional tendencies about COVID-19 mortality were significantly more negative, and more neutral or positive about COVID-19 incidence. Online newspaper reported significantly more information in negative or positive sentiment than posts on online forums or social media. Keyword networks showed that most topics of public concern followed closely the progression of the COVID-19 situation during the outbreak: the situation regarding imported cases before the outbreak; development of the global pandemic and vaccination; the epidemiological characteristics of the unfolding outbreak in Vietnam (including the first COVID-19 related fatalities in Vietnam); prevention and control measures; and the subsiding of the outbreak after two months.

Conclusion

This study shows how online information can reflect the development of a public health threat in real time, and provides important insights about changes in the levels and topics of public awareness and perception during different outbreak phases. Our findings can help public health decision makers in Vietnam and other low and middle income countries with high internet penetration rates to design more effective communication strategies during critical phases of an epidemic.

Keyword: COVID-19, online information, Vietnam, sentiment polarity, text social network.

Introduction

Infodemics, defined as "rapid and far-reaching spread of both accurate and inaccurate information about something, such as a disease" [1] has emerged as an area of concern during the COVID-19 pandemic [2]. WHO considers infodemics to be able to create ambiguity and distrust between population and government officials, thus mitigate effectiveness public health policy to prevent and contain the disease [3].

Vietnam implemented a series of public health interventions in combat with COVID-19. During the first half of 2020, Vietnam had successfully contained the outbreak with limited number of community clusters, no COVID-19 related deaths, and achieved a 99-consecutive-day duration without community transmission [4,5]. However, on 25 July 2020, a surge of locally acquired COVID-19 cases were identified in the city of Da Nang in Central Vietnam, a center for foreign trade activities and tourism [6–8]. The outbreak quickly spread to more than 10 provinces and cities across Vietnam, generating nearly 400 cases and causing 35 fatalities in total [9]. This outbreak marked the biggest COVID-19 outbreak in the country during 2020, and also the first with COVID-19 deaths. By the end of August 2020, the Da Nang outbreak was declared under control. During this outbreak, public awareness and perceptions were of paramount importance as new information of daily COVID-19 situation in the country was made available online, and was broadcasted widely in all types of media [10,11].

Online platforms can provide rich and useful information to predict and explain the characteristics and status of disease outbreaks, and at the same time be reflective of public awareness and perceptions concerning the health issues. Analysis of online data has become one of the most important focus areas in medical informatics research in recent years [12–14]. As a new emerging pandemic, COVID-19 has been in the focus of media coverage all over the world since early 2020, with people accessing their daily information of the current outbreak situation and where real-time reactions are posted and achieved. Recent research measured behavioral awareness and public attention in responses to COVID-19 using data from Facebook, Google, and popular online media [15–18]. While most of this work focused on countries with high ongoing COVID-19 transmission and/or high levels of online use such as China, Italy, and US, little work has been done to analyze the topics and sentiment dynamics in countries with low community transmission levels of SARS-CoV-2 such as Vietnam.

With relatively low number of cases and no deaths due to COVID-19 recorded before the Da Nang outbreak, collecting and analyzing online information about the evolving COVID-19 situation at that time provides a unique opportunity to gain an in-depth understanding of how the population engaged and responded online, as well as how online information of COVID-19 were disseminated across platforms. We aimed to analyze characteristics and trends of online information during the Da Nang outbreak in order to understand public awareness and perceptions during an unfolding epidemic.

Methods

Study design

We collected online information posted on popular online platforms and social media operated in Vietnam between 1 July to 15 September 2020 that focused on the COVID-19 outbreak in Da Nang, Vietnam, in particular about COVID-19 incidence and mortalities. We divided the study period according to the three phases of outbreak in Da Nang: (i) Pre-outbreak (1 – 24 July 2020); (ii) during the outbreak (25 July – 31 August 2020); (iii) post-outbreak (1 – 15 September 2020).

Data collection

Inclusion criteria for online content were: (i) related to COVID-19 incidence or mortalities (identified through pre-defined keywords in Table 1); (ii) posts were published in 'public mode' and remained in the public domain at the time of data collection; (iii) posts were made and posted in the format of posts on social media networks, entries on online forums, and online newspaper contributions; (iv) the geographical area from where the posts were uploaded is Vietnam. Exclusion criteria were: (i) being unrelated to the study topic (i.e. not containing pre-defined keywords as per Table 1); (ii) not being in the public domain at time of collection; and (iii) not generated in Vietnam geographically.

Table 1. Search keywords for online information by SMCC software.

Topic	Search keywords
COVID-19 incidence	*Vietnamese*: "ca mắc mới", "covid", "dương tính".
	English: "new case", "incidence", "covid", "positive"
COVID-19 mortalities	*Vietnamese*: "ca tử vong", "covid", "t.ử.v.o.n.g", "t.ử vong", "c.hết", "c.h.ế.t."
	English: "fatalities", "mortalities", "covid", "deaths".

We used the software package "Social Media Command Center – SMCC" used by the Vietnam Ministry of Science and Technology for online data collection. This software has been routinely used by National Steering Committee of COVID-19 Prevention in Vietnam since the start of the COVID-19 pandemic to assess public understanding and perception of public health interventions. Data source for collection included public social media networks, popular online forums, and leading online newspapers in Vietnam (See Table 2). Based on a pre-identified keyword search to cover the study topics (see Table 1 for details), we extracted the following data from each included online posts: (i) source, (ii) influence score, (iii) date of posting, (iv) engagement level, (v) sentiment polarity and (vi) content (See Appendix 1 and Appendix 2 for details and definition for all variables). Influence score was categorized through number of followers and/or views of source of posting (Appendix 2), and sentiment polarity was processed through Vietnamese Natural language processing function to identify signal wording and categorize into sentiment based on Vietnamese Lexicon Sentimental Dictionary developed by Tran et al [19] (Appendix 1). All data extraction was done and de-identified by the Ministry of Science and Technology.

Table 2. Online platforms source for data collection. More details can be found at lists of official online platforms in Vietnam [20–23].

Source	Platform name
Social media	Facebook, Instagram, Zalo, Zingme, Twitter, etc.
Online forums	Tinhte.vn, webtretho.com, lamchame.com, 5giay.vn, vatgia.com, vozforums.com, spiderum.com, chodientu.vn, etc.
Online newspapers	dantri.com, vnexpress.com, ngoisao.net, vovnews.vn, nhandan.vn, laodong.vn, etc.

Data processing

We used the Vietnamese word segmentation package "VnCoreNLP" packages [24] on Python 3.8 to segment words in each post, then processed to delete Vietnamese stop words and clean special symbols.

Data analysis

We plotted the number of posts and number of COVID-19 incidence and mortality by date to explore awareness and perception with regards to the Da Nang outbreak over time. Variables were summarized by frequency and percentage, and differentiated between the three outbreak periods (before, during, and after the outbreak) by Chi square or Fisher's exact tests. We summarized the influence score by calculating means and standard deviations (SD). We used the Spearman correlation coefficient to explore the correlation between COVID-19 incidence and mortality reported in Vietnam with the number of posts over time. We used multinomial logistic regression to assess the predictive relationship between sentiment polarity and outbreak periods adjusted for the posts' variables, reporting odds rations (OR) and 95% confidence intervals (CI). We used zero inflated Poisson regression to explore the relationship between engagement levels and outbreak periods adjusted for the posts' variables, reporting relative risks (RR), robust standard errors (SE) and 95%CI. These analyses were performed in Stata 16.0.

From the word segmentation, we calculated word frequencies to identify high-frequency keywords stratified by the three outbreak periods using the "NLTK" software package [25]. After extracting the most common words in each topic, we constructed a word-word co-occurrence matrix using "NetworkX" [26] in Python 3.8. We then extracted the matrix to VOSViewer software [27] to create a network of word co-occurrence analysis and cluster analysis, by using the co-occurrence frequency as the edge weight, and word frequency as node weight. In the network, the larger the size of the nodes would be, the higher number of links the node would have with its neighbours. The connection between the nodes would indicate that the keywords on the two nodes had appeared together, the stronger the connection would be, the higher the frequency of word co-occurrence and the closer the connection would be between the nodes. Nodes of the same cluster in each network were grouped by colour.

Ethics

This research was approved by the Australian National University's Human Research Ethics committee (Protocol 2020/605) and the Vietnam National Institute of Hygiene and Epidemiology's Institutional Review Board (NIHE IRB – 29/2020).

Results

Characteristics of online information

Table 3 and Figure 1 describe the progression of the COVID-19 outbreak in relation to the amount of online information for the three outbreak phases. For both incidence and mortality, a significantly sharp increase in the number of posts was seen during the outbreak. Higher number of posts per day reporting COVID-19 incidence than reporting COVID-19 mortality was observed, especially during the outbreak. Online newspaper was the main source of COVID-19-related online information throughout the study period. While the information source's influence score for reporting COVID-19 incidence was not different between outbreak periods, we saw a significant gradual decrease in influence score for COVID-19 mortality towards the end of the outbreak. Information about COVID-19 incidence were mostly reported with neutral tone during the outbreak, and transited to more posts in positive tone after the outbreak was controlled. Meanwhile, negative news about COVID-19 mortality were dominant throughout the three periods. The Pearson correlation analysis showed that the number of posts reporting COVID-19 incidence was positively correlated with daily incidence of COVID-19 (Pearson coefficient (r) = 0.7852, $P<.001$) higher than with daily fatality of COVID-19 (r=0.4310, $P<.001$), while the opposite was true to the number of posts concerning COVID-19 mortality (r=0.6479, $P<.001$ with daily incidence versus and r=0.7353, $P<.001$ with number of COVID-19 mortality in Vietnam).

Table 3. Description of online information reporting COVID-19 incidence and mortality stratified by outbreak periods.

A: Incidence							
Variables	**Pre-outbreak**		**During outbreak**		**Post-outbreak**		***P*-value**
	No. (n)	**Percentage (%)**	**No. (n)**	**Percentage (%)**	**No. (n)**	**Percentage (%)**	
Number of posts per day	389.25		1208.95		443.60		
Source							
Social media	2239	23.97	13775	29.22	543	8.16	<.001[a]
Online forum	333	3.56	2190	4.64	136	89.80	

Online newspaper	6770	72.47	31184	66.14	5975	2.04	
Sentiment polarity							
Positive	3049	32.64	16348	34.67	2731	41.04	
Neutral	3060	32.76	17597	37.32	1851	27.82	<.001[a]
Negative	3233	34.61	13204	28.00	2072	31.14	
Influence score (mean, SD)	4.63 (3.15)		4.64 (3.13)		4.59 (3.14)		.380[b]

B: Mortality

Variables	**Pre-outbreak**		**During outbreak**		**Post-outbreak**		***P*-value**
	No. (n)	**Percentage (%)**	**No. (n)**	**Percentage (%)**	**No. (n)**	**Percentage (%)**	
Number of posts per day (mean)	224.58		512.03		238.87		
Source							
Social media	707	13.12	3374	19.38	119	3.32	
Online forum	264	4.90	718	3.12	124	3.46	<.001[a]
Online newspaper	4419	81.99	13317	76.49	3340	93.22	
Sentiment polarity							
Positive	1620	30.06	4473	25.69	1202	33.55	
Neutral	1358	25.19	5810	33.37	905	25.26	<.001[a]
Negative	2412	44.75	7126	40.93	1476	41.19	
Influence score (mean, SD)	4.88 (3.33)		4.52 (3.25)		3.60 (3.21)		<.001[b]

[a] *P*-value was calculated by Chi-square test

[b] *P*-value was calculated by Fisher's exact test

Figure 1. Distribution of online information and number of COVID-19 incidence and mortality in Vietnam divided into three outbreak periods: Pre-outbreak (1 – 24 July 2020), during outbreak (25 July – 31 August 2020), and post-outbreak (1 – 15 September 2020). The yellow line indicates daily number of online information about COVID-19 incidence, the green line indicates daily number of online information about COVID-19 mortality. The blue bar indicates daily COVID-19 incidence recorded in Vietnam; the red bar indicates daily COVID-19 mortality recorded in Vietnam.

Table 4 shows the sentiment polarity distribution of online information. During the outbreak, neutral information was dominating, while there was more online information with positive and negative sentiment before and after the outbreak. While the majority of social media and online forum posts were made in neutral sentiment, the opposite was true for online newspapers. More positive and neutral posts about COVID-19 incidence were seen, and more negative posts on COVID-19 mortality were observed compared to the other sentiments.

Table 4. Distribution of sentiment polarity across posts' characteristics.

Variables	Positive sentiment (N = 29,423)		Neutral sentiment (N = 30,581)		Negative sentiment (N = 29,523)	
	n	**%**	**n**	**%**	**n**	**%**
Outbreak periods						
Pre-outbreak	4669	15.87	4418	14.45	5645	19.12
During outbreak	20821	70.76	23407	76.54	20330	68.86
Post-outbreak	3933	13.37	2756	9.01	3548	12.02
Source						
Social media	4321	14.69	11875	38.83	4561	15.45
Online forum	467	1.59	2460	8.04	838	2.84
Online newspaper	24635	83.73	16246	53.12	24124	81.71
Topic						
Incidence	22128	75.21	22508	73.60	18509	62.69
Mortality	7295	24.79	8073	26.40	11014	37.31

Table 5 shows the multinominal logistic regression analysis of three categories of posts' sentiment polarity with neutral sentiment as reference category. After adjusting for influence score, sources, and topics, the posts' sentiment polarity showed a significant association with the outbreak phases, with both information in positive and negative sentiment being less likely to be posted during the outbreak than before and after the outbreak compared to which in neutral sentiment. Online newspapers were also significantly more likely to contain information in negative and positive sentiment than neutral sentiment as compared to social media (OR 4.11 (3.94 – 4.29), *P*<.001 and OR 3.58 (3.44 – 3.72), *P*<.001 respectively). Posts' topics were positively associated with posts' sentiments, as posts about mortality were more likely to be negative and less likely to be positive than being neutral in posts about incidence (OR 1.43 (1.38 – 1.48), *P*<.001 and OR 0.77 (0.76 – 0.82), *P*<.001 respectively).

Table 5. Multinominal logistic regression of sentiment polarity over outbreak periods adjusted for posts' influence score, sources, and topics, using posts in neutral sentiment as reference category.

Variables	Unadjusted analyse		Adjusted analyses	
	Crude OR (95% CI)	***P*-value**	**Adjusted OR (95% CI)**	***P*-value**

A: Posts with positive sentiment (vs. neutral sentiment)				
Outbreak periods				
During outbreak	*Ref*		*Ref*	
Pre-outbreak	1.19 (1.13 – 1.24)	<.001	1.11 (1.06 – 1.16)	<.001
Post-outbreak	1.60 (1.52 – 1.69)	<.001	1.17 (1.11 – 1.24)	<.001
Source				
Social media	*Ref*		*Ref*	
Online forum	0.53 (0.47 – 0.58)	<.001	0.53 (0.47 – 0.59)	<.001
Online newspaper	4.17 (4.00 – 4.34)	<.001	4.11 (3.94 – 4.29)	<.001
Topic				
Incidence	*Ref*		*Ref*	
Mortality	0.92 (0.87 – 0.95)	<.001	0.77 (0.76 – 0.82)	<.001
Influence score	1.05 (1.04 – 1.05)	<.001	1.03 (1.02 – 1.03)	<.001
B: Posts with negative sentiment (vs. neutral sentiment)				
Outbreak periods				
During outbreak	*Ref*		*Ref*	
Pre-outbreak	1.47 (1.41 – 1.54)	<.001	1.31 (1.25 – 1.37)	<.001
Post-outbreak	1.48 (1.41 – 1.56)	<.001	1.06 (1.00 – 1.12)	.036
Source				
Social media	*Ref*		*Ref*	
Online forum	0.89 (0.81 – 0.97)	.006	0.85 (0.78 – 0.92)	<.001
Online newspaper	3.87 (3.72 – 4.02)	<.001	3.58 (3.44 – 3.72)	<.001
Topic				
Incidence	*Ref*		*Ref*	
Mortality	1.66 (1.60 – 1.72)	<.001	1.43 (1.38 – 1.48)	<.001
Influence score	1.05 (1.04 – 1.05)	<.001	1.03 (1.02 – 1.03)	<0.001

Note. Model was calculated by multinomial logistic regression to explore the distribution of positive and negative sentiment polarity over outbreak periods, compared to neutral sentiment polarity, and adjusted for posts' source, influence score and topics. Model Wald's likelihood Ratio = 10236.99; *P*-value < .001; Pseudo R2 = 0.0520.

Table 6 shows the distribution of source of information by post characteristics. Across outbreak periods, online newspapers were the main source of information reporting about the COVID-19 situation, both in terms of incidence as well as mortality. Information on social media had higher influence scores (mean 4.84, SD 3.35) than on online forums (mean 4.15, SD 3.08) and online newspapers (mean 4.04, SD 2.45).

Table 6. Distribution of source of information across posts' characteristics.

Variables	Social media (N = 20,757)		Online forum (N = 3,765)		Online newspaper (N = 65,005)		*P*-value
	n	%	n	%	n	%	
Outbreak periods							<.001[a]
Pre-outbreak	2,946	14.2	597	15.9	11,189	17.2	
During outbreak	17,149	82.6	2,908	77.2	44,501	68.5	
Post-outbreak	662	3.2	260	6.9	9,315	14.3	
Sentiment polarity							<.001[a]
Positive	4,321	20.8	467	12.4	24,635	37.9	
Neutral	11,875	57.2	2,460	65.3	16,246	25.0	
Negative	4,561	22.0	838	22.3	24,124	37.1	
Topic							<.001[a]
Incidence	16,557	79.8	2,659	70.6	43,929	67.6	
Mortality	4,200	20.2	1,106	29.4	21,076	32.4	
Influence score (mean, SD)	4.84 (3.35)		4.15 (3.08)		4.04 (2.45)		<.001[b]

[a] *P*-value was calculated by Chi-square test

[b] *P*-value was calculated by Fisher's exact test

Table 7 presents Poisson regression models for posts' engagement levels over outbreak periods. The model adjusted for posts' source, influence score, sentiment polarity, and topics, showed that collected online information received significantly higher engagement levels during the outbreak than before or after the outbreak (*P*<.001). Engagement levels were positively associated with influence score of the source (RR 1.25 (1.24 – 1.25)), posts reporting COVID-19 mortality in particular had more engagements than posts reporting COVID-19 incidence (RR 1.06 (0.84 – 1.34)). Posts with neutral sentiment also got significant higher engagements than posts with negative or positive sentiment, while posts on social media received significantly higher engagements than posts on online newspaper and online forum.

Table 7. Poisson regression of engagement levels over outbreak periods adjusted for posts' source, influence score, sentiment polarity, and topics.

Variable	Number of engagements	Unadjusted analysis	Adjusted analyses		
		Crude RR (95%CI)	Adjusted RR (95%CI)	SE	*P*-value
Outbreak periods					

During outbreak	11.02×10^6	*Ref*	*Ref*		
Pre-outbreak	1.05×10^6	0.58 (0.45 – 0.75)	0.60 (0.47 – 0.77)	0.08	<.001
Post-outbreak	0.12×10^6	0.20 (0.11 – 0.35)	0.19 (0.11 – 0.33)	0.05	<.001
Source					
Social media	12.1×10^6	*Ref*	*Ref*		
Online forum	6.95×10^4	0.08 (0.05 – 0.12)	0.15 (0.10 – 0.23)	0.03	<.001
Online newspaper	5.48×10^4	0.005 (0.005 – 0.007)	0.001 (0.000 – 0.0012)	0.00	<.001
Sentiment polarity					
Neutral	8.68×10^6	*Ref*	*Ref*		
Positive	1.69×10^6	0.42 (0.33 – 0.54)	0.37 (0.28 – 0.47)	0.05	<.001
Negative	1.82×10^6	0.41 (0.32 – 0.51)	0.37 (0.29 – 0.47)	0.04	<.001
Topic					
Incidence	2.57×10^6	*Ref*	*Ref*		
Mortality	9.62×10^6	1.02 (0.81 – 1.29)	1.06 (0.84 – 1.34)	0.12	0.605
Influence score	--	1.23 (1.22 – 1.25)	1.25 (1.22 – 1.27)	0.01	<.001

Note. Model was calculated by zero inflated Poisson regression to explore the association between outbreak periods and engagements levels adjusted for posts' source, influence score, sentiment polarity, and topics. Model Wald's Likelihood ratio = 180,424.08; *P*-value < .001.

Keywords distribution and frequency in online information

Figure 2 and Figure 3 show the top 15 frequency words appearing in online posts concerning COVID-19 incidence and mortality, respectively, stratified by the three stages of the outbreak. "COVID-19" and "patients" were the two keywords appearing consistently in all three periods for both topics. Meanwhile, "infection" had the highest frequency in all periods for information reporting COVID-19 mortality, but only in first period for information reporting COVID-19 incidence. Before the outbreak, it showed that COVID-19 situation in the "world", in particularly in some "states" in "United States", was covered alongside with Vietnam situation. Meanwhile, no deaths were reported in Vietnam, and all COVID-19 cases in Vietnam at that time were reported cases and were "quarantine" at "immigration". Compared with the pre-outbreak phase, the during-outbreak phase showed a shift in keywords such as "Da Nang province" (the epicenter of the outbreak in July), "comorbidity" (most cases were hospital patients with pre-existing conditions), "tests", and "community" (this outbreak was of community transmission). Information about COVID-19 deaths was more articulate, with descriptions of the first COVID-19 deaths reported in Vietnam such as "severe", "comorbidity" and "prognosis". Into the post-outbreak period, "prevention", "discharge", "tests" and "negative" were frequently used keywords. At this stage, the outbreak was under control and more and more cases were "discharged", and the attention had shifted to prevention and control mode in "Da Nang". While the number of new cases remained stagnant for some time, COVID-19 cases with severe prognosis were the main focus of attention in online discussions about COVID-19 deaths. Frequency of each keyword can be found in Appendix 3.

Figure 2. Top 15 keywords with highest appearance frequency in online information about COVID-19 incidence collected divided into three outbreak periods: Pre-outbreak (1 – 24 July 2020), during outbreak (25 July – 31 August 2020), and post-outbreak (1 – 15 September 2020).

Figure 3. Top 15 keywords with highest appearance frequency in online information about COVID-19 mortality collected divided into three outbreak periods: Pre-outbreak (1 – 24 July 2020), during outbreak (25 July – 31 August 2020), and post-outbreak (1 – 15 September 2020).

Semantic social networks of online information

Semantic networks of keywords over all three periods are shown in Figure 4 (COVID-19 incidence) and Figure 5 (COVID-19 mortality) (Separated networks for keywords appearing in each period can be found in Appendix 4 – 9).

Figure 4. Semantic social network of high-frequency keywords amongst online information about COVID-19 incidence.

"Cases", "COVID-19", and "patients" were at core position in the network about COVID-19 incidence (Figure 4) and grouped into four interconnected clusters. Cluster 1 (yellow) involved keywords and/or posts discussing COVID-19 situation in a worldly view, including "countries", "cases", "United States", "world", "government". Cluster 2 (blue) involved keywords of more domestic view to "Vietnam" National "Steering Committee" of "COVID-19", and related "outbreak" "transmission" and "prevention" "information". Cluster 3 (red) was the densest cluster in the network, including 24 nodes for news reporting COVID-19 situation inside the "hot spots" areas: "Da Nang" "city" and "Quang Nam" "province". While the cluster at that time was first detected in local "hospitals", transmission was rapidly spread to "community" and to other localities including "Hanoi". Many "measures" were implemented, including extensive "contact tracing", mass "testing" and "quarantine" "centres", case "isolation", "entry" control to "cluster" "commune", and personal protection such as "masks". During the outbreak, many "healthcare workers" from other provinces were mobilized to Da Nang for "medical support" to treat COVID-19 cases. Cluster 4 (green) displays information about COVID-19 "patients" "treatment", which keywords involved "SARS-CoV-2" "virus" testing, "disease", "infection", "health", "negative" "results", and "discharge".

Figure 5. Semantic social network of high-frequency keywords amongst online information about COVID-19 mortality.

Online information of COVID-19 mortality (Figure 5) was grouped into six clusters and had more interconnected nodes between clusters than the network on incidence. "COVID-19", "cases", and "patients" were at core of the network with highest links to other keywords. Cluster 1 (purple), cluster 2 (pink), and cluster 3 (yellow) were smaller clusters in the network with only three to four keywords each. While cluster 3 contained information of SARS-CoV-2 testing (featuring "negative", "result", "virus"), cluster 1 and 2 presented news about Vietnam's COVID-19 situation and response (featuring national "Steering committee" of COVID-19 "prevention", "outbreak", "country", and "infection"). Cluster 4 (green) included news about COVID-19 "pandemic" "situation" in "world" view, with "India" and "United States" which had global highest "deaths" count at that time. "Vaccine" "development" in "Russia" was also in the focus, while "governments" were implementing many "control" "measures" for COVID-19. Cluster 5 (blue) involved online information about COVID-19 "treatment", especially to more "severe" cases at that time. Example of keywords included "hospitals", "disease", "health", "prognosis", "isolation", "comorbidity". Cluster 6 (red) depicts COVID-19 progression in cluster areas – "Da Nang" "City", "Quang Nam" "province", and others – "Hanoi" and "Hai Duong". Since all COVID-19 deaths in Vietnam at that time were cases with pre-existing chronic diseases, keywords such as "lung", "kidney", "stages", and "pneumonia" were in focus.

Discussion

Main findings

In this study, we found three strong associations between online information characteristics and the evolution of the COVID-19 outbreak. First, we found that the three outbreak phases had significant associations with posts' engagement levels and sentiment polarity. Specifically, online information received significantly higher engagements during the outbreak than before or after the outbreak. Secondly, sentiment polarity was closely associated with posts' sources, with online newspaper reporting more negative and positive information. There were also significantly more negative posts about COVID-19 mortality and more positive and neutral posts about COVID-19 incidence. Thirdly, keyword analysis and semantic network analysis showed that trending keywords followed closely the evolution of the outbreak.

Growing public interest of online discussions on COVID-19

At the time the Da Nang outbreak started, Vietnam had been virtually COVID-19 free domestically for nearly two months. Unlinked new cases in Da Nang City – the epicenter of the outbreak in July – in high-risk areas of several regional hospitals [6,8], certainly alarmed the Vietnamese population. As engagements are highly sensitive and context specific, our findings showed significantly higher engagements during the outbreak than before or after the outbreak. Growing public interest in face of emerging infectious disease outbreaks has been explained as the reason to click on or engage with news trending or relevant to people's daily lives [28]. Similar trends of online information as during the Da

Nang outbreak were observed in early stages of the COVID-19 pandemic across the world, of which the number of tweets, newspaper headlines, and internet searches aligned with the increasing COVID-19 incidence [29,30]. Especially for breaking news such as the first COVID-19 deaths in Vietnam, we observed a significantly higher engagement than for COVID-19 incidence. This was also observed in previous outbreaks of influenza [31,32], Ebola [33,34], or during disaster emergency responses [35], and now with COVID-19 in several other countries [36–38].

Despite being the dominant information provider, online newspapers did not receive as many engagements from readers as social media's posts, similar to online forum. Similar trends of lower interactions to online forums than mainstream online platforms were reported by Cinelli et al [39]. This can be explained by the lower influence score of online newspaper and forums (as in views per article or entries) comparing to that of social media (as in followers per user account), which means online newspaper and forum could not attract as much attention as posts on social media accounts. As Vietnam has repeatedly ranked high in global comparisons for the numbers of social media users per capita, and with more and more people obtaining their news from these platforms in recent years [40–42], the impact of social media on perception and awareness on major public events can be expected to be bigger and more influential than from online newspaper and online forum.

Sentiment polarity and sources of online information

Sentiment analysis showed an association with the progression of the COVID-19 situation in our study. Previous research also identified similar trends of sentiment polarity followed by an increase of COVID-19 cases and fatalities [29,43]. While no clear impact of sentiments on users' engagement to the information was observed, we saw that neutral information covering the outbreak were dominating our collected data. This could be explained as this was not the first community outbreak of COVID-19 in Vietnam, both public and news outlet was more acquainted with the COVID-19 situation. Even though this was the first outbreak detected after nearly two months, the public was already well aware of the disease, and the news covering the outbreak was more likely to report the number of cases with neutral informing tone rather than in highly positive or negative sentiment. The same observation was observed in Xu et al, which stated that public opinion was more affected by the novelty of the pandemic in the beginning, and deeper into the pandemic, sentiment in online news or social media was less polarized [44]. We also saw that the overall trend of sentiment tendency was that negative tone decreased over time as positive tone increased at the end of the outbreak. Similar trends were shown in Zhao et al [45] and Sakun et al [46]'s research on COVID-19-covering posts, as they explained by the close relationship between hazard events, emotions and content on social media [47,48]. As the epidemic progressed further and eventually got under control, the public sentiment tended to skew towards neutral or even positive, as trust in successful government responses to the epidemic was strengthened. This was also evident in the use of positive keywords in the latter stage of the post-outbreak phase in our research, covering topics of recovering, prevention, and control.

On the other hand, our study showed that newspapers were more likely to report information positively or negatively than being neutral, compared to social media and online forum, and most prominently during the outbreak. Indeed, while newspapers have often been regarded as neutrally reporting sources, the opposite has been observed in the global news coverage of COVID-19 incidence and government response to COVID-19 [49–52]. With an emerging pandemic such as COVID-19, newspapers were more likely to portray the COVID-19 situation from a more negative perspective, especially in heavily-affected countries [29,43,52]. Konrad et al [52] showed a heterogeneity of sentiments in reporting COVID-19 through a substantial volume of negatively associated COVID-19 articles on online newspaper, especially in few first month of the pandemic. Both Rizvee et al [53] and Rao et al [54] hypothesized that the increasing severity of COVID-19 seen in local context (e.g. in Vietnam, the first COVID-19-related fatalities, the outbreak mongering amongst patients and vulnerable population in hospital) controlled the newspapers covering of COVID-19, resulted in a majority of warning/negatively-toned news to reframe population perception of the seriousness of the outbreak comparing to reassuring/neutral-toned ones.

Public discussion surrounding the topic of COVID-19

The keywords and semantic social networks closely mimicked the ongoing outbreak in Vietnam, as well as the evolution of COVID-19 situation globally. During the pre-outbreak period, we found that the public was mostly discussing about global COVID-19 issue from a distant perspective, as there were no COVID-19 domestic cases observed but only “imported” cases in the country. The quick shift in focus during the second period was observed as keywords concerning “Da Nang” or “hospitals” – closely describing the outbreak – were controlling the news coverage. While in the last period, descriptions of the outbreak’s progression such as “severe”, “comorbidity" and "prognosis”, were replaced by the “next step” of containment words, such as “prevention” or “discharge”. In comparison to surveys, online information mining and analysis gives a more comprehensive picture in countries with higher internet use of how the population reacts and discusses ongoing outbreaks in real time. While our findings clearly showed that source’s influence, topics and sentiment could drive users’ attention and engagement to reported information, keyword and semantic analysis proved its strengths in monitoring online awareness and perceptions to COVID-19 epidemic at different stages. Similar conclusions were drawn from Zhao et al [45] and Lazard et al [55], stating the importance of keyword analysis to produce higher accuracy and serve as a credible tool to monitor public health and risk communication.

Limitations

We acknowledged some limitations of our study. First, our study covered a set study period of before and after the outbreak, which limits the generalization of the study findings beyond the scope of the outbreak in focus. Secondly, although out study did not limit the selection of sources for content collection, we did not categorize data source further than newspaper, forum, and social media. Considering that while different sources and platforms with different authorities and/or reputation (e.g. government agencies, public health agencies, personal blogs) would target different audience, our current categorizations of posts' sources is relatively broad and unspecific. We also did not collect other detailed information including geospatial distribution or user/followers' demographics, which would have provided a more comprehensive depiction of online population reacting and engaging with COVID-19 related news. More detailed analyses into the interrelationship between sources of information (users, organizations, etc.), platforms, and its acclaimed 'influence' (followers, connections) could be a valuable basis for subsequent research on the drivers and viral ability of online information or 'infodemics'. Lastly, the concept of online information collectively excluded people with no or poor access to internet at the same time focused more on more active users of internet. While our study could not capture the general population, extrapolation should not be made lightly to general perceptions of the evolution of the COVID-19 situation in Vietnam.

Implications

Our findings demonstrate the importance of sources and sentiment polarity in disseminating online information in understanding public perceptions during an unfolding epidemic. Our study approach has implications for future development and implementation of social media data to public health research and policy. Online data analysis opens new horizons for 'infodemiology' and 'infosurveillance' in the COVID-19 era and future epidemic. Public health education and promotion has long realized the importance of social media, and the power of digital world in facilitating or fabricating information in the quickest and most effective way [56,57]. Yet, online platforms should not only be used as one-sided information supply tools, but also as an effective multi-way communication channel between the general population, public health institutions, and the government during epidemics. In COVID-19, public-health-related online information spread wider and faster than ever before. It is highly important to recognize influential outlets with higher engagement-driven power, and its impact to polarize (or even distort negatively) public attention and perceptions of the ongoing outbreak. Public health institutions should consider utilizing big data tools during public health emergencies to better understand public reactions and perceptions, and to develop appropriate health communication strategies. Social media campaigns should take the evolution of 'infodemics' into account over the course of such events [49,58].

