Transmission Dynamics of SARS-CoV-2 in a Mid-size City of China

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Research article

Keywords: SARS-CoV-2, COVID-19, Asymptomatic patient, Transmission dynamics, R_0 , R_t , Prevention and control strateg

Posted Date: September 21st, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-59402/v1>

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Version of Record: A version of this preprint was published at BMC Infectious Diseases on August 10th, 2021. See the published version at <https://doi.org/10.1186/s12879-021-06522-9>.

Abstract

Background: An outbreak of pneumonia associated with the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) emerged in Wuhan city and then spread to other cities. It is very urgent to delineate the epidemiological and clinical characteristics of these affected patients.

Methods: To investigate the epidemiological characteristics of the COVID-19, we describe a case series of 473 patients with confirmed COVID-19 in Wenzhou of China from January 27 to March 2, 2020.

Results: The median age of all patients was 47.6 years, 48.4% of which were female. 33.8% of the patients had a history of residence in Wuhan. Fever (71.7%) and cough (43.1%) were the most common symptoms. In addition, three kinds of unconventional cases were observed, namely 4.9% asymptomatic patients, 7.6% confirmed patients who had no link to Wuhan city but contact with individuals from Wuhan without any symptoms at the time of contact, and 12.9% confirmed patients who had an unknown source of transmission. We estimated that the basic reproductive number (R_0) was 2.75 (95%CI: 2.37-3.23). The effective reproduction number (R_t) fluctuated within the range of 2.50 to 3.74 from January 11 to January 16 while gradually reached the peak of 3.74 on January 16. R_t gradually decreased after January 16 and decreased to 1.00 on January 30. R_t continually decreased and reached the lowest point (0.03) on February 21, 2020.

Conclusion: Our findings presented the possibility of asymptomatic carriers affected with SARS-CoV-2, and this phenomenon suggested that chances of uncontrollable transmission in the larger population might be higher than formerly estimated, and transmission by these three kinds of unconventional patients in Wenzhou may be an important characteristic of infection in other mid-sized cities in the world. This study evaluated the epidemic characteristics of Wenzhou after having cases imported from Hubei Province and the effects after adopting a series of strict prevention and control strategy.

Background

It has been seven month since life-threatening pneumonia associated with the severe acute respiratory syndrome coronavirus 2(SARS-CoV-2) were reported in Wuhan, China on December 31, 2019[1, 2]. In the first few months, the epidemic spread rapidly to other Chinese cities and was circulating in some other countries in the world [3–5]. An increasing number of epidemiological evidence indicated the existence of person-to-person transmission in hospitals and family settings [6–8], suggesting a formidable challenge for prevention and control of this novel coronavirus pneumonia (NCP).

The World Health Organization had declared this NCP as a “Public Health Emergency of International Concern” (PHEIC) and officially termed it Corona Virus Disease 2019 (COVID-19). As of March 2, 2020, the Chinese government reported 79, 824 confirmed cases in mainland China[9]. Apart from the Wuhan city area, which includes the initial epidemic city and its surrounding cities, other major cities in China and other countries have been experiencing localized outbreaks [10, 11]. Despite the outbreaks around the

world, the clinical characteristics of COVID-19 have not been fully clarified. Huang, et al first reported on the cases of COVID-19, among which most patients had a history of exposure in a Seafood Wholesale Market [2]. Wang, et al also identified that patients with COVID-19 shared common symptoms including fever, fatigue, and dry cough[1]. Furthermore, several case reports confirmed the existence of human-to-human transmission [6, 7].

To better understand and control the COVID-19 outbreak, an updated analysis of this epidemic in other areas in China is urgently warranted. As of March 2, with the exception of Hubei Province, the slowdown in the increase rate of confirmed patients and suspected patients also indicated that the measures and strategies of prevention and control had proven effective [12]. Wenzhou (a mid-city with 8 million residents) is a prefecture-level city of Zhejiang province and has been identified as an epidemic area because one of the cities had a large number of confirmed cases outside Wunhan in China. There are many people of this city engaging in trade and businessmen of this city are famous for being distributed throughout China, even in the world. The important thing is that many people returned to this city from the initial epidemic area before the lockdown because of the Spring Festival. There was also evidence indicating that the epidemic situation in some cities might potentially shift from the import stage to the community spread stage in the coming period. And the emergence of unconventional cases also suggested that while implementing prevention and control measures and strategies to halt the spread of COVID-19, we need to be vigilant of the shifting trend of the epidemic moving from the import stage to the community spread.

