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Cluster infections play important roles in the rapid evolution of COVID-19 transmission: A systematic review

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ABSTRACT

Objectives: To summarise the major types of SARS-CoV-2 cluster infections worldwide through a comprehensive systematic review.
Methods: All studies published between 01 January–15 June 2020 on COVID-19 cluster infections in English electronic databases were searched, including PubMed, Embase, Web of Knowledge, and Scopus. All included studies were independently screened and evaluated by two authors, and information from each study was extracted using a standard form.
Results: Sixty-five studies were included, which involved 108 cluster infections from 13 countries, areas or territories. Seventy-two (66.7%) of the cluster infections were reported in China. The major types of cluster infections were families, community transmission, nosocomial infection, gatherings, transportation, shopping malls, conferences, tourists, religious organisations, workers, prisons, offices, and nursing homes.
Conclusions: The SARS-CoV-2 can be transmitted in various circumstances, and cluster infections play an important role in the rapid evolution of COVID-19 transmission. Prevention and control measures such as social distancing must be strictly implemented to contain these cluster infections.

Introduction

An emerging infectious disease named COVID-19 caused by SARS-CoV-2 virus was first reported in Wuhan, Hubei Province, China in December 2019 (Epidemiology Working Group for NCIP Epidemic Response, 2020). Since then, more and more countries have also reported COVID-19 (Liu et al., 2020a). The World Health Organization (WHO) declared COVID-19 as a public health emergency of international concern on 30 January 2020 (WHO, 2020a), and further declared it a global pandemic on 11 March 2020 (WHO, 2020b). As of 24 June 2020, 9,273,773 confirmed cases with 477,807 deaths had been reported in more than 210 countries, areas or territories (Hopkins, 2020).

Although the whole world is endeavouring to contain COVID-19, and several countries have successfully controlled the pandemic, this novel norovirus is still rapidly spreading in many countries. Since late May 2020, daily confirmed cases have been in excess of 100,000, and there has been an increased trend worldwide, which indicates that COVID-19 is still serious. Additionally, studies have reported the characteristics of SARS-CoV-2 as being different from other coronaviruses (Tan et al., 2005). For example, people could be infected with SARS-CoV-2 by asymptomatic carriers and pre-symptomatic people (Qian et al., 2020; Zhang et al., 2020a), which could prolong the infectious period. Meteorological factors, including temperature and UV radiation, may not impact the transmission risk of SARS-CoV-2 (Yao and Pan, 2020). Several super-spreaders of COVID-19 have been reported in settings such as religious organisations (Wikipedia, 2020). These characteristics partially contribute to the high transmission risk of SARS-CoV-2 and indicate that more research is needed to further understand this infectious disease.

Understanding the transmission routes and circumstances of SARS-CoV-2 as a novel coronavirus is critical for preventing and controlling its spreading. In the early stage of the epidemic, the transmission routes of SARS-CoV-2 were mainly reported from wild animals to humans, and limited transmissibility between humans. However, as COVID-19 rapidly spread, more and more

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transmission routes and circumstances were reported, including families, communities, nosocomial infections, etc. However, no study has systematically summarized the types of cluster infections of SARS-CoV-2. This study summarised the major types of SARS-CoV-2 cluster infections, which could provide critically important implications for the prevention and control of COVID-19 worldwide.

Methods

Data sources and search strategy

According to the Preferred Reporting Items for Systematic Reviews and Meta-analysis (PRISMA) (Moher et al., 2009), the literature search was conducted in English databases, including PubMed, Embase, Web of Knowledge, and Scopus. Time was restricted between 01 January–15 June 2020 and no other limitations were applied.