Conclusion

Online information reflected public perceptions toward the epidemic sensitively and timely, both in its coverage and influence. This study was novel in its usage of online data in real-time public health emergencies, and provides a valuable basis to further integrate the strengths of big data analysis of online information into public health research and policy. Our findings can help public health decision makers in Vietnam and other low and middle income countries with high internet penetration rates to better communicate with population health and information needs, design more effective communication strategies, and translate this into comprehensive prevention and control measures during critical phases of an epidemic.

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Conflicts of Interest

The authors declare no conflicts of interest.

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Abbreviations

SMCC: Social Media Command Center

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Figure 1. Distribution of online information and number of COVID-19 incidence and mortality in Vietnam divided into three outbreak periods: Pre-outbreak (1 – 24 July 2020), during outbreak (25 July – 31 August 2020), and post-outbreak (1 – 15 September 2020). The yellow line indicates daily number of online information about COVID-19 incidence, the green line indicates daily number of online information about COVID-19 mortality. The blue bar indicates daily COVID-19 incidence recorded in Vietnam; the red bar indicates daily COVID-19 mortality recorded in Vietnam.

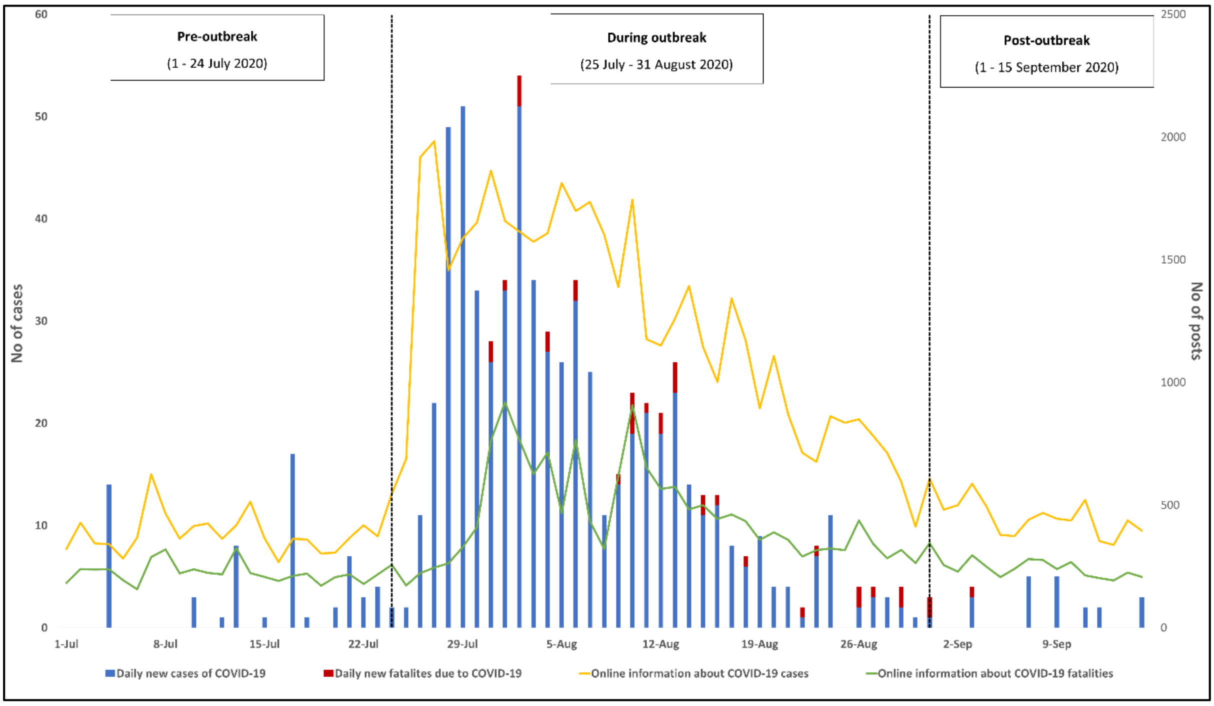


Figure 2. Top 15 keywords with highest appearance frequency in online information about COVID-19 incidence collected divided into three outbreak periods: Pre-outbreak (1 – 24 July 2020), during outbreak (25 July – 31 August 2020), and post-outbreak (1 – 15 September 2020).

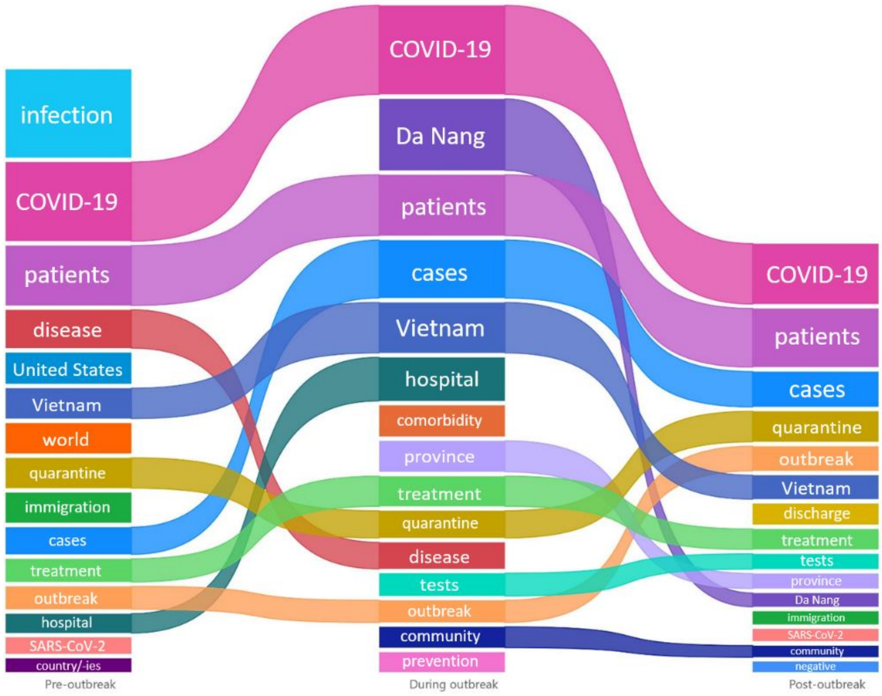


Figure 3. Top 15 keywords with highest appearance frequency in online information about COVID-19 mortality collected divided into three outbreak periods: Pre-outbreak (1 – 24 July 2020), during outbreak (25 July – 31 August 2020), and post-outbreak (1 – 15 September 2020).

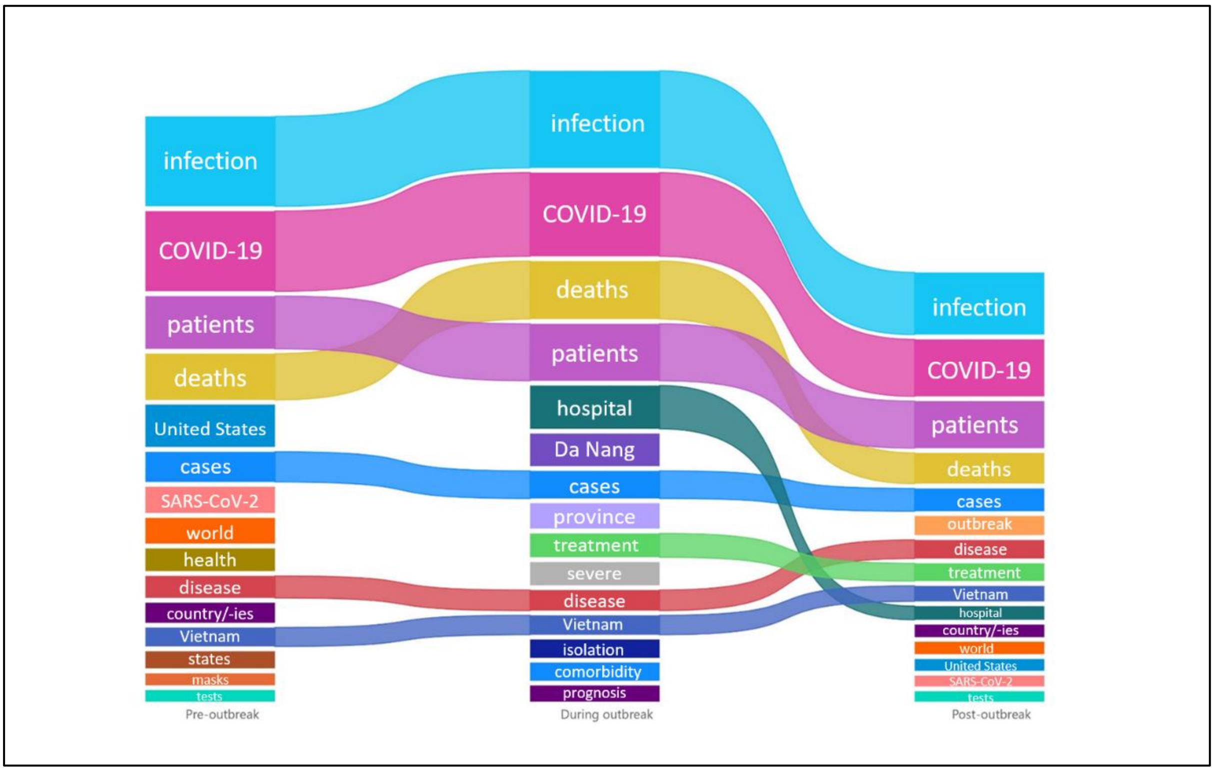


Figure 4. Semantics social network of high-frequency keywords amongst online information about COVID-19 incidence.

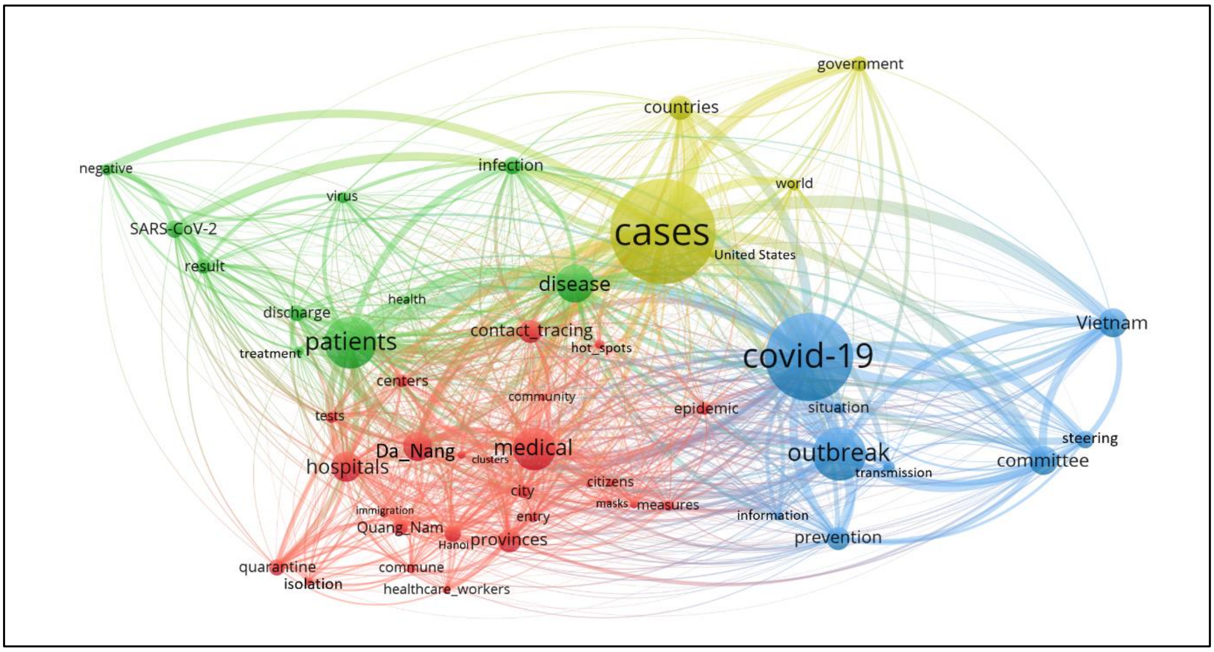
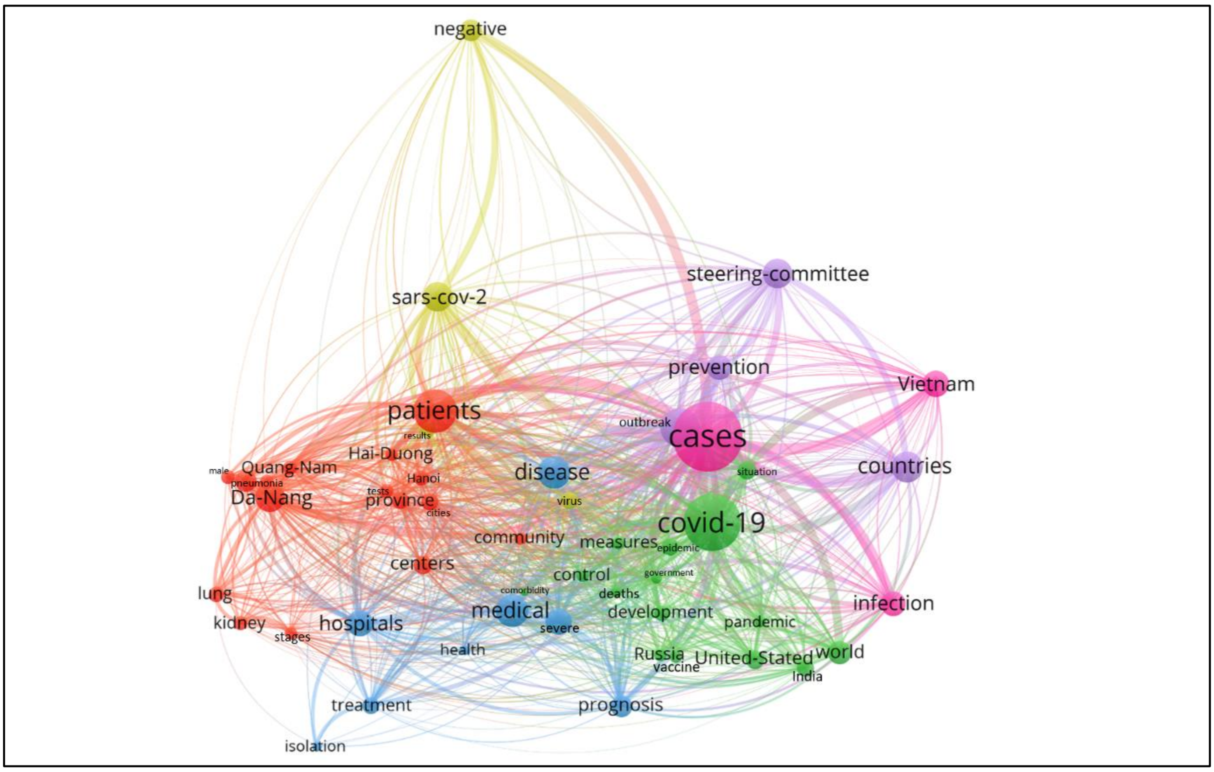


Figure 5. Semantics social network of high-frequency keywords amongst online information about COVID-19 mortality.



Supplement file

Appendix 1. Definitions of collected variables for online information by SMCC software.

Variables	Retrieving/Categorization method	Definition	Type
Source	Based on the built-in function of the software, each post was labeled by its source from where it was retrieved.	Online platform where the post was initially made public (does not contain identifiable information about who made the post).	Nominal variable: - Online articles - Online forum -Social network
Influence score	Based on the built-in function of the software, each source was given a score of influence calculated by number of followers of the source.	Quantitative value of influence that the software calculates for each source of the posts, based on number of followers of the source.	Continuous variable ranking from 1 (lowest influence) to 10 (highest influence)
Date of posting	Based on the built-in function of the software.	Date when the post was initially made available on the platform.	Date variable
Engagement level	The built-in function of the software retrieved quantitative number of engagements (in form of likes, comments, and shares) of each posts	Quantitative number of engagements (likes, shares, comments) calculated for each post	Discrete variable - Number of likes - Number of shares - Number of comments
Sentiment polarity	Based on the built-in function of the software, each posts content was processed through Vietnamese Natural language processing function to identify signal wording and categorize into sentiment based on Vietnamese Lexicon Sentimental Dictionary developed by Tran et al*.	Polarity identification of objective textual concept in the posts	Nominal variable - Negative - Positive - Neutral
Content	Retrieved by built-in function of SMCC based on selection criteria and selected keywords of the study.	Textual content of the posts that meet the selection criteria and selected keywords of the study (does not contain identifiable information about who made the post).	Text variable

*Reference drawn from Tran TK, Phan TT. A hybrid approach for building a Vietnamese sentiment dictionary. J Intell Fuzzy Syst. 2018 Jan 1;35(1):967–78.

Appendix 2. Influence score calculation by number of followers and/or views of each source based on built-in function of the SMCC software.

Followers/ Views*	Influence score
Less than 10	0
From 10 to 10.000	1
From 10.000 to 20.000	2
From 20.000 to 50.000	3
From 50.000 to 100.000	4
From 100.000 to 200.000	5
From 200.000 to 500.000	6
From 500.000 to 1.000.000	7
From 1.000.000 to 2.000.000	8
From 2.000.000 to 5.000.000	9
From 5.000.000 up	10

*Views are applied to online newspaper and forum entries, followers are applied for Facebook.

Appendix 3. Keywords frequency of online information of COVID-19 incidence and mortalities by outbreak periods.

Topic: COVID-19 incidence

Rank	Pre-outbreak		During outbreak		Post-outbreak	
	Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
1	infection	51315	COVID-19	51671	COVID-19	35005
2	COVID-19	45861	Da Nang	41478	patients	34066
3	patients	34738	patients	35317	cases	20466
4	disease	22181	cases	33609	quarantine	17706
5	United States	18133	Vietnam	29280	outbreak	14236
6	Vietnam	17630	hospital	25273	Vietnam	13871
7	world	17614	comorbidity	18005	discharge	12140
8	quarantine	17602	province	17965	treatment	11883
9	immigration	17476	treatment	17459	tests	8811
10	cases	15756	quarantine	15744	province	8699
11	treatment	13435	disease	15367	Da Nang	8026
12	outbreak	13297	tests	13138	immigration	7616
13	hospital	11179	outbreak	12785	SARS-CoV-2	7132
14	SARS-CoV-2	9548	community	12098	community	6731
15	country/ies	8012	prevention	11621	negative	6121

Topic: COVID-19 mortalities

Rank	Pre-outbreak		During outbreak		Post-outbreak	
	Keyword	Frequency	Keyword	Frequency	Keyword	Frequency
1	infection	37545	infection	40560	infection	25962
2	COVID-19	33504	COVID-19	34939	COVID-19	23770
3	patients	22048	deaths	24209	patients	19640
4	deaths	19302	patients	23770	deaths	12812
5	United States	17666	hospital	18056	cases	9494
6	cases	12617	Da Nang	13560	outbreak	7984
7	SARS-CoV-2	10959	cases	11512	disease	7748
8	world	10740	province	10583	treatment	7398

9	health	9482	treatment	9939	Vietnam	6463
10	disease	9172	severe	9692	hospital	5672
11	country/ies	8363	disease	8533	country/ies	5192
12	Vietnam	7865	Vietnam	8084	world	5118
13	states	7171	isolation	7614	United States	4969
14	masks	5030	comorbidity	7555	SARS-CoV-2	4505
15	tests	4818	prognosis	6748	tests	4323

Appendix 4. Semantic network of keywords appearing in online information concerning COVID-19 incidence in pre-outbreak period.

Appendix 5. Semantic network of keywords appearing in online information concerning COVID-19 incidence during outbreak period.

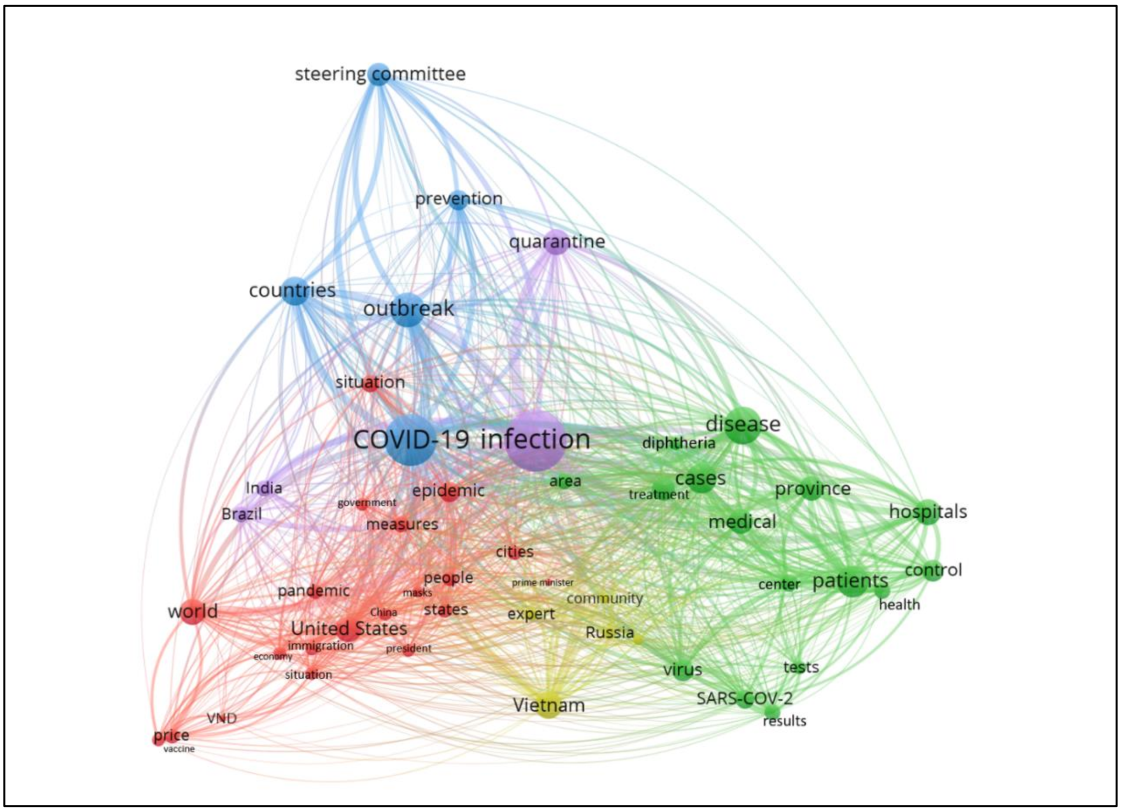
Appendix 6. Semantic network of keywords appearing in online information concerning COVID-19 incidence in post-outbreak period.

Appendix 7. Semantic network of keywords appearing in online information concerning COVID-19 mortality in pre-outbreak period.

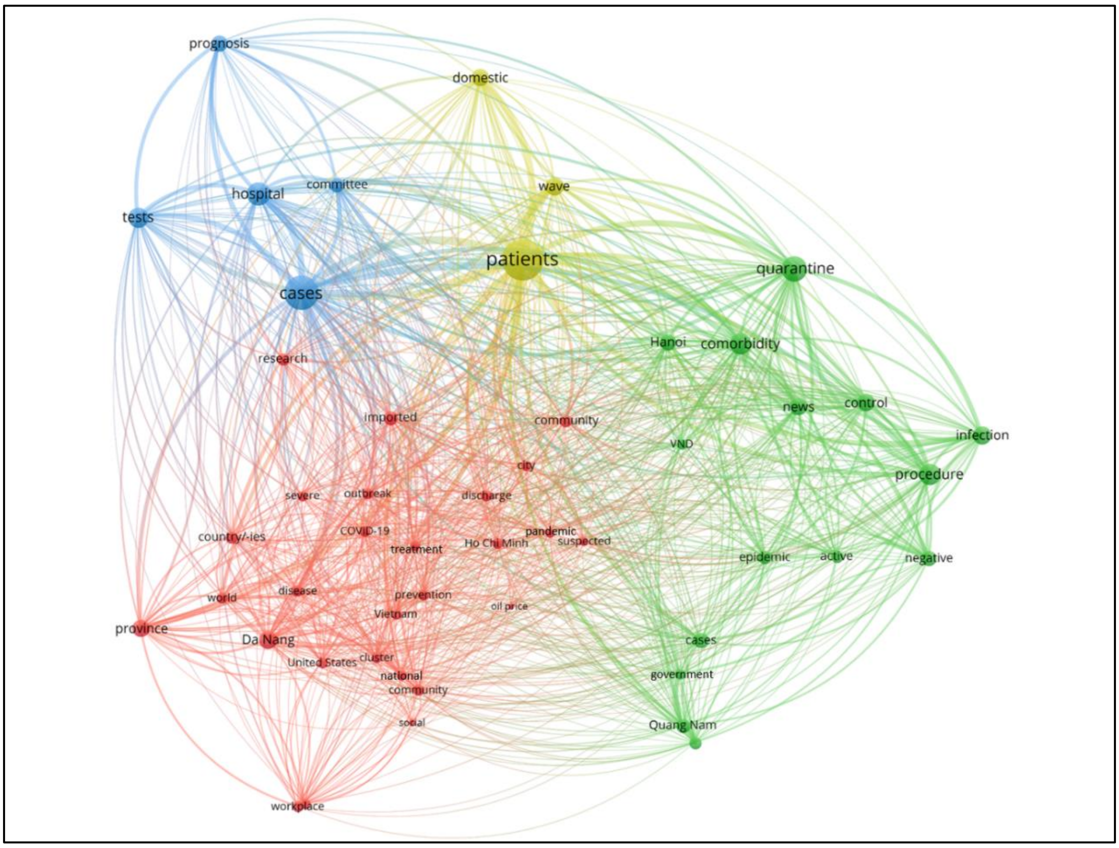
Appendix 8. Semantic network of keywords appearing in online information concerning COVID-19 mortality during outbreak period.

Appendix 9. Semantic network of keywords appearing in online information concerning COVID-19 mortality in post-outbreak period.

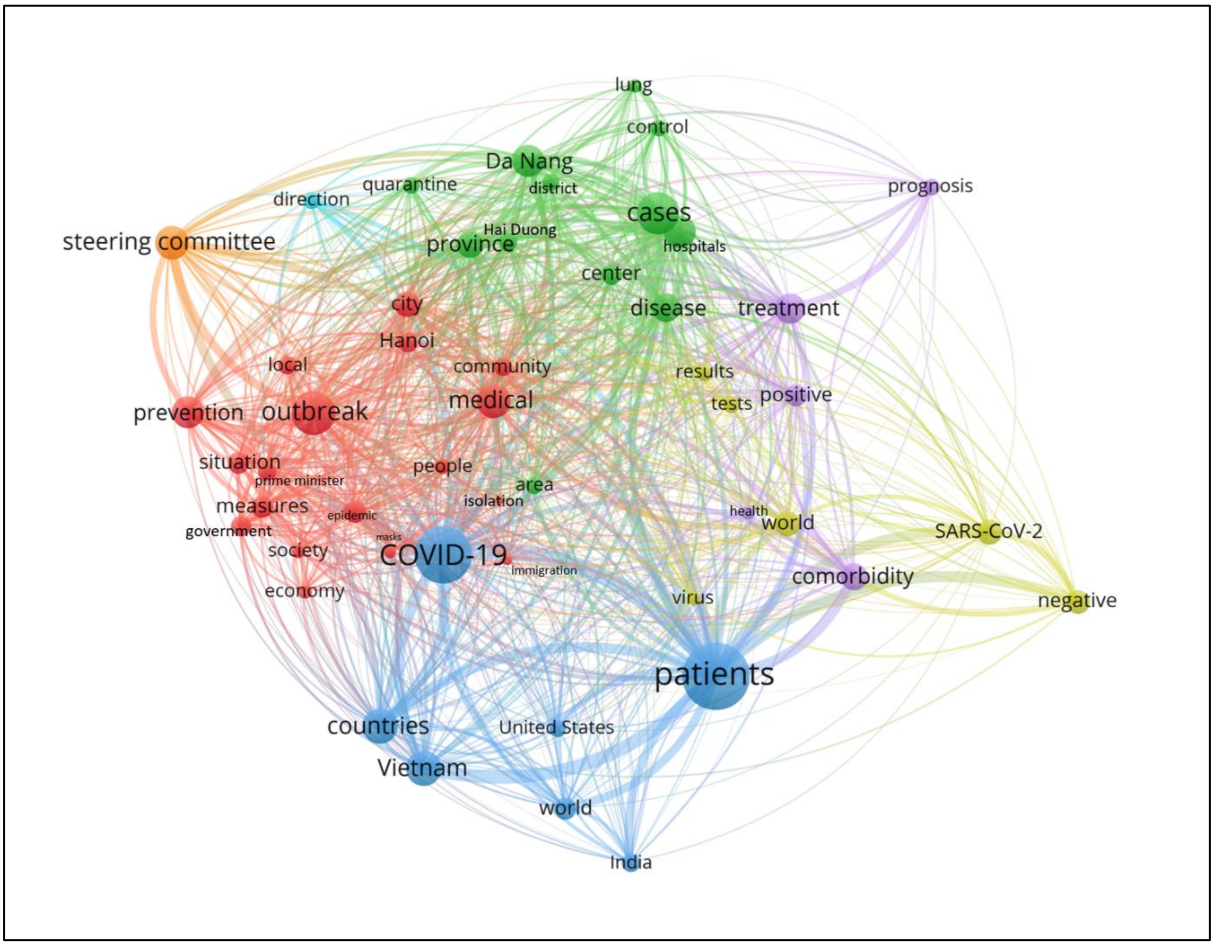
Supplement Figure 1. Semantic network of keywords appearing in online information concerning COVID-19 incidence in pre-outbreak period.



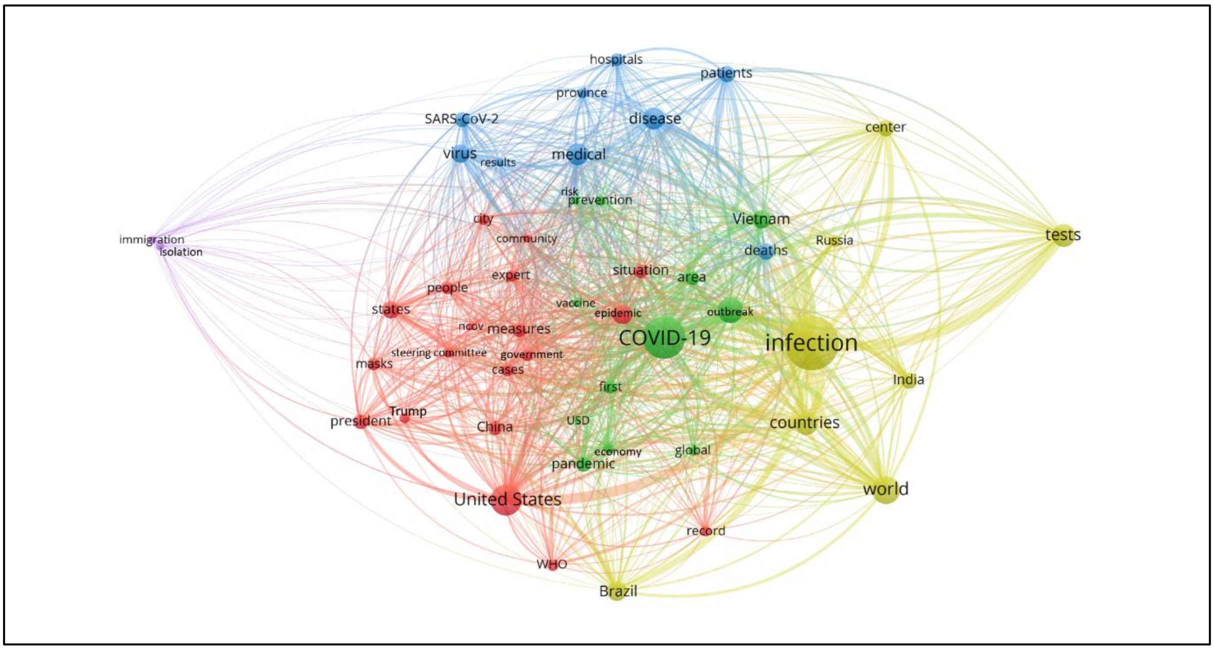
Supplement Figure 2. Semantic network of keywords appearing in online information concerning COVID-19 incidence during outbreak period.