Methods

Data collection

Epidemiological investigators conducted the epidemiological surveys on confirmed cases for collecting and organizing information and finding close contacts of those cases. Afterwards, all information, including epidemiological, clinical, and laboratory outcomes of SARS-CoV-2 nucleic acid test were published by the Municipal Health Commission (**Website:** <http://wjw.wenzhou.gov.cn/col/col1209919/index.html>).

Study Definitions

The COVID-19 patient is determined by a positive result of real-time reverse-transcriptase–polymerase-chain-reaction (RT-PCR) assay of the SARS-Cov-2 virus in patient’s pharyngeal and anal swab specimens. Only the laboratory-confirmed patients are included in the final analysis.

The asymptomatic patient is defined as someone who was a patient with no clinical symptoms and a positive result of SARS-CoV-2 on RT-PCR, found through close contact screening, cluster epidemic investigation and source tracing investigation based on the official document “New coronavirus pneumonia case surveillance program (from Second to Sixth Edition)”[13].

The exposure is defined as the following situations within 14 days before the onset of illness applicable to individuals: 1) traveled to or lived in Wuhan or other regions with severe epidemics abroad; 2) had contact with SARS-CoV-2 infected individuals whose nucleic acid test was positive or with patients who had a fever or respiratory symptoms coming from Wuhan or other regions abroad that have been severely affected by the epidemic; 3) had been to areas where 2 or more cases developed fever or respiratory symptoms in a small confined area (such as home, office, school class, etc.).

Cluster outbreak is defined as 2 or more cases developing fever or respiratory symptoms in a small area (such as home, office, school class, workshop, construction site, etc.) within 14 days, which allows for possible interpersonal transmission and being infectious due to co-exposure.

Close contacts refer to people who had not taken effective protection while being in close contact with suspected or confirmed cases 2 days before the onset of symptoms or 2 days before the collection of asymptomatic specimens.

The suspected case is defined by both epidemiological history and clinical characteristics. For epidemiological history: (1) History of traveling to or living in Wuhan and surrounding areas, or other communities in China with case reports, or countries and regions with severe epidemics abroad within 14 days before the onset of illness; (2) History of contact with SARS-CoV-2 infected patients (individuals whose nucleic acid test was positive) within 14 days before the onset of illness; (3) History of contact with patients who had a fever or respiratory symptoms, coming from Wuhan and surrounding areas, or other communities with case reports in China, or countries and regions with severe epidemics abroad within 14 days before the onset of illness; (4) Cluster onset: 2 or more cases developing fever or respiratory symptoms in a small area (such as home, office, school class, workshop, construction site, etc.) within 14 days. For clinical characteristics: (1) Fever and / or respiratory symptoms; (2) Radiologic imaging features of SARS-CoV-2 pneumonia; (3) Total count of white cells was normal or decreased, or the lymphocyte count was normal or decreased in the early stage of onset. An individual is a suspected case with any one type of epidemiological history meets any two of the clinical characteristics; those without a clear epidemiological history meet three of the clinical characteristics. Co-exposed individuals are defined as people who shared the same risks of exposure as a suspected or confirmed case of COVID-19.

Co-exposed person is defined as an individual who shared the same risks of exposure as a suspected or confirmed case of COVID-19.

The unconventional patients include asymptomatic patients, and patients who had no link to Wuhan city but had contact with individuals from Wuhan without any symptoms at the time of contact, and patients who had an unknown source of transmission.

The conventional patients are those who had a known source of transmission and symptoms.

Laboratory Confirmation

Laboratory confirmation of the SARS-CoV-2 by RT-PCR assay was conducted in Wenzhou Center for Disease Prevention and Control (WZCDC) [14]. The RT-PCR assay was performed in accordance with the protocol established by the World Health Organization[15]. SARS-CoV-2 nucleic acid testing was performed using RT-PCR assay according to the National Health Commission guidelines for laboratory testing of pneumonia with novel coronavirus infection (Second Edition, Third Edition) [2].

Statistical analysis

Continuous variables were presented using the mean and standard deviation or median and interquartile range (IQR) as appropriate, and categorical variables were described as frequency rates and percentages.

