

# Epidemiology and quarantine measures during COVID-19 outbreak on the cruise ship Diamond Princess docked at Yokohama, Japan in 2020: a descriptive analysis

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**Abstract:** The outbreak of coronavirus disease 2019 (COVID-19) on the cruise ship Diamond Princess docked at Yokohama, Japan was highlighted due to its number of cases in the early stage of the global epidemic when the picture of the virus itself, as well as epidemiological characteristics, were being established. We conducted an observational epidemiological study of the outbreak, focusing on a total of 403 individuals who developed a fever of  $\geq 37.5^{\circ}\text{C}$  from 20 January to 22 February 2020. Quarantine measures are also discussed with a descriptive method. Of a total of 3,711 individuals (2,031 males) from 57 countries, 2,666 (71.8%) and 1,045 (28.2%) were passengers and crew with mean age of 66.0 (range: 2-98) and 36.6 (range: 19-64), respectively. Among 403 febrile individuals, 165 passengers and 58 crew members were diagnosed as laboratory-confirmed COVID-19 cases. Until 6 February, the number of confirmed cases was three or less per day. However, distribution of thermometers on 7 February revealed 43 confirmed cases, and it then started decreasing. The outbreak was initiated from decks for passengers and expanded to areas for crew. As of 17 March, when more than 14 days had passed after disembarkation of all passengers and crew, there was no report of forming a cluster of infections in Japan from them. At the time of the initiation of quarantine, the outbreak had already expanded to most of the decks from those for passengers, and the results might suggest the contribution of the set of quarantine measures in unprecedented challenges of the control operation.

**Keywords:** COVID-19, disease outbreaks, ships, quarantine, Japan

## Introduction

An ongoing international outbreak of coronavirus disease 2019 (COVID-19) started from Wuhan, China has rapidly expanded worldwide, and the World Health Organization declared a pandemic on 11 March 2020. Asian neighboring countries that have close human and economic relations with China were first affected. The case of the cruise ship Diamond Princess was highlighted due to its number of cases in the early stage of the global epidemic when the picture of the virus itself, as well as epidemiological characteristics, were being established.

In February 2020, a cruise ship named Diamond Princess, under the flag of the United Kingdom and operated by an American company, was quarantined at Yokohama city, Kanagawa, Japan. The cruise ship departed from Yokohama on 20 January 2020 and was scheduled to return to Yokohama after calling at Kagoshima (Japan), Hong Kong, Chan May (Vietnam),

Cai Lan (Vietnam), Keelung (Taiwan), and Okinawa (Japan). During this voyage, a passenger who had been coughing since 23 January disembarked in Hong Kong on 25 January and was confirmed positive for COVID-19 on 1 February. This information was immediately notified to Japan through International Health Regulations as early as 2 February after the ship left Okinawa. Hence, when the ship reached Yokohama in the evening of 3 February, the Japanese government adopted an anchorage quarantine approach by sending quarantine officers to the ship for health evaluation of all passengers and crew members as well as collecting specimens from the individuals with fever or respiratory symptoms, their close contacts, and close contacts of the index case for reverse transcriptase-polymerase chain reaction (RT-PCR) tests. The first reports of the tests revealed ten positive cases (1), and isolation in cabins was initiated from 5 February.

This study aims to elucidate the epidemiology of COVID-19 during an outbreak on the cruise ship and discuss the contribution of quarantine strategies,

including isolation in cabins for passengers and crew members.

## Materials and Methods

### *Study design and data collection*

We conducted an observational epidemiological study of the COVID-19 outbreak on the cruise ship Diamond Princess, covering the period from 20 January (start of the cruise voyage) to 22 February, 2020 (completion of disembarkation of almost all of the passengers). In addition to this, the follow-up information of the passengers and crew after disembarkation was assessed on 17 March, 2020. Age, sex, nationality, room size, deck number, date of fever onset, and results of RT-PCR tests of passengers and crew members were compiled for analysis. Information on the follow-up and assessment of disembarked persons was collected from the official press release of the Ministry of Health, Labour and Welfare (MHLW), and local governments.

