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COVID-19 outbreaks on ships: Analysis of three representative cases

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ABSTRACT

Objectives: Coronavirus disease (COVID-19) outbreaks occurred on ships during the global pandemic of COVID-19. Investigation of the management and outcomes of these outbreaks will help guide future prevention and control strategies for respiratory infectious diseases on ships.
Study design: Non-systematic narrative review.
Methods: PubMed and Embase databases were searched using the keywords "ship", "cargo ship", "fishing boat", "cruise ship", "yacht", "merchant ship", "port", "SARS-COV-2" and "COVID-19", connected by "OR" internally and "AND" between two keywords. After review of the titles and abstracts, and exclusion of irrelevant articles, the infection situation and details of the response measures were recorded. Cases were subsequently selected for this study based on the detailed information and records available on the COVID-19 outbreak prevention and control measures and experiences.
Results: Three representative cases were selected; the outbreak timeline and infection situation for these cases were summarised. Infection prevention and control measures and experiences for the three outbreaks were investigated in detail, including analysis of epidemic reports, and isolation, detection, screening, treatment and transportation procedures.
Conclusions: This study demonstrates that timely detection and intervention, exposure reduction, control of asymptomatic infections, treatment and transport of patients, preparation for prevention and control in advance, the communication and cooperation of various stakeholders, and the establishment of short-term and long-term response mechanisms are key elements to improve the efficiency of infection prevention and control on ships.

1. Introduction

At the end of 2019, coronavirus disease (COVID-19), caused by the novel severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was first reported in Wuhan, China [1]. COVID-19 then rapidly spread throughout the world, resulting in the World Health Organisation (WHO) declaring it a global pandemic in March 2020. With the development of the transportation industry, the worldwide movement of people and goods has become more frequent and convenient; however, this is also conducive to the spread of various pathogens, including viruses. In particular, the increase in sea navigation has played a significant role in the transmission of infectious diseases [2].

There is growing evidence that SARS-CoV-2 can spread rapidly in confined environments, including hospitals, cruise ships, prisons and churches [3]. Most ships have mixed and enclosed spaces, a high density of people and frequent contact among individuals onboard, all of which make it difficult to control spread of the virus in the event of an outbreak [4]. Additionally, international cruise ships may gather crew and passengers from different countries. In the closed environment of a ship, passengers and crew have extensive contact in public areas, such as restaurants, recreation rooms and swimming pools, which create excellent conditions for the spread of disease onboard [5]. Longer sailing times and limited on-board professional medical resources and services also make it difficult to manage disease outbreaks. Additionally, the majority of passengers on cruise ships are older individuals who may have underlying chronic diseases and are more susceptible than the general population to infection and related complications. Thus, it is expected that an epidemic will have serious consequences on a cruise ship [5].

Following the outbreak of a respiratory infectious disease on ships,

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rapid isolation and a reduction in human contact are important measures to slow down the spread of the pathogen. However, on international cruise ships, isolation faces various challenges, including language barriers, limited medical support, inadequate living spaces, difficulties in distinguishing infected and noninfected individuals, and infected crew members who are responsible for the daily operation of the ship [6]. In addition, if cruise ships do not follow protocols for infection control or staff lack training in infection prevention and control, this may lead to delayed detection and reduced capacity to prevent and control respiratory infectious diseases at sea.

Based on extensive investigation of the maritime epidemic prevention and control literature, this study summarises and analyses the prevention and control measures and experiences of COVID-19 outbreaks on three ships. This study aims to provide guidance for future prevention and control strategies for respiratory infectious diseases on ships.

2. Methods

PubMed and Embase databases were searched using the keywords “ship”, “cargo ship”, “fishing boat”, “cruise ship”, “yacht”, “merchant ship”, “port”, “SARS-COV-2” and “COVID-19”, connected by “OR” internally and “AND” between two keywords. All articles were published after 2019.

After review of the titles and abstracts, articles irrelevant to maritime epidemic prevention and control were excluded. The infection situation and response measures of cases in the remaining articles were recorded, which enabled subsequent selection of the cases warranting further study.