The basic reproductive number (R_0) was defined as the expected number of additional cases that one case will generate on average, over the course of its infections period in other uninfected population. We estimated the basic reproductive number (R_0) on the cases with symptom onset between January 9 and January 22, during which we expected the number of infections would increase soon in Wenzhou. The effective number (R_t) was defined as the mean number of secondary cases generated by a typical primary case at time t in a population [16]. We estimated R_t and its 95% credible interval on each day from January 11 to March 2 via a 7-day moving average. We used the serial interval with a mean of 7.5 and a standard deviation of 3.4 based on the study of Li Q, et al [17]. The analyses of R_0 and R_t were conducted by using the R_0 and EpiEstim packages in the R statistical programming language, version 3.6.3 (R Foundation for Statistical Computing). Other analyses were performed using SPSS software (Statistical Package for the Social Sciences) version 26.0 (SPSS Inc). All the figures were drawn using GraphPad Prism 8 software.

Results

Clinical and epidemiological characteristics

As shown in Table 1 and Fig. 1, of all 504 patients reported as of January 12 in one city in China, 31(6.2%) patients were excluded due to the incomplete status of the information (including clinical outcomes and symptoms) by the publishing date, because complete information collection and organization requires more time and effort, and 473(93.8%) patients had completed characteristics. The median age was 47.6 years (IQR, 37–56; range, 2–93 years), and 222 (48.4%) were females. The median time from onset to diagnosis was 6.0 days (range: 0–23 days). Fever (71.7%) and cough (43.1%) were the most common symptoms, whereas diarrhea or anorexia (3.2%) were rare. 160 (33.8%) patients had a history of travel or residence to Wuhan. As of March 2, 2020, 51 (10.8%) were severe patients and 422 (89.2%) were non-severe patients. There were 425 cases discharged in total, 47 cases staying, and 1 death occurred in Wenzhou.

Table 1
Clinical and epidemiological characteristics of the COVID-19 patients

Early clinical symptoms	Wenzhou
	n/(%)
Female sex–No., %	222/473(48.4%)
Age, Median (range) – years	47.6(2–93)
Travel or residence history within 14 days–No., %	
Recently been to Wuhan	160/473(33.8%)
Outside Wuhan or WZ city	24/473(5.1%)
No	289/473 (61.1%)
Contact with source of transmission within 14 days–No., %	
Contacted with people from Wuhan	36/473(7.6%)
Contacted with patient	195/473(41.2%)
Related the Yintai world trade center	17/473(3.6%)
Unknow	225/473(47.6%)
Discovered source of transmission	
Undiscovered source of transmission	61/473(12.9%)
Symptoms	
Asymptom–No., %	23/473(4.9%)
Symptoms	
Fever	339/473(71.7%)
Headache	31/473(6.6%)
Cough	204/473(43.1%)
Sore throat	39/473(8.2%)
Sputum production	50/473(10.6%)
Fatigue	57/473(12.1%)
Diarrhea or castalgia	15/473(3.2%)
Muscle soreness	29/473(6.1%)
Disease severity	
Severe–No., %	51/473(10.8%)

Early clinical symptoms	Wenzhou
	n/(%)
Clinical outcomes*	
Discharge from hospital	425/473(89.9%)
Staying in hospital	47/473(9.9%)
Death	1/473(0.2%)
Time from onset to diagnosis (days)	
Median (range)	6.0(0–23)

Features Of Asymptomatic Transmission Of Sars-cov-2 In Wenzhou

The point worth noting about this novel coronavirus pneumonia in Wenzhou city is the emergence of three kinds of unconventional cases. As shown in Table 1, there are 23 asymptomatic carriers accounts for 4.9% of the total patients, 36 (7.6%) patients who had no link to Wuhan city but contact with individuals from Wuhan without any symptoms at the time of contact and 61 (12.9%) patients who had an unknown source of transmission, which suggests that asymptomatic carriers were also likely to have transmitted the virus. We divided all patients into two groups, one with a history of residence and travel in Wuhan and the other without, and then made a time distribution chart based on the time of onset of diseases. As indicated in Fig. 1, in addition to the change in the daily number of new cases with a history of residence and travel in Wuhan, we can see the change in the daily number of new cases with no link to Wuhan. 313 cases that had no link to initial epidemic area account for 66.2% of 473 cases and 160 cases with links to initial epidemic area account for 33.8% of the total. We described the curve of onset dates for both imported and local cases in Fig. 1. The earliest onset time of the imported cases was January 4, with a peak on January 21. The number of new cases gradually reduced after January 27. The local cases started to onset on January 6, numbers peaked on January 26, and decreased significantly after that. After February 14, no case occurred in Wenzhou.