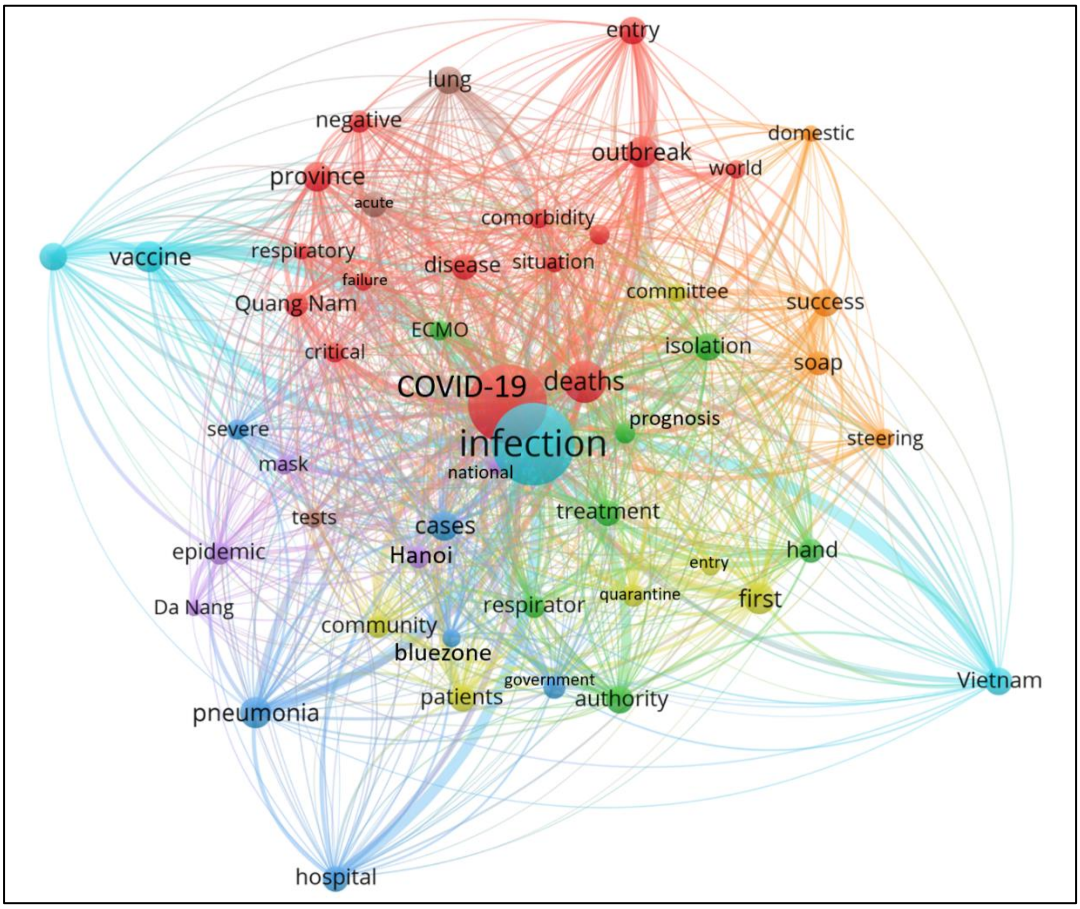
Supplement Figure 3. Semantic network of keywords appearing in online information concerning COVID-19 incidence in post-outbreak period.



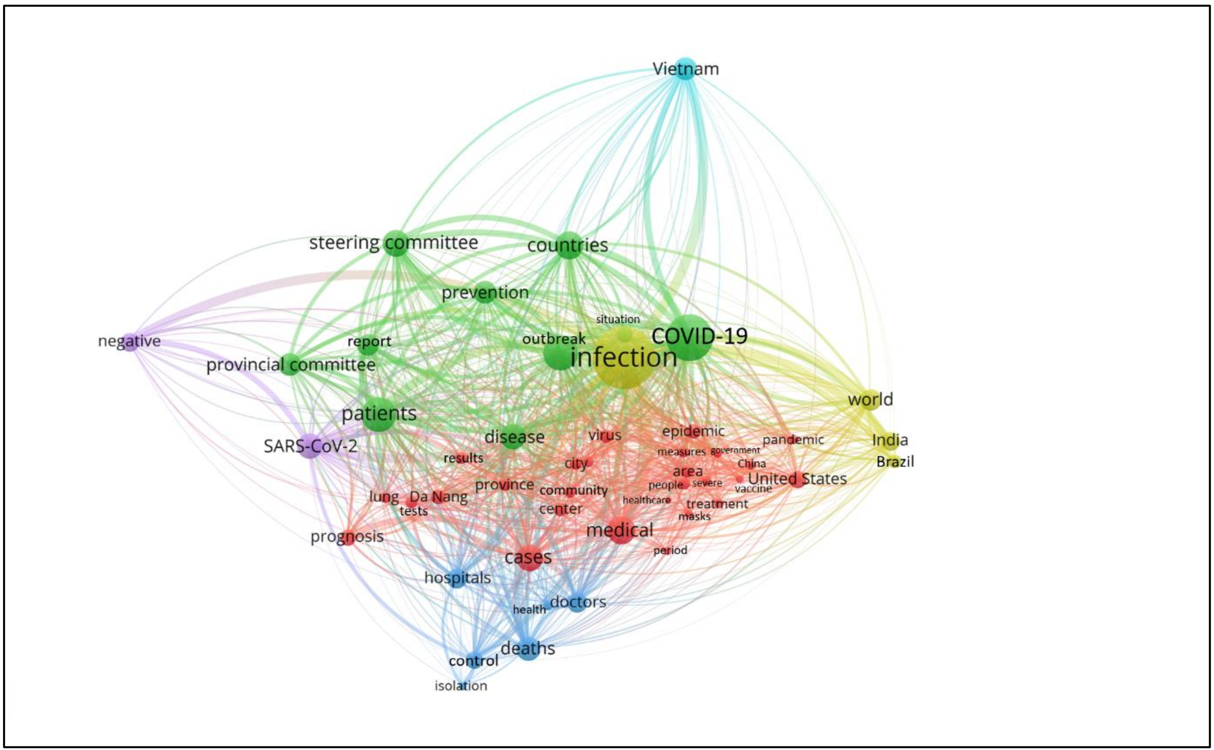
Supplement Figure 4. Semantic network of keywords appearing in online information concerning COVID-19 mortality in pre-outbreak period.



Supplement Figure 5. Semantic network of keywords appearing in online information concerning COVID-19 mortality during outbreak period.



Supplement Figure 6. Semantic network of keywords appearing in online information concerning COVID-19 mortality in post-outbreak period.



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Appendix 2. Submitted Article Manuscript 2.

Quach HL[#^], Pham QT, Hoang NA, Phung CD, Nguyen VC, Le HS, Le CT, Le HD, Dang DA, Tran ND, Ngu DN, Vogt F[*], Nguyen CK[*]. **Understanding COVID-19 'infodemics': An analysis of user-generated online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020**. Submitted to *Health Informatics Research* in September 2021.

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[*] (shared) last authorship
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Understanding COVID-19 'infodemics': An analysis of user-generated online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020

Running title: COVID-19's 'infodemics' in Vietnam

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Understanding COVID-19 'infodemics': An analysis of user-generated online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020

Abstract

Background

Online information about COVID-19 has been spreading widely since the beginning of the pandemic. A better understanding of these 'online infodemics' is crucial to improve outbreak response and public health communication.

Methods

We analyzed user-generated online information about five public health interventions that were implemented during a large COVID-19 outbreak in Vietnam, July-August 2020. We compared the volume, source, sentiment polarity, and engagements of online posts before, during and after the outbreak using negative binominal and logistic regression, and assessed the content validity of the 500 most influential posts.

Results

Most of the 54,528 online posts included were generated during the outbreak (46,035; 84.42%) and by online newspapers (32,034; 58.75%). Among the 500 most influential posts, 316 (63.20%) contained genuine information, 10 (2.00%) contained misinformation, 152 (30.40%) were non-factual opinions, and 22 (4.40%) contained unverifiable information. All misinformation posts were made during the outbreak, mostly on social media, and were predominantly negative. Higher levels of engagement were observed for information that was unverifiable (IRR 2.83, 95%CI 1.33-0.62), posted during the outbreak (IRR before: 0.15, 95%CI 0.07-0.35; IRR after: 0.46, 95%CI 0.34-0.63), and with negative sentiment (IRR 1.84, 95%CI 1.23-2.75). Negatively-toned posts were more likely to be misinformation (OR 9.59, 95%CI 1.20-76.70) or unverified (OR 5.03, 95%CI 1.66-15.24).

Conclusions

The overall volume of misinformation and unverified information was low and clustered during the outbreak, with social media being particularly affected. This in-depth assessment demonstrates the value of analyzing 'online infodemics' during a COVD-19 outbreak to inform public health response.

Keywords: infodemics, misinformation, public health interventions, COVID-19, Vietnam.

Introduction

Since December 2019, COVID-19 epidemic has caused significant health and economic burden at a global scale (1). Before SARS-CoV-2 was identified as its causal agent, COVID-19-related information was already spreading uninhibitedly over traditional and social media platforms at a strikingly rapid pace (2). This phenomenon, called "infodemics" – the over-abundance of information regarding an emerging event (3), has been observed during prior public health emergencies (4–6). During the COVID-19 pandemic, infodemics have reached unprecedented levels, and governments, and public health organizations around the world are now calling for measures to limit their effects (7).

Vietnam was one of the first countries reporting COVID-19 cases outside of Mainland China. Very early into the epidemic, many interventions were put in place before any cases were reported, including border closures and travel restrictions, extensive case detection and contact tracing, and stringent quarantine measures. A series of public health interventions were gradually and timely imposed to control the outbreak domestically (8), helping Vietnam to achieve 99 days without community transmission between April and late July, 2020 (Figure 1). On 25 July 2020, a surge of unlinked COVID-19 cases without evidence of imported infection from abroad was spotted in Da Nang, a municipal city in Central Vietnam of high importance for foreign trade and tourism (9,10). The outbreak affected mostly patients and staff of linked to several hospitals, people in community of Da Nang, and sporadic cases among people in other provinces with travel history to Da Nang. Overall, more than 500 cases were reported in relation to this outbreak, with 495 (89.84%) in Da Nang, and 56 (10.16%) in ten other provinces and cities across Vietnam. It was the first outbreak in Vietnam with COVID-19 related deaths since the beginning of the pandemic, with a total of 35 related fatalities were confirmed. By the end of August 2020, the Da Nang outbreak was declared under control.

Figure 1 is about here

A series of public health measures were implemented by Vietnam government in response to this outbreak to limit and prevent further spread (8,11). While some of these measures had already been introduced before the outbreak, the scope and enforcement were greatly intensified due to the urgency of this outbreak. To keep the public informed, information about these policies were frequently broadcasted by governmental agencies and various other outlets, including online platforms. Many of the estimated 69 million internet users in Vietnam use online media and user-generate online information as their main source of information about current events (12). It is therefore important to recognize online information as a crucial mean to communicate about health and risk during a COVID-19 outbreak, and to understand its capacity to impact public adherence to public health interventions.

Since most online platforms do not fact-check user-generated online information, this creates an opportune environment for misinformation, defined in the field of public health as a "claim of fact that is currently false due to lack of scientific evidence" (13), to spread widely with no curation or verifications. The viral ability of these misinformation becomes amplified by the rapid reciprocate nature of internet and gets easily content-tailored for specific target audience who are receptive to specific types of misinformation (14). It has been recognized that online misinformation during the COVID-19 pandemic can create either a false sense of security or threat, and thus impact any prevention and control efforts of public health (15,16). Existing evidence about online misinformation about COVID-19 is restricted to the evolution of the pandemic, conspiracy theories, or discriminative misinformation (17,18). However, the 'infodemics' surrounding specific public health interventions imposed by governments has not been studied to date. Recently, WHO published a research agenda to improve evidence-based tools, methods, and interventions for 'infodemics' management (19). The agenda highlighted the need to first measure and detect the spread and impact of misinformation in a localized context during the ongoing epidemic. Similarly, this study aimed to analyze the magnitude and dynamics of misinformation and unverified user-generated online information about five distinct public health interventions in response to the COVID-19 outbreak in Da Nang, Vietnam between July to September 2020.

Method

Study design

This is a longitudinal study using publicly available online information about COVID-19-related public health interventions between 1 July to 15 September 2020 on popular online platforms in Vietnam. Study topics included five distinct public health interventions implemented at national scale during the study period in response to the outbreak at the time:

i. Cordon sanitaire of outbreak areas including Da Nang city and a nearby province;
ii. Re-scheduling of national high school examination nation-wide and the exclusion of examination for students from outbreak areas and/or students who were identified as COVID-19 cases or close contacts of COVID-19 cases;
iii. National-wide campaign to promote the use of '*Bluezone*', Vietnams official contact tracing mobile phone application for COVID-19;
iv. National tracking and prosecution of illegal border crossing and individuals who breached COVID-19 quarantine requirements; and
v. National contact tracing, serology testing and quarantine for all people with travel history from outbreak areas.

Data collection

Inclusion criteria for data collected in the analysis were (i) made in public mode during the study periods and stay public at time of data collection; (ii) made and posted in the format of online newspaper, online forums or social media posts; and (iii) had verified postal area of operation in Vietnam. Our search was limited to online posts in Vietnamese. Data was provided by the Ministry of Science and Technology through an internet archive database named "Social Media Command Center" (SMCC). The process of keyword development for data collection was carried out by the research team, and then compiled into a list of keywords (*Supplement Table 1*). We then used the keywords into the system to collect online information from several sources (including social media platforms, online forums, and online newspapers) operating in Vietnam (*Supplement Table 2*). Based on the topic identified keyword, the following variables of online information were collected: (i) source, (ii) periods, (iii) number of engagements, (iv) influence score, and (v) text (Definition in *Supplement Table 3* and *Supplement Table 4*). Collected data was compiled and extracted into Microsoft Excel by personnel from Ministry of Science and Technology, no identifiable data was collected.

Data processing

We selected the 100 posts with the highest number of engagement from each of the five topics, which yielded 500 posts for analysis. From these 500 selected posts, the following variables were manually collected/categorized by the research team and further processed. First, we conducted content classifications to categorize these posts based on textual content into the following categories: genuine information, misinformation, opinions, and unverified information. These categories were adapted from previous research by Kouzy et al (20) on COVID-19 Twitter data and defined in Table 1. Two independent researchers followed the definition to categorize all selected posts separately by reading each post's textual content. Final results were cross-checked between two sets, and any disputes were consulted with a third researcher and additional information search. No posts were excluded after the process due to unresolved dispute.

Table 1 is about here

Next, we conducted sentiment classifications based on textual content of selected posts. All selected posts were analyzed for sentiment analysis using Vietnamese sentiment lexicon (21) and VnCoreNLP packages (22) for Vietnamese language word and sentiment processing on Python 3.6. For each post, number of positive and negative words appeared were calculated. Each post was further classified to one of three sentiment classifications: positive, neutral, negative, based on automatic calculation of sentiment score of each post.

Data analysis

Variables were summarized and plotted chronically by date of the posts to the timeline of outbreak and/or intervention implemented, and differentiated between content categories by appropriate statistical tests. We used negative binominal regression to explore the relationship between number of engagements and selected posts' characteristics, incidence relative risk (IRR) and 95% confidence interval (95% CI) were reported. Univariate and multivariable logistic regression were used to explore the association between posts' characteristics and posts categories, focusing on misinformation and unverified information versus other post categories, odd ratio (OR) and 95%CI were reported. Median number of negative and positive words stratified by posts' characteristics were summarized and differentiated by ANOVA test. All analyses were performed using Stata 16.

Ethics

We obtained approval from the Australian National University's Human research ethics committee (Protocol 2020/605) and Vietnam National Institute of Hygiene and Epidemiology's Institutional review board (NIHE IRB – 29/2020) for this research.

Results

Descriptive characteristics of all collected online posts

Table 2 and Figure 2 display distribution of online posts' characteristics stratified by search topics of five distinct NPIs implemented in Vietnam during the study outbreak. Across five topics, "COVID-19 quarantine breach" discussion had the highest number of posts (22170), highest number of posts made per day (287.92 posts per day), and highest median of engagements (180.81 engagements per post). Meanwhile, posts concerning "national high school examination schedule" had the least number of engagements (36.82 engagement per posts), and posts mentioning "national wide contact tracing" were posted least regular during the study period (33.61 posts per day). While "cordon sanitaire" information was made by sources with highest influence score among five topics (mean 5.00, standard deviation – SD 3.38), the opposite was true to information about "Bluezone application" (mean 3.91, SD 3.02). Figure 2 shows that while highest number of posts were made during outbreak for all five topics, online newspaper was the consistent source reporting highest number of posts about these topics. Number of posts about "Bluezone application", while with lowest traffic before the outbreak, increased drastically during the outbreak and even with highest rank amongst five topics after the outbreak (Table 2). Similar trend was observed for posts on "national-wide contact tracing". On the other hand, the remaining three topics saw a considerable decline of number of posts after the outbreak that was even lower than those made before the outbreak.

Table 2 is about here.

Figure 2 is about here.

Descriptive and analyzed characteristics of selected online posts

Table 3 presents the characteristics of all selected posts stratified by posts' categories. Among selected 500 posts with highest number of engagement, there were 316 (63.20%) genuine information posts, 10 (2.00%) misinformation posts, 152 (30.40%) opinions, and 22 (4.40%) unverified posts. Kruskal-Wallis test showed that there was a significant difference ($P<.001$) between median number of engagements of each posts' categories, with highest number of engagements observed for unverified information (median 13415, Interquartile range – IQR 8507 – 22869). Except for mean of influence score among four posts' categories, significant differences were observed in distribution of number of posts displayed in three sentiments

(P<.000), made by three sources (P<.005) and posted in three periods (P<.05). Highest number of genuine information and opinion pieces were made on newspaper and during the outbreak. Most neutral sentiment selected posts (196/207) were categorized as genuine information, and most positive sentiment selected posts (81/147) were opinion-expressing posts. Meanwhile, most misinformation posts were made on social media (8/10) and half of unverified information (11/22) were posted on online forum. While all identified misinformation posts were made during the outbreak, none of these posts were made in neutral sentiment nor in online newspaper platform. Similarly, identified unverified information posts were not displaying neutral sentiment nor posted after the outbreak.

Table 3 is about here.

Negative binominal regression was conducted in Table 4 to demonstrate the association of identified posts' categories and number of engagements, adjusted for several characteristics. Number of engagements for unverified information was significantly higher for genuine information, with an IRR of 2.83 (95%CI 1.33 – 6.02), and remained significant after adjusted for source, time periods, or sentiment of the posts. Adjusted model of posts' categories shows online information made during outbreak received significantly higher number of engagements than online information made before or after the outbreak (IRR 0.15 (95%CI 0.07 – 0.35) and 0.46 (0.34 – 0.63), respectively). After controlling for sentiment, number of engagements of neutral posts were significantly higher than those of positive posts (IRR 0.60 (95%CI 0.37 – 0.97)) while being significantly lower than those of negative posts (IRR 1.84 (1.23 – 2.75)).

Table 4 is about here.

Analysis of identified misinformation and unverified information posts

Table 5 shows multivariable logistic regression for posts' characteristics between identified misinformation (Model 1), unverified information (Model 2) versus other post categories. Negative posts were significantly more likely being misinformation (OR 9.59 (95%CI 1.20 –

76.70)) or unverified information (OR 5.03 (95%CI 1.66 – 15.24)) than positive posts. There were no significant differences in probabilities of posts made in different time periods or made by different source being misinformation nor unverified information.

Table 5 is about here.

Sentiment analysis of selected online posts

There were 2660 positive words and 4748 negative words used in 500 selected posts. Higher uses of negative words than positive words were observed across all posts' categories, sources, and time periods (Figure 3). It can be seen that there was significantly higher number of negative words used in online newspaper, during post-outbreak, and in misinformation and unverified information (*Supplement Table 5*). Significantly higher number of positive words was also found in posts reporting misinformation and unverified information as compared to the other categories.

Figure 3 is about here.

Discussion

We found the volume of misinformation and unverified information amongst online information about public health interventions during the Da Nang COVID-19 outbreak to be low. Online posts containing unverified and misinformation were more likely to have negative sentiment and contain a higher number of negative or positive words, and unverified information receiving higher engagements than other posts categories.

Our study reported lower rates of misinformation than previous studies of COVID-19 or other recent epidemics (20,23,24). This might be explained previously by Gallotti et al (25), whose research found a lower risk of infodemics in countries with stable political contexts and consistent public health interventions and messages throughout the epidemic. In 2020, Vietnam was regularly praised of its stringent and strict measures in response to COVID-19, and achieved one of the lowest COVID-19 infections and fatalities rates of globally during 2020. This success might have mitigated the spread of infodemics in Vietnam (25).

Many other studies on 'infodemics' and 'infodemics' within COVID-19 context focused solely on Twitter (4,5,26). Meanwhile, our study extended to all publicly available in-country online information, and beyond social media platforms, included online newspapers and online forums, both being powerful information dissemination outlets in Vietnam. This thereby helped provide a reflection of online information flow outside the main international platforms that were used in previous research. Thanks to this, we found that online forums and online newspapers were also a source for misinformation and unverified information. This highlights both the gap in current research on COVID-19 misinformation, and the need for infodemics control by public health agencies.

We found a strong relationship between misinformation and unverified information with sentiment polarity. This finding is in line with Shahi et al (27) on COVID-19 misinformation on Twitter, which showed false claims featuring more negatively and more negative emotions than other news. In this study , more polarizing sentiments in misinformation were also closely related to the number of engagements of posts, which was also observed in previous studies on number of retweet to COVID-19 information (28,29). Our study showed that both unverified information and posts with negative sentiment were receiving higher engagements than other posts. Similar conclusions were drawn from other studies on COVID-19, showing that negative information received more retweets (30). Misinformation relies heavily on the implication of uncertainty and ambiguity of the situation, and create fear, anxiety, or negative emotions in the content they deliver to their readers. This may have also been the reason why we saw higher engagements for online information during the outbreak, the time when the general public might perceive as most uncertain towards the outbreak's evolution as well as the many measures implemented to contain it. Yet, this phenomenon of higher engagements towards unverified information indicated that false or partially false information was more likely to spread and engage users. This implies not only the wide spread of misinformation, but also the danger of infodemics during times of uncertainty during the pandemic. Public health agencies, governments and leaders should recognize this threat and strategize to effectively counter misinformation and unverified information, as the role of health education is crucial during pandemic times.

Our study was subject to several limitations. We did not explore more in more detail the account characteristics or the semantics used, which would have given a more comprehensive depiction of not only the content of the posts, but also the entities who spread such information. We also limited our analysis to three sentiment status (positive, negative, neutral). A more in-depth study on posts sentiments might have captured more accurately the emotions underlying the generation of online information, and more importantly, misinformation. Thirdly, we selected only the 500 most influential posts among all collected posts due to limited resources for data processing. Forth, due to nature of retrospective study, the accurate rate of information in real time during the outbreak might not have been captured since some information might have been retracted or deleted. Moreover, our study was limited to only five distinct public health interventions over a short period of time, which might have an impact on the generalizability of the findings. Nevertheless, we believe that, overall, our study offers a robust and valid analysis of online 'infodemics' on a serious public health threat during the ongoing COVID-19 epidemic.

Conclusion

Our study provides important evidence about the volume and dynamics of misinformation and unverified information as part of 'online infodemics' during the ongoing COVID-19 pandemic. While the volume of incorrect or unverifiable online information was low overall, we showed that social media are not the only affected type of online platform. Choice of words, sentiment, and influence of the source had strong impacts on their distribution. This study offers important insights for public health decision makers in Vietnam and other countries in the region with high rates of internet use to understand public perceptions of health interventions in response to COVID-19.

Abbreviations

SMCC: Social Media Command Center

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Conflicts of Interest

The authors declare no conflicts of interest.

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Table 1. Definitions of content categories.

Categories	Definition
Genuine information	Posts expressed information that cross-matched with the information presented by Official Guideline of Vietnam Ministry of Health, Official news outlet from Vietnam Government, World Health Organization, and/or at least two peer-reviewed scientific journals.
Misinformation	Posts expressed information that was easily refuted by at least one of abovementioned references.
Opinions	Posts expressed an opinion and did not relay any novel information.
Unverified information	Posts expressed information that could not be proven correct or incorrect by the references.

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Table 2. Descriptive characteristics of all collected online posts of NPIs during COVID-19 outbreak in Vietnam in July – September 2020.

Variables	Topics				
	Cordon sanitaire (N = 10099)	**National high school examination (N = 3529)**	**Bluezone application (N = 16769)**	**COVID-19 quarantine breach (N = 22170)**	**National contact tracing (N = 1961)**
Number of posts per day (n)	131.16	45.83	254.07	287.92	33.61
Number of engagements per posts (n)	101.38	36.82	54.70	180.81	86.17
Influence score per post (Mean, SD)	5.00 (3.38)	4.59 (3.21)	3.91 (3.02)	4.31 (3.28)	4.71 (3.27)
Number of posts per source (n, %)					
Social media	1647 (16.31)	438 (12.41)	5322 (31.74)	6435 (28.62)	191 (9.97)
Online forum	318 (3.15)	49 (1.39)	3511 (20.94)	4588 (20.69)	40 (2.09)
Online newspaper	8134 (80.54)	3042 (86.02)	7936 (47.33)	11237 (50.69)	1685 (87.94)
Number of posts per period (n, %)					
Pre-outbreak	1216 (12.04)	703 (19.92)	47 (0.28)	2351 (10.60)	8 (0.42)
During outbreak	8224 (81.43)	2471 (70.02)	14684 (87.57)	18874 (85.13)	1782 (93.01)
Post-outbreak	659 (6.53)	355 (10.06)	2038 (12.15)	945 (4.26)	126 (6.58)
Number of posts per day per period (n)					
Pre-outbreak	50.67	29.29	1.96	97.96	0.33
During outbreak	216.42	65.03	386.42	496.68	46.89
Post-outbreak	43.93	23.67	135.87	63.00	8.4

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Table 3

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Table 3. Descriptive characteristics of selected online posts stratified between posts' categories.

Variables	Posts' categories				Total	*P*
	Genuine information	**Misinformation posts**	**Opinion**	**Unverified information**		
Number of posts (n, %)	316 (63.20)	10 (2.00)	152 (30.40)	22 (4.40)	500 (100)	
Number of engagements (Median, IQR)	2004 (200.5 – 11230)	1964.5 (43 – 5052)	2474.5 (924 – 11160.5)	13415 (8507 – 22869)	2474.5 (407 – 11777.5)	<.001[a]
Influence score (Mean, SD)	4.43 (2.09)	4.50 (1.58)	4.60 (2.18)	4.59 (2.11)	4.49 (2.10)	.878[c]
Source (n, %)						
Social media	99 (31.33)	8 (80)	41 (26.79)	4 (18.18)	152 (30.40)	
Online forum	80 (25.32)	2 (20)	51 (33.55)	11 (50.00)	144 (28.80)	.002[b]
Online newspaper	137 (43.35)	0 (0)	60 (39.47)	7 (31.82)	204 (40.80)	
Sentiment categories (n, %)						
Positive	61 (19.30)	1 (10)	81 (53.29)	4 (18.18)	147 (29.40)	
Neutral	196 (62.03)	0 (0)	11 (7.24)	0 (0)	207 (41.40)	<.001[b]
Negative	59 (18.67)	9 (90)	60 (39.47)	18 (81.82)	146 (29.20)	
Periods (n, %)						
Pre-outbreak	19 (6.01)	0 (0)	6 (3.95)	3 (13.64)	28 (5.60)	
During outbreak	257 (81.33)	10 (100)	139 (91.45)	19 (86.36)	425 (85.00)	.017[b]
Post-outbreak	40 (12.66)	0 (0)	7 (4.61)	0 (0)	47 (9.40)	

Note. p-value was calculated by [a]Kruskal-Wallis rank test, [b]Fisher's exact test or [c]ANOVA test.

1

* Updated table 3 is on the next page.

Variables	Posts' categories				Total	*P*
	Genuine information	Misinformation posts	Opinion	Unverified information		
Number of posts (n, %)	316 (63.20)	10 (2.00)	152 (30.40)	22 (4.40)	500 (100)	
Number of engagements (Median, IQR)	2004 (200.5 – 11230)	1964.5 (43 – 5052)	2474.5 (924 – 11160.5)	13415 (8507 – 22869)	2474.5 (407 – 11777.5)	<.001[a]
Influence score (Mean, SD)	4.43 (2.09)	4.50 (1.58)	4.60 (2.18)	4.59 (2.11)	4.49 (2.10)	.878[c]
Source (n, %)						
Social media	99 (31.33)	8 (80)	41 (26.79)	4 (18.18)	152 (30.40)	
Online forum	80 (25.32)	2 (20)	51 (33.55)	11 (50.00)	144 (28.80)	.002[b]
Online newspaper	137 (43.35)	0 (0)	60 (39.47)	7 (31.82)	204 (40.80)	
Sentiment categories (n, %)						
Positive	61 (19.30)	1 (10)	81 (53.29)	4 (18.18)	147 (29.40)	
Neutral	196 (62.03)	0 (0)	11 (7.24)	0 (0)	207 (41.40)	<.001[b]
Negative	59 (18.67)	9 (90)	60 (39.47)	18 (81.82)	146 (29.20)	
Topics (n, %)						
Cordon sanitaire	63 (19.94)	2 (20.00)	31 (20.39)	4 (18.18)	100 (20.00)	<.001[b]
National high school examination	63 (20.25)	1 (10.00)	35 (23.03)	0 (0)	100 (20.00)	
Bluezone application	46 (14.56)	3 (30.00)	51 (33.55)	0 (0)	100 (20.00)	
COVID-19 quarantine breach	51 (16.14)	2 (20.00)	29 (19.08)	18 (81.82)	100 (20.00)	
National contact tracing	92 (29.11)	2 (20.00)	8 (3.95)	0 (0)	100 (20.00)	
Periods (n, %)						
Pre-outbreak	19 (6.01)	0 (0)	6 (3.95)	3 (13.64)	28 (5.60)	
During outbreak	257 (81.33)	10 (100)	139 (91.45)	19 (86.36)	425 (85.00)	.017[b]
Post-outbreak	40 (12.66)	0 (0)	7 (4.61)	0 (0)	47 (9.40)	

Note. p-value was calculated by [a]Kruskal-Wallis rank test, [b]Fisher's exact test or [c]ANOVA test.

Table 4 Click here to access/download;Table;7. Table 4_Infodemics_PHIs_20 Sep 2021.docx

Table 4. Negative binominal regression for the association between number of engagements and posts' categories.

Variables	Univariate analysis		Model 1		Model 2		Model 3	
	IRR	95% CI	IRR	95% CI	IRR	95% CI	IRR	95% CI
Posts' categories								
Genuine information	*Ref*		*Ref*		*Ref*		*Ref*	
Misinformation	0.91	0.28 – 2.98	0.84	0.26 – 2.71	0.80	0.24 – 2.62	0.58	0.18 – 1.83
Opinion	1.17	0.81 – 1.71	1.19	1.83 – 1.70	1.09	0.75 – 1.58	1.29	0.81 – 2.04
Unverified information	2.83*	1.33 – 6.02	3.15*	1.40 – 7.10	2.81**	1.42 – 5.56	1.98*	0.99 – 3.98
Source								
Social media	*Ref*		*Ref*					
Online forum	0.88	0.56 – 1.37	0.74	0.51 – 1.06				
Online newspaper	0.97	0.67 – 1.41	0.94	0.65 – 1.35				
Period								
During outbreak	*Ref*				*Ref*			
Pre-outbreak	0.17***	0.08 – 0.35			0.15***	0.07 – 0.35		
Post-outbreak	0.42	0.31 – 0.57			0.46***	0.34 – 0.63		
Sentiment								
Neutral	*Ref*						*Ref*	
Positive	0.70	0.47 – 1.05					0.60**	0.37 – 0.97
Negative	2.12***	1.45 – 3.09					1.84**	1.23 – 2.75

$^{*}P< .5$; $^{**}P< .005$; $^{***}P< .001$.
Model 1: Number of engagements by posts' categories adjusted for source of posts
Model 2: Number of engagements by posts' categories adjusted for time periods
Model 3: Number of engagements by posts' categories adjusted for sentiment polarities

1

Table 5 Click here to access/download;Table;8. Table 5_Infodemics_PHIs_20 Sep 2021.docx

Table 5. Logistic regression for posts' characteristics between misinformation and verified information versus other post categories.

Variables	Model 1: Misinformation					Model 2: Unverified information				
	Proportion (n/N)	Univariate analysis		Multivariable analysis		Proportion (n/N)	Univariate analysis		Adjusted analysis	
		OR	95% CI	OR	95% CI		OR	95% CI	OR	95% CI
Source										
Social media	8/152	*Ref*		*Ref*		4/152	*Ref*		*Ref*	
Online forum	2/144	0.25	0.05 – 1.21	0.23	0.05 – 1.13	11/144	3.06	0.95 – 9.84	3.04	0.91 – 10.24
Online newspaper	0/204					7/204	1.31	0.38 – 4.57	1.84	0.50 – 6.73
Sentiment polarity										
Positive	1/147	*Ref*		*Ref*		4/147	*Ref*		*Ref*	
Negative	9/146	9.59*	1.20 – 76.70	7.62	0.93 – 62.05	18/146	5.03**	1.66 – 15.24	5.05**	1.63 – 15.65
Neutral	0/207					0/207				
Period										
During outbreak	10/425					19/425	*Ref*		*Ref*	
Pre-outbreak	0/28					3/28	2.56	0.71 – 9.25	2.77	0.68 – 11.32
Post-outbreak	0/47					0/47				

$^{*}P < .05$; $^{**}P < .005$.
Model 1: Logistic regression for source and sentiment of posts between misinformation versus other post categories.
Model 2: Logistic regression for source, sentiment, and time periods between unverified information versus other post categories.

1

Figure 1. (A) Epidemic curve of COVID-19 epidemic in Vietnam from June to August 2020. Shaded area indicates the outbreak period in Da Nang. (B) Epidemic curve of COVID-19 outbreak in Da Nang, Vietnam from 25 July – 31 August 2020.