The search terms were ("novel coronavirus" OR "2019-nCoV" OR "COVID-19" OR "SARS-CoV-2") AND ("cluster" OR "infection"); "2019-nCoV" was included in the search terms because the novel coronavirus was temporarily named as 2019-nCoV in the early stages of the epidemic. All records were retrieved, and duplicates identified by title and author were removed. The remaining records were initially screened on title and abstract. Full text was retrieved for potentially eligible records and to be further assessed. Reference lists of full-text articles were also screened for additional publications. Two authors (TL and DXG) independently searched and screened to identify eligible studies. Disagreements between them were reconciled by a third author.

Selection criteria

Studies were included if they reported a cluster of COVID-19 cases in any setting, such as in households, vehicles, shopping malls, communities, etc. The exclusion criteria were editorials, comments, and letters or articles with irrelevant topics. For studies sharing the same case series, the one with the most meaningful information was included.

Data extraction

The following information was independently extracted by the two authors: author names, date of publishing, study setting, type of cluster infection, and number of infections involved. Differences were addressed by a third author. Authors of studies with unclarified data were contacted to update information.

Results

The search strategy initially identified 981 records, and five references were added by referring to the reference sections. A total of 500 duplicated articles were excluded through screening titles and abstracts. In the remaining 486 articles, 417 were

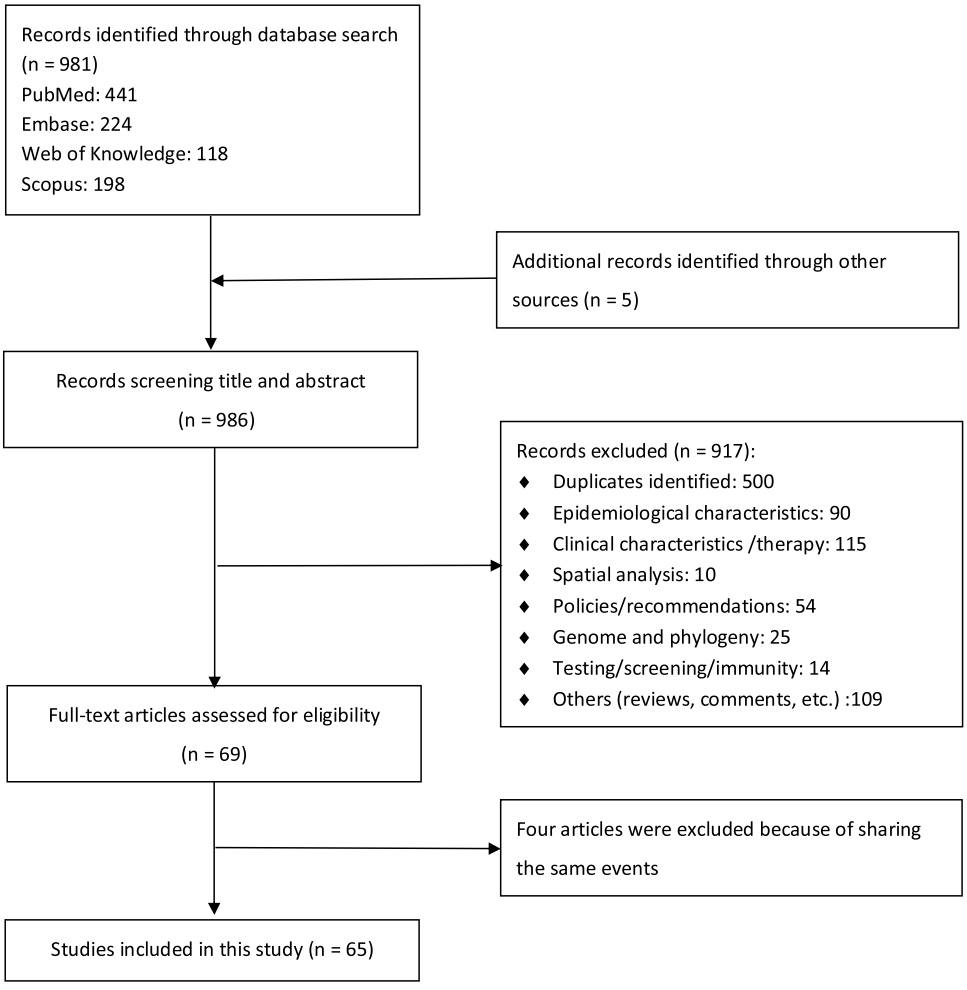

Figure 1. Flowchart for literature search and selection in systematic review.