An Outbreak Of Infection In A Public Place

Moreover, there was an outbreak of infection in a public place at the Yintai world trade center. On January 20, a 39-year-old saleswoman went to a local hospital for treatment by herself after breaking out with a fever at 38.5° C, accompanied by chills, dizziness, and headache, and symptoms of soreness and fatigue. She was subsequently diagnosed with COVID-19 on January 28, but the source of which is unknown. As of the date of publication, a total of 16 additional patients resulting from a contact within this mall have

been confirmed, namely two staff members, two salesmen, one janitor, nine customers, and two individuals outside the mall but with close contact with one of the above.

Intervention And Surveillance Strategy

On January 21, 2020, Wenzhou government publicly announced the 24/7 telephone hotline to 13 local CDC and WZCDC in Wenzhou. At the same time, Wenzhou government mobilized the staffs of towns, districts, villages and grids to survey people from Wuhan and deploy primary medical staff to conduct the follow-up surveys. Moreover, with the aim of curbing the transmission of COVID-19, the government implemented strict intervention measures, such as implementing the hospital's pre-inspection and triage system, isolating suspected patients, strengthening the management of close contacts, strengthening the temperature measurement, disinfection in critical public places (stations, airports and other transportation sites), as well as publicizing hygiene knowledge [18, 19].

On January 22, 2020, Wenzhou government cancelled all public events and banned the wildlife trading. It also implemented a daily and zero-reporting systems for COVID-19 cases by Direct Network Report systems of Infectious Diseases and established proactive self-reporting channels for people returning from Wuhan and those with symptoms. Meanwhile, it publicly announced 33 24-hour fever clinical institutions and 9 designated medical institutions [19, 20].

On January 23, 2020, Wenzhou government launched the first-level response to major public health emergencies [21].

On January 24, 2020, Wenzhou government implemented stricter interventions. It suspended live poultry trading, postponed or canceled all large gatherings (including those in religious venues), and closed public entertainment venues (including theaters, video halls, amusement halls, dance hall, karaoke halls, Internet cafes, public bath, public swimming pools and cultural auditoriums). Body temperature testing and daily disinfection was implemented in public places. Individuals in Wenzhou must wear masks when going out. People who came to Wenzhou from Wuhan and their close contacts were required to quarantine at home for 14 days. If they had fever or respiratory symptoms, especially persistent fever, they must go to the local fever clinic in time [21].

On January 26, 2020, Wenzhou government set up a 24-hour public telephone hotline for citizens to encourage active self-report who had recently come to Wenzhou and had not undergone medical isolation [22].

On January 27, 2020, Wenzhou government implemented other intervention measures. People from Hubei Province, close contacts, and fever cases were required to self-quarantine at home or at designated locations for 14 days. Inter-provincial and inter-city shuttle buses and chartered passenger transport were suspended. The essential public places for public, such as farmers' markets, large shopping malls or supermarkets, were required to reasonably adjust business hours and regularly have disinfection. Elderly

care service agencies were required to temporarily implement closed management. All colleges, primary and secondary schools were required to suspend all gathering activities and were forbidden to start new semester on schedule while all kinds of extracurricular training activities were also put on hold. Wenzhou government required the society postpone resumption of work [23].

On January 29, 2020, 14 highway intersections entering Wenzhou were closed and the S1 line of the municipal railway and all ferries in Wenzhou were suspended [24].

From February 1 to February 15, 2020, Wenzhou introduced a regulation that only one person in each household could go out for purchase every 2 days [25, 26].

Starting from February 16, 2020, a normalization mode of the epidemic prevention and control was implemented in Wenzhou and the "Wenzhou Health Code" was promoted and applied throughout the city. Villages (residential areas) and communities continued to implement closed management. But when a cluster of cases break out, the community must immediately implement full or partial closed management according to the risk level. When one confirmed case occurred, the whole building must implement closed management. During the closed management period, cadres of the towns (streets) and villages (communities, residential) were on rotational duty 24 hours a day and were obliged to provide psychological counseling services. Village (resident) residents were in principle not allowed to enter and exit except for special circumstances [27, 28].