This study was approved by the Human Research Ethics Committee of the National Center for Global Health and Medicine (NCGM), Tokyo, Japan (NCGM-G-003505-00). Written informed consent was waived as only anonymized data was used.

### *Definitions of study cases*

During this voyage and quarantine starting from 20 January to 22 February, a total of 403 passengers and crew members developed a fever of  $\geq 37.5^{\circ}\text{C}$ , and this study focused on them. Confirmed cases in this study were defined as cases with a fever of  $\geq 37.5^{\circ}\text{C}$  and RT-PCR positive by pharyngeal swab specimen. Close contact is defined as those cabinmates of the confirmed cases and their family members or partners staying in other cabins.

### *Laboratory confirmation*

Pharyngeal swab specimens were placed in plastic containers and transported to the laboratories under  $4^{\circ}\text{C}$ . Laboratory confirmation by RT-PCR test for COVID-19 was performed following the protocol established by the National Institute of Infectious Diseases (NIID), Tokyo, Japan (2). The tests were conducted at NIID, quarantine stations in Tokyo, Yokohama and Narita, prefectural or city institutes of public health, medical universities, and a commercial laboratory.

### *Quarantine measures*

First, starting from 5 February, all passengers were isolated in their cabins for 14 days. Second, crew members were given instructions on appropriate infection prevention and control practice, and minimum

services for passengers were provided by the crew. Third, all RT-PCR positive patients, regardless of symptoms, were promptly sent to hospitals outside the ship for isolation and care, and their close contacts were tested. In addition, those with health conditions that do not allow quarantine on the ship were sent to appropriate facilities. Fourth, on 7 February, thermometers were distributed and self-monitoring of body temperature twice a day was requested from all passengers and crew. Fifth, to separate routine health services for chronic conditions of the large population of senior passengers on board from those for possible infections, in addition to the existing Medical Center, a dedicated Fever Call Center (FCC) was also established on the ship to manage calls from passengers who had a fever of  $\geq 37.5^{\circ}\text{C}$  and other suspicious symptoms. The FCC was opened on 7 February and closed on 22 February after disembarkation of almost all passengers. Sixth, for COVID-19 testing, RT-PCR test was initially performed only for symptomatic cases until 10 February, but systematic screening was started from 11 February as testing capacity was expanded. The priority of the screening was based on age and comorbidities. Passengers aged  $\geq 80$  years and their cabinmates were tested first; followed by those in the seventies and their cabinmates; and those in the sixties and their cabinmates. Those who had comorbidities (including diabetes, chronic pulmonary diseases, and cardiac diseases) were also prioritized. Then, all other passengers were tested by visiting all remaining cabins. Seventh, the 14-day quarantine period was completed after confirming a negative RT-PCR test, no fever, or other physical conditions.

### *Statistical analysis*

Categorical variables were counted and presented as proportion. Continuous variables were expressed as mean and range. All statistics are analyzed descriptively with the Stata IC version 16.1.

## Results

A total of 3,711 individuals (2,031 males and 1,680 females) were on board at the beginning of quarantine. Of these, 2,666 (71.8%) were passengers with mean age of 66.0 (range: 2-98) and 1,045 (28.2%) were crew members with mean age of 36.6 (range: 19-64). Passengers accounted for 99.2% (2,144/2,162) of those aged  $\geq 60$  years, whereas 82.1% (669/815) of those aged  $< 40$  years were crew members. For the nationalities of all individuals on board from 57 countries, Japanese occupied the largest proportion (36.1% [1,341/3,711]), followed by nationals of the Philippines (14.5% [538/3,711]), United States (11.5% [428/3,711]), Hong Kong (7.0% [260/3,711]), Canada (6.9% [255/3,711]), and Australia (6.1% [226/3,711]).

Passengers and crew members stayed alone in a cabin

or shared a cabin with 2 to 4 persons, and most of them stayed in double rooms during the voyage and quarantine (89.8% and 79.7%, respectively). Upper decks (*i.e.* deck nos. 8-12 and 14) were mostly used for passengers, while lower decks (*i.e.* deck nos. 2, 3, 5, and 7) were mainly for crew members.