excluded because they were related to epidemiological characteristics of COVID-19 cases (n = 90), clinical characteristics or therapy (n = 115), spatial analysis (n = 10), policies or recommendations (n = 54), genome and phylogeny (n = 25), testing/screening/immunity (n = 14), or others such as review or comments (n = 109). Of the 69 potentially eligible studies, four repeated studies were further excluded, leaving 65 studies to finally be included in this study (Figure 1). The included 65 studies involved 108 cluster infections in 13 regions. Of the cluster infections, 72 (66.7%) were reported in China, and 58 (53.7%) were family clusters (Table 1). The major types of clusters were families (62), communities (4), nosocomial infections (3), transmission during gatherings (15), transportation (6), shopping malls (3), conferences (4), tourists (6), and religious organisations (5).

Table 1
Detailed characteristics of studies included in the systematic review.

Study name	Region	Type of cluster infection	Number of infectionsinvolved
Ji et al. (2020)	Hubei, China	Family cluster	4
Tang et al. (2020)	Guizhou, China	Family cluster	2
Phan et al. (2020)	Ho Chi Minh, Vietnam	Family cluster	2
Zhang et al. (2020a)	Beijing, China	Family cluster	5
To et al. (2020)	Hong Kong, China	Family cluster	18
Ye et al. (2020)	Sichuan, China	Family cluster	5
Deng et al. (2020)	Shenzhen, China	Family cluster	6
Chiu et al. (2020)	Taiwan, China	Family cluster	4
Du et al. (2020)	Jilin, China	Family cluster	9
Wolf et al. (2020)	Munich, Germany	Family cluster	4
Liu et al. (2020b)	Taiwan, China	Family cluster	22
Huang et al. (2020a)	Nanjing, China	Family cluster	2
Jiang et al. (2020a)	Shandong, China	Family cluster	8
Liu et al. (2020c)	Taiwan, China	Family cluster	13
Xiong et al. (2020)	Hubei, China	Family cluster	3
Gao et al. (2020a)	Beijing, China	Family cluster	3
Chen et al. (2020a)	Guangzhou, China	Family cluster	6
Yu et al. (2020)	Shanghai, China	Family cluster	4
Yang et al. (2020)	Taiwan, China	Family cluster	6
Tong et al. (2020)	Zhejiang, China	Family cluster	7
Qiu et al. (2020b)	Henan, China	Family cluster	8
Pan et al. (2020)	Guangdong, China	Family cluster	3
Luo et al. (2020)	Hubei, China	Family cluster	5
Lu et al. (2020a)	Guangdong, China	Family cluster	3
Li et al. (2020a)	Zhejiang, China	Family cluster	5
Li et al. (2020b)	Jiangsu, China	Family cluster	5
Huang et al. (2020b)	Zhejiang, China	Family cluster	11
Huang et al. (2020c)	Anhui, China	Family cluster	8
Gao et al. (2020b)	Jiangsu, China	Family cluster	15
Chen et al. (2020b)	Hubei, China	Family cluster	3
Chen et al. (2020c)	Hubei, China	Family cluster	3
Bai et al. (2020a)	Gansu, China	Family cluster	7
Liu et al. (2020d)	Wuhan, China	Family cluster	3
Chan et al. (2020)	Wuhan, China	Family cluster	6
Bai et al. (2020b)	Anyang, China	Family cluster	6
Qiu et al. (2020a)	Beijing, China	Family cluster, transportation	4
Qian et al. (2020)	Zhejiang, China	Family cluster, religious organisations	8
Jiang et al. (2020b)	Henan, China	Family cluster, gatherings	8
Ghinai et al. (2020)	Chicago, USA	Family cluster, community transmission	7
Zhang et al. (2020c)	Hangzhou, China	Family cluster, tourists	12
Zhang et al. (2020b)	Tianjin, China	Family cluster, conference	17
Zhang et al. (2020b)	Zhejiang, China	Family cluster, religious organisations, transportation	67
Lu et al. (2020b)	Guangdong, China	Family cluster, community transmission	9
Cao et al. (2020)	Hubei, China	Family cluster, nosocomial infection	6
Wei et al. (2020a)	Singapore	Family cluster, tourists, religious organisations	18
Wei et al. (2020b)	Hubei, China	Nosocomial infection	12
Danis et al. (2020)	Alps, French	Gathering	13
Jang et al. (2020)	Cheonan, Korea	Gathering	112
Kim et al. (2020)	Korea	Community transmission	4
Hoefer et al. (2020)	Tenerife, Spain	Tourists	8
Emma (2020)	France	Gathering	13
Yang et al., 2020a	Zhejiang, China	Transportation	12
Eldin et al. (2020)	Marseille, France	Transportation	1
Pongpirul et al. (2020)	Bangkok, Thai	Transportation	1
Kakimoto et al. (2020)	Yokohama, Japan,	Transportation	20
Vivian Thangaraj et al. (2020)	New Delhi, India	Tourists	17
Escalera-Antezana et al. (2020)	Bolivia	Tourists	12
Pung et al. (2020)	Singapore	Shopping malls, conference, religious organisations	36
Cai et al. (2020)	Zhejiang, China	Shopping malls	7
Wu et al. (2020)	Tianjin, China	Shopping malls	40
Le et al. (2020)	Vietnam	Tourists	12
Kupferschmidt (2020)	Washington, USA	Religious organisations	53
Hara et al. (2020)	Kyoto, Japan	Nosocomial infection	1
Xiao et al. (2020)	Shanghai, China	Conference	20
Böhmer et al. (2020)	Bavaria, Germany	Conference	16