Personnel and three kinds of people who were ready to return to work, return to school or return to Wenzhou could apply online for "Wenzhou Health Code" by themselves. They would open Alipay and search for "Wenzhou Health Code", fill in personal health information, and submit the application after confirmation (after successful application). After application, the "health code" is available in the Alipay "card package" certificate column. Applicants must fill in the information truthfully, and those who fail to fill in factfully could potentially face legal consequences that would be shown in the personal integrity record. Those who caused serious medical consequences would be held accountable in accordance with the law. After the application was reviewed, a three-color "health code" would be generated, including green, yellow and red code. Those who displayed a "green code" and whose temperature measurement was normal were allowed to pass while those who displayed a "yellow code" would be subject to 14-day and 7-day home quarantine observation according to the epidemic-risk areas and low-risk areas respectively. Those that displayed the "red code" were send to designated hospital for treatment or medical isolation and observation for 14 days. Villages (residential areas) and communities were continually implemented closed-loop management in Wenzhou. When entering the implementation of one-way temperature measurement, the village and community personnel shall rely on the "health green code" passes, and those who had not applied for the health code could enter with valid certificates. Individual with a "yellow health code" could enter for the first time, and strictly followed the regulations to implement home isolation observation after entering. The closed-loop measures were implemented by the local township (street) government for open communities without management and security. In key areas

for prevention and control, the relevant counties (cities, districts) could appropriately extend the village (resident) travel control measures as deemed appropriate.

From February 20 to 22, 2020, work and production activities gradually resumed in Wenzhou. The relevant checkpoints were removed and the highway entrances and exits were simultaneously reopened [29].

Evaluation Of Effects For Prevention And Control Strategy

We estimated that the basic reproductive number (R_0) to be 2.75 (95%CI: 2.37–3.23) for the cases with symptom onset between January 9 and January 22 by Exponential Growth method, thus we expected the proportion of infections would increase thereafter in Wenzhou. The results showed that in the early stage of the epidemic, COVID-19 in Wenzhou had strong infectivity, consistent with results of previous studies [17].

Based on the study of Li Q, et al [17], we estimated the effective reproduction number (R_t) of Wenzhou from January 11 to March 2, 2020 with a 7-day moving average, which was an index to evaluate the effect of prevention and control strategy. R_t fluctuated within the range of 2.50 to 3.74 from January 11 to January 16 while gradually reached the peak of 3.74 on January 16. R_t gradually decreased after January 16 and decreased to 1.00 on January 30. R_t continually decreased and reached the lowest point (0.03) on February 21. Though the trend of R_t was slightly increasing between February 22 to March 2, the estimation of R_t still below 0.38. The daily estimated values of R_t were shown in Table 2 **and** Fig. 2.

Table 2
Estimates of the effective reproduction number (Rt) for
laboratory-confirmed COVID-19 cases from January 11
to March 2, 2020

Date	Mean	Std	Median	95% CI
2020/1/11	3.69	1.84	3.38	1.00 ~ 8.08
2020/1/12	2.98	1.49	2.73	0.81 ~ 6.53
2020/1/13	3.06	1.37	2.86	0.99 ~ 6.26
2020/1/14	2.50	1.12	2.34	0.81 ~ 5.13
2020/1/15	3.21	1.14	3.08	1.39 ~ 5.79
2020/1/16	3.74	1.08	3.63	1.93 ~ 6.13
2020/1/17	3.29	0.88	3.21	1.80 ~ 5.22
2020/1/18	2.07	0.60	2.02	1.07 ~ 3.40
2020/1/19	1.75	0.47	1.71	0.96 ~ 2.78
2020/1/20	1.74	0.40	1.71	1.05 ~ 2.60
2020/1/21	1.84	0.35	1.82	1.21 ~ 2.59
2020/1/22	2.10	0.33	2.08	1.51 ~ 2.79
2020/1/23	1.85	0.27	1.84	1.36 ~ 2.41
2020/1/24	1.83	0.23	1.82	1.40 ~ 2.31
2020/1/25	1.72	0.19	1.71	1.36 ~ 2.12
2020/1/26	1.76	0.17	1.76	1.44 ~ 2.12
2020/1/27	1.44	0.14	1.44	1.18 ~ 1.73
2020/1/28	1.30	0.12	1.30	1.07 ~ 1.54
2020/1/29	1.10	0.10	1.09	0.91 ~ 1.30
2020/1/30	0.91	0.09	0.91	0.75 ~ 1.09
2020/1/31	0.82	0.08	0.82	0.68 ~ 0.98
2020/2/1	0.76	0.07	0.75	0.62 ~ 0.90
2020/2/2	0.63	0.06	0.63	0.52 ~ 0.76
2020/2/3	0.60	0.06	0.60	0.49 ~ 0.72
2020/2/4	0.54	0.06	0.54	0.44 ~ 0.65
2020/2/5	0.48	0.05	0.47	0.38 ~ 0.59