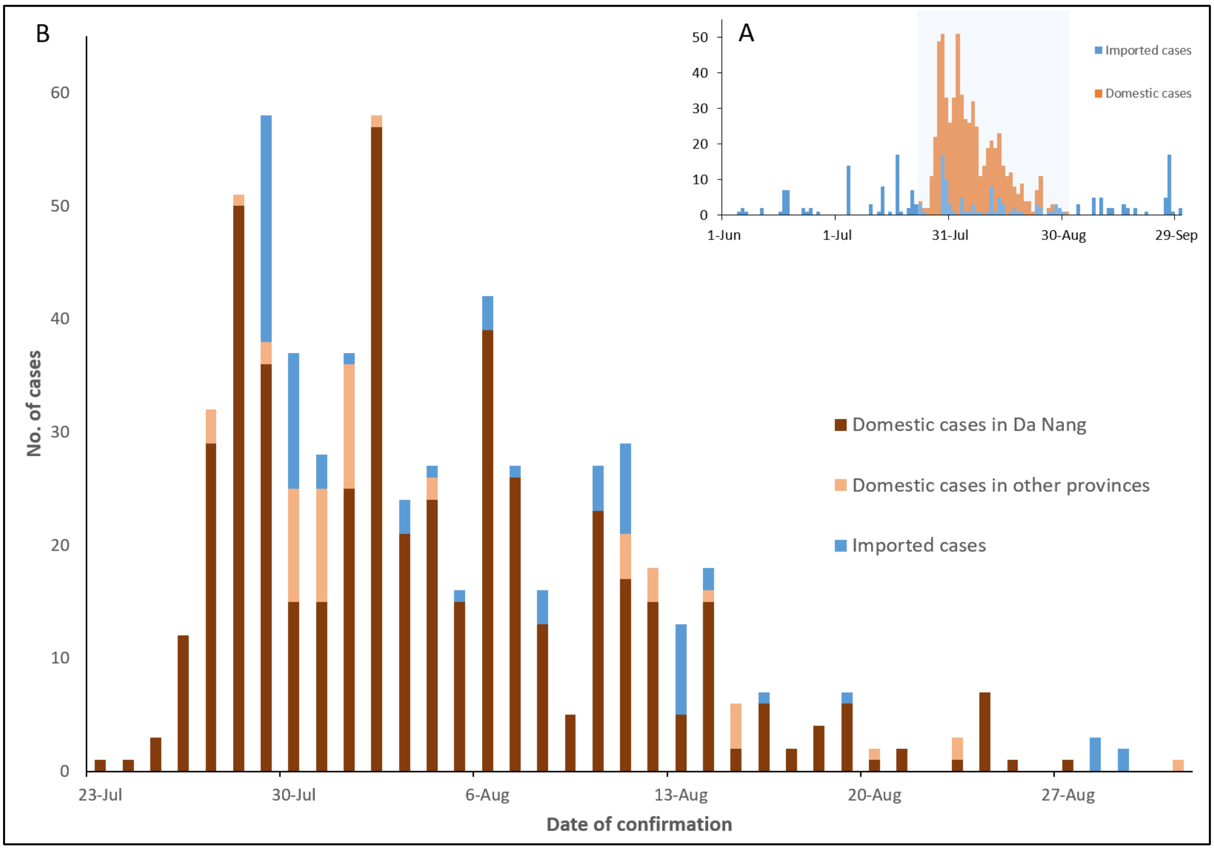


Figure 2. Distribution of online information across time periods of the outbreak stratified by five NPIs topics.

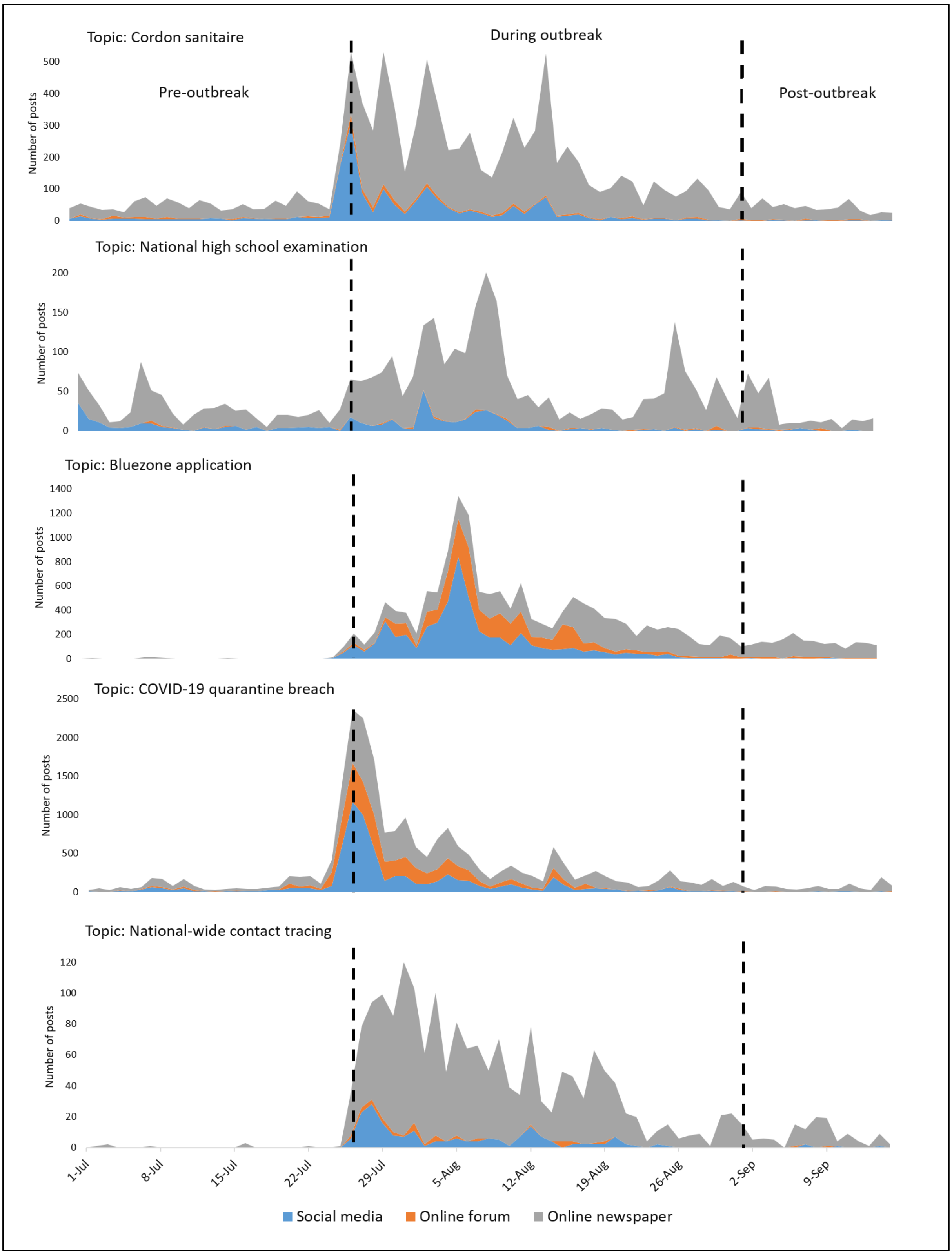
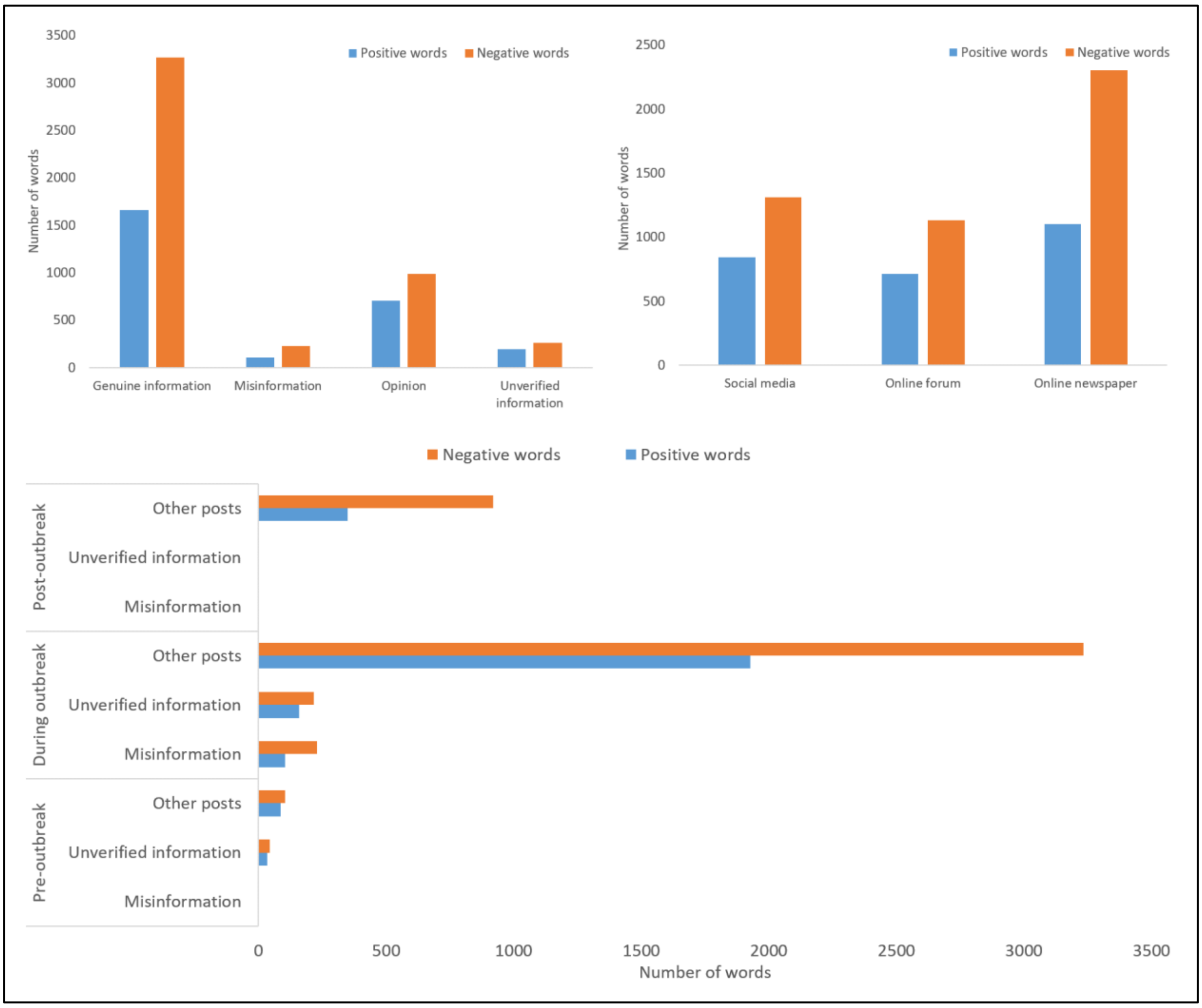
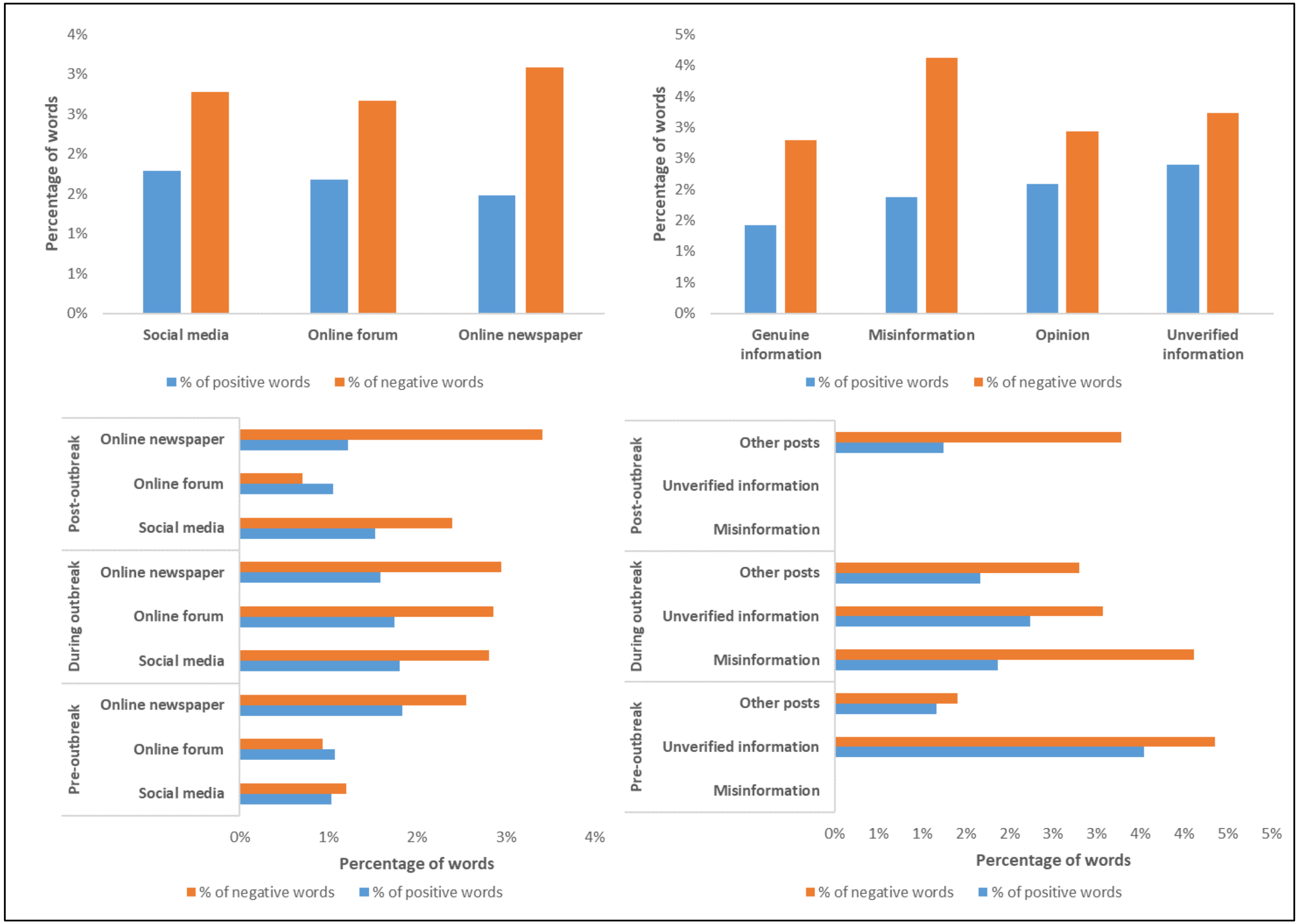


Figure 3[*]**.** Distribution of positive and negative words used in 500 selected online posts stratified by posts' characteristics.



[*] Corrected figure is on the next page.

Corrected Figure 3. Percentage of positive and negative words over all words used in 500 selected online posts stratified by posts' characteristics.



Supplement Table 1. Keywords identified for data collection

Topic 1: Cordon sanitaire for cluster areas

Main keywords	*Vietnamese*: Đà Nẵng, Quảng Nam, Hội An, cách ly, chỉ thị, số 16, thủ tướng, chính phủ, phòng chống, covid, covid19, virus, corona, dương tính, cộng đồng, lây nhiễm, nguy cơ, dịch bệnh, giãn cách, xã hội, SARS-CoV-2 *English*: Da Nang, Quang Nam, Hoi An, cordon sanitaire, lock down, policy no.16, prevention, covid, covid19, virus, corona, positive, community, infection, risk, disease, gap, social, SARS-CoV-2
Assisting keywords	*Vietnamese*: khẩu trang, dừng, hoạt động, hành khách, phương tiện, lương thực, thực phẩm, xét nghiệm, lây lan, khoanh vùng, dập dịch, Ban Chỉ đạo, làn sóng, thứ hai, chuyên gia, bộ y tế, bệnh viện, khoảng cách, phong tỏa, đóng cửa, truy vết, điều tra, dịch tễ, diện rộng, vắng người, bệnh nặng, bệnh nhân, nghi nhiễm, ca bệnh. *English*: mask, passenger, vehicle, essential activities, test, spread, zoning, epidemic, social distance, blockade, closure, trace, investigation, serious illness, patient, suspected infection, case.

Topic 2: National high school examination

Main keywords	*Vietnamese*: Kỳ thi, tốt nghiệp, THPT, phổ thông, Quốc gia, bộ GD&ĐT, nghỉ học, dịch, lịch, thời gian, dời, bài thi, điều chỉnh, lùi, kế hoạch, ôn thi, kết thúc, covid-19, covid, cả nước, đợt hai, đợt một *English*: Exams, graduation, high school, university, entrance, national, Ministry of Education and Training, schedule, time, reschedule, adjustment, schedule, covid-19 covid, nationwide.
Assisting keywords	*Vietnamese*: Đề xuất, chỉ thị, số 16, thủ tướng, chính phủ, phòng chống, Quảng Nam, Đà Nẵng, tâm dịch, tiếp xúc gần, F1, F2, tinh giản, phân hóa, tổ hợp, xét tuyển, đại học, mức điểm, công bố, diễn biến, phức tạp, điểm thi, chấm thi, an toàn, thí sinh, sức khỏe, dự phòng, đặc cách, đề thi, điểm chuẩn, hoang mang, lo lắng, sĩ tử, trắc nghiệm. *English*: Proposal, directive number 16, prime minister, government, prevention, Quang Nam, Da Nang, close contact, F1, F2, streamline, differentiate, combine, admission, university, score, announcement, safety, candidate, health, prevention, benchmarking, multiple choice .

Topic 3: Bluezone application

Main keywords	*Vietnamese:* Bluezone, blue, zone, ứng dụng, cài đặt, truy vết, tiếp xúc, gần, covid, covid19, virus, corona, dương tính, ca bệnh, nhiễm, F0, F1, F2, quét *English*: Bluezone, blue, zone, application, settings, trace, contact, close, covid, covid19, virus, corona, positive, case, infection, F0, F1, F2, scan.
Assisting keywords	*Vietnamese*: cảnh báo, Bluetooth, hệ thống, điện thoại, app store, ghi nhận, cảnh báo, nguy cơ, mắc, bảo vệ, thông tin, an toàn, riêng tư, chính phủ, truy cập, dữ liệu, phát hiện, khoanh vùng, đẩy lùi, dịch, phòng chống, lây lan, cộng đồng, khoảng cách, liên tục, 15 phút, 2 mét, cấp quyền, theo dõi, vị trí, bảo vệ, bộ y tế, sức khỏe, xung quanh, lịch sử, ẩn danh. *English*: alert, Bluetooth, system, phone, app store, recording, warning, risk, cost, protection, information, safety, privacy, government, access, data, detection, lock region, repel, epidemic, prevention, spread, community, distance, continuous, 15

	minutes, 2 meters, authorization, track, location, department of health, surrounding, history, anonymity.

Topic 4: COVID-19 quarantine breach

Main keywords	*Vietnamese*: trốn, cách ly, y tế, án tù, hình sự, khai báo, gian dối xử lý, pháp luật, cửa khẩu, biên giới, vượt biên, xử phạt, Trung Quốc, Lào, Campuchia, Việt Nam, nước ngoài, covid, covid19, virus, corona, dịch bệnh. *English*: escapee, isolation, medical, quarantine, criminal, declaration, punishment, fraudulent handling, law, border gate, border, cross border, sanction, China, Laos, Cambodia, Vietnam, abroad, covid, covid19, virus, corona, epidemic.
Assisting keywords	*Vietnamese*: nguy cơ, nguy hiểm, an toàn, lây truyền, lây nhiễm, cộng đồng, nghiêm, hành vi, quy định, phạt tiền, truyền nhiễm, trường hợp, xét nghiệm, âm tính, dương tính, nghi nhiễm, mắc bệnh, chế tài, gian dối, giấu dịch, phát hiện, vận chuyển, vi phạm *English*: risk, danger, safety, transmission, infectious, community, strict, behavior, regulation, fine, contagious, case, test, negative, positive, suspected, infected, sanctions, cheating, hiding translation, detection, transport, violations.

Topic 5: Contact tracing

Main keywords	*Vietnamese*: Du lịch, công tác, Đà Nẵng, xét nghiệm, lấy mẫu, lây lan, kháng thể, RT-PCR, PCR, khai báo, y tế, du khách, khách du lịch, âm tính, dương tính, phòng chống, covid, covid19, virus, corona, chủ động, dịch bệnh, SARS-CoV-2. *English*: Travel, business, Da Nang, test, sampling, spread, antibody, RT-PCR, PCR, health declaration, medical, tourist, traveler, negative, positive, prevention, covid , covid19, virus, corona, proactive, epidemic, SARS-CoV-2.
Assisting keywords	*Vietnamese*: Quảng Nam, Hội An, nguy cơ, lây nhiễm, cộng dồng, tâm dịch, lây lan, cách ly, thân nhiệt, theo dõi, sức khỏe, tiền sử, lịch sử, tiếp xúc, F1, F2, test nhanh, nước ngoài, giám sát, bệnh nhân, nghi nghiễm, ho sốt, tức ngực, biểu hiện, trường hợp. *English*: Quang Nam, Hoi An, risk, infection, community, epidemic, isolation, body temperature, history, exposure, F1, F2, rapid test, foreign, surveillance, patient, suspected, cough, fever, chest pain, manifestation, case.

Supplement Table 2. Online platforms source for data collection.

Source	Platform name
Social media	YouTube, Facebook, Instagram, Zalo, Zingme, Twitter, etc. More details can be found at lists of social media in Vietnam (1,2).
Online forum	Tinhtc.vn, webtretho.com, lamchame.com, 5giay.vn, vatgia.com, vozforums.com, spiderum.com, chodientu.vn, etc. More details can be found at lists of online forums in Vietnam (1).
Online newspaper	dantri.com, vnexpress.com, ngoisao.net, vovnews.vn, nhandan.vn, laodong.vn, etc. More details can be found at lists of official online news outlet in Vietnam (3,4).

Supplement Table 3. Definition of variables collected for online posts.

Variables	Definition
Sources	Nominal data of types of online platforms where the posts were made public, categorized into three types: online newspaper, online forum, and social media network
Periods	Nominal data of date when the post officially went public, categorized into three stages: Pre-outbreak (1 – 24 July 2020); during outbreak (25 July – 31 August 2020); and post-outbreak (1 – 15 September 2020)
Number of engagements	Numeric data equivalent to the total number of likes, shares, and comments for each posts
Influence score	Influence score given to each source calculated from number of followers and/or viewers of the source (Calculated by Supplement Table 4)
Text	Textual data of each posts

Supplement Table 4. Influence score calculation based on data software function.

Number of followers/views	Influence score
Less than 10	0
From 10 to 10.000	1
From 10.000 to 20.000	2
From 20.000 to 50.000	3
From 50.000 to 100.000	4
From 100.000 to 200.000	5
From 200.000 to 500.000	6
From 500.000 to 1.000.000	7
From 1.000.000 to 2.000.000	8
From 2.000.000 to 5.000.000	9
From 5.000.000 up	10

Note. Views were applied to online newspaper and forum entries, followers were applied for social media.

Supplement Table 5. Mean and standard deviation of number of positive and negative words in 500 selected online posts.

Variables	Positive words		Negative words	
	Mean (SD)	***P***	**Mean (SD)**	***P***
Source				
Social media	5.55 (8.03)		8.62 (9.46)	
Online forum	4.95 (7.01)	.762	7.87 (9.98)	.005
Online newspaper	5.41 (6.93)		11.29 (11.21)	
Period				
Pre-outbreak	4.36 (8.15)		5.29 (9.39)	
During outbreak	5.15 (7.35)	.103	8.66 (9.51)	<.001
Post-outbreak	7.40 (5.92)		19.57 (13.30)	
Posts' categories				
Genuine information	5.25 (7.00)		10.34 (10.37)	
Misinformation	10.4 (14.77)	.010	22.90 (16.62)	<.001
Opinion	4.62 (6.28)		6.52 (8.72)	
Unverified information	8.77 (11.07)		11.82 (12.12)	

Note. *P* was calculated by ANOVA test.

References

1. 100 largest social media and forums in Vietnam [Internet]. HTL IT. [cited 2021 Aug 13]. Available from: https://htlit.maytinhhtl.com/kien-thuc-it/danh-sach-100-mang-xa-hoi-lon-nhat-viet-nam.html
2. Quoc Khanh. Top 16 social medias with highest users in Vietnam in 2021 [Internet]. ATP Web. 2020 [cited 2021 Aug 13]. Available from: https://atpweb.vn/blog/cac-mang-xa-hoi-pho-bien-tren-the-gioi/
3. Vietnam Yellow Page. Online Newspaper [Internet]. [cited 2021 Aug 13]. Available from: https://www.yellowpages.vn/cls/87250/bao-dien-tu.html
4. Wikipedia. Online News Outlet in Vietnam [Internet]. [cited 2021 Aug 13]. Available from: https://vi.wikipedia.org/wiki/Danh_sách_báo_điện_tử_tiếng_Việt

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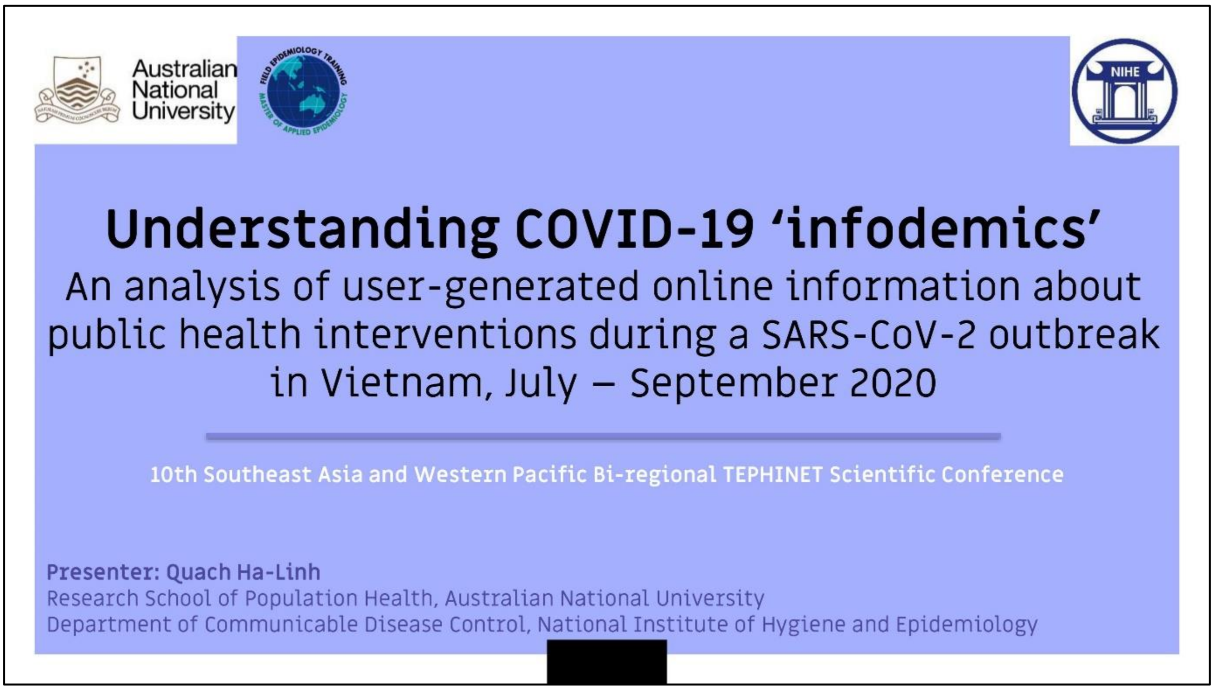
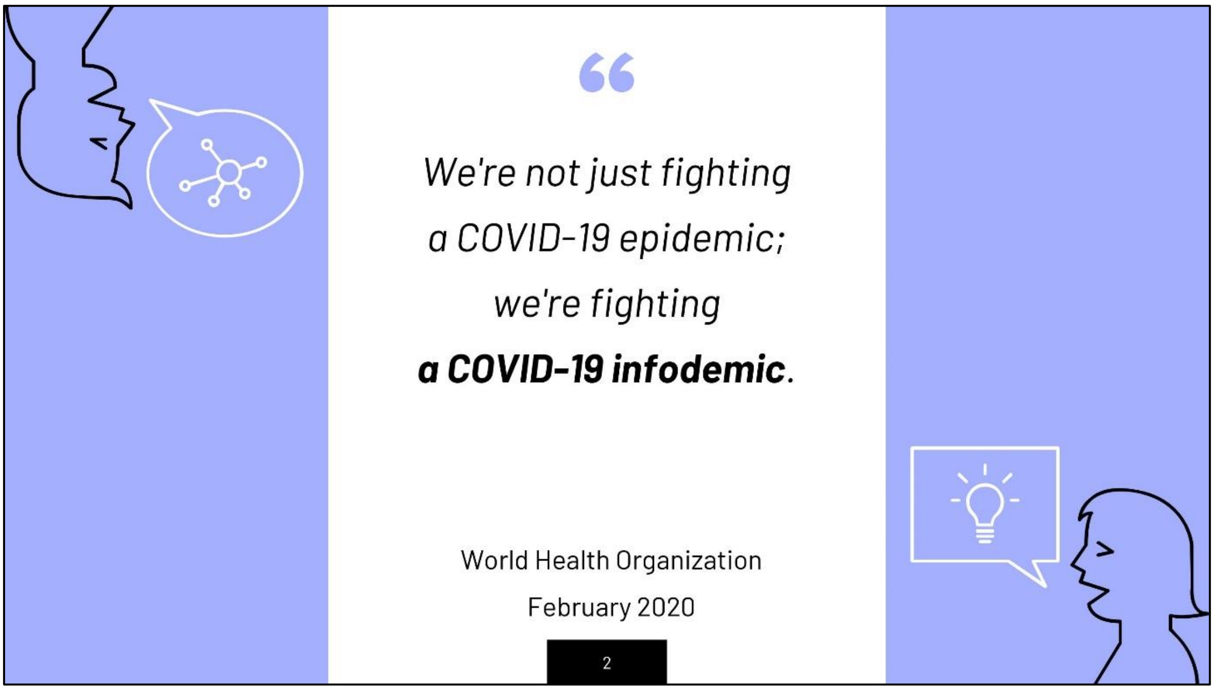
Appendix 3. Conference presentation 2.

<u>Quach HL</u>, Hoang NA, Nguyen CK, Pham QT, Phung CD, Le HS, Le CT, Vogt F, **Understanding COVID-19 'infodemics': An analysis of user-generated online information about public health interventions during a SARS-CoV-2 outbreak in Vietnam, July – September 2020**, Oral presentation, 10th Southeast Asia and Western Pacific Bi-regional TEPHINET Scientific Conference (virtual conference), 01-05 November 2021.

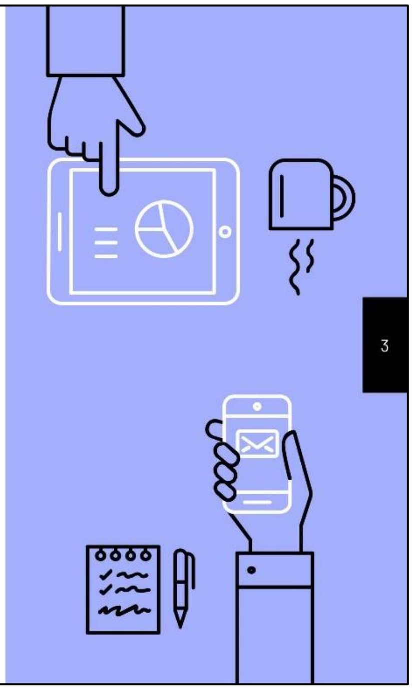




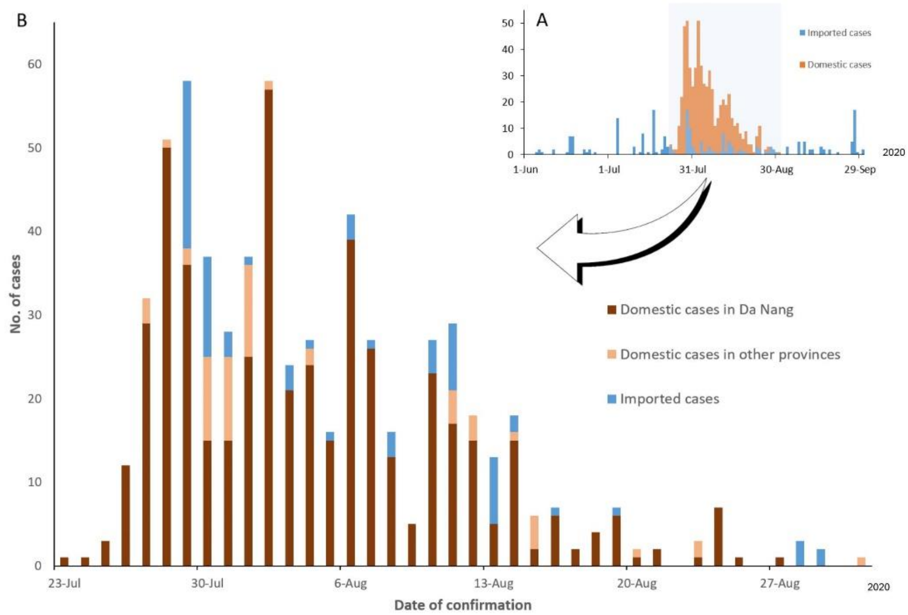
BACKGROUND

- COVID-19-related information has been spreading uninhibitedly over **traditional and social media platforms**.
- **"Infodemics"** is defined as the **over-abundance of information** regarding an emerging event

→ Impact **public perception and public health** in response to the event

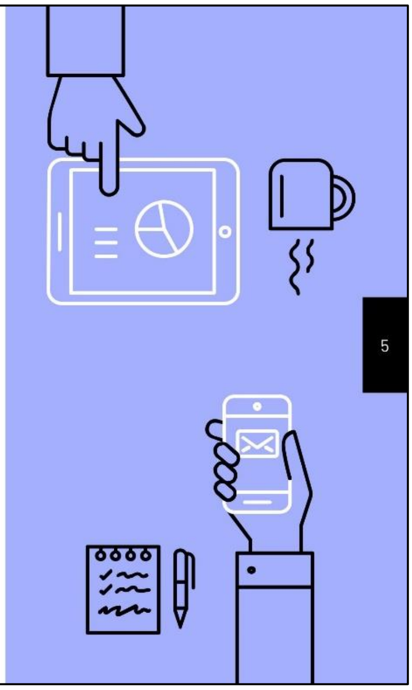


Epidemic curve of COVID-19 in Da Nang outbreak, Vietnam from July to August 2020



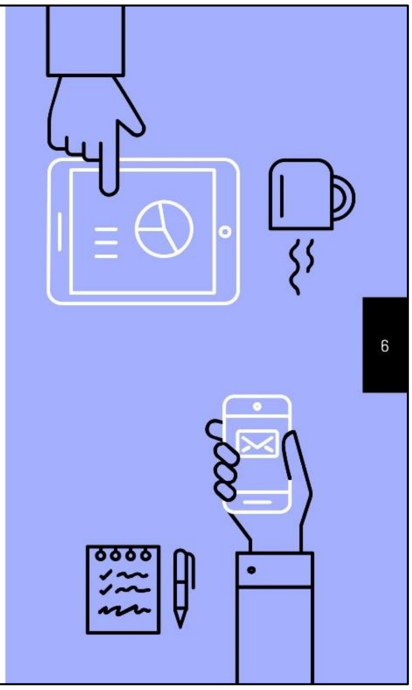
SETTING

- **A series of public health interventions** were implemented in response to this outbreak.
- Information about these policies were frequently broadcasted by **various other outlets**, including online platforms to **estimated 69 million internet users** in Vietnam.