Family clusters

Family is the dominant circumstance where clusters of SARS-CoV-2 infection occur. The WHO reported that 78–85% of infection clusters occurred in families in the early stages of the COIVD-19 epidemic in China (Mission, 2020). The first family cluster was reported as early as 24 January 2020 in Shenzhen, China, in which household members who had no travel history to Wuhan or exposure to wild animals were infected by a COVID-19 case who travelled from Wuhan (Chan et al., 2020). This was the first study that confirmed human-to-human transmission of SARS-CoV-2. Since then, many family clusters of COVID-19 have been reported worldwide (Qian et al., 2020; Zhang et al., 2020a; Chan et al., 2020; Xu et al., 2020; Wolf et al., 2020; Chiu et al., 2020; To and Fok, 2020; Qiu et al., 2020a; Liu et al., 2020b; Wei et al., 2020a; Zhang et al., 2020b; Ye et al., 2020; Tang et al., 2020; Ji et al., 2020; Phan et al., 2020; Deng et al., 2020; Du et al., 2020; Huang et al., 2020a; Jiang et al., 2020a; Liu et al., 2020c; Xiong et al., 2020; Gao et al., 2020a; Chen et al., 2020a; Yu et al., 2020; Yang et al., 2020; Tong et al., 2020; Qiu et al., 2020b; Pan et al., 2020; Luo et al., 2020; Lu et al., 2020a; Li et al., 2020a,b; Huang et al., 2020b,c; Gao et al., 2020b; Chen et al., 2020b,c; Bai et al., 2020a; Liu et al., 2020d; Bai et al., 2020b; Jiang et al., 2020b; Ghinai et al., 2020; Zhang et al., 2020c; Lu et al., 2020b; Cao et al., 2020). Family clusters usually have a higher risk of infection due to their close and frequent contact (Bi et al., 2020). Hence, prevention of infection among household members is an important strategy to contain the transmission of COVID-19 worldwide. For example, in families with confirmed COVID-19 cases it is crucial to quarantine their close contacts and detect SARS-CoV-2 as early as possible.