In total, three cases of COVID-19 outbreaks on ships were selected for this study. These three cases were selected based on the detailed information and records available on the COVID-19 outbreak prevention and control measures and experiences, and included the following ships [1]: the Diamond Princess (25 studies) [2]; the USS Theodore Roosevelt (five studies); and [3] the Costa Atlantic (four studies). In all three cases, detailed records of the outbreak and measures taken were available; hence, they were selected as representative cases. In addition, this study also refers to the prevention and control experiences of other cases to supplement the prevention and control recommendations.

The main objectives of this study were [1]: to summarise and analyse three representative cases of COVID-19 outbreaks on ships during the global pandemic; and [2] to provide recommendations for the prevention and control of respiratory infectious diseases on ships.

3. Results

3.1. Overview of selected cases

See Table 1 for an overview of the selected ships with COVID-19 outbreaks.

3.1.1. The Diamond Princess

Several articles have studied COVID-19 infection onboard the Diamond Princess. The data reported varied across studies, but there was little difference overall. Passengers on this cruise ship came from more than 50 countries [7]. The ship began its voyage in Yokohama (Japan) on January 20, 2020 and docked in Kagoshima (Japan), Hong Kong, Vietnam, Keelung (Taiwan, China) and Okinawa (Japan) [8]. The first confirmed case was an 80-year-old man who boarded the ship in Hong Kong on 25 January 2020. The Hong Kong health authorities confirmed the case on 1 February 2020 and alerted the Japanese authorities, after which the passengers and crew were not allowed to disembark when arriving in Yokohama [2,9]. The subjects of the study included all individuals onboard on 3 February 2020 (2666 passengers and 1045 crew members). The average age of the passengers was 66.1 years, with 55% women. The average age of the crew members was 36.6 years, with 81% being men. A total of 544 (20.4%) passengers were infected, with 314 (57.7%) of the infected patients being asymptomatic; 143 (13.7%) crew members were infected, with 64 (44.8%) being asymptomatic [9].

3.1.2. The USS Theodore Roosevelt

At the end of March 2020, a COVID-19 outbreak occurred on a nuclear-powered aircraft carrier with 4779 crew [10]. Three crew members tested positive for SARS-CoV-2 on 23 March 2020. Four days later, they were sent to the base in Guam and received further tests and isolation [2]. The subjects of the study included all crew members onboard the aircraft carrier, with an average age of 27 years. During the outbreak, a total of 1271 (26.6%) crew members tested positive for SARS-CoV-2 by real-time reverse transcription polymerase chain reaction (RT-PCR). Another 60 crew members were considered suspected cases. Of the cases with positive laboratory tests, 76.9% (978 out of 1271) had no symptoms when they tested positive [10].

3.1.3. The Costa Atlantic

At the end of March 2020, a COVID-19 outbreak started onboard a Japanese cruise ship, which peaked at the end of April 2020 [4]. On 19 April 2020, the Costa Atlantic moored in Nagasaki (Japan) for maintenance and reported a crew member with a fever [4,11] to the Nagasaki City Public Health Centre. A total of 623 multinational crew members (median age 31 years; 84% men) were tested and quarantined in their cabins [4,11]. After SARS-CoV-2 PCR tests were conducted on the crew, 149 positive cases were confirmed. Note: there were no passengers on board the cruise ship.

3.2. Measures to manage COVID-19 outbreaks

3.2.1. The Diamond Princess

The Diamond Princess arrived in Yokohama on 3 February 2020. Over a 2-day period, throat swabs from 31 passengers were tested for SARS-CoV-2 by PCR, of which 10 cases were positive. Therefore, on 5 February 2020, the Japanese government decided to isolate all passengers and crew onboard for 14 days [12]. All passengers onboard were restricted to their cabins, with cabins having a capacity of one to four persons [9]. As the crew maintained normal operation of the cruise ship, it was difficult for them to remain isolated. However, if a crew member had symptoms or a positive test result, they were quickly isolated and transferred [6]. The Japanese government implemented comprehensive epidemic response measures, including surveillance, basic health care, food supply, isolation, infection prevention and control, sampling and disembarkation treatments [7]. The passengers were allowed to stay on the outer deck for 60 min a day, during which they were required to wear masks, not touch anything and maintain at least 1 m distance from each other. Everyone onboard was required to regularly monitor their body temperature with a thermometer. If a temperature >37.5 °C was recorded, they were required to call the fever call centre on the ship [9]. Due to the limited detection capacities, testing could only be gradually

Table 1
Selected ships with COVID-19 outbreaks.