Date	Mean	Std	Median	95% CI
2020/2/6	0.49	0.05	0.49	0.39 ~ 0.60
2020/2/7	0.46	0.05	0.46	0.36 ~ 0.57
2020/2/8	0.46	0.05	0.46	0.36 ~ 0.58
2020/2/9	0.43	0.05	0.43	0.33 ~ 0.54
2020/2/10	0.43	0.06	0.42	0.32 ~ 0.54
2020/2/11	0.38	0.06	0.38	0.28 ~ 0.50
2020/2/12	0.40	0.06	0.40	0.29 ~ 0.53
2020/2/13	0.36	0.06	0.36	0.26 ~ 0.49
2020/2/14	0.30	0.06	0.30	0.20 ~ 0.43
2020/2/15	0.19	0.05	0.19	0.11 ~ 0.30
2020/2/16	0.15	0.04	0.14	0.07 ~ 0.25
2020/2/17	0.11	0.04	0.10	0.04 ~ 0.20
2020/2/18	0.12	0.05	0.12	0.05 ~ 0.23
2020/2/19	0.04	0.03	0.03	0.00 ~ 0.11
2020/2/20	0.05	0.03	0.04	0.01 ~ 0.13
2020/2/21	0.03	0.03	0.02	0.00 ~ 0.11
2020/2/22	0.04	0.04	0.02	0.00 ~ 0.13
2020/2/23	0.04	0.04	0.03	0.00 ~ 0.17
2020/2/24	0.06	0.06	0.04	0.00 ~ 0.21
2020/2/25	0.08	0.08	0.05	0.00 ~ 0.28
2020/2/26	0.10	0.10	0.07	0.00 ~ 0.38
2020/2/27	0.14	0.14	0.10	0.00 ~ 0.52
2020/2/28	0.20	0.20	0.14	0.00 ~ 0.73
2020/2/29	0.28	0.28	0.19	0.01 ~ 1.02
2020/3/1	0.39	0.39	0.27	0.01 ~ 1.44
2020/3/2	0.55	0.55	0.38	0.01 ~ 2.03

Discussion

In the current study with a total of 473 patients with COVID-19 in a city of China, we found emergence of three kinds of unconventional patients, including 4.9% cases with asymptomatic, 7.6% patients who had no link to Wuhan but contact with individuals from Wuhan without any symptoms at the time of contact, and 12.9% cases who had unknown source of transmission, indicated that COVID-19 presence and prevalence may be underestimated at present, increasing the difficulty of prevention and control.

Along with the rapid spread of SARS-CoV-2 throughout China and worldwide, more concerns and new strategies should be undertaken in the future [30]. It is difficult to differentiate and screen patients with atypical symptoms, and the rapid human-to-human transmission among close contacts is a crucial characteristic for SARS-CoV-2 [7, 31]. As of March 2, 2020, Wenzhou had become one of the cities with a large number of COVID-19 patients outside of Wuhan in China [12]. In addition, previous studies have reported asymptomatic transmission of SARS-CoV-2 infection through close contacts in both familial and hospital settings [32]. Also, clustered outbreaks caused by asymptomatic individuals were reported. Based on the fact that the SARS-CoV-2 virus can be positively detected in asymptomatic patients, we could reasonably assume that these asymptomatic patients may carry a certain amount of active virus in the body and might pollute the surrounding environment, and thus the asymptomatic patients might become a potentially threatening source of SARS-CoV-2 infection [33]. In this study, we found the emergence of unconventional patients with COVID-19, and this phenomenon suggested that potential danger of uncontrollable transmission in the larger population might be higher than formerly estimated, and asymptomatic transmission may be one of the characteristics of infection in other area.