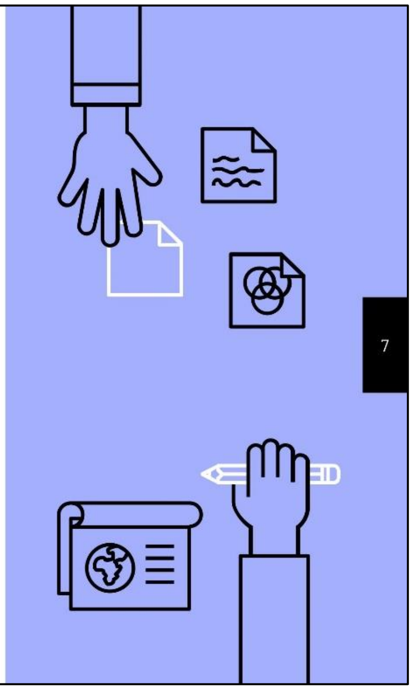
OBJECTIVES

- Analyse the **magnitude and dynamics** of **user-generated online information** about five distinct public health interventions in response to the COVID-19 outbreak in Da Nang, Vietnam between July to September 2020.



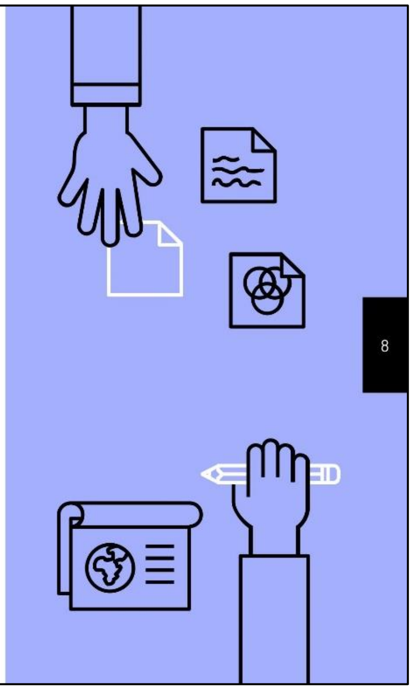
PUBLIC HEALTH INTERVENTIONS

- **Cordon sanitaire** of outbreak areas
- Re-scheduling of **national high school examination**
- '*Bluezone*' – Vietnam's **official contact tracing mobile phone app** for COVID-19
- **National tracking and prosecution** of illegal border crossing and quarantine breaches.
- **National contact tracing**, serology testing and quarantine for all people from outbreak areas.



Data sources

- Publicly available information posted on **online platforms in Vietnam** from **1 Jul – 15 Sep 2020** in Vietnamese language.
- Data extraction from an **internet archive database** ("**Social Media Command Center**" software) by Vietnam Ministry of Science and Technology.
- **Collected variables**: (i) source, (ii) outbreak periods, (iii) number of engagements, (iv) influence score, and (v) text.



Definitions

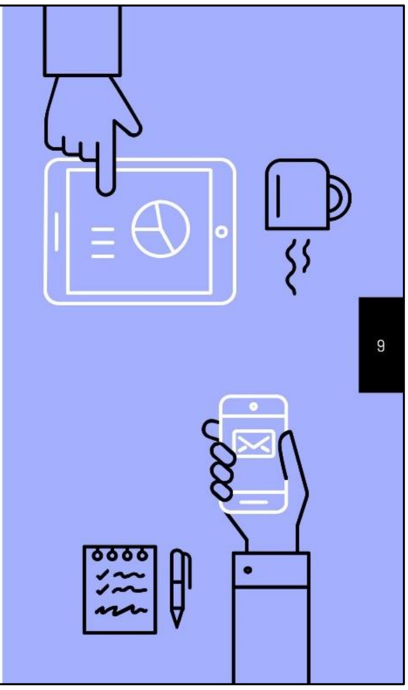
Sources
Online newspaper, online forum, social media

Periods
Pre-outbreak, During outbreak, Post-outbreak

Engagements
Likes + Shares + Comments to the posts

Influence score
Based on number of followers of the source

Textual content



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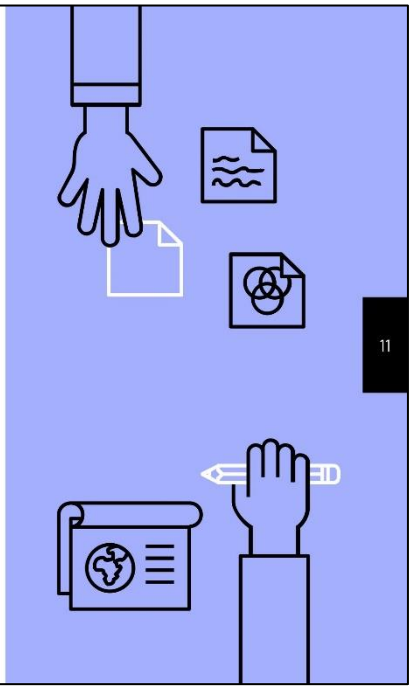
Data processing

- Selected the 500 posts with **highest number of engagement**
- Categorized 500 posts based on textual content:

Categories	Definition
Genuine information	Posts expressed information that cross-matched with the information presented in official guidelines of the Vietnam Ministry of Health, World Health Organization, and/or peer-reviewed scientific journals.
Misinformation	Posts expressed information that was easily refuted by at least one of abovementioned references.
Opinions	Posts expressed an opinion and did not relay any factual information.
Unverified information	Posts expressed information that could not be proven correct or incorrect by the references.

Data analysis

- **Sentiment classifications** based on textual content of selected posts using Natural Language Processing → classify to: **positive, neutral, negative,** and **number of negative and positive words**.
- **Negative binominal regression** to explore the relationship between number of engagements and posts' categories
- **Logistic regression** to explore the distribution of posts' characteristics amongst posts categories.



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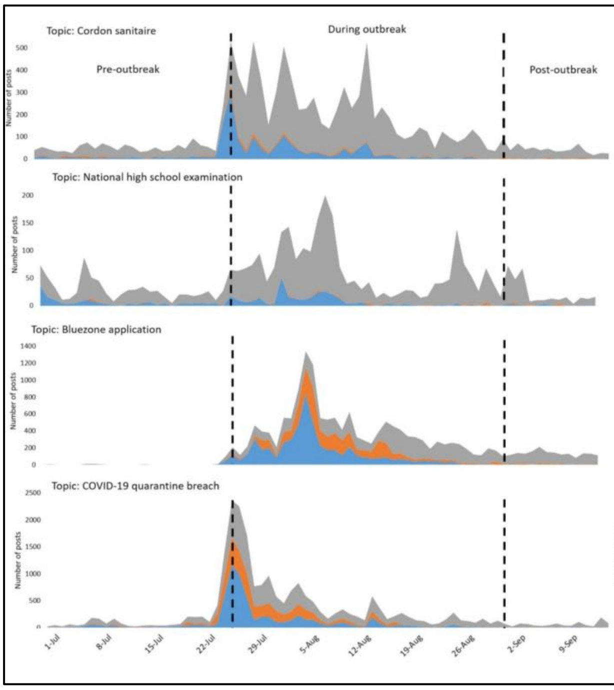
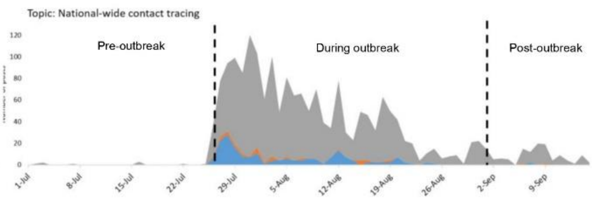


RESULTS

- Highest number of posts **during outbreak**.
- **Online newspaper** was the consistent source reporting highest number of posts.

■ Social media ■ Online forum ■ Online newspaper

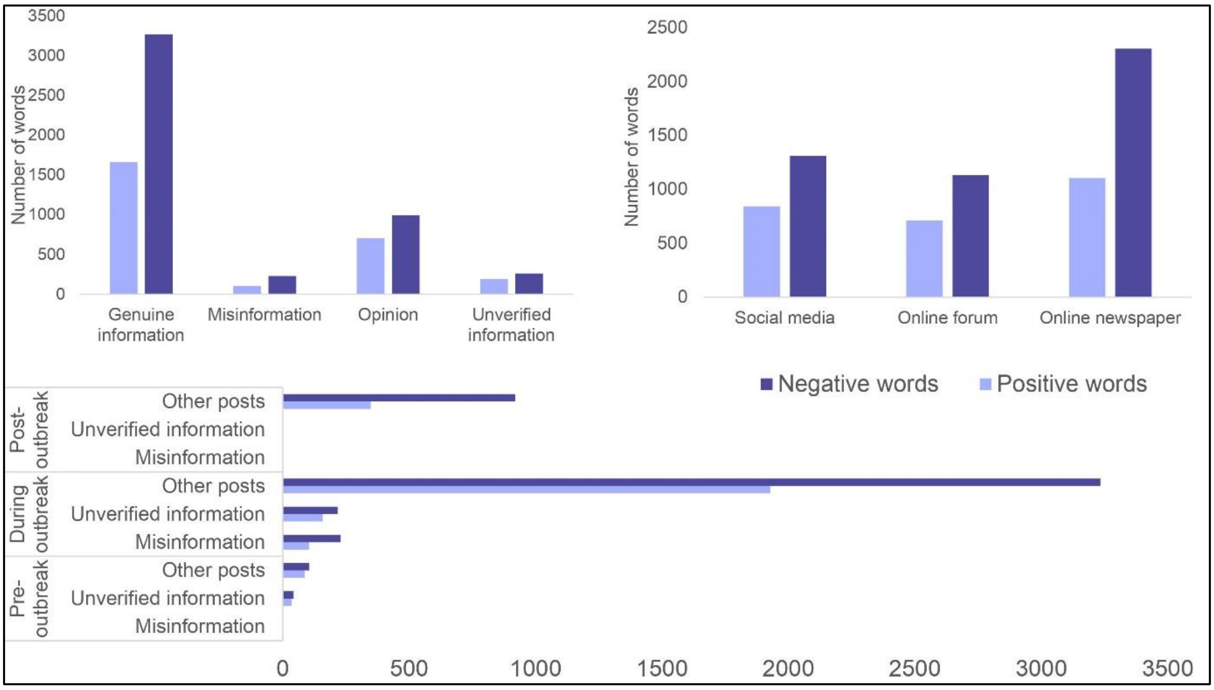


RESULTS

Genuine information (N=316, 63.20%)	• Highest number made on online newspapers and during the outbreak. • Account for most of neutrally-toned posts
Misinformation (N=10, 20.00%)	• Most made on social media (8/10) • All made during the outbreak • None on newspaper or neutral
Opinions (N=152, 30.40%)	• Highest number made on newspaper and during the outbreak. • Account for most of negative-toned posts
Unverified information (N=22, 4.40%)	• Half made on online forum • None made with neutral sentiment or after the outbreak

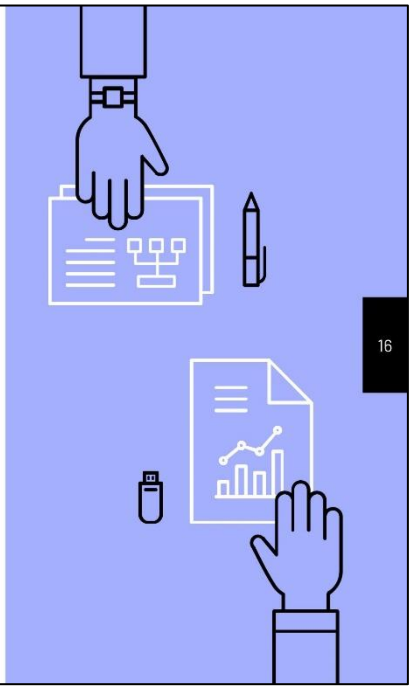
RESULTS

- **Unverified information** got significantly higher engagements than **genuine information** (IRR 2.83 (95%CI 1.33 – 6.02)).
- Posts **during outbreak** got significantly higher engagements than **before or after the outbreak** (IRR 0.15 (95%CI 0.07 – 0.35) and 0.46 (0.34 – 0.63)).
- Number of engagements of **negative posts >> neutral posts >> positive posts**.
- **Negative posts** were predominantly **misinformation** (OR 9.59 (95%CI 1.20 – 76.70)) or **unverified information** (OR 5.03 (95%CI 1.66 – 15.24)) compared to positive posts.



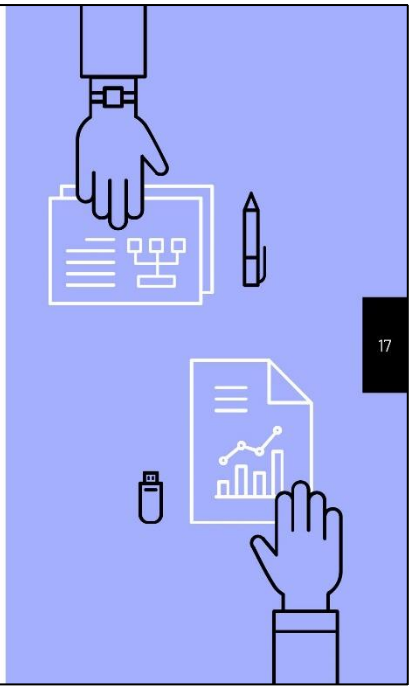
DISCUSSION

- **Lower rates of misinformation and unverified information** than seen in previous studies.
- **Online forums and online newspapers** identified as source of misinformation and unverified information.
- Strong relationship between content validity and **sentiment polarity, engagements and influence** online.



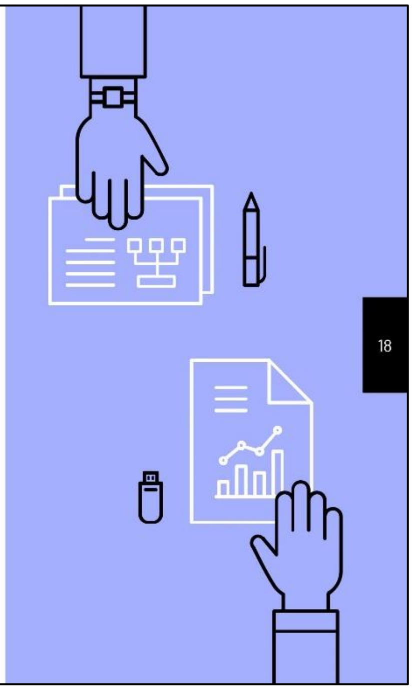
LIMITATIONS

- Limited analysis into account, semantics, and sentiment analysis
- Limited number of posts for in-depth analysis (N=500)
- Lack of timely data capture in real-time of the outbreak



CONCLUSIONS

- **Social media** are not the only affected platform by infodemics.
- **Choice of words and sentiments** have significant impact to information spread.
- Countries with **high rates of internet use** should consider **analyze infodemics** during epidemics.




ACKNOWLEDGEMENT
• Dr Florian Vogt, Research School of Population Health, Australian National University
• Dr Nguyen Cong Khanh, National Institute of Hygiene and Epidemiology
• Ms Ngoc-Anh Hoang, Master of Applied Epidemiology scholar
• INFORE Company, Ministry of Science and Technology, and Rapid Response Team of National Steering Committee of COVID-19 Prevention and Control
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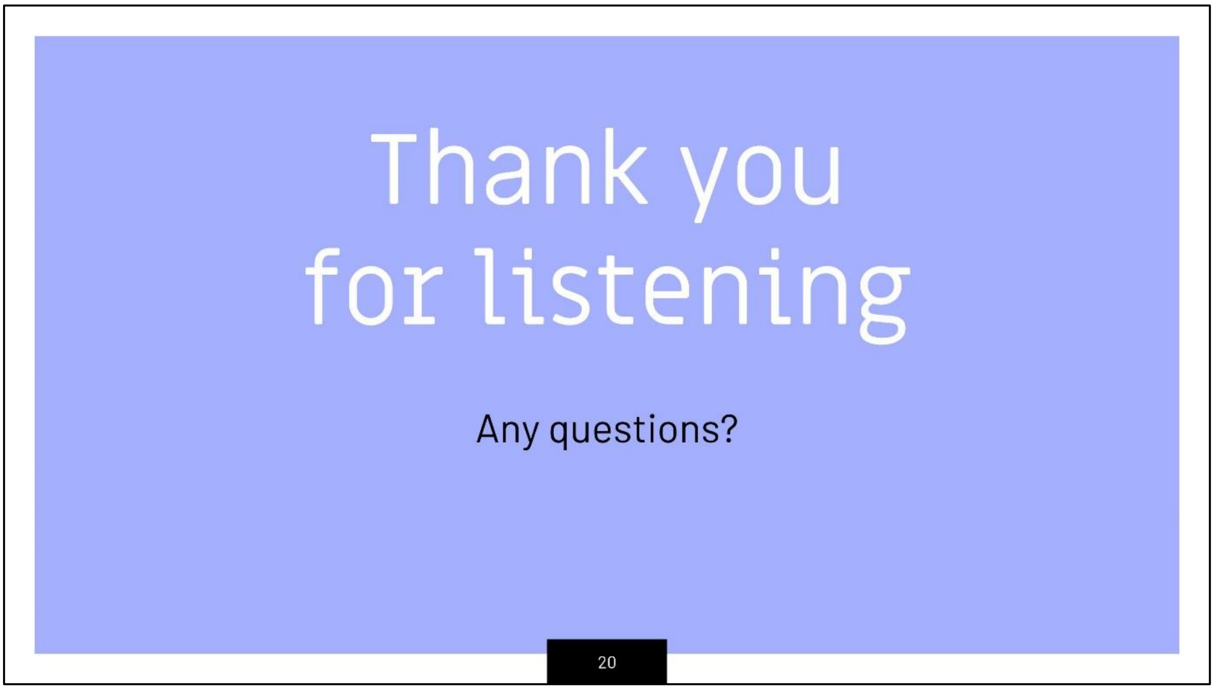
Thank you for listening
Any questions?
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Chapter 6. Other MAE Requirements

Lay audience report: "Equality in COVID-19 vaccination administration – a dilemma"

Lesson from the field: "An introduction to MicrobeTrace"

Teaching: "An introduction to MicrobeTrace"

Table of Content – Chapter 6

List of Abbreviations – Chapter 6

CDC	Center for Disease Control and Prevention
COVID-19	Coronavirus 2019
LFF	Lesson From the Field
MAE	Master of Applied Epidemiology
NIHE	National Institute of Hygiene and Epidemiology
SARS-CoV-2	Severe Acute Respiratory Syndrome Coronavirus 2
WHO	World Health Organization

1. Lay audience report

The report was written by me and edited by Dr. Pham Quang Thai – another Master of Applied Epidemiology (MAE)’s field supervisor in my field placement. The report is available on the internet and as print version on the Vietnam Ministry of Health’s Official Press Outlet named “Suc Khoe & Doi Song” (Health & Lifestyle). This journal is run by the Vietnam Ministry of Health’s Department of Health Communication and Rewards. Both the online and print versions are distributed free of charge among the Vietnamese public to promote health education and health literacy.

Official citation:

Quach Ha Linh, Pham Quang Thai (2021) “*Equality in COVID-19 vaccination administration – a dilemma*” (Original title in Vietnamese: “Bình đẳng trong sử dụng vắc-xin COVID-19 – bài toán khó”), Suc Khoe & Doi Song Newspaper – Official press representatives of Vietnam Ministry of Health, Vol 4 (4973), 7 Jan 2021. Available at: https://suckhoedoisong.vn/binh-dang-trong-su-dung-vac-xin-covid-19-bai-toan-kho-n185112.html.

1.1. Web version

Available in Vietnamese at: https://suckhoedoisong.vn/binh-dang-trong-su-dung-vac-xin-covid-19-bai-toan-kho-n185112.html

Y TẾ

Bình đẳng trong sử dụng vắc-xin COVID-19 - Bài toán khó

ThS. Quách Hà Linh - TS.BS. Phạm Quang Thái - 15:59 07/01/2021 GMT+7 Thích 60 Chia sẻ

Suckhoedoisong.vn - 1 năm, sau khi dịch COVID-19 được ghi nhận tại Vũ Hán (Trung Quốc), các quốc gia trên thế giới đang trong cuộc đua phát triển, nhập khẩu vắc-xin phòng COVID-19 để đảm bảo an ninh y tế và sự phục hồi của nền kinh tế. Tuy nhiên, lượng vắc-xin ban đầu còn khan hiếm chưa đáp ứng hết nhu cầu, làm nảy sinh sự bất bình đẳng trong sử dụng vắc-xin giữa các quốc gia và các đối tượng được "thụ hưởng" những liều vắc-xin đầu tiên.

Sự độc quyền của các nước giàu

Tính đến cuối năm 2020, nhiều loại vắc-xin đã được thử nghiệm trên người và cho kết quả triển vọng. Một số loại vắc-xin đã được cấp phép sử dụng của Cục Quản lý thực phẩm và Dược phẩm Hoa Kỳ cho mục đích bảo vệ sức khỏe cộng đồng và thương mại.

Cùng lúc đó, nhiều báo cáo đã ghi nhận các quốc gia phát triển đã và đang đặt mua số lượng vắc-xin COVID-19 dự trữ nhiều hơn nhiều so với dân số cần tiêm. Tính tới 25/12/2020, Chính phủ Hoa Kỳ đã đặt hàng đủ lượng vắc-xin để tiêm chủng cho hơn 400% dân số của họ, Chính phủ Canada cũng đăng ký cho hơn 500% dân số trong nước. Điều này được dự báo dẫn đến việc thiếu hụt vắc-xin tại các quốc gia có tình trạng kinh tế thấp hơn, đẩy lùi thời gian phổ cập vắc-xin chống COVID-19 toàn cầu đến năm 2022-2023. Để giảm tình trạng bất bình đẳng này, các tổ chức quốc tế như Tổ chức Y tế Thế giới (WHO) và các trường đại học lớn trên thế giới hình thành liên minh COVAX và lên kế hoạch dự trữ, vận chuyển vắc-xin chống COVID-19 tới các quốc gia thu nhập thấp và trung bình, đặc biệt tại các quốc gia có tình hình dịch diễn biến rất nặng như Ấn Độ. Tuy vậy, việc thiếu hụt vắc-xin COVID-19 là gần như chắc chắn tại nhiều quốc gia phản ứng chậm trong sản xuất hay nhập khẩu vắc-xin trong bối cảnh khan hiếm toàn cầu.

https://suckhoedoisong.vn/binh-dang-trong-su-dung-vac-xin-covid-19-bai-toan-kho-n185112.html

Chuẩn bị tiêm thử nghiệm vắc -xin COVID-19 cho người Việt Nam đầu tiên.

Đối tượng nào cần được ưu tiên?

Bên cạnh đảm bảo nguồn vắc-xin đầy đủ, các hệ thống y tế quốc gia đều gặp cùng một thách thức về phân phối vắc-xin cũng như xác định xem đối tượng nào cần được ưu tiên nhận những mũi vắc-xin đầu tiên? Là những người cao tuổi và những người có tình trạng y tế nghiêm trọng hay những lao động thiết yếu, trong đó bao gồm nhân viên y tế tuyến đầu cho COVID-19, hay những người có nguy cơ lây nhiễm cao nhất? Đây là một vấn đề mang tính cấp thiết bởi những lo ngại về sự bất bình đẳng do đại dịch COVID-19 gây ra, từ tỷ lệ lây nhiễm và tử vong cao không tương xứng ở người nghèo, người da màu cho đến khả năng tiếp cận khác nhau đối với dịch vụ xét nghiệm, dịch vụ chăm sóc sức khỏe và khả năng làm việc và học tập từ xa hoặc trực tuyến.

Theo hướng dẫn mới nhất của Trung tâm Kiểm soát và Phòng ngừa dịch bệnh Hoa Kỳ (USCDC), nhân viên chăm sóc sức khỏe và những người già yếu nhất, thường sống trong các viện dưỡng lão và trung tâm chăm sóc y tế dài hạn, sẽ được tiêm những mũi vắc-xin COVID-19 đầu tiên. Tại các quốc gia châu Âu, cuộc vận động để đưa nhân viên y tế và người lao động thiết yếu tại cửa hàng bán thực phẩm hoặc thuốc nhận vắc-xin sớm vẫn đang diễn ra. Ngoài vấn đề đánh giá và định nghĩa "người lao động thiết yếu" đa dạng và khác nhau giữa các quốc gia và vùng lãnh thổ, sự chú trọng đến tình hình dịch bệnh và văn hóa xã hội tại từng nơi cũng xuất hiện trong quyết định đưa ra đối tượng ưu tiên được tiêm chủng. Tính đến thời điểm cuối năm 2020, vắc-xin COVID-19 đã được tiêm trên các chính trị gia cấp cao, người cao tuổi và nhân viên y tế tuyến đầu tại Mỹ và một số quốc gia Tây Âu.

Các chuyên gia về chính sách y tế công cộng trên thế giới cho thấy, đây là quyết định ưu tiên giữa việc ngăn ngừa tử vong (với việc tiêm cho người già và người có sức khỏe suy giảm) hay là giảm sự lây truyền virus (tiêm cho nhân viên y tế và người lao động thiết yếu). Hơn nữa, các kết quả thử nghiệm vắc-xin cho đến nay chỉ cho thấy rằng các mũi tiêm có thể bảo vệ những người được tiêm, nhưng chưa chứng minh được rằng một người được tiêm chủng sẽ không lây nhiễm cho người khác. Để đưa ra đánh giá hợp lý nhất, nhiều chuyên gia kêu gọi các quốc gia sử dụng "Chỉ số đánh giá mức độ dễ bị tổn thương" của USCDC. Chỉ số này bao gồm 15 thước đo rút ra từ cuộc tổng điều tra, chẳng hạn như: nhà ở quá đông, thiếu phương tiện đi lại và nghèo đói, để xác định mức độ khẩn cấp của một cộng đồng cần được hỗ trợ y tế, với mục tiêu giảm bất bình đẳng. Ngoài ra, lưu ý về khả năng trùng lặp đối tượng ưu tiên (ví dụ, một số người lao động thiết yếu cũng có vấn đề sức khỏe mạn tính, hoặc nằm trong nhóm cao tuổi) cũng được đề cập.

Trong cuộc đua vắc-xin của tất cả các quốc gia, ngoài việc chế tạo ra vắc-xin, các vấn đề về đạo đức và bình đẳng trong y tế công cộng cũng cần được xem xét. Các hệ thống y tế cũng cần đánh giá khả năng cung cấp vắc-xin cùng lúc với khả năng chữa trị cho các bệnh nhân COVID-19 sẵn có. Và có một câu hỏi chưa thể lượng giá trước khi chúng ta thực sự cung cấp vắc-xin: tỷ lệ người dân lo ngại phản ứng không mong muốn của vắc-xin và phong trào chống vắc-xin đang diễn ra trên thế giới, sẽ có bao nhiêu đối tượng ưu tiên thực sự tiếp nhận vắc-xin COVID-19?

ThS. Quách Hà Linh - TS.BS. Phạm Quang Thái

((Khoa Kiểm soát bệnh truyền nhiễm, Viện Vệ sinh dịch tễ TW))

TIN LIÊN QUAN

Thích 60 Chia sẻ

CÓ THỂ BẠN QUAN TÂM

Dinh dưỡng và chức năng nhận thức

Bảy bước để có một bộ não khoẻ mạnh

Những sự thật và con số về bệnh Alzheimer

Rối loạn nhận thức

Suy giảm nhận thức chủ quan

RỐI LOẠN NHẬN THỨC VÀ SA SÚT TRÍ NHỚ

[Video] Bệnh nhân từng ở trong tâm dịch COVID-19 tại Đà Nẵng nói gì?

Chiều 13/1, cô gái 27 tuổi mắc COVID-19, Việt Nam có 1.521 bệnh nhân

TIN CHÂN BÀI

Cảnh báo ngày càng nhiều người trẻ mắc bệnh thoái hóa khớp

Quản lý chặt việc nhập cảnh trái phép qua các cửa khẩu, đường mòn lối mở

1.2. Printed version

Bình đẳng trong sử dụng vắc-xin COVID-19 - Bài toán khó

> ThS. QUÁCH HÀ LINH - TS.BS. PHẠM QUANG THÁI
(Khoa Kiểm soát bệnh truyền nhiễm, Viện Vệ sinh dịch tễ TW)

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Đối tượng nào cần được ưu tiên?

Bên cạnh đảm bảo nguồn vắc-xin đầy đủ, các hệ thống y tế quốc gia đều gặp cùng một thách thức về phân phối vắc-xin cũng như xác định xem đối tượng nào cần được ưu tiên nhận những mũi vắc-xin đầu tiên? Là những người cao tuổi và những người có tình trạng y tế nghiêm trọng hay những lao động thiết yếu, trong đó bao gồm nhân viên y tế tuyến đầu cho COVID-19, hay những người có nguy cơ lây nhiễm cao nhất? Đây là một vấn đề mang tính cấp thiết bởi những lo ngại về sự bất bình đẳng do đại dịch COVID-19 gây ra, từ tỷ lệ lây nhiễm và tử vong cao không tương xứng ở người nghèo, người da màu cho đến khả năng tiếp cận khác nhau đối với dịch vụ xét nghiệm, dịch vụ chăm sóc sức khỏe và khả năng làm việc và học tập từ xa hoặc trực tuyến.

Chuẩn bị tiêm thử nghiệm vắc-xin COVID-19 cho người Việt Nam đầu tiên.

Theo hướng dẫn mới nhất của Trung tâm Kiểm soát và Phòng ngừa dịch bệnh Hoa Kỳ (USCDC), nhân viên chăm sóc sức khỏe và những người già yếu nhất, thường sống trong các viện dưỡng lão và trung tâm chăm sóc y tế dài hạn, sẽ được tiêm những mũi vắc-xin COVID-19 đầu tiên. Tại các quốc gia châu Âu, cuộc vận động để đưa nhân viên y tế và người lao động thiết yếu tại cửa hàng bán thực phẩm hoặc thuốc nhận vắc-xin sớm vẫn đang diễn ra. Ngoài vấn đề đánh giá và định nghĩa "người lao động thiết yếu" đa dạng và khác nhau giữa các quốc gia và vùng lãnh thổ, sự chú trọng đến tình hình dịch bệnh và văn hóa xã hội tại từng nơi cũng xuất hiện trong quyết định đưa ra đối tượng ưu tiên được tiêm chủng. Tính đến thời điểm cuối năm 2020, vắc-xin COVID-19 đã được tiêm trên các chính trị gia cấp cao, người cao tuổi và nhân viên y tế tuyến đầu tại Mỹ và một số quốc gia Tây Âu.