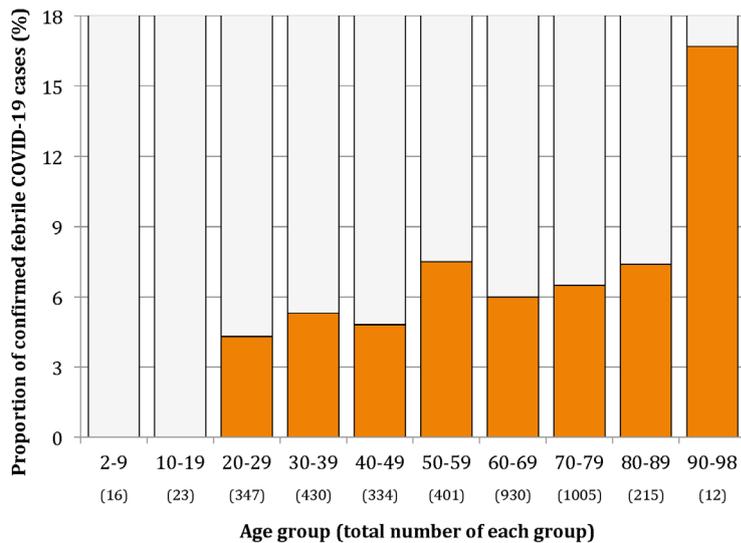
Among a total of 403 febrile individuals, 223 individuals (165 passengers and 58 crew members) were diagnosed as confirmed COVID-19 cases. With regard to the proportions of the cases stratified by age group (Figure 1), they ranged from 4.3% to 7.5% consistently across age groups between 20 and 89 years. There were no confirmed febrile cases aged 19 years or younger, while the largest proportion was observed in the nineties (16.7%), although the denominator of these age groups was small compared to other groups.

Figure 2 shows the fever onset of confirmed cases defined as those with fever of  $\geq 37.5^{\circ}\text{C}$  and RT-PCR positive, and illustrates implementation dates of control

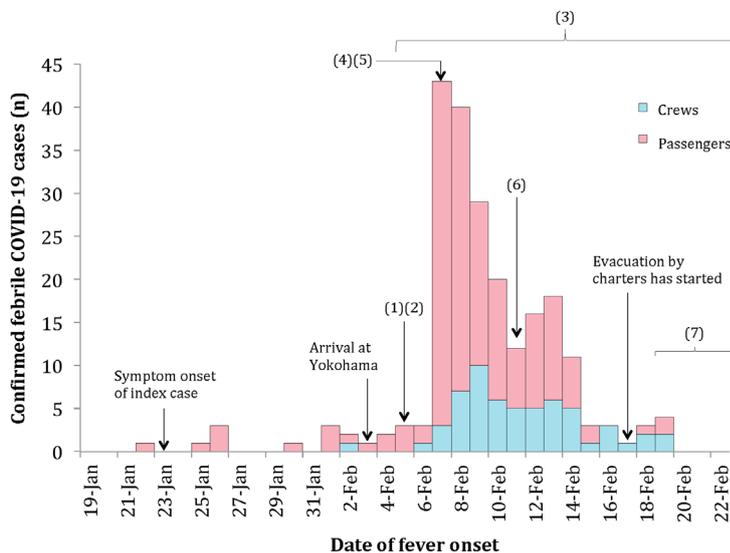
measures. Until 6 February, the number of confirmed cases was three or less per day. However, immediately after distribution of thermometers for self-monitoring and open of FCC on 7 February, a substantial number of confirmed cases was revealed and it started decreasing after 8 February. On the other hand, the number of confirmed cases among crew members peaked on 9 February, and then the daily numbers of cases gradually decreased with some fluctuation.

The pattern of spread of the infection based on deck number is described in Figure 3. As illustrated, the outbreak seemed to have spread from the area of the passengers. At the time when FCC was opened, the outbreak had already expanded to most of the decks.