For asymptomatic transmission, our presumed that there were two likely sources of infection, including indirect transmission and airborne aerosol transmission. The indirect transmission of virus may result from virus contamination of surfaces of objects. Researchers have detected SARS-CoV-2 on surfaces of objects in a symptomatic patient's room and toilet area, a doorknob at a patient's house, a contaminated areas intensive care unit (ICU) or general COVID-19 ward (GW) for floor swab samples, the floor of the pharmacy, the floor of medical staff dressing room, half of the samples from the soles of the ICU medical staff shoes, computer mice frequently touched by medical staff or patients, sickbed handrails, doorknobs, patient masks, sleeve cuffs and gloves of medical staff, and so on [34–36]. SARS-CoV-2 was widely detected on object surfaces, implying a potentially high infection risk spread via fomites. Aerosol is the small respirable particles $< 5\text{--}10\text{ }\mu\text{m}$ that can remain airborne and are capable of short and long-range transport [37–39]. Long-range aerosol transport was indicated as the cause of the spread of the disease in several studies [40, 41]. For the aerosol and surface stability of virus, SARS-CoV-2 can remain viable and infectious in aerosols for hours and on surfaces up to days, so aerosol and contact transmission of the virus is reasonable [42].

In light of the emergence of unconventional patients, it suggested that co-exposed person or suspected patients should include not only patients with clinical symptoms but also those whose epidemiological history includes close contact with individuals from epidemic areas, although they may not be confirmed cases or show any symptoms at the time of contact. So far, our understanding of the epidemic characteristics of SARS-CoV-2 is still insufficient, and we still need to track the development of COVID-19

patients, close contacts and co-exposed person, further collect and analyze information through epidemiological investigations. Based on early recognition of droplet transmission and contact transmission, the unknown source of infection may have neglected possibility of indirect transmission and airborne aerosol transmission[34, 42].

The epidemic characteristics of infection of COVID-19 in Wenzhou may be typical of the outbreaks in other mid-size cities in the world. Besides, since the outbreak of infection of COVID-19 in a public place in Wenzhou city occurred, this is a typical incidence of outbreak that should be of great concern.

Successful implementation of strict measures requires unusual and unprecedented speed of decision-making by top leaders, operational thoroughness by public health systems, and cooperation of the whole society in Wenzhou. This study evaluated the epidemic characteristics of Wenzhou after having imported cases from Hubei Province and the outcomes after adopting a series of strict prevention and control measures. In the early stage of the epidemic, COVID-19 cases in Wenzhou was dominated by imported cases, and the number of imported cases peaked on January 21. With the expansion of the epidemic, the number of local cases had increased and became the majority in Wenzhou. However, strict prevention and control measures were not implemented nationwide and in Wenzhou on January 21. At this time, Wenzhou had more imported cases, which triggered local transmission in Wenzhou and Wenzhou was dominated by local cases in the middle and late stages, as indicated in Fig. 2. As the time changes, there is a trend that the epidemic situation shift from the import stage to the local community spread stage in Wenzhou, and the occurrence of new patients have been slowing down, and no case occurred after February 14.

After the pandemic of COVID-19 outbreak, Wenzhou government launched the first-level response to major public health emergencies on January 23, 2020 [21], and implemented joint a series of prevention and control measures which was focused on preventing importations, curbing the spread of the disease [18–20]. However, after more local cases occurred, Wenzhou conducted strong prevention and control measures that was to reduce the intensity of the epidemic and to slow down the increase in cases to strictly control the import and spread of the epidemic[22, 23], such as closing high-speed entrances, limiting the number and frequency of households going out, regularly releasing information about the epidemic and prevention and control measures, strengthening public risk communications and health education and cancelling mass gathering activities [24–26]. After launching a series of prevention and control measures, the epidemic was effectively controlled. The epidemic prevention and control measures became the normalization mode from February 16. The “Wenzhou Health Code” was promoted and applied throughout the city. Villages and communities continued to implement closed-loop management. However, when a cluster of epidemics occurred, the community must immediately implement full or partial closed management according to the risk level, and when a confirmed case occurred, the building must implement closed management. After the epidemic was gradually under control, the relevant checkpoints were gradually cancelled and the highway entrances and exits were simultaneously restored [27–29]. The resumption of work and production were promoted in Wenzhou. Since January 16, the R_t of Wenzhou began to gradually decline, and it successfully dropped below 1 on January 30, and then

continued to decline, which fully proves that the implementation of strict prevention and control measures in Wenzhou had effectively controlled the epidemic spread.