Các chuyên gia về chính sách y tế công cộng trên thế giới cho thấy, đây là quyết định ưu tiên giữa việc ngăn ngừa tử vong (với việc tiêm cho người già và người có sức khỏe suy giảm) hay là giảm sự lây truyền virus (tiêm cho nhân viên y tế và người lao động thiết yếu). Hơn nữa, các kết quả thử nghiệm vắc-xin cho đến nay chỉ cho thấy rằng các mũi tiêm có thể bảo vệ những người được tiêm, nhưng chưa chứng minh được rằng một người được tiêm chủng sẽ không lây nhiễm cho người khác. Để đưa ra đánh giá hợp lý nhất, nhiều chuyên gia kêu gọi các quốc gia sử dụng "Chỉ số đánh giá mức độ dễ bị tổn thương" của USCDC. Chỉ số này bao gồm 15 thước đo rút ra từ cuộc tổng điều tra, chẳng hạn như: nhà ở quá đông, thiếu phương tiện đi lại và nghèo đói, để xác định mức độ khẩn cấp của một cộng đồng cần được hỗ trợ y tế, với mục tiêu giảm bất bình đẳng. Ngoài ra, lưu ý về khả năng trùng lặp đối tượng ưu tiên (ví dụ, một số người lao động thiết yếu cũng có vấn đề sức khỏe mạn tính, hoặc nằm trong nhóm cao tuổi) cũng được đề cập.

Trong cuộc đua vắc-xin của tất cả các quốc gia, ngoài việc chế tạo ra vắc-xin, các vấn đề về đạo đức và bình đẳng trong y tế công cộng cũng cần được xem xét. Các hệ thống y tế cũng cần đánh giá khả năng cung cấp vắc-xin cùng lúc với khả năng chữa trị cho các bệnh nhân COVID-19 sẵn có. Và có một câu hỏi chưa thể lượng giá trước khi chúng ta thực sự cung cấp vắc-xin: tỷ lệ người dân lo ngại phản ứng không mong muốn của vắc-xin và phong trào chống vắc-xin đang diễn ra trên thế giới, sẽ có bao nhiêu đối tượng ưu tiên thực sự tiếp nhận vắc-xin COVID-19? □

1.3. Translated version

Equality in COVID-19 vaccine administration – a dilemma

A year after the COVID-19 epidemic was recorded in Wuhan (China), countries around the world are in a race to develop and import COVID-19 preventive vaccine to ensure health security and the recovery of the economy. However, the initial scarcity of vaccines has not met all demand, resulting in inequalities in vaccine use between countries and those who "beneficiaries" of vaccine doses.

The monopoly of the rich countries

By the end of 2020, many vaccines have been tested in humans with promising results. Some vaccines have been licensed by the US Food and Drug Administration for public and commercial protection purposes.

At the same time, many reports have noted that developed countries have been ordering higher stock of COVID-19 vaccine than their populations' needs. As of December 25, 2020, the US Government has ordered enough vaccines to vaccinate more than 400% of its population, and the Government of Canada has registered more than 500% of the population of the country. This is expected to vaccine shortages in countries with lower economic status, pushing the global prevalence of the non-COVID-19-vaccinated population to 2022-2023. To reduce this inequality, international organizations such as the World Health Organization (WHO) and major universities around the world formed the COVAX alliance and is planning to store and transport vaccines to low-income and middle-income countries, especially in countries with very severe epidemics such as India. However, the shortage of COVID-19 vaccine is almost certain in many countries that are slow to respond to vaccine production or importation in the context of global scarcity.

Caption: Preparing for the first Vietnamese trial of COVID-19 vaccine

Who should be prioritized?

In addition to ensuring adequate supply of vaccines, national health systems face the same challenge of vaccine distribution as well as determining who should be given priority to receive the first shots. Should it be the elderly and those with serious medical conditions, or essential workers, which include the frontline health worker for COVID-19, or those most at risk of infection? This is a critical inequality issue further caused by the COVID-19 pandemic, from disproportionately high rates of infection and mortality among the poor and people of color to potential accessibility to testing services, healthcare services and the ability to work and learn from either distance or online.

According to the latest US Centers for Disease Control and Prevention (US CDC) guidelines, health-care workers and the weakest elderly, often live in nursing homes and long-term care centres. The first shots of COVID-19 will be given. In European countries, the campaign to get medical workers and essential workers at grocery or medicine stores to get their vaccines early is still ongoing. In addition to the assessment and definition of "essential workers" which are diverse and varied between countries and regions, the emphasis on the epidemic and socio-cultural situation in each place also appears in the decision. is intended to give priority to be vaccinated. As of the end of 2020, the COVID-19 vaccine has been administered to senior politicians, the elderly, and frontline health care workers in the US and some Western European countries.

Experts in public health policy around the world show that this is a priority decision between preventing fatalities (by vaccinating the elderly and the poor) or reducing the transmission of the virus (by vaccinating health care workers and essential workers). On the other hand, vaccine trial results to date have only shown protection to those who get the shot, but has not shown that one person being vaccinated will not infect others. In order to make the most plausible assessment, many experts urge countries to use the US CDC's "Vulnerability Assessment Index". This index includes 15 metrics drawn from the census, such as: overcrowded housing, lack of transportation and poverty, to determine how urgently a community is in need of assistance. economy, with the goal of reducing inequality. In addition, the potential overlapping of priority audiences (e.g., some essential workers also have chronic health problems, or are in the elderly group) are also mentioned.

In the vaccine race of all countries, in addition to making vaccines, the issues of ethics and equity in public health also need to be considered. Health systems also need to evaluate the possibility of extensive vaccination program at the same time as existing COVID-19 case management and treatment. And there is a question that we cannot evaluate before vaccination is administered: in face of the growing proportion of anti-vaccination movement and anti-trust in government's interventions to COVID-19, how many people in target population will actually receive COVID-19 vaccine?

Quach Ha-Linh, Pham Quang Thai

Department of Communicable Disease Control, National Institute of Hygiene and Epidemiology

2. Lesson from the field

I was inspired by MicrobeTrace as a useful tool for epidemiology and contact tracing after an introductory session by US CDC in Vietnam in April 2020 at NIHE. MicrobeTrace is an online Visualization tool developed and provided free by the US CDC. MicrobeTrace is used to construct network analysis for molecular and epidemiologic data collected during an outbreak investigation, which can be accessed through this link: https://microbetrace.cdc.gov/MicrobeTrace/.

The tool is very easy to use and effective in visualizing quickly contact networks during the COVID-19 outbreak. After that initial session, I used MicrobeTrace more often during my time in Rapid Information Team in National Steering Committee, and even got a chance to present it in the minister brief once. The usefulness and convenience of the tool encouraged me to use it in my Lesson from the Field (LFF), as I saw that many of my cohort mates were enthusiastic about social network analysis techniques for contact tracing in Course Block 2.

I conducted the LFF in 4 May 2021 with five scholars in my cohort. The LFF was divided to three sessions: (i) Basic definitions and introduction to the program; (ii) Interactive session where the group navigated through the tools and did some exercises; and (iii) Final reflections. The evaluation polling is depicted below.

This session included three sections, pre-reading materials for the LFF, PowerPoint introduction, and some practice exercises.

2.1. Pre-reading material

An introduction to MicrobeTrace

This lesson from the field (LFF) is a self-directed learning exercise and will be emailed to participants:

Topic: MAE LFF - Ha-Linh Quach
Time: May 4, 2021 13:00 Vietnam

Join Zoom Meeting
https://anu.zoom.us/j/87432216556?pwd=WWgyQURFNHprY0FHdkZobWZMY293QT09

Meeting ID: 874 3221 6556
Password: 983215

Learning Objectives

By the end of this LFF you should be able to:

- Understand the use of MicrobeTrace in social network analysis
- Construct a simple map from MicrobeTrace and use different built-in functions
- Construct node and edge lists from available case data

Overview

MicrobeTrace is an online Visualization Multi-tool for Molecular Epidemiology and Bioinformatics developed by the US CDC. MicrobeTrace is a tool to compare and construct network analysis for molecular and epidemiologic data collected during an outbreak investigation. It is an interactive free platform which allows users to upload data from their own computers and visual transmission networks. It works on both sequences and epidemiologic data, but this lesson only concerns the latter. MicrobeTrace is designed for infectious disease including HIV, TB, and other pathogens where contact tracing is normally applied to understand the transmission cycle and control the outbreak. MicrobeTrace best performs on Google Chrome, and is not compatible on Internet Explorer.

What differs MicrobeTrace from other software like R or Stata:

- Easy to construct raw data from an Excel spreadsheet
- Easy to manipulate display (colour, labels, etc.) without long codes
- Easy to download outputs in many forms

A simple introduction of social network analysis

The aim of social network analysis is to understand a community by mapping the relationships that connect them as a network, and then trying to draw out key individuals, groups within the network ('cluster'), and/or associations between the individuals.

A network is simply a number of points (or 'nodes') that are connected by links (or edge'). In an epidemiological social network, the nodes are individuals and the links are any epidemic connection between them – for example, social relations, exposure.

Two types of edges can be present in a network: (1) a *directed* edge: the nodes are connected and one head of the edge has an arrowhead indicating a one-way effect, or (2) an *undirected* edge: the nodes have a connecting line indicating some mutual relationship but with no arrowheads to indicate direction of effect. Networks can be described as being directed (i.e. all edges are directed) or undirected (i.e. no edges are directed). Edges convey information about the direction and strength of the relationship between the nodes, such as positive edge (e.g. positive correlation/covariance between variables) or negative (e.g. negative correlation/covariance between variables). Edges can be weighted to reflect the strength of the relationship between nodes by varying the thickness and color density of the edge connecting the nodes.

Key network statistics of a social network

Variable	**Definition**	**Measurement**
Number of nodes	Size of the network	Number of individuals in the network
Number of edges	How 'busy' the network in total	Number of relationships between individuals in the network (in total)
Number of unique links	How 'busy' the network is, taking out relationships that are duplicated	Number of relationships between individuals in the network, with duplicates removed
Clusters	Whether there may be subgroups in the network	Number of discrete groups in the network
Density	The extent to which nodes are interconnected – lower density networks have fewer links between nodes	The proportion of all links that are actually present
Mean average distance between nodes	How 'close' (in network terms) the nodes are to each other	Average number of steps needed to go from one node to any other
Mean degree	How central (on average) nodes in the network are	Average number of links that pass through the nodes
Mean betweenness	How central (on average) nodes in the network are	Average number of unique paths that pass through the nodes

Data construct

MicrobeTrace handles a variety of file types and formats that are traditionally collected during public health investigations, including pathogen genomic information, epidemiologic and other metadata about cases (node lists) and their high-risk contacts (edge or link lists) can be integrated as spreadsheets.

MicrobeTrace can import a variety of file formats depending on your different analytic goals (Figure 1).

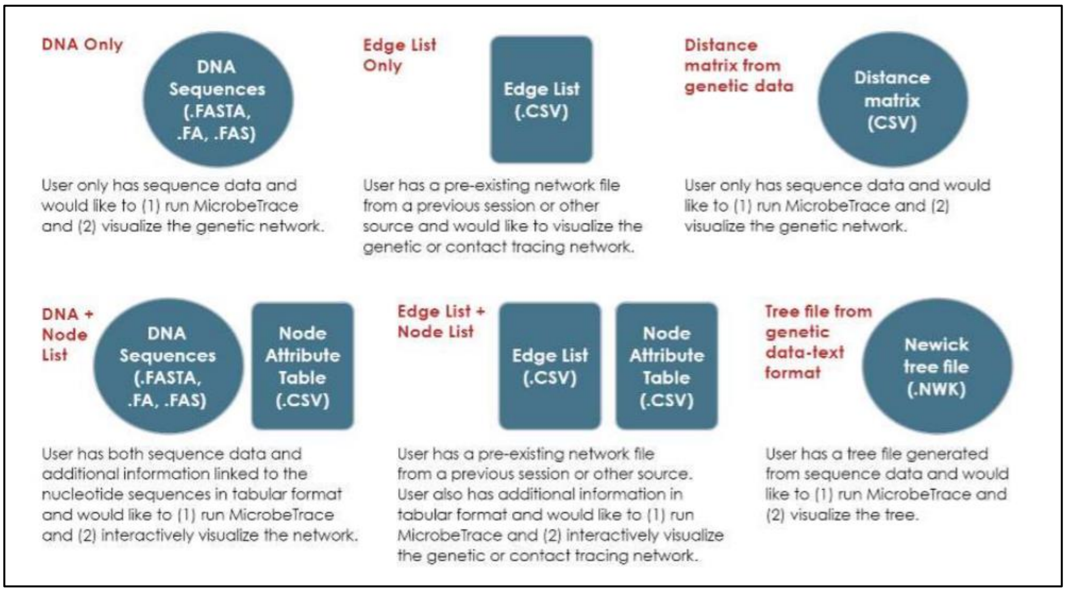


Figure 1: Different dataset for MicrobeTrace - adapted from Campbell et al. (2020)

Two types of dataset we will use in this exercise:

- Line list (denoted as Node list): lists of individuals/cases where each line is an individual/case. You can put more data to enrich the networks, from demographic characteristics to important epidemiological data (such as date of symptoms onset, date of exposure, risk factors, etc.). Each case/individual represents a node.
- Contact tracing data (denoted as Edge list): lists of partners/pairs of individual/cases where contacts/exposures had happened. Each line represents one connection from person A to person B. You can also put more data in terms of type of contact, location of contact, etc. Each line represents an edge.

Input data are typically in these formats:

- Excel (CSV or XLSX)
- Distance matrix format
- Raw sequences data (.FASTA)

For this LFF, we will only use excel data. You can download and try the remaining two data types in this link: https://github.com/CDCgov/MicrobeTrace

Recap

Hopefully you can understand the aim and basic characteristics of social network analysis, and the purpose of MicrobeTrace. Please have a look-through of the sample dataset, and we will load and navigate the dataset on MicrobeTrace together during the session.

Further reading

1. Ellsworth M. Campbell, Anthony Boyles, Anupama Shankar, Jay Kim, Sergey Knyazev, William M. Switzer (2020), MicrobeTrace: Retooling Molecular Epidemiology for Rapid Public Health Response. bioRxiv 2020.07.22.216275; doi: https://doi.org/10.1101/2020.07.22.216275
2. GitHub sharing for MicrobeTrace instruction and sample dataset
   https://github.com/CDCgov/MicrobeTrace
3. Interactive instruction to MicrobeTrace
   https://bio.tools/microbetrace
4. How to install MicrobeTrace as a package to Rstudio
   https://github.com/CDCgov/MicrobeTraceShiny
5. MicrobeTrace uses in sequence analysis
   https://www.youtube.com/watch?v=puys17g_hPc
6. More on genome sequencing analysis – How to use the “Prune” and “Filter threshold” function
   https://medium.com/microbetrace-reports/playing-with-your-nearest-neighbor-ef7910312ebf
   https://medium.com/microbetrace-reports/demoing-the-tree-of-life-in-microbetrace-3e6a34d4645b
7. Over plotting problem in MicrobeTrace, and how to use the “Jitter” function
   https://medium.com/microbetrace-reports/how-to-jitter-well-c5e2462047f9
   http://ermalltd.co.uk/1991-cadillac-nz3tt/jitter-overplotting.html

2.2. Lesson presentation

MicrobeTrace

An introduction to MicrobeTrace

Lesson from the field

Quach Ha-Linh – MAE 2020

04 May 2021

LFF objectives

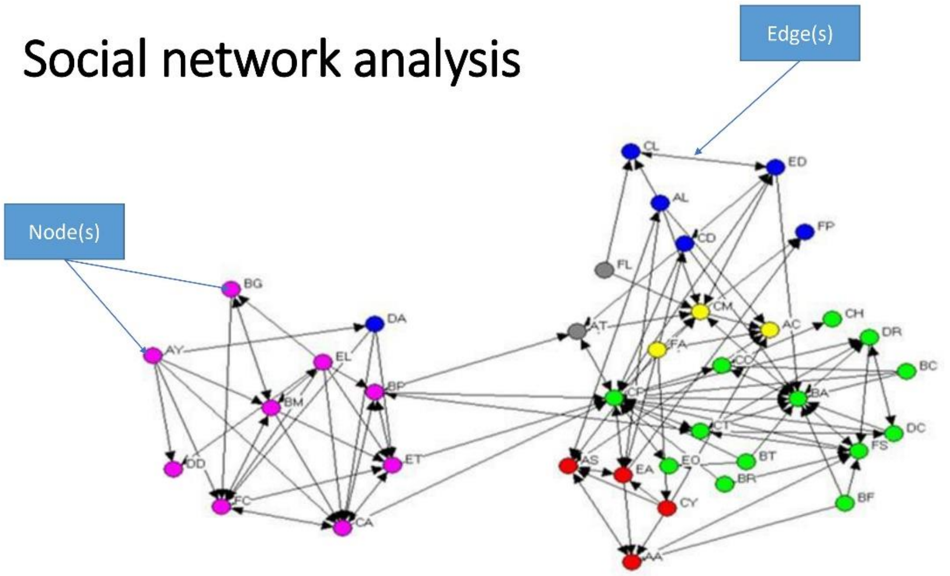
MicrobeTrace

- Understand the use of MicrobeTrace in social network analysis
- Construct a simple map from MicrobeTrace and use different built-in function
- Construct node and edge lists from available case data

What is MicrobeTrace?

- Visualization tool for Molecular Epidemiology and Bioinformatics
- Product of US CDC, free for all to use
- Construct network analysis on an interactive platform
- What differs MicrobeTrace from other software like R or Stata:
  - Easy to construct raw data
  - Easy to manipulate without long codes
  - Easy to download outputs in many forms

Social network analysis



Source: https://stangarfield.medium.com/social-network-analysis-sna-ona-vna-4df5547a0a7f

Variable	Definition	Measurement
Number of nodes	Size of the network	Number of individuals in the network
Number of edges	How 'busy' the network in total	Number of relationships between individuals in the network (in total)
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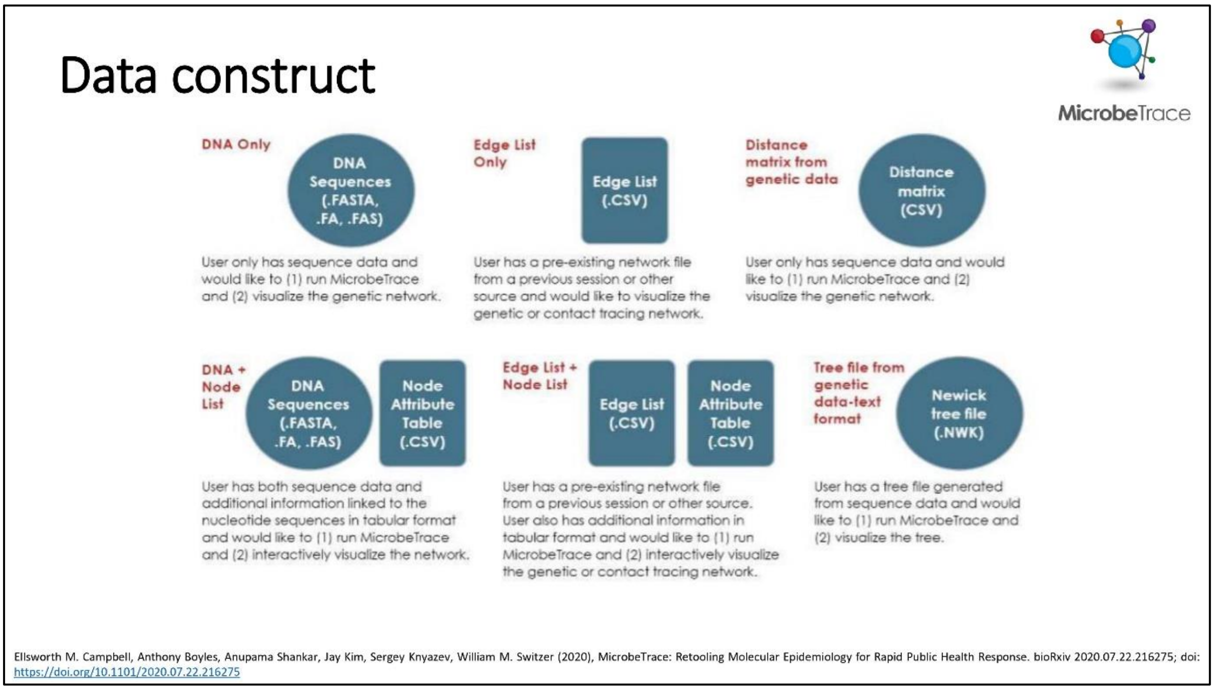


Data construct

MicrobeTrace

- Line list (denoted as Node list): lists of individuals/cases where each line is an individual/case.

ID	Sex	Age
1bcd	F	34
2bcd	M	23

- Contact tracing data (denoted as Edge list): lists of partners/pairs of individual/cases where contacts/exposures had happened. Each line represents one connection from person A to person B.

Source	Target	Type
1bcd	4scd	House
2bcd	4scd	Non-house
3hid	1bcd	House

MicrobeTrace

Let's practice!

Please have the two sample dataset ready!

https://microbetrace.cdc.gov/MicrobeTrace/

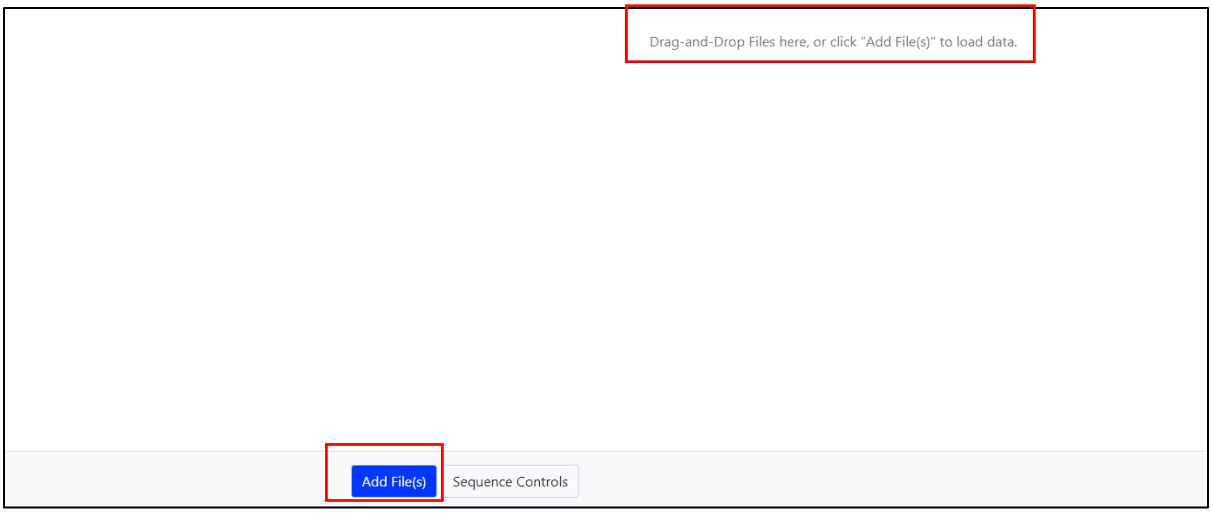
2.3. Practice exercises

Activity 1.

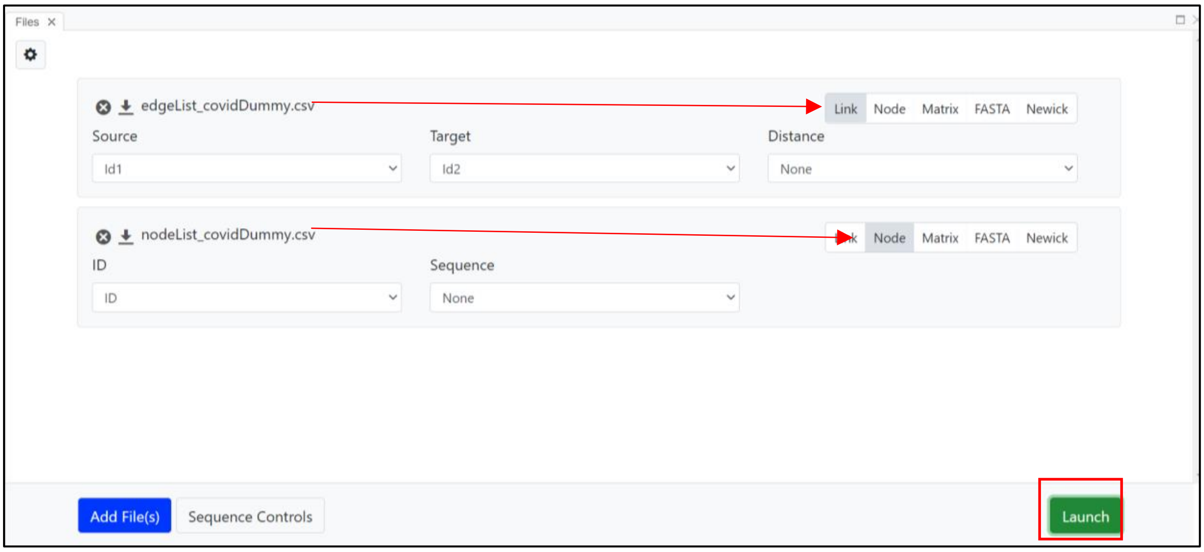
Please navigate to MicrobeTrace website on your browser: https://microbetrace.cdc.gov/MicrobeTrace/ From this point, the application download itself to your computer, and you can use it on your browser without internet connection. You can save your workspace where you left off and come back later. This is to ensure a data security system for personal data and patients' data.

Activity 2.

Upload dataset into MicrobeTrace.



We use two dummy csv files for this exercise, the node list and the edge list. Once you upload the files, MicrobeTrace automatically identifies which one is the edge list (as "Link") and which one is the node list (as "Node"). Here we can specify the basic elements for the network. For the node list, you need to specify the unique ID for each node in your raw data, which in here is correspondence to the column "ID" in the csv file. For the edge list, you need to specify who is person A and B in your network, which is corresponding to the "Source" and the "Target" on the screen, which in here is the "Id1" and "Id2" columns in the csv file. After this, we hit "Launch" to create the dataset.



Activity 3.

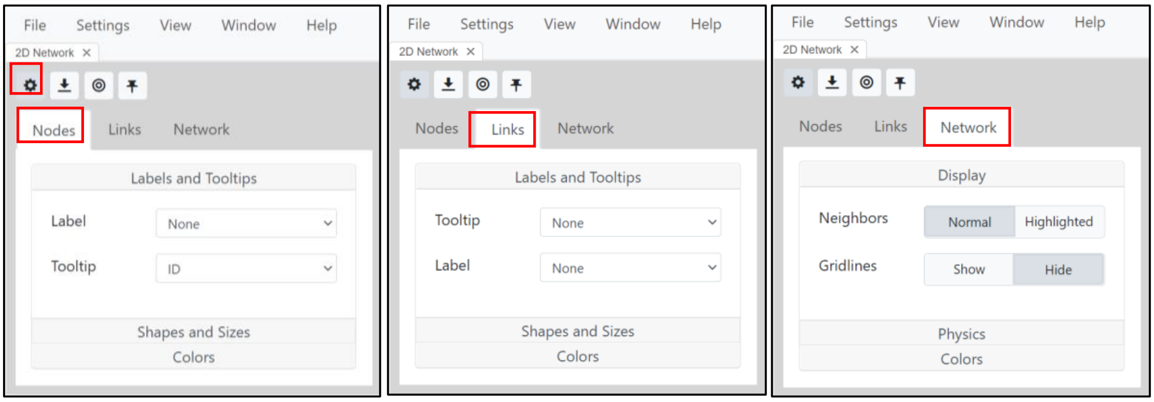
3.1. Load the dataset and navigate through the dataset.

The default map is a 2D network, with each node is a circle, and each line is the connection between two nodes.

On the bottom right of the screen, you can see a summary of the network, which includes number of nodes, links, clusters, and singletons. On the top right of the screen, you can select for specific nodes based on their variables in the csv file, and selected nodes will be highlighted on the screen.

3.2. Format and label the network.

On the top left of the screen, you can find the gear icon which is to set the display of label, shape and color of the network, based on the richness of the dataset you have.



Important indicators in the Node tab:

- Degree: weight each node by the number of connections it has in the network (calculated automatically)
- Cluster: classify nodes by cluster they belong to

Important indicators in the Network/Physics tab:

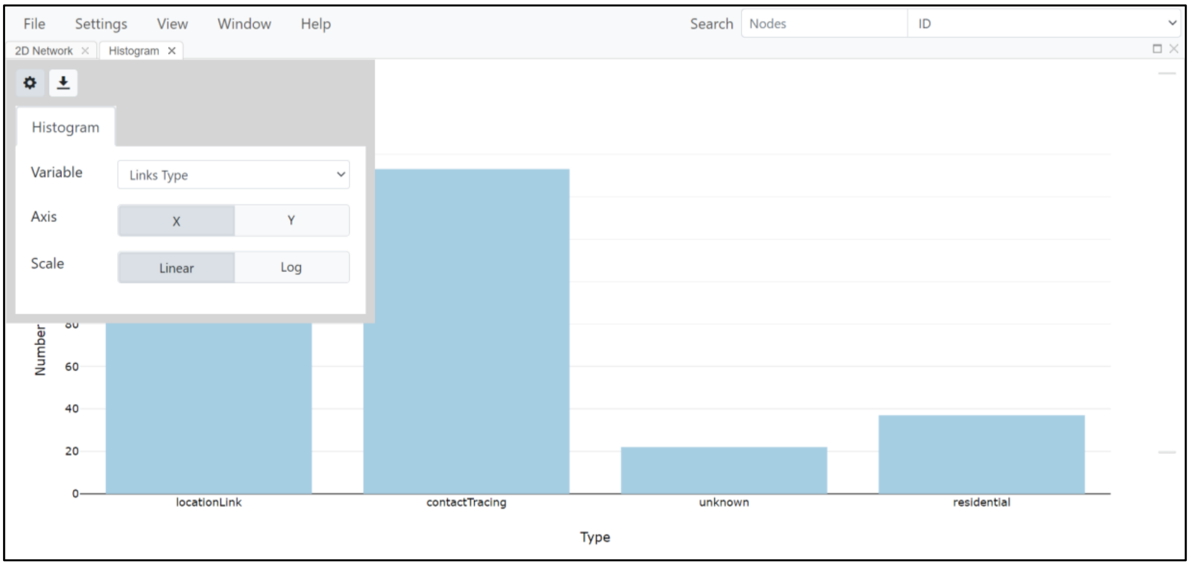
- Highlight: only highlight the neighbouring nodes of the selected nodes.
- Charge: modify the magnitude of the nodes to its closest cluster
- Gravity: modify the magnitude of all the nodes to the central of the network
- Friction: modify the friction between the nodes

Ex.1. Customize node size by degree, node shape by race/ethnicity, node color by gender, and edge color by type of exposure. Describe the three nodes with highest degree in the network.

Activity 4.

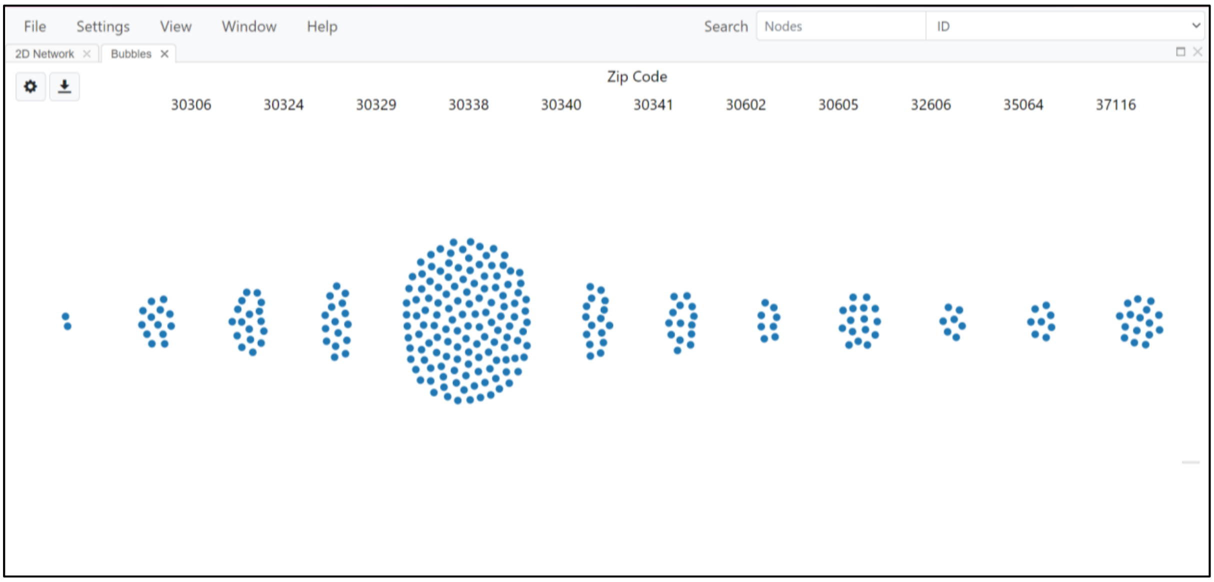
4.1. Set up histogram view

Select View/Histogram on the tool tab. Histogram view provides histogram chart for frequency of variables on your dataset, along with some auto-computed variables by MicrobeTrace.