Community transmission

Community transmission is one of the most important modes facilitating the widespread transmission of COVID-19. Several studies have reported community transmission cases (Ghinai et al., 2020; Lu et al., 2020b; Liu et al., 2020e; Kim et al., 2020; The Centre for Health Protection, 2020). For example, the Centers for Disease Control and Prevention (CDC) reported community transmissions occurring in Chicago in April, in which 16 COVID-19 cases were infected in non-household gatherings (a birthday party, funeral and church attendance) (Ghinai et al., 2020). These cases indicate the importance of social distancing for preventing COVID-19 transmission. Additionally, other studies have shown extensive environmental contamination of SARS-CoV-2 (Jiang et al., 2020a; Ong et al., 2020), suggesting that contaminated environments are a potential medium of virus transmission among families in communities. Environmental management and disinfection are also important for preventing the community transmission of COVID-19.

Nosocomial infection

Nosocomial infection is also an important mode of COVID-19 transmission, which is similar to Severe Acute Respiratory Syndrome (SARS) and Middle East Respiratory Syndrome (MERS) (Tsang et al., 2003; Assiri et al., 2013; Sina News, 2020). It was reported that as of 11 February 2020, 3019 healthcare workers had been infected by SARS-CoV-2 in China, with 1716 confirmed cases and five deaths (0.3%) (The Novel Coronavirus Pneumonia Emergency Response Epidemiology, 2020). Another report on 138 COVID-19 cases in Zhongnan Hospital of Wuhan University during the early period of COVID-19 outbreak presumed that nosocomial transmission of 2019-nCoV was suspected in 41% (57/138) of patients, including 40 healthcare workers and 17 patients who were already hospitalised for other reasons (Wang et al., 2020).

These nosocomial infections were mainly due to a lack of understanding on the novel coronavirus, and insufficient personal protection equipment (PPE) in the early stages. As knowledge of COVID-19 increased, nosocomial infections dramatically decreased in China. For example, more than 42,000 healthcare workers were sent to assist Wuhan from other provinces in China, but none of them was infected (Liu et al., 2020f). Nosocomial infections were also reported in many other studies (Cao et al., 2020; von Freyburg et al., 2020; Wei et al., 2020b; Hara et al., 2020; WHO, 2020c). It has been reported that over 90,000 healthcare workers were infected with COVID-19 worldwide (Mantovani, 2020). Healthcare workers play an essential role in containing the COVID-19 outbreak. They provide care for patients during routine health services, offer critical care to severe patients, and ensure that the infection prevention and control measures are implemented and adhered to in healthcare facilities in order to limit nosocomial infections. Until a vaccine for SARS-CoV-2 becomes available, healthcare workers remain susceptible to COVID-19. However, evidence from Wuhan has shown that appropriate PPE in addition to adhering to standard recommendations could effectively protect them from SARS-CoV-2 infection, even in the clinical settings with higher risk of exposure (Liu et al., 2020f). Hence, healthcare workers must be given priority to procurement and distribution of PPEs, and be given adequate training to protect themselves from infection.

Transmission from gatherings

Indoor gathering activities could also lead to cluster infections of COVID-19. Transmission from activities have been reported in several studies (Jiang et al., 2020b; Emma, 2020; Danis et al., 2020; Jang et al., 2020). For example, Danis et al. reported a confirmed case that was infected in a chalet in France (Danis et al., 2020). The index case had attended an international conference in Singapore that was linked to COVID-19-confirmed cases. He flew to France and had a gathering with several English tourists and French residents, which led to 11 people becoming infected. Such transmissions also occurred in other countries (Jang et al., 2020; Takeuchi, 2020). People in gatherings rarely wear PPEs such as face masks, which make them at higher risk of infection. These transmissions further support the WHO recommendations to stay at home and avoid any gatherings with people from multiple households.