Our study had some obvious limitations. Firstly, the case information of Wenzhou was extracted from the website of Wenzhou Health Commission, which were incomplete (31 cases) in the early stage of the epidemic. Secondly, it is necessary to dynamically observe for a period of time to determine whether patients without symptoms are asymptomatic and pro-symptomatic. We did not have dynamic observation therefore we could not distinguish the asymptomatic and pro-symptomatic patients. Lastly, our study was based on case report data, which were more likely to report patients with severe or obvious symptoms, indicating that the proportion of asymptomatic infections was underestimated.

Conclusions

In summary, the epidemic characteristics of infection of COVID-19 in Wenzhou may be typical of the outbreaks in other mid-size cities in the world. The asymptomatic infected individuals have a infectivity and may be the source of infection. There were likely indirect transmission and airborne aerosol transmission. Therefore, we need to be alert of the trend of the epidemic shifting from the import stage to the community spread stage, while continuing to implement the measures and strategies of prevention and control to stop the spread of SARS-CoV-2. Fundamental to these strict prevention and control measures are extremely proactive monitoring to immediately detect cases, very rapid diagnosis and immediate case isolation, rigorous tracking and quarantine of close contacts, and an exceptionally high degree of understanding and acceptance among the population for these measures. Managing, monitoring and screening of people moving into areas with severe epidemics and three kinds of people who were ready to return to work, return to school or return to Wenzhou were the key to controlling COVID-19. At this stage, a normalized mode of epidemic prevention and control was implemented to limit public gatherings. Universal temperature monitoring, wearing masks, washing hands frequently, and strengthening personal hygiene (spitting, blowing) Nose, etc.) could effectively control the spread of the epidemic. Taken together, timely and strict measures of control and prevention were of great significance to the control of the COVID-19 epidemic in Wenzhou. However, the enormous and adverse impacts on public health, economy and society, caused by these high-strength prevention and treatment measures, would be increased significantly.

Abbreviations

SARS-CoV-2: Severe acute respiratory syndrome coronavirus 2; COVID-19: Corona virus disease 2019; NCP: Novel coronavirus pneumonia; PHEIC: Public Health Emergency of International Concern; WZCDC: Wenzhou Center for Disease Prevention and Control; R_0 : basic reproduction number; R_t : effective reproduction number; ICU: an intensive care unit; GW: a general COVID-19 ward; IQR: Interquartile range

Declarations

Acknowledgements

We thank Zhi Li, Wenhui Lun, Chun Mao, Yingyi Feng, Yujie Pan, Zeqin Huang, and Junyi Ye from Guangzhou Medical University (Guangzhou, China) for assisting with data collection. We thank Zhi Li for his assistance in preparing the figures. We are very grateful to Wenzhou Municipal Health Commission for public the data and all medical staff members and field workers who are working on the frontline of caring for patients and collecting the data.

Authors' contributions

HZ and JL designed the study. WL and BR collated the data, and TL, DW and DW interpreted the results. HZ analyzed the results and wrote the manuscript. XL, FQ, JL and ZY revised the manuscript. All authors read and approved the final manuscript.

Funding

This study was supported by the National Natural Science Foundation of China 81872694, 81673267 and 81473040 (J. Lu); 81602289 and 81872127 (F. Qiu).

Local Innovative and Research Teams Project of Guangdong Pearl River Talents Program 2017BT01S155 (J Lu); Health Industry Scientific Research Project of Gansu Province GSWSKY2018-18(H Zhao). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript.

Availability of data and materials

All data generated or analyzed during this study are included in this published article.

Ethics approval and consent to participate

This study was approved by the Ethics Committee of Guangzhou Medical University. We collected data from the official website of Municipal Health Commission (**Website:** <http://wjw.wenzhou.gov.cn/col/col1209919/index.html>), which was considered exempt from approval.

Consent for publication

Not applicable.

Conflict of interest

The authors declare no competing interests.

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Figures

Figure 1

The time distribution of imported and local cases

Figure 2

The Effective Reproduction Number Estimates Based on Laboratory-Confirmed COVID-19 cases in Wenzhou city Results were shown since January 11, calculated for the whole period (from January 11 to March 2) over 7-day moving average. The black horizontal line indicated $R_t=1$, below which sustained transmission is unlikely so long as antitransmission measures were sustained, indicating that the outbreak is under control. The 95% credible intervals (CI) were presented as light orange shading. Daily estimates of R_t with 95% Crls were shown in Table 2.

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