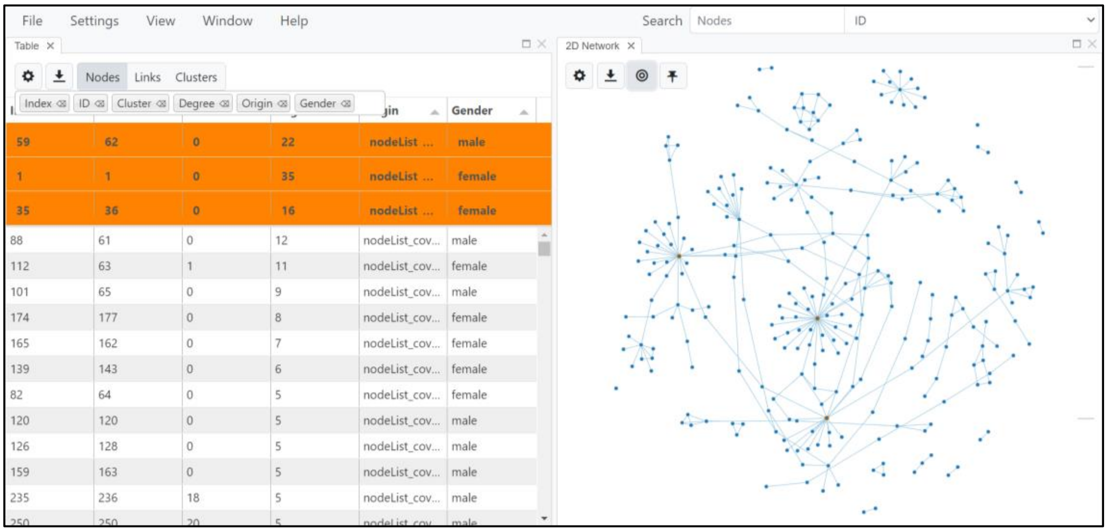
Ex.2. Create histogram plot for epi curve.

Another quick way to look at the distribution of variables is through View/Bubbles option.



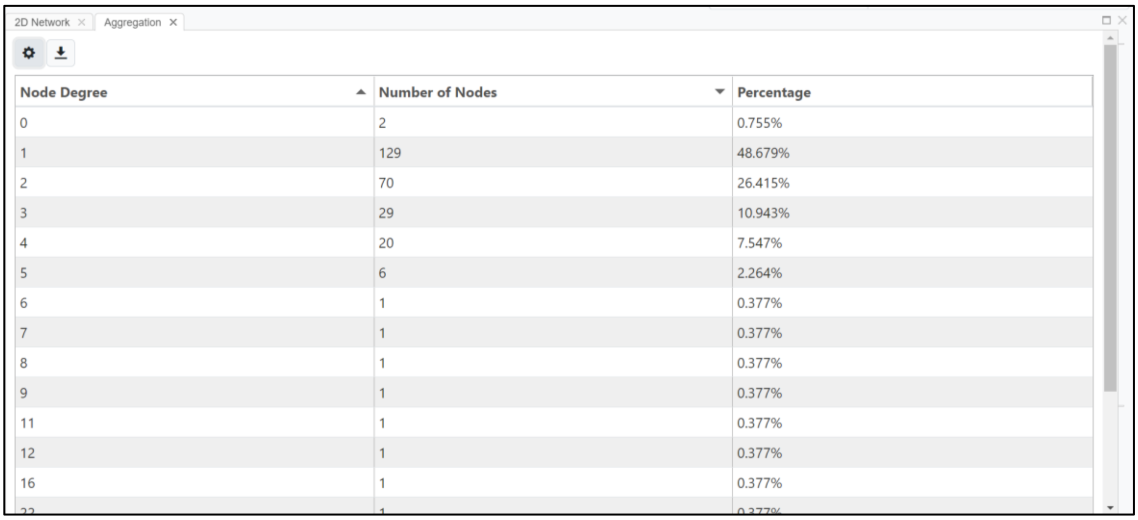
4.2. Set up table view

Select View/Table on the tool tab. Table view is basically your dataset, where you can add/drop/sort each variable in your preference. You can identify nodes with specific characteristics in the network by selecting the node in the Table view, and apply sorting function to each variable.

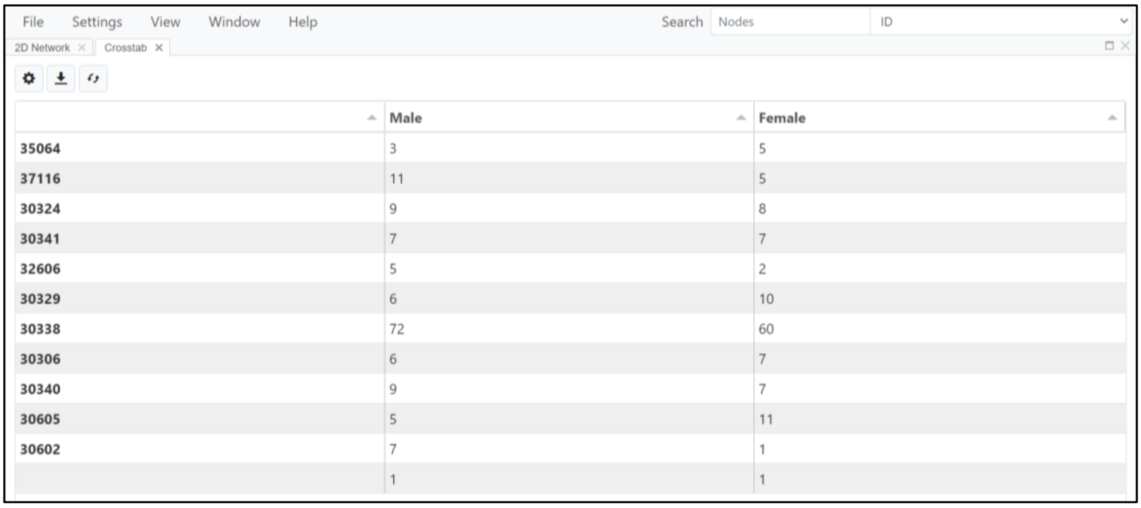


4.3. Set up aggregation view

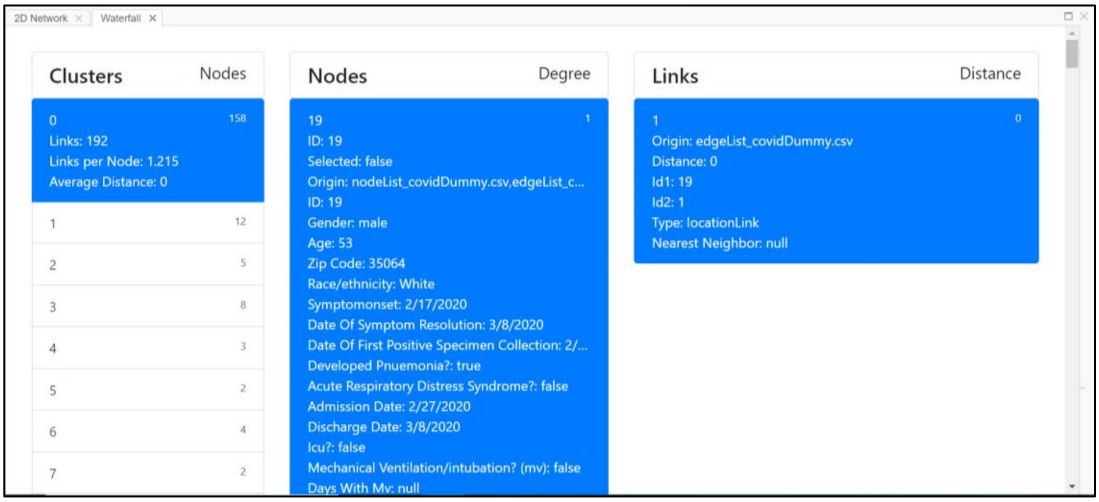
Select View/Aggregation on the tool tab. Aggregation view represents summary for frequency (%) of nodes/links/clusters stratified by different variables on your dataset.



View/Crosstab also provides table view to a more variety of variables in the dataset.

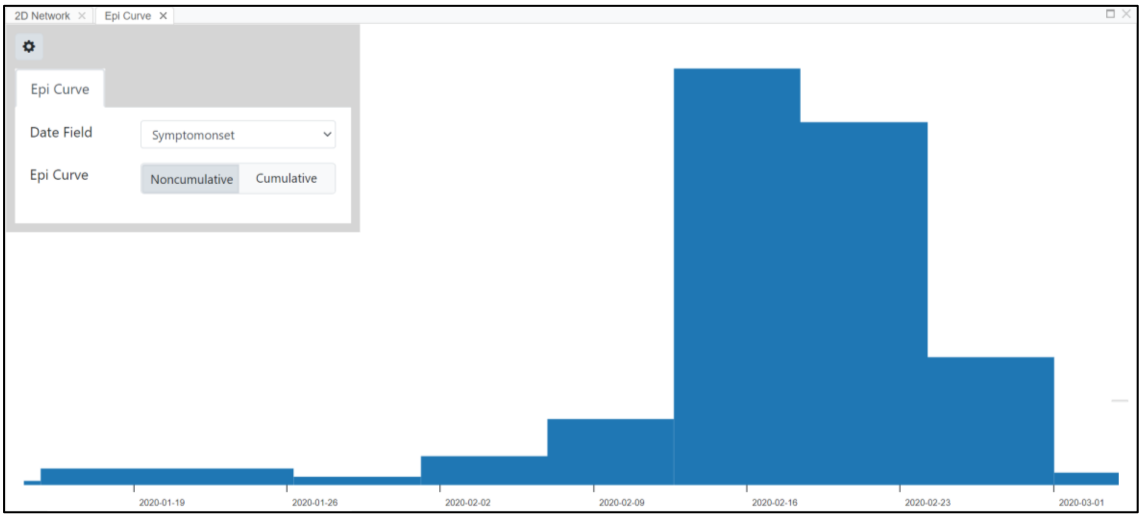


Another way to quickly look up Clusters/Nodes characteristics is through View/Waterfall option.

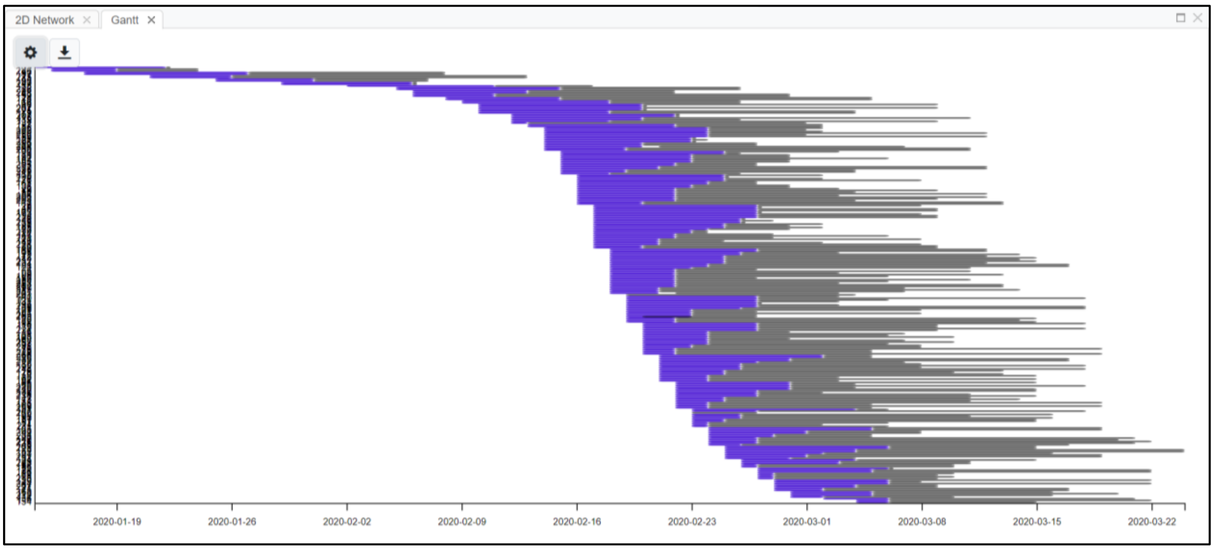


4.4. Set up Epi curve

You can also create epi curve by inserting the date data field in your dataset to View/Epi curve option in the tool bar.

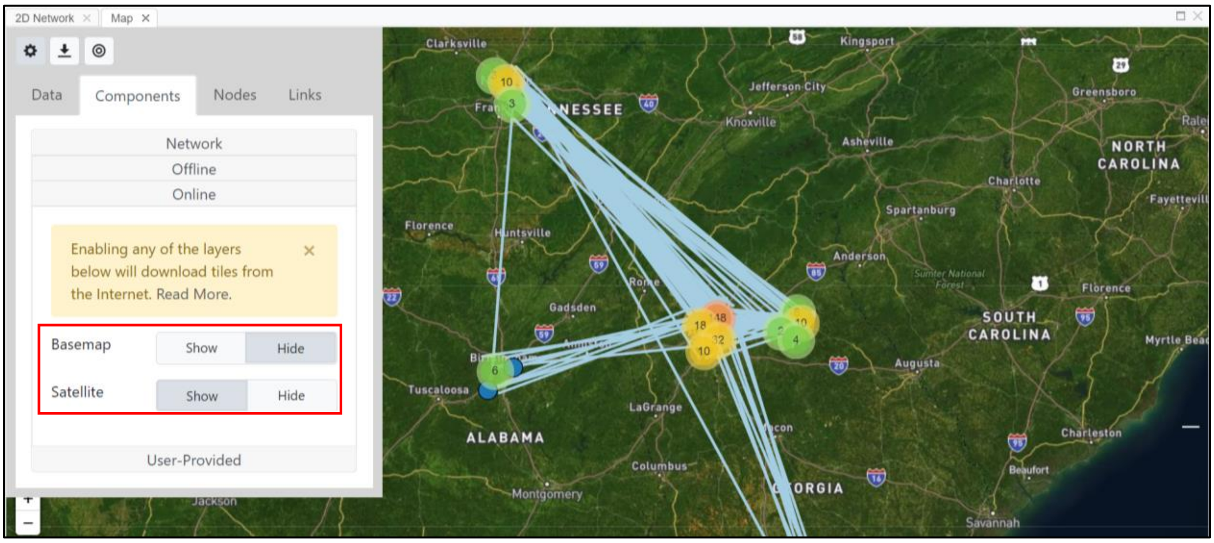


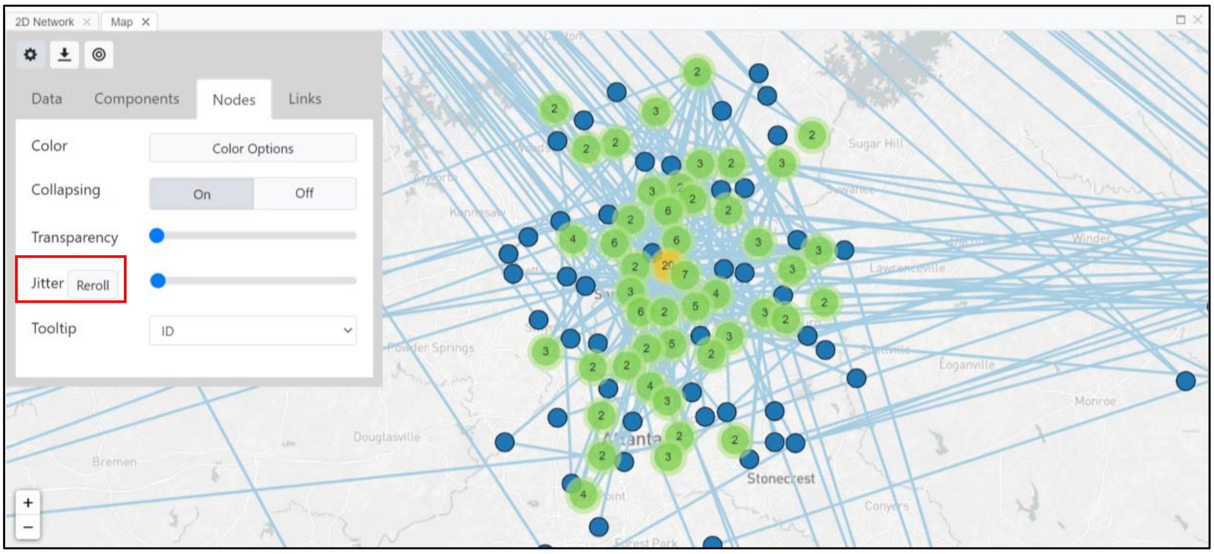
Another way to display your dataset in time distribution is View/Gantt option. Gantt chart provides layover time course for each nodes in the network. (Purple bars are time course from symptom onset to first COVID-19 specimen collection, black bars are time course from admission to discharge)



4.5. Set up Map/globe view

Select View/Map or View/Globe on the tool tab. This function shows geographical distribution of nodes based on available zip code, longitude and latitude, etc. You can select details of your map to display to country/state/county level, and choose to display the links between nodes. The "Jitter" function is to distribute your nodes in a random algorithm to ensure patients' personal privacy (You can read more on this function [in this link](). Users can layover the graph with baseline map or satellite map (requires internet connection), or use your own map layer (JSON format).

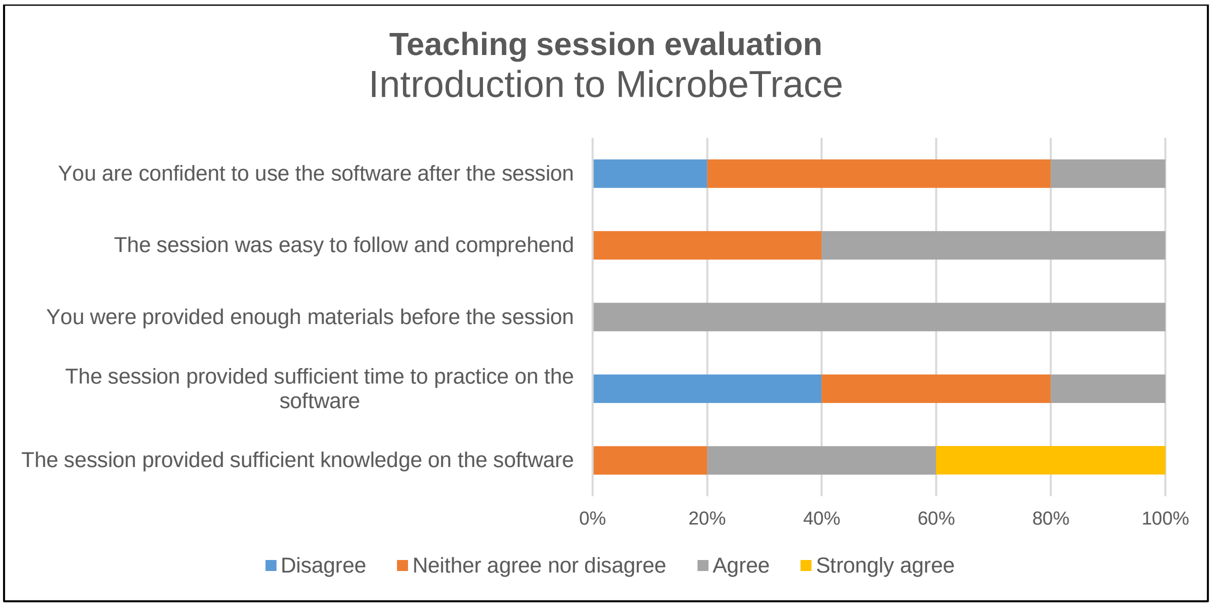




3. Teaching experience

I conducted a teaching session on 30 June 2021, also on MicrobeTrace, for 6 staffs and medical students working/interning at Department of Communicable Disease Control, NIHE. The session was 1.5 hours long, conducted both in person at NIHE and online through Zoom. The basic materials are the same with the LFF session but in Vietnamese. I was able to work through the exercises and conducted a fruitful discussion with all attendees, with the assistance of my MAE colleague – Ms Ngoc-Anh.

Materials for the teaching session included a PowerPoint presentation, a handout of basic information on MicrobeTrace and Social network analysis, and a practice take-home exercise. Below is the evaluation of the session.



3.1. Reading handout

Quách Hà Linh
NIHE, 30/6/2021

Giới thiệu phần mềm MicrobeTrace

Mục tiêu

- Giới thiệu phần mềm MicrobeTrace và ứng dụng trong phân tích mạng lưới
- Thực hành xây dựng mạng lưới lây nhiễm và sử dụng một số công cụ biểu đồ và mô hình hóa trên phần mềm MicrobeTrace
- Thực hành xây dựng bộ dữ liệu điểm/nốt và điểm nối giữa các ca bệnh

Tổng quan

MicrobeTrace là phần mềm mô hình hóa cho dữ liệu y sinh học và dịch tễ học của CDC Hoa Kỳ. Các công cụ trên MicrobeTrace được sử dụng để xây dựng mạng lưới sơ đồ lây nhiễm dựa trên dữ liệu ca bệnh và phân tử học thu thập trong điều tra vụ dịch. Phần mềm này được xây dựng để biểu diễn sơ đồ lây nhiễm cho bệnh truyền nhiễm bao gồm HIV, Tb, SARS-CoV-2, các vụ dịch này thường xuyên được truy vết để phát hiện và ngăn chặn chuỗi lây nhiễm.

Đây là một nền tảng miễn phí trực tuyến cho nhà dịch tễ học, khoa học y sinh, và sinh viên y khoa. Buổi trình bày sẽ chỉ đề cập đến dữ liệu dịch tễ học, thông tin về dữ liệu phân tử học và di truyền học có thể đọc thêm ở phần tài liệu tham khảo.

Ưu điểm của phần mềm:

- Dễ dàng tải lên dữ liệu thô từ Excel
- Dễ dàng định dạng mô hình mà không cần lập trình code
- Có thể đọc được dữ liệu tiếng Việt

Nhược điểm:

- Chỉ tương thích tốt nhất trên GG Chrome
- Định dạng sản phẩm chỉ ở dạng hình ảnh (png, jpeg, svg, webp)
- Không chỉnh sửa data trực tiếp được trên phần mềm

Định dạng dữ liệu cho MicrobeTrace

MicrobeTrace xử lý nhiều loại tệp và định dạng khác nhau thường được thu thập theo cách truyền thống trong quá trình điều tra vụ dịch, ví dụ như dữ liệu giải mã gene, dữ liệu dịch tễ học, dữ liệu danh sách người tiếp xúc và mối quan hệ giữa ca bệnh và người tiếp xúc. MicrobeTrace có thể nhập nhiều định dạng tệp khác nhau tùy thuộc vào mục tiêu phân tích khác nhau của người dùng (Hình 1).

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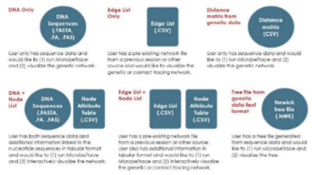

Hình 1: Định dạng dữ liệu cho phần mềm MicrobeTrace – Tham khảo Campbell et al. (2020)

Hai loại tập dữ liệu sẽ sử dụng trong bài tập này:

- **Dữ liệu nốt/điểm** (line list – Node list): danh sách các cá nhân/ca bệnh, mỗi dòng là một cá nhân/ca bệnh. Người dùng có thể đưa thêm các dữ liệu khác để làm phong phú mạng lưới, từ đặc điểm nhân khẩu học đến dữ liệu dịch tễ học quan trọng (chẳng hạn như ngày khởi phát triệu chứng, ngày phơi nhiễm, các yếu tố nguy cơ, v…v…). Mỗi nốt/điểm tương ứng với một dòng tương ứng với một cá nhân/ca bệnh trong mạng lưới.

- **Dữ liệu liên kết** (Edge list): danh sách các đối tác/cặp ca bệnh có liên hệ/phơi nhiễm/tiếp xúc với nhau. Mỗi dòng đại diện cho một kết nối từ người A đến người B. Người dùng cũng có thể đưa thêm các dữ liệu khác về loại liên hệ, vị trí liên hệ, v.v. Mỗi dòng đại diện cho một liên kết (edge) trong mạng lưới.

Dữ liệu đầu vào phần mềm MicrobeTrace thường ở các định dạng sau:

- Excel (CSV hoặc XLSX)
- Định dạng ma trận khoảng cách
- Dữ liệu chuỗi thô (.FASTA)

Đối với LFF này, chúng tôi sẽ chỉ sử dụng dữ liệu excel. Bạn có thể tải xuống và thử hai loại dữ liệu còn lại trong link.

Giới thiệu cơ bản về phân tích mạng lưới

Mục đích của phân tích mạng lưới là lập bản đồ các mối quan hệ kết nối các cá nhân/nhóm cá nhân trong một mạng lưới nhằm tìm ra các cá nhân/nhóm cá nhân quan trọng trong mạng và/hoặc chỉ ra các liên kết quan trọng nổi bật giữa các cá nhân này.

Đặc điểm cơ bản của một mạng lưới được xây dựng từ các điểm/nốt ("nodes") kết nối với nhau bằng các liên kết/cạnh ("edges"). Trong một mạng lưới dịch tễ học, các điểm/nốt ("nodes") thường là các ca bệnh và/hoặc người tiếp xúc gần; và các liên kết ("edges") là bất kỳ kết nối dịch tễ nào giữa hai cá thể (ví dụ, mối quan hệ gia đình, bạn bè, phơi nhiễm trên phương tiện, v…v…)

Quách Hà Linh
NIHE, 30/6/2021

Hai loại liên kết có thể xuất hiện trong một mạng lưới: (1) liên kết có hướng (directed edges): các điểm/nốt được kết nối và một đầu của liên kết có đầu mũi tên chỉ ra hiệu ứng một chiều hoặc hai chiều (phụ thuộc vào dữ liệu về ca bệnh); hoặc (2) liên kết vô hướng: các điểm/nốt được kết nối bằng một mối quan hệ tương hỗ nào đó nhưng không có đầu mũi tên để chỉ hướng (ví dụ, hai ca bệnh có liên quan đến nhau nhưng không rõ nguồn lây). Các cạnh có thể được tính trọng số để phản ánh độ mạnh của mối quan hệ giữa các nốt/điểm.

Một số chỉ số thống kê của một mạng lưới

Chỉ số	Định nghĩa	Phương pháp tính
Số điểm/nốt	Số cá nhân trong mạng lưới	Tổng số điểm/nốt (nodes) xuất hiện trong mạng lưới
Số liên kết/cạnh	Mức độ "bận rộn" của mạng lưới	Tổng số mối quan hệ (edges) giữa các cá nhân xuất hiện trong mạng lưới
Số liên kết/cạnh độc nhất (unique edges)	Mức độ "bận rộn" của mạng lưới, loại bỏ các liên kết trùng	Tổng số mối quan hệ (unique edges) giữa các cá nhân xuất hiện trong mạng lưới, loại bỏ các liên kết trùng
Số nhóm (clusters)	Số nhóm trong mạng lưới	Tổng số các nhóm nhỏ xuất hiện trong mạng lưới
Số cá nhân đơn (singletons)	Số cá nhân đơn không liên kết với các cá nhân khác trong mạng lưới	Tổng số điểm/nốt đơn không liên kết với các điểm/nốt khác trong mạng lưới
Hệ số cố kết của mạng lưới (density)	Mức độ liên kết giữa các điểm/nốt trong mạng lưới – mạng lưới có độ dày đặc thấp có ít mối liên hệ giữa các cá nhân hơn	Tỷ lệ tổng các mối liên hệ thực tế trong mạng lưới và tổng các mối liên hệ trên lý thuyết của mạng lưới. D = k/(n(n-1)/2) Trong đó: k = tổng các mối liên hệ thực tế trong mạng lưới n = tổng số nốt/điểm trong mạng lưới
Hệ số trung tâm trực tiếp (degree centrality)	Tính trung tâm của một nốt/điểm. Các nốt/điểm có hệ số trung tâm trực tiếp cao sẽ có nhiều liên kết với các nốt/điểm khác trong mạng lưới.	Trung bình số liên kết trực tiếp của một nốt/điểm với các nốt/điểm khác trong mạng lưới. $C_D = \frac{k}{n-1}$ Trong đó: k = tổng các mối liên hệ trực tiếp trong mạng lưới n = tổng số nốt/điểm trong mạng lưới
Hệ số trung tâm lân cận (closeness centrality)	Tính gần gũi/lân cận của một nốt/điểm. Các nốt/điểm có hệ số trung tâm lân cận cao sẽ càng gần với trung điểm của mạng lưới và càng gần với các nốt/điểm khác trong mạng lưới.	Tổng số bước (steps) của đoạn đường ngắn nhất (shortest distance) mà một nốt/điểm phải đi để đến với tất cả các nốt/điểm khác trong mạng lưới. $C_C = \frac{n-1}{\sum d(x,y)}$ Trong đó: n = tổng số nốt/điểm trong mạng lưới $\sum d(x,y)$= tổng số bước (step) của đọna đường ngắn nhất mà nốt A đi đến mọi nốt khác trong mạng lưới.
Hệ số trung tâm trung gian (betweeness centrality)	Tính trung gian của một nốt/điểm. Các nốt/điểm có hệ số trung tâm trung gian cao, nghĩa là nhiều nốt/điểm cần phải đi qua nốt/điểm này để đi đến các nốt/điểm khác → các nốt/điểm có hệ số trung gian cao sẽ là cầu nối quan trọng trong mạng lưới.	Trung bình số liên kết độc nhất đi qua một nốt/điểm. $C_B = \frac{n(j,z,x)}{(n-1)(n-2)/2}$ Trong đó: n(j,z,x) = Tổng số lần làm trung gian của nốt/điểm n = tổng số nốt/điểm trong mạng lưới

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NIHE, 30/6/2021

Phần mềm MicrobeTrace sẽ tính trực tiếp các chỉ số được bôi vàng, các chỉ số còn lại có thể tìm hiểu sâu hơn trong tài liệu tham khảo bên dưới.