Ship	Passenger case/total number (%)	Crew case/total number (%)	Average age	Time of first case identified	Dock
Diamond Princess	544/2666 (20.4%)	143/1045 (13.7%)	66.1 years (passengers)	25 January 2020	Yokohama (Japan)
USS Theodore Roosevelt		1271/4779 (26.6%)	27 years	23 March 2020	Guam (USA)
Costa Atlantic		149/623 (23.9%)	31 years	19 April 2020	Nagasaki (Japan)

expanded from close contacts to all personnel. Once a positive result was confirmed, all close contacts had to recalculate their isolation time to include an additional 14 days. All patients with positive test results for SARS-CoV-2 or other diseases were sent to hospitals for treatment. The Japanese Disaster Medical Assistance Team (DMAT) successfully categorised and transported patients with COVID-19 using a new classification system that prioritised patients according to the urgency of their illnesses. The DMAT sent 203 patients to hospitals in Kanagawa and another 566 to hospitals in 15 different regions [12].

3.2.2. The USS Theodore Roosevelt

During the voyage, three crew members reported symptoms of COVID-19. Their subsequent PCR confirmed COVID-19 [13]. Over the next 24 h, other symptomatic crew members and approximately 400 close contacts were identified through contact tracking. The aircraft carrier entered the port of Guam on 27 March 2020 and docked 7 days later on 3 April 2020. At that time, approximately one-third of the crew tested positive for SARS-CoV-2. Crew members with confirmed COVID-19 were quarantined at a naval base or the base hospital in Guam, while those who tested negative and who were asymptomatic were quarantined at a hotel outside the base or at a naval base in Guam [10]. As the infection was expected to lead to a surge in requirements for medical resources, the military built a tent hospital and provided medical services to crew members quarantined in nearby hotels [13]. The quarantined crew members were isolated for 14 days, while nearly 700 crew members remained on the USS Theodore Roosevelt to sterilise the ship [13]. Patients who were positive for SARS-CoV-2 underwent symptom and temperature monitoring, with pulse oximetry tests twice a day during the isolation period. Additionally, crew members conducted daily health screening and symptom reports, which were reliant on symptom testers developed by Defense Digital Services. Additional screening was conducted for individuals with progressive symptoms or possible adverse consequences. Any crew members requiring closer observations or treatments (as determined by on-site medical providers) were sent to Guam Naval Hospital for advanced care. In addition to COVID-19–related health monitoring, the crew received primary care, pharmacy and psychiatric consulting to ensure adequate medical services. All crew members of the USS Theodore Roosevelt were followed-up for 10 weeks, irrespective of whether they were symptomatic or infected [10].

3.2.3. The Costa Atlantic

After the outbreak on the cruise ship, the Japanese government set up an emergency operations centre at the prefectural office and an on-site response centre at the port near the cruise ship. Crew members without an essential mission (i.e. those involved in the operation or maintenance of the ship's operations and functions) were isolated in their cabins and were not allowed to leave. Every day, the heads of emergency operations centres, response centres, hospitals and the cruise ship discussed and exchanged information, and analysed countermeasures. Additionally, in order to reduce unnecessary exposure and risk of infection, the Japanese government developed a remote health monitoring system through which each crew member reported their own information and symptoms. Medical staff also made judgments according to the symptoms and observations of the crew. When there was a medical need, patients were transferred off the ship for treatment and care. Simultaneously, thermometers were distributed to the crew onboard to monitor any suspicious cases [4,11]. Because of the introduction of a remote health monitoring system and the absence of passengers on the cruise ship, each crew member was isolated in a single cabin. For this reason, compared with the Diamond Princess, 2 months previous, enforcing quarantine measures on the Costa Atlantic appeared to be easier and more effective.

4. Discussion

Following analysis and the study results, the following key areas were identified to improve the efficiency of infection prevention and control on ships.

4.1. Timely detection and intervention

In the confined space of a ship, it is critical to detect any infectious disease in a timely manner and install necessary interventions. The mathematical model established by Rocklöv et al. [14] suggests that there would have been an additional 2000 cases on the Diamond Princess if no intervention had been taken. Evacuating and quarantining all passengers and crew as soon as possible may prevent more passengers and crew from being infected. Therefore, daily health monitoring is essential when sailing at sea. If passengers or crew members have any symptoms of respiratory infectious disease, they should report to the relevant authorities immediately, leading to timely detection and intervention of a disease outbreak.