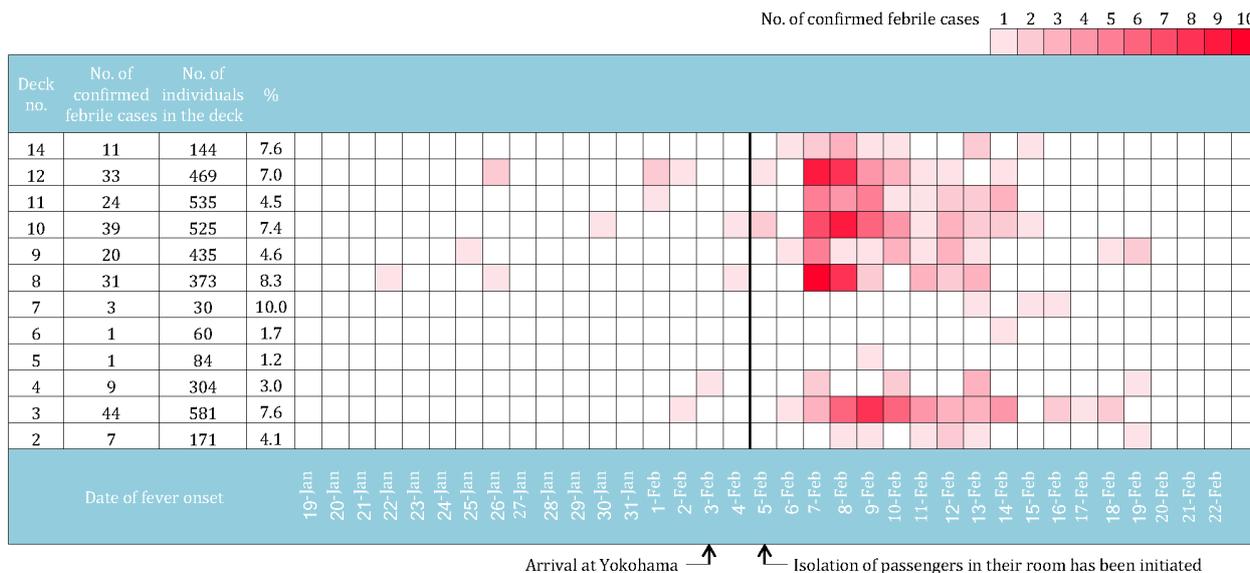
As of 17 March 2020 when more than 14 days had passed after disembarkation of all passengers and crew on 1 March, there were six cases whose PCR results were initially negative but turned out to be positive after returning to communities. However, there was no report



**Figure 1. Proportion of confirmed febrile COVID-19 cases in each age group.** The proportions of the cases ranged from 4.3% to 7.5% consistently across age groups between 20 and 89 years. No confirmed febrile case aged 19 years or younger was observed, while the largest proportion was in the nineties (16.7%), although the small denominator of these age groups should be considered.



**Figure 2. The number of confirmed febrile COVID-19 cases and the implementation date of quarantine measures.** The numbers in the figure describes following quarantine measures implemented: (1) isolation of all passengers in their cabins for 14 days was started, (2) crew members were given instructions of appropriate infection prevention and control practice, (3) all RT-PCR positive patients regardless of symptoms are sent to hospitals or other facilities for isolation and care, (4) thermometers were distributed and self-monitoring was requested for all passengers and crew members, (5) a dedicated Fever Call Center was established on the ship, (6) systematic screening of RT-PCR test for COVID-19 was initiated, and (7) on 19 February, disembarkation was started after confirming negative RT-PCR test, no fever, or other physical conditions.



**Figure 3. Outbreak dynamics of confirmed febrile COVID-19 cases stratified by deck numbers.** This figure shows the association between the fever onsets of the confirmed febrile COVID-19 cases and the deck where the cases stayed during travel and quarantine. Passengers’ cabins were located on deck nos. 4, 6, 8-12, and 14, whereas crew members’ cabins were located on deck nos. 2-7, 12, and 14. This revealed that COVID-19 had already spread to most of the decks before arrival at Yokohama and initiation of isolation strategy in cabins.

of forming a cluster of infections in Japan from those passengers.