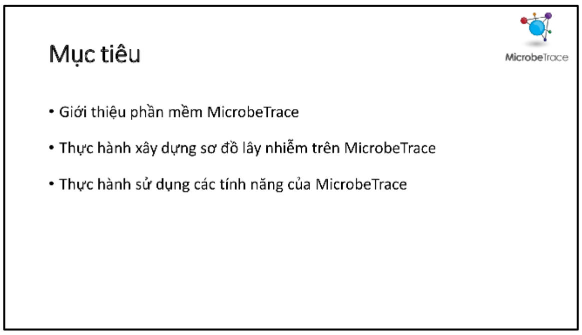
Tài liệu tham khảo

1. Ellsworth M. Campbell, Anthony Boyles, Anupama Shankar, Jay Kim, Sergey Knyazev, William M. Switzer (2020), MicrobeTrace: Retooling Molecular Epidemiology for Rapid Public Health Response. bioRxiv 2020.07.22.216275; doi: https://doi.org/10.1101/2020.07.22.216275
2. GitHub sharing for MicrobeTrace instruction and sample dataset
   https://github.com/CDCgov/MicrobeTrace
3. Interactive instruction to MicrobeTrace
   https://bio.tools/microbetrace
4. How to install MicrobeTrace as a package to Rstudio
   https://github.com/CDCgov/MicrobeTraceShiny
5. MicrobeTrace uses in sequence analysis
   https://www.youtube.com/watch?v=puys17g_hPc
6. More on genome sequencing analysis – How to use the "Prune" and "Filter threshold" function
   https://medium.com/microbetrace-reports/playing-with-your-nearest-neighbor-ef7910312ebf
   https://medium.com/microbetrace-reports/demoing-the-tree-of-life-in-microbetrace-3e6a34d4645b
7. Overplotting problem in MicrobeTrace, and how to use the "Jitter" function
   https://medium.com/microbetrace-reports/how-to-jitter-well-c5e2462047f9
   http://ermalltd.co.uk/1991-cadillac-nz3tt/jitter-overplotting.html

3.2. PowerPoint Presentation

1

2



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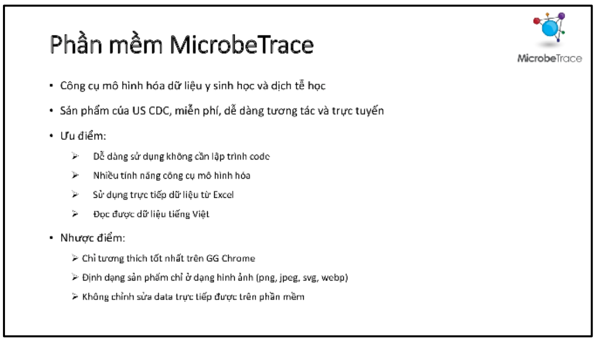

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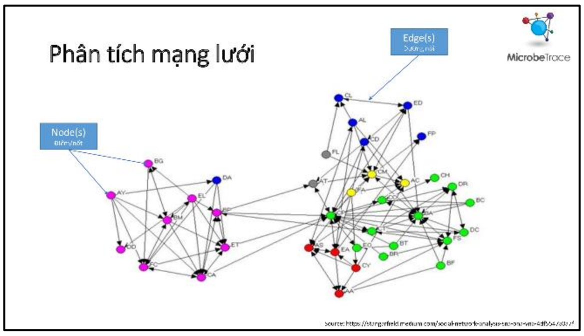

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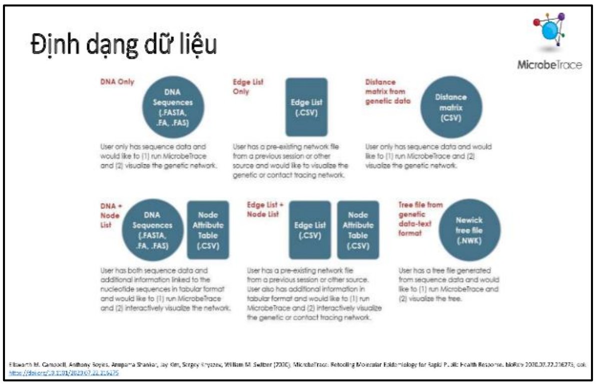

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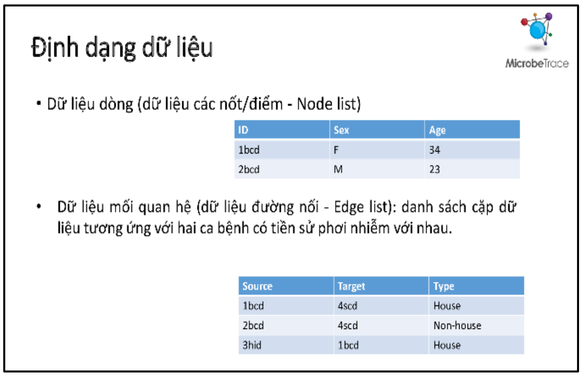

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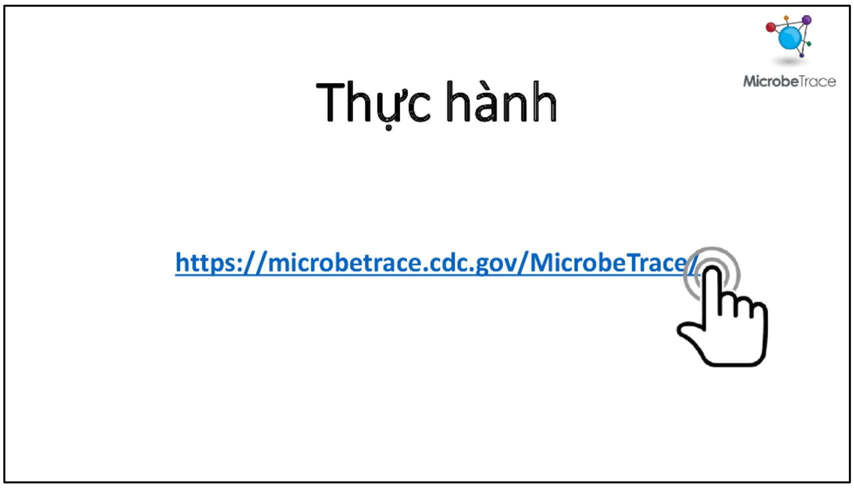
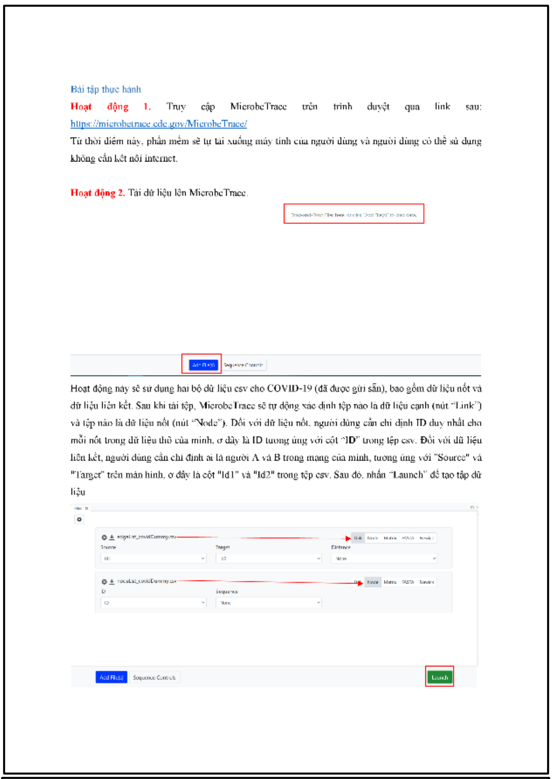


3.3. Practice take-home exercise



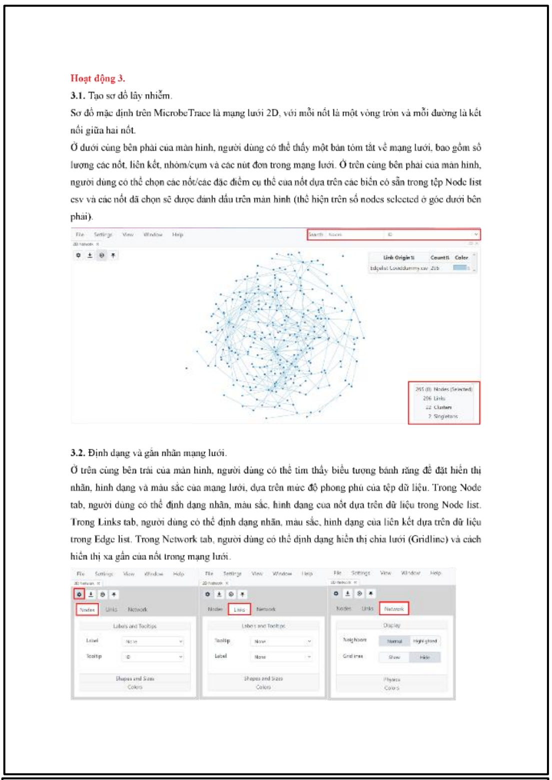
Bài tập thực hành

Hoạt động 1. Truy cập MicrobeTrace trên trình duyệt qua link sau: https://microbetrace.cdc.gov/MicrobeTrace/

Từ thời điểm này, phần mềm sẽ tự tải xuống máy tính của người dùng và người dùng có thể sử dụng không cần kết nối internet.

Hoạt động 2. Tải dữ liệu lên MicrobeTrace.

Hoạt động này sẽ sử dụng hai bộ dữ liệu csv cho COVID-19 (đã được gửi sẵn), bao gồm dữ liệu nốt và dữ liệu liên kết. Sau khi tải tệp, MicrobeTrace sẽ tự động xác định tệp nào là dữ liệu cạnh (nút "Link") và tệp nào là dữ liệu nốt (nút "Node"). Đối với dữ liệu nốt, người dùng cần chỉ định ID duy nhất cho mỗi nốt trong dữ liệu thô của mình, ở đây là ID tương ứng với cột "ID" trong tệp csv. Đối với dữ liệu liên kết, người dùng cần chỉ định ai là người A và B trong mạng của mình, tương ứng với "Source" và "Target" trên màn hình, ở đây là cột "Id1" và "Id2" trong tệp csv. Sau đó, nhấn "Launch" để tạo tập dữ liệu



Hoạt động 3.

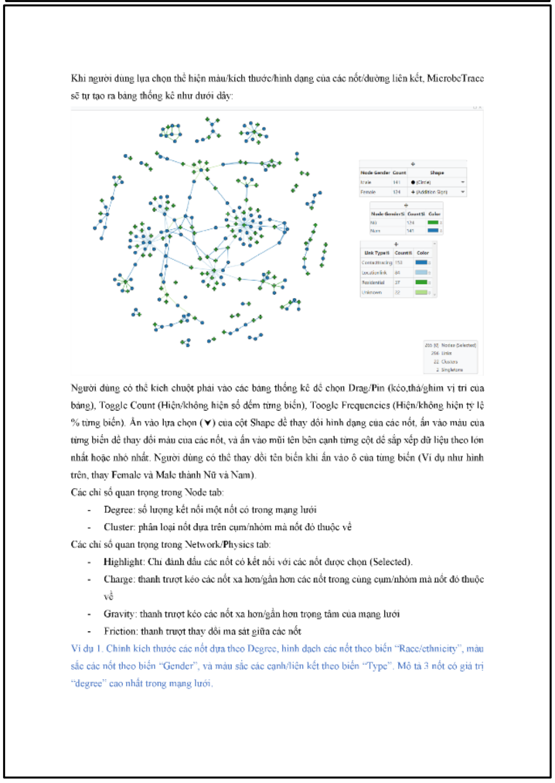
3.1. Tạo sơ đồ lây nhiễm.

Sơ đồ mặc định trên MicrobeTrace là mạng lưới 2D, với mỗi nốt là một vòng tròn và mỗi đường là kết nối giữa hai nốt.

Ở dưới cùng bên phải của màn hình, người dùng có thể thấy một bản tóm tắt về mạng lưới, bao gồm số lượng các nốt, liên kết, nhóm/cụm và các nút đơn trong mạng lưới. Ở trên cùng bên phải của màn hình, người dùng có thể chọn các nốt/các đặc điểm cụ thể của nốt dựa trên các biến có sẵn trong tệp Node list csv và các nốt đã chọn sẽ được đánh dấu trên màn hình (thể hiện trên số nodes selected ở góc dưới bên phải).

3.2. Định dạng và gắn nhãn mạng lưới.

Ở trên cùng bên trái của màn hình, người dùng có thể tìm thấy biểu tượng bánh răng để đặt hiển thị nhãn, hình dạng và màu sắc của mạng lưới, dựa trên mức độ phong phú của tệp dữ liệu. Trong Node tab, người dùng có thể định dạng nhãn, màu sắc, hình dạng của nốt dựa trên dữ liệu trong Node list. Trong Links tab, người dùng có thể định dạng nhãn, màu sắc, hình dạng của liên kết dựa trên dữ liệu trong Edge list. Trong Network tab, người dùng có thể định dạng hiển thị chia lưới (Gridline) và cách hiển thị xa gần của nốt trong mạng lưới.



Khi người dùng lựa chọn thể hiện màu/kích thước/hình dạng của các nốt/đường liên kết, MicrobeTrace sẽ tự tạo ra bảng thống kê như dưới đây:

Người dùng có thể kích chuột phải vào các bảng thống kê để chọn Drag/Pin (kéo,thả/ghim vị trí của bảng), Toggle Count (Hiện/không hiện số đếm từng biến), Toogle Frequencies (Hiện/không hiện tỷ lệ % từng biến). Ấn vào lựa chọn (▼) của cột Shape để thay đổi hình dạng của các nốt, ấn vào màu của từng biến để thay đổi màu của các nốt, và ấn vào mũi tên bên cạnh từng cột để sắp xếp dữ liệu theo lớn nhất hoặc nhỏ nhất. Người dùng có thể thay đổi tên biến khi ấn vào ô của từng biến (Ví dụ như hình trên, thay Female và Male thành Nữ và Nam).

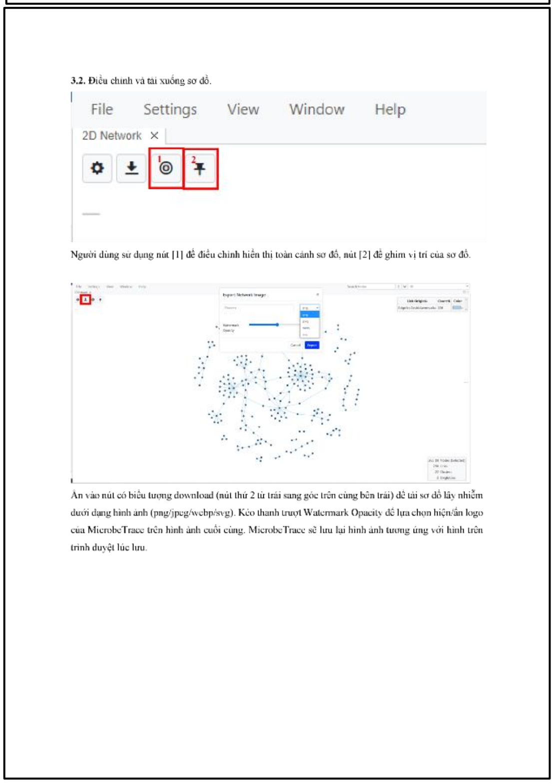
Các chỉ số quan trọng trong Node tab:

- Degree: số lượng kết nối một nốt có trong mạng lưới
- Cluster: phân loại nốt dựa trên cụm/nhóm mà nốt đó thuộc về

Các chỉ số quan trọng trong Network/Physics tab:

- Highlight: Chỉ đánh dấu các nốt có kết nối với các nốt được chọn (Selected).
- Charge: thanh trượt kéo các nốt xa hơn/gần hơn các nốt trong cùng cụm/nhóm mà nốt đó thuộc về
- Gravity: thanh trượt kéo các nốt xa hơn/gần hơn trọng tâm của mạng lưới
- Friction: thanh trượt thay đổi ma sát giữa các nốt

Ví dụ 1. Chỉnh kích thước các nốt dựa theo Degree, hình dạch các nốt theo biến "Race/ethnicity", màu sắc các nốt theo biến "Gender", và màu sắc các cạnh/liên kết theo biến "Type". Mô tả 3 nốt có giá trị "degree" cao nhất trong mạng lưới.



3.2. Điều chỉnh và tải xuống sơ đồ.

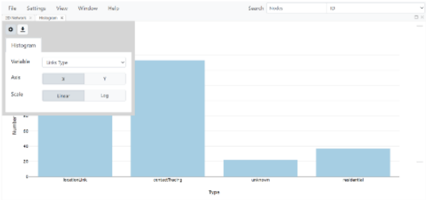
Người dùng sử dụng nút [1] để điều chỉnh hiển thị toàn cảnh sơ đồ, nút [2] để ghim vị trí của sơ đồ.

Ấn vào nút có biểu tượng download (nút thứ 2 từ trái sang góc trên cùng bên trái) để tải sơ đồ lây nhiễm dưới dạng hình ảnh (png/jpeg/webp/svg). Kéo thanh trượt Watermark Opacity để lựa chọn hiện/ẩn logo của MicrobeTrace trên hình ảnh cuối cùng. MicrobeTrace sẽ lưu lại hình ảnh tương ứng với hình trên trình duyệt lúc lưu.

Hoạt động 4.

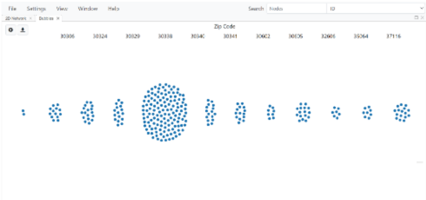
4.1. Histogram view

Chọn View/Histogram trên thanh công cụ. Đây là công cụ biểu đồ historgram dựa trên tần số của các biến có sẵn trong hai bộ dữ liệu của mạng lưới, cùng với một số biến được tính toán tự động bởi MicrobeTrace (degree, cluster, origin).



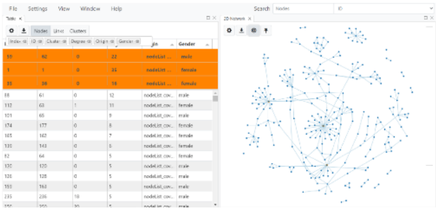
Ví dụ 2. Sử dụng biểu đồ Histogram để vẽ diễn biến thời gian của ngày ca bệnh xét nghiệm dương tính.

Một cách khác để thể hiện sự phân bố của các biến là thông qua View/Bubbles. Sử dụng bánh rang ở bên trái màn hình, người dùng có thể thể hiện phân bố biến số theo trục X và Y dựa trên các biến có sẵn trong dữ liệu.



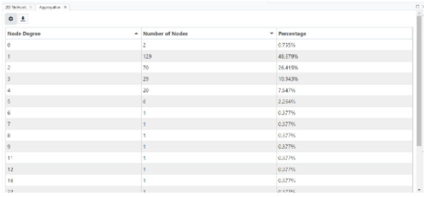
4.2. Table view

Chọn View/Table trên thanh công cụ. Công cụ này về cơ bản là dữ liệu của người dùng tải lên từ file Excel (không cần chuyển từ MicrobeTrace sang Excel để xem dữ liệu). Người dùng có thể thêm hoặc xóa hoặc sắp xếp các dữ liệu theo nhu cầu. Người dùng có thể xác định các nốt có đặc điểm cụ thể trong mạng lưới bằng ấn vào từng dòng trong Table và các biến đó sẽ được lựa chọn trên mạng lưới bên cạnh (Selected).

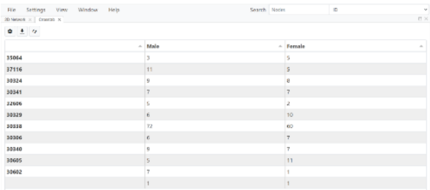


4.3. Aggregation

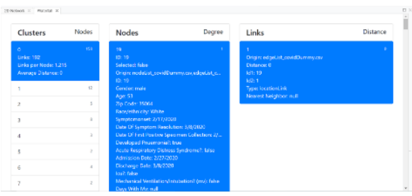
Chọn View/Aggregation trên thanh công cụ. Công cụ này tạo bảng tóm tắt tần suất (%) của các nốt/liên kết/cụm được phân tầng theo các biến khác nhau trên tập dữ liệu của người dùng. Cơ bản công cụ này thay thế cho Pivot Table trên Excel để người dùng không cần phải chuyển tiếp giữa hai phần mềm. Người dùng có thể thêm bảng tóm tắt tần suất khi ấn vào nút rang bên trái của màn hình.



Công cụ View/Crosstab thể hiện phân bố của các biến trong bộ số liệu tương tác với nhau (thay vì chỉ là phân bố của từng biến trên số nốt/liên kết).

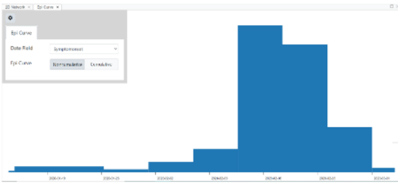


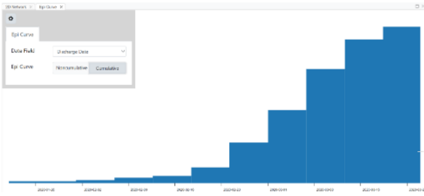
Một cách khác để tra cứu nhanh các đặc điểm của các cụm/nốt trong mạng lưới là thông qua công cụ View/Waterfall, thông tin trong công cụ Waterfall thể hiện đầy đủ dữ liệu hơn của từng kết nốt một.

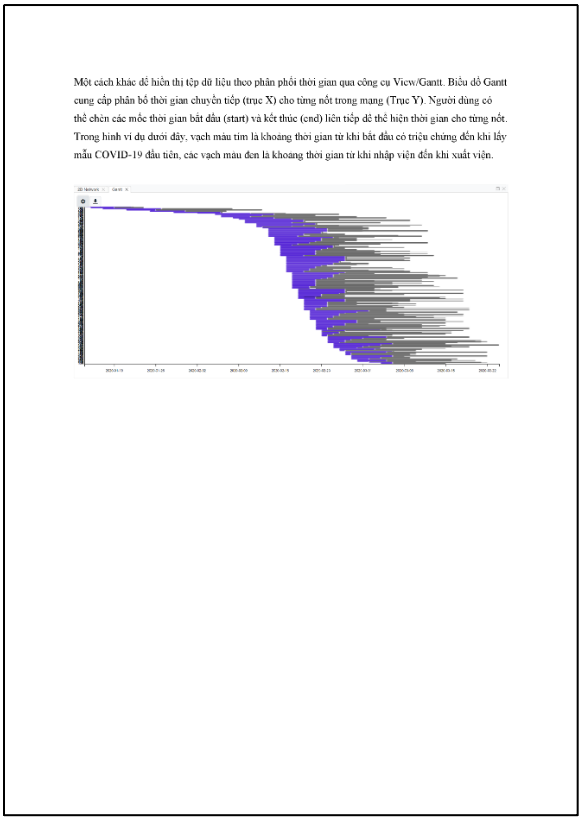


4.4. Epi curve

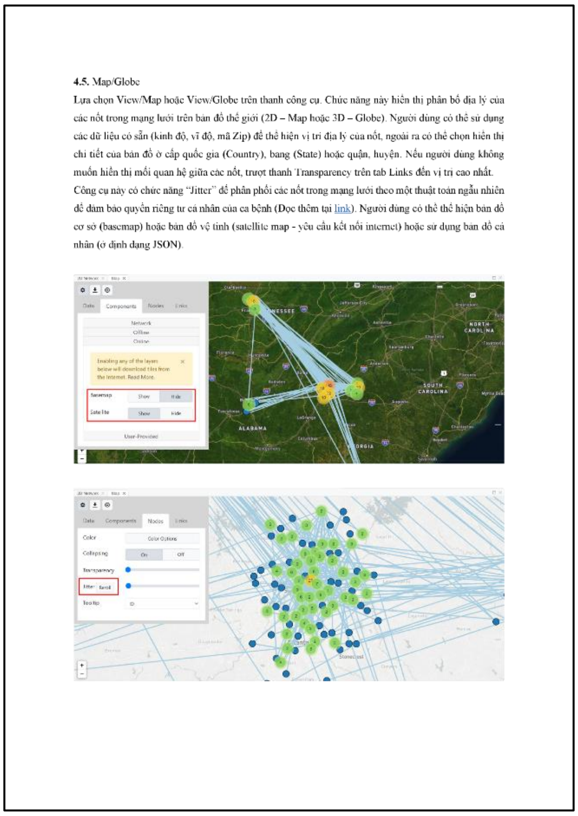
Người dùng có thể tạo phân bố dịch tễ (epi curve) bằng cách chèn trường dữ liệu ngày (trong tệp dữ liệu Node list) trong thanh công cụ View/Epi curve. Người dùng lựa chọn "Noncumulative" thể hiện số nốt theo ngày, và "Cumulative" thể hiện số nốt cộng dồn.







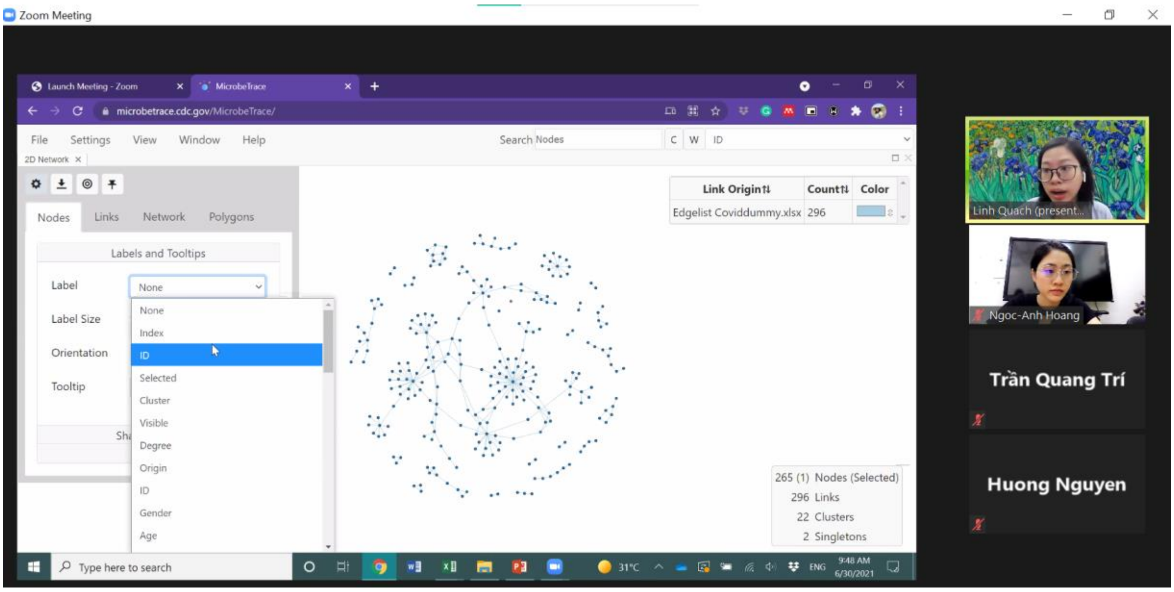
Một cách khác để hiển thị tệp dữ liệu theo phân phối thời gian qua công cụ View/Gantt. Biểu đồ Gantt cung cấp phân bố thời gian chuyển tiếp (trục X) cho từng nốt trong mạng (Trục Y). Người dùng có thể chèn các mốc thời gian bắt đầu (start) và kết thúc (end) liên tiếp để thể hiện thời gian cho từng nốt. Trong hình ví dụ dưới đây, vạch màu tím là khoảng thời gian từ khi bắt đầu có triệu chứng đến khi lấy mẫu COVID-19 đầu tiên, các vạch màu đen là khoảng thời gian từ khi nhập viện đến khi xuất viện.

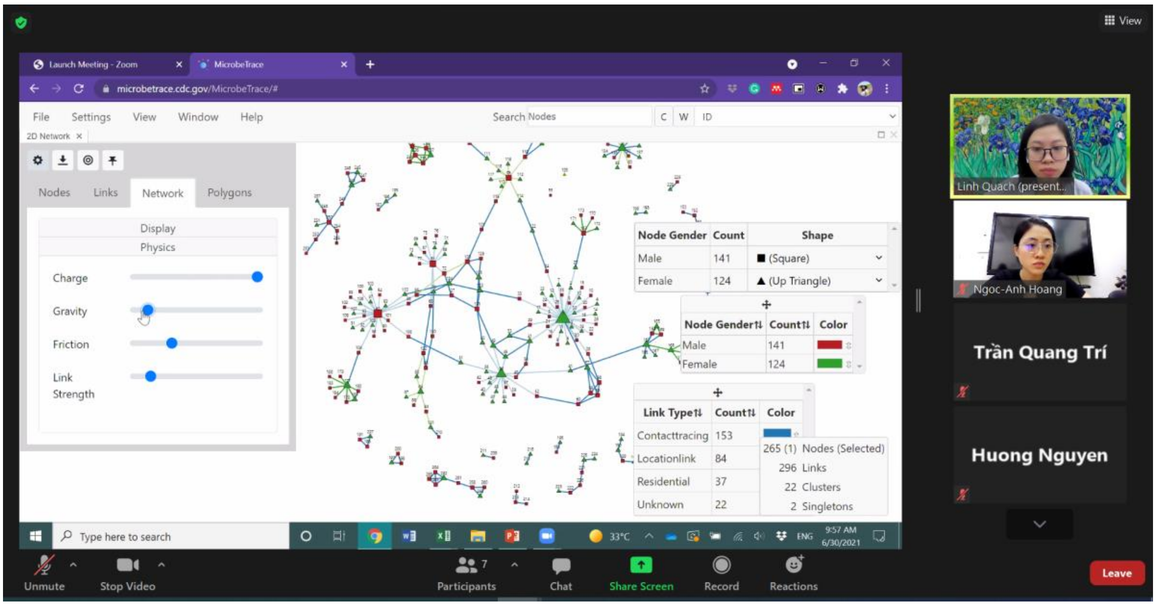
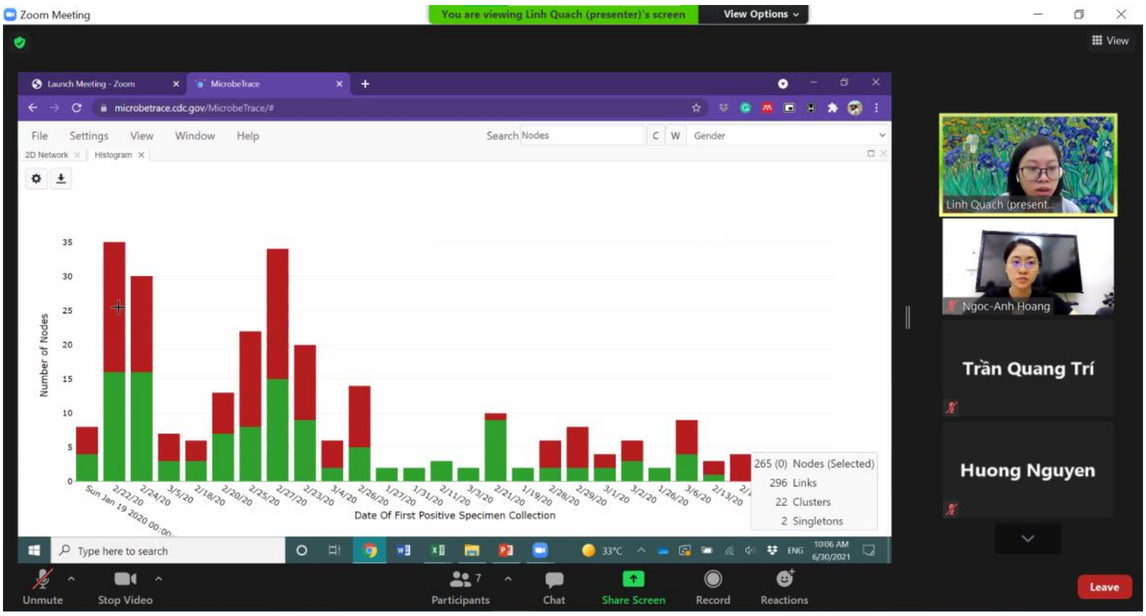
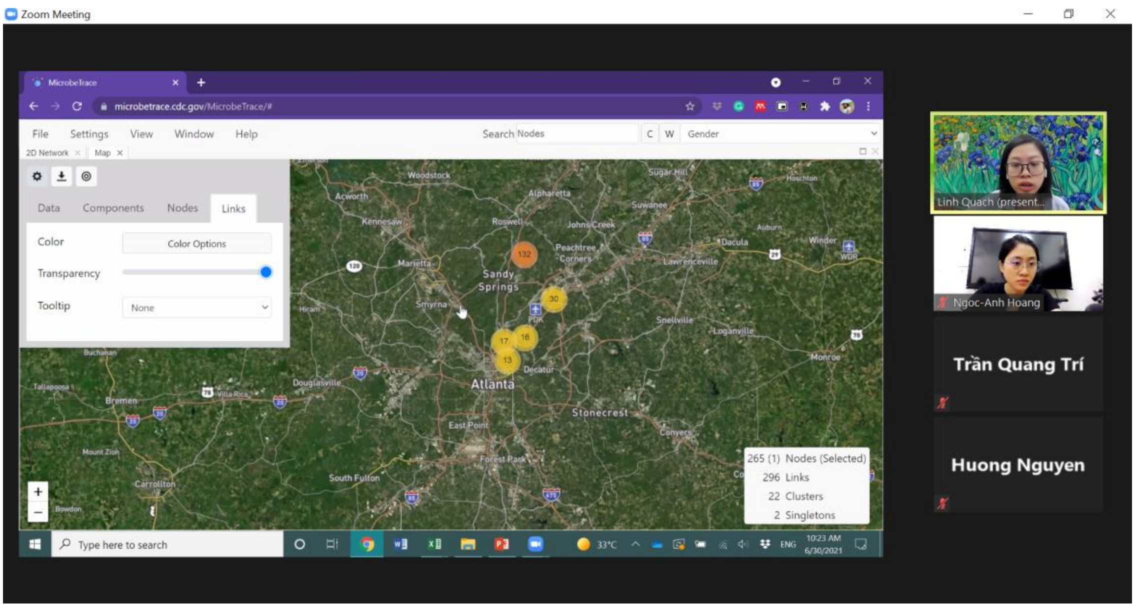


4.5. Map/Globe

Lựa chọn View/Map hoặc View/Globe trên thanh công cụ. Chức năng này hiển thị phân bố địa lý của các nốt trong mạng lưới trên bản đồ thế giới (2D – Map hoặc 3D – Globe). Người dùng có thể sử dụng các dữ liệu có sẵn (kinh độ, vĩ độ, mã Zip) để thể hiện vị trí địa lý của nốt, ngoài ra có thể chọn hiển thị chi tiết của bản đồ ở cấp quốc gia (Country), bang (State) hoặc quận, huyện. Nếu người dùng không muốn hiển thị mối quan hệ giữa các nốt, trượt thanh Transparency trên tab Links đến vị trí cao nhất. Công cụ này có chức năng "Jitter" để phân phối các nốt trong mạng lưới theo một thuật toán ngẫu nhiên để đảm bảo quyền riêng tư cá nhân của ca bệnh (Đọc thêm tại link). Người dùng có thể thể hiện bản đồ cơ sở (basemap) hoặc bản đồ vệ tinh (satellite map - yêu cầu kết nối internet) hoặc sử dụng bản đồ cá nhân (ở định dạng JSON).

3.4. Screenshots from the session




microbetrace.cdc.gov/MicrobeTrace/#
File
Settings
View
Window
Help
Nodes
Links
Network
Polygons
Display
Physics
Charge
Gravity
Friction
Link Strength
Node Gender
Count
Shape
Male
141
(Square)
Female
124
(Up Triangle)
Color
Link Type
Contacttracing
153
Locationlink
84
Residential
37
Unknown
22
265 (1) Nodes (Selected)
296 Links
22 Clusters
2 Singletons
Linh Quach (present...
Ngoc-Anh Hoang
Trần Quang Trí
Huong Nguyen
Unmute
Stop Video
Participants
Chat
Share Screen
Record
Reactions
Leave

Zoom Meeting
You are viewing Linh Quach (presenter)'s screen
View Options
microbetrace.cdc.gov/MicrobeTrace/#
2D Network
Histogram
Number of Nodes
Date Of First Positive Specimen Collection
265 (0) Nodes (Selected)
296 Links
22 Clusters
2 Singletons
Linh Quach (present...
Ngoc-Anh Hoang
Trần Quang Trí
Huong Nguyen
Unmute
Stop Video
Participants
Chat
Share Screen
Record
Reactions
Leave

Zoom Meeting
microbetrace.cdc.gov/MicrobeTrace/#
2D Network
Map
Data
Components
Nodes
Links
Color
Color Options
Transparency
Tooltip
None
Atlanta
Sandy Springs
Marietta
Stonecrest
265 (1) Nodes (Selected)
296 Links
22 Clusters
2 Singletons
Linh Quach (present...
Ngoc-Anh Hoang
Trần Quang Trí
Huong Nguyen

END OF THESIS