4.2. Exposure reduction

The route of transmission of COVID-19 is mainly via close respiratory droplet transmission, as well as direct and indirect contact with the virus [15]. Ships often have a high density of passenger flow, with limited spaces for activities. Therefore, in the event of respiratory disease outbreaks, the isolation policy must be strictly implemented. During this process, close contacts, suspected cases and other personnel must be separated. They should be isolated by floor or area and quarantined in single compartments as much as possible. It has been shown that the transmission rate of the virus increased with the increase in cabin occupancy [9]. Isolation reduces all possible contacts, including human-to-human contacts and contact with the environment. A study by Yamagishi et al. [16] showed that SARS-CoV-2 RNA was detected on the environmental surfaces of both symptomatic and asymptomatic case cabins on the Diamond Princess, demonstrating that the environmental surface played a role in the spread of the virus. Therefore, when the detection ability allows, detection of suspected personnel and environmental surfaces should be encouraged to facilitate the implementation of isolation protocols. Additionally, the use of mobile phones and other media to provide remote health monitoring systems can reduce unnecessary contact while maintaining adequate medical monitoring.

4.3. Control of asymptomatic infections

Asymptomatic infection is easy to be ignored at the initial stage of a disease outbreak at sea. During the voyage of a ship, asymptomatic patients are unlikely to seek medical services. Meanwhile, the limited medical resources onboard make it difficult to detect asymptomatic infections. All of these factors could contribute to the rapid spread of a respiratory infection [17,18]. However, clinical results have suggested that the viral load of asymptomatic patients is similar to that of symptomatic patients [19]. There is also evidence that asymptomatic patients could infect others before they develop any symptoms,[20–23]. Another study found that the total contribution of asymptomatic individuals to epidemic transmission was greater than that of symptomatic patients [24]. Therefore, adequate attention should be paid to asymptomatic infected individuals to prevent and control the disease outbreak. However, due to the limitations of various factors (e.g. limited space and maintaining cruise ship operations) during the voyage, it is difficult to isolate everyone. When confirmed cases are reported, close contacts should be tracked in a timely manner and quarantine measures should be taken, rather than isolation based solely on health conditions or the presence or absence of symptoms.

4.4. Treatment and transport

During a large-scale infection outbreak, the medical system is often overwhelmed, especially the ship's own medical system. Therefore, the transport and treatment of severe cases needs to be prioritised. Classifying patients based on the severity of illness and sending them to different medical institutions for treatment can avoid the overload of medical facilities and improve patient prognosis. However, transportation of infectious patients is challenging [13] and requires professional medical teams to guide and operate under safe transit protocols.

4.5. Prevention and control in advance

Raising awareness of respiratory infectious diseases is a fundamental and necessary measure. During epidemics this should be conducted regularly for all crew members and passengers to increase their attention to the outbreak and improve cooperation at critical moments. Simultaneously, ships taking international and long voyages should develop plans to manage respiratory infectious diseases during navigation according to their practical situations. Moreover, crew should receive adequate drills and desktop exercises to familiarise themselves with the process and their individual responsibilities to ensure that they can respond to infectious diseases in a timely manner. Advanced training should be organised for medical personnel, ship commanders and other personnel who may play a major role in outbreak prevention and control to improve the ability to deal with emergencies [2].

At the beginning of the epidemic, there was no effective vaccine against COVID-19. However, now that vaccines have been produced in large quantities, every crew member or passenger on a long voyage should be vaccinated. If conditions permit, the shipping company can play a role in vaccination and regular testing, to ensure that every passenger and crew member is vaccinated in advance and receives effective virus testing during navigation. A well-prepared disease prevention and control plan can maximise the ability to manage sudden outbreaks of respiratory infectious diseases and stop viral spread.