Transmission from transportation

Transportation is another circumstance causing the transmission of COVID-19, including flights, trains, taxis, buses, cruises, etc. (Eldin et al., 2020; Kakimoto et al., 2020; Pongpirul et al., 2020; Qiu et al., 2020; Yang et al., 2020). For example, Yang et al. reported that 10 of 325 passengers and crew members were infected during a flight from Singapore to Hangzhou, China (Yang et al., 2020a). Pongpirul et al. reported a confirmed case infected in a taxi in Thailand. Transportation usually has an enclosed space and passengers usually have close contact, and droplets can easily be generated in enclosed spaces, which may transmit SARS-CoV-2 from those carriers. Previous studies have demonstrated that SARS-CoV transmission on transport is more likely airborne (Chan et al., 2020), small-particle (Setti et al., 2020) and through close contact (Olsen et al., 2003). Therefore, travellers should avoid all nonessential travel and must implement strict measures to protect themselves when they have to travel, such as wearing face masks, sanitising and disinfecting.

Transmission in shopping malls

A shopping mall is a place with a high density of people, which can increase the transmission risk of SARS-CoV-2. Cai et al. reported a cluster of 35 confirmed cases associated with a shopping mall in Wenzhou, China (Cai et al., 2020). A similar cluster of COVID-19 was reported in a shopping mall in Tianjin, China, which caused 42 confirmed cases by 22 February (Tianjin Health Commission, 2020). It was proposed that SARS-CoV-2 may be spread in shopping malls via fomites (e.g. elevator buttons or restroom taps) or virus aerosolisation in confined public places (e.g. restrooms or elevators) (Cai et al., 2020). A report from Guangzhou, China, also detected the nucleic acid of SARS-CoV-2 on a doorknob at a patient's house (Guo, 2020), which further clarified the transmission of SARS-CoV-2 in a shopping mall. In addition, close contacts among people in shopping malls may also lead to low-intensity transmission. In order to prevent the spread of COVID-19 in shopping places, many commercial activities have been prohibited during the worldwide pandemic. In addition, it is suggested that customers wear face masks, practice social distancing while shopping, and wash their hands.

Transmission at conferences

Conferences are also gatherings that favour the transmission of SARS-CoV-2. A typical case was reported in Singapore, where 109 people from several countries attended an international conference, which led to at least seven confirmed cases (WHO, 2020d). More importantly, these infected cases spread the SARS-CoV-2 to many other countries including Malaysia, UK, France, and Spain through international flights. Therefore, many countries stopped international flights to and from those epidemic regions.

Transmission among tourists

Tourists usually have close contact when taking the same transportation, having meals together and staying in the same hotel. Hence, the infection risk is high if any of them are virus carriers. Such a cluster of cases was reported in India where a group of 23 Italian tourists along with three Indians visited several tourist places, and the index case infected 16 tourists with an attack rate of 65.4% (Vivian Thangaraj et al., 2020), which was higher than existing literature such as 5.7% in Shenzhen, China (Bi et al., 2020). Another study also reported a cluster of eight cases infected in a hotel in Spain (Hoefer et al., 2020). These studies illustrate the high risk of infections among tourists, and protection measures must be strictly implemented.