**Discussion**

This is the first comprehensive epidemiological report of COVID-19 outbreak on the cruise ship Diamond Princess in 2020 covering the period from the beginning of the cruise voyage to disembarkation of passengers with follow-up information of passengers after disembarkation, further to earlier publications from the NIID for the shorter period (3-5). When Japan faced this challenge in early February 2020, there was extremely scarce information available for dealing with outbreaks of infectious diseases on cruise ships. Indeed, we found some information about other infections such as gastrointestinal infections, influenza, and measles (6-9), but there is no report of a huge outbreak on a cruise ship caused by an emerging infectious disease.

The epidemic curve reveals that the COVID-19 outbreak on the cruise ship had already expanded before the initiation of quarantine (Figure 2). Since some previous studies reported mean and median incubation periods of 5.2 days (95% confidence interval [CI] 4.1-7.0) and 4 days (interquartile range [IQR] 2-7), respectively (10,11), many of the cases confirmed on 7 February should have been contracted before initiation of isolation measures on 5 February. In addition, the peak of infection among the confirmed cases could be before 7 February because the number of confirmed cases sharply decreased then. Moreover, the cases had been distributed in most of the decks by 5 February (Figure 3), possibly

through recreational activities and facilities shared by all on board that were available to some extent before the isolation was initiated on 5 February.

The number of confirmed cases decreased substantially shortly after the initiation of quarantine. This might suggest the contribution of the set of countermeasures implemented to overcome this outbreak. To control an epidemic, the passengers were isolated into their cabins immediately after the initiation of quarantine. Cabins were selected as the isolation place because there were no available facilities on shore to isolate all passengers and crew members from 57 countries, and some suitable facilities were occupied with people who were evacuated from Wuhan by another national operation. For early detection of the cases and suspected cases, thermometer distribution, FCC establishment, and systematic screening with RT-PCR were implemented to improve detection of cases with mild symptoms and asymptomatic cases. In addition, once their diagnoses were confirmed, cases including asymptomatic patients were promptly transported to outside facilities for isolation and care, and their close contacts were tested. The effectiveness of these measures is supported by two small studies reporting that COVID-19 viral load peaked within 5-6 days after symptom onset (earlier than that of severe acute respiratory syndrome: 6-11 days after illness onset) and high viral loads were detected shortly after symptom onset (12,13). However, at the same time, these studies also indicated the difficulty of controlling COVID-19. Moreover, to avoid transmission between passengers and crew during quarantine period, instruction for personal

protective equipment was performed for crew members. Thus, these control measures seemed to contribute to reduction of transmission, although additional studies are required to determine with confidence the degree of contribution.

Another point is the outcome of quarantine exercise to protect the inflow of epidemics into Japan. Considering no report of formation of clusters in Japanese communities despite the follow-up of the passengers and crew for two weeks after disembarkation and careful monitoring of the close contacts of the cases whose PCR result turned out to be positive after disembarkation (14), this might suggest the contribution of the quarantine exercise on board.

The present study has some limitations. First, individuals who have only respiratory symptoms without fever were not included in the epidemic curve because of the lack of such information. This was due to best allocate limited resources, such as laboratory capacity for the novel pathogen. Second, it was possible that some crew members were reluctant to report mild symptoms in order to maintain minimum function on the huge cruise ship. This was suspected from the fluctuation pattern of the epidemic curve of crew members, although there was no solid evidence.

Acknowledging the above limitations, the authors believe that this study provides some insight on COVID-19 and similar events in the future including a clear and detailed description of the epidemiology of an outbreak in a unique environment of a cruise ship in terms of physical environment and a predominantly older high-risk population, and possibly effective quarantine exercises to protect inflow of epidemics into a country. Furthermore, the importance of collaboration among various teams such as the ministry of health, quarantine stations, and medical and pharmaceutical support units, and effective management of a massive amount of information using a systematically constructed integrated data platform accessible to each team should be highlighted to overcome unprecedented challenges of control operations in a very limited timeframe.

### Acknowledgements

We thank Hiroki Nakatani, National Center for Global Health and Medicine, and all other colleagues who supported us for this study and are also grateful to many front-line co-workers on the cruise ship Diamond Princess for their dedication to countermeasures to overcome this outbreak.

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Received April 21, 2020; Revised April 27, 2020; Accepted April 28, 2020.

Released online in J-STAGE as advance publication April 29, 2020.

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