4.6. Cooperation of stakeholders

The voyage of international cruise and cargo ships often involves many countries. If an outbreak occurs at sea, communication and cooperation with the next port city plays a vital role in controlling the spread of disease. In the study by Fanoy et al. [25], a cargo ship flying the Panamanian flag had an outbreak onboard before arriving at the port of Amsterdam. With the efficient coordination and cooperation of the public health department (PHS), the regional port coordination centre (HCC), shipping agents, captains, shipping companies and other relevant departments, the outbreak was rapidly brought under control. However, since different stakeholders were involved in the response to the outbreak, individual responsibilities were unclear and there were often problems during the coordination. The study confirmed that strengthening communication among stakeholders and establishing a channel of communication and cooperation are essential in controlling future outbreaks on ships. In the process of coordination, the role of the government cannot be ignored. In response to public health emergencies, the government should play the role of bridge and guidance when necessary. For example, after the outbreak onboard the Costa Atlantic, the Japanese local government immediately set up an emergency centre to coordinate and guide the infection prevention, control and treatments, which played a significant role in the outbreak management [4, 11]. Thus, cooperation and communication among various departments is critical. For a highly contagious disease, such as COVID-19, inadequate cooperation and communication will have a negative impact on the timely management of the outbreak. The study by Fanoy et al. [25] recommended that, when COVID-19 cases are identified on ships carrying international crew members, the National Coordination Centre (NFP) should be notified immediately to assign jobs and tasks to appropriate individuals to quickly facilitate the emergency response.

4.7. Establish short- and long-term coping mechanisms

As international ships commonly visit different countries and use different ports, the onboard cruise operators, crew and passengers are often of different nationalities. All of these components can contribute to the international spread of infectious diseases and increase the risk of public health events [26]. Therefore, it is necessary to establish short- and long-term response mechanisms for the infection prevention and control on ships.

The short-term response mechanism should be aimed at ship managers to quickly identify the infection source and initiate effective isolation and safe transport during the outbreak [26]. In addition, the short-term response mechanism also includes a series of other necessary measures for disease prevention and control, such as disinfection, testing and life and medical care. However, at the time of the outbreak, it may be difficult to completely control the spread of the disease on a ship. A study by Guagliardo et al. [27] demonstrated that, despite all interventions, including reducing the number of passengers and crew, restricting access to ports, shortening cruise time, increasing testing, screening individuals with suspected symptoms, contact tracking and isolation, and vaccination, cruise travel still carried a significant risk of SARS-CoV-2 transmission. The goal of short-term response mechanisms is to slow down the spread of the virus and eliminate the risk of infection.

The long-term response mechanism is directed at relevant organisations and government. The study by Liu and Chang [26] suggested promoting the construction of long-term infection emergency mechanisms from three aspects [1]: a ship risk emergency management mechanism [2]; a health and epidemic prevention supervision mechanism; and [3] an international cooperation mechanism for infectious disease prevention. First, cruise ship companies must effectively manage infectious diseases by establishing risk management systems and emergency management mechanisms and by taking all possible measures to ensure comprehensive and dynamic health risk assessment. Subsequently, through maritime and other departments, the supervision of ship infection prevention management, dynamic and static information management, and the supervision and prevention of emergencies should all be strengthened and an auditing system should be established. Finally, through the cooperation between countries and international organisations, an international cooperation mechanism for preventing infectious diseases should be established to actively respond to public health events of multinational interest.

4.8. Limitations

Due to time limitations, only PubMed and EMBASE databases were searched, which could have impacted the quantity and quality of the literature included in the study to a certain extent. Due to the academic level of researchers and authors, the content of the paper may be controversial. In addition, most of the research articles were epidemic prevention cases during the first year of the COVID-19 outbreak. The short research time period may also be a limitation of this study.

5. Conclusions

This study summarises the experiences of managing COVID-19 outbreaks by analysing the infection situation and prevention and control measures on three ships. This study demonstrates that timely detection and intervention, exposure reduction, control of asymptomatic infections, treatment and transport of patients, preparation for prevention and control in advance, the communication and cooperation of various stakeholders, and the establishment of short-term and long-term response mechanisms are key elements to improve the efficiency of infection prevention and control. The findings provide guidance for future prevention and control strategies for respiratory infectious diseases on ships.

Conflicts of interest

The authors declare no conflict of interest.

Author statements

None.

Ethical approval

None required. PubMed and EMBASE are public databases, and inclusion of patients obtained ethical approval. Users can download relevant data for free for research purposes and publish relevant articles. Our study is based on open source data, so there are no ethical issues or other conflicts of interest.

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Declaration of competing interest

The authors declare no conflict of interest.

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