Transmission in religious organisations

Outbreaks of COVID-19 have also been reported in religious organisations (Qian et al., 2020; Wei et al., 2020a; Zhang et al., 2020b; Pung et al., 2020; Kupferschmidt, 2020; The Ministry of Health and Welfare, 2020). One outbreak event occurred in South Korea, where the index case, a follower of the Shincheonji Church of Jesus, infected at least 456 confirmed cases in a series of church activities (The Ministry of Health and Welfare, 2020). Another example was reported in Malaysia, where a religious gathering was held in Sri Petaling Mosque, Kuala Lumpur; 16,000 people attended the event, which led to at least 3375 confirmed cases linked to it (Wikipedia, 2020). Super-spreading events occurred in both examples. Therefore, the risk of SARS-CoV-2 transmission is very high in such large gatherings and must be prohibited during the pandemic.

Transmission in workers

Workers such as miners and migrant workers usually constitute an underserved, isolated, medically vulnerable and often underinsured population. In addition, these workers usually perform jobs in an enclosed space and have close contact with each other. Hence, they are susceptible to COVID-19, which can easily outbreak once the virus appears among the population (Sood et al., 2020). For example, COVID-19 hit the first Quantum's Cobre Panamá mine and killed workers (Latin America Copper, 2020). It has been reported that miners accounted for almost 20% of COVID-19 cases in Poland, where more than 10 coal mines had to be closed to contain COVID-19 (Barteczko, 2020). Sood et al. have called for intensifying the implementation of prevention and control measures among those workers (Sood et al., 2020), such as providing primary care, health education, separate or isolated living spaces, disinfecting high-touch common areas, providing hand-washing stations and hand sanitizer, and providing adequate PPEs.

Others

Cluster infections of SARS-CoV-2 have also been reported in other circumstances, including prisons (Xinhuanet, 2020), offices (Zhang et al., 2020b) and nursing homes (The Beijing News, 2020). For example, five prison epidemics of COVID-19 including 511 confirmed cases were reported in China at the end of February 2020 (Xinhuanet, 2020). A cluster of cases infected in an office were reported in a German company (Rothe et al., 2020; Böhmer et al., 2020). Nursing homes are another important setting with high risk of SARS-CoV-2. It has been demonstrated that older people are more susceptible to SARS-CoV-2, and older COVID-19 patients have poorer prognosis (Guan et al., 2020). Statistics from the Swedish Board of Health and Welfare showed that 90% of COVID-19 patients who had died as of 28 April were over the age of 70, and half were nursing home residents (Bangkok Post, 2020). These results suggest that transmission of SARS-CoV-2 could occur in various circumstances, which increases the difficulty in controlling and preventing the spread of COVID-19. These characteristics of COVID-19 also differ from SARS and MERS (Kwok et al., 2019). The majority of SARS and MERS cases occurred in healthcare settings. While most SARS cases were among healthcare workers, substantial number of MERS cases were patients.

Conclusions

Studies have demonstrated that SARS-CoV-2 has stronger transmissibility than other coronaviruses, including SARS-CoV and MERS-CoV (Petrosillo et al., 2020). Of the many driving factors of this strong transmissibility, cluster infections play critical roles in the rapid evolution of COVID-19 transmission, which exponentially increases the number of cases and drives the new emerging disease to spread worldwide through modern transportation.

COVID-19 is still spreading over the world, and countries that are in pandemic should be particularly cautious about cluster infectious in various settings. Governments are advised to track COVID-19 cases and conduct extensive epidemiological investigations as early as possible. Additionally, proper and effective risk communication is essential when taking social restrictions to minimise people's gatherings (meals, religious gatherings, etc.) and journeys outside the home. Preventing and controlling cluster infections of SARS-CoV-2 is an important strategy to contain the spread and flatten the curve of COVID-19. As many challenges continue to be faced on containing this infectious disease, collaborative work and efforts from global communities to reduce

cluster infections are particularly important to suppress the spread.

Ethical approval

Not required.

Authors' contributions

TL and DG performed the database research, statistical analysis, and wrote the first draft of the manuscript; JX, JH, GH and ZR critically reviewed the manuscript for contents; WM conceptualised and guaranteed this study. All authors agreed with the content of the manuscript and approved the final manuscript.

Competing interests

None declared.

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