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Transmission potential and severity of COVID-19 in South Korea

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Objectives: Since the first case of 2019 novel coronavirus (COVID-19) identified on Jan 20, 2020, in South Korea, the number of cases rapidly increased, resulting in 6284 cases including 42 deaths as of Mar 6, 2020. To examine the growth rate of the outbreak, we present the first study to report the reproduction number of COVID-19 in South Korea.

Methods: The daily confirmed cases of COVID-19 in South Korea were extracted from publicly available sources. By using the empirical reporting delay distribution and simulating the generalized growth model, we estimated the effective reproduction number based on the discretized probability distribution of the generation interval.

Results: We identified four major clusters and estimated the reproduction number at 1.5 (95% CI: 1.4–1.6). In addition, the intrinsic growth rate was estimated at 0.6 (95% CI: 0.6, 0.7), and the scaling of growth parameter was estimated at 0.8 (95% CI: 0.7, 0.8), indicating sub-exponential growth dynamics of COVID-19. The crude case fatality rate is higher among males (1.1%) compared to females (0.4%) and increases with older age.

Conclusions: Our results indicate an early sustained transmission of COVID-19 in South Korea and support the implementation of social distancing measures to rapidly control the outbreak.

Introduction

A novel coronavirus (SARS-CoV-2) that emerged out of the city of Wuhan, China, in December 2019 has already demonstrated its potential to generate explosive outbreaks in confined settings and cross borders following human mobility patterns (Mizumoto et al., 2020). While COVID-19 frequently induces mild symptoms common to other respiratory infections, it has also exhibited an ability to generate severe disease among certain groups, including older populations and individuals with underlying health issues such as cardiovascular disease and diabetes (Adler, 2020). Nevertheless, a clear picture of the epidemiology of this novel coronavirus is still being elucidated.

The number of cases of COVID-19 in the province of Hubei, the disease epicenter, quickly climbed following an exponential growth trend. The total number of COVID-19 cases is at 80,859, including 3100 deaths in China as of Mar 8, 2020 (WHO, 2020). Fortunately, by Feb 15, 2020, the daily number of newly reported cases in China started to decline across the country, although Hubei Province reported 128 cases on average per day in the week of March 2–8, 2020 (WHO, 2020). While the epidemic continues to decline in China, 24,727 COVID-19 cases have been reported in more than 100 countries outside of China, including South Korea, Italy, Iran, Japan, Germany, and France (WHO, 2020). In particular, South Korea quickly became one of the hardest-hit countries with COVID-19, exhibiting a steadily increasing number of cases over the last few days. Hence, it is crucial to monitor the progression of these outbreaks and assess the effects of various public health measures, including the social distancing measures in real-time.

The first case in South Korea was identified on Jan 20, 2020, followed by the detection of one or two cases on average in the subsequent days. However, the number of confirmed cases of SARS-CoV-2 infection started to increase rapidly on Feb 19, 2020, with a total of 6284 confirmed COVID-19 cases including 42 deaths reported as of Mar 6, 2020, according to the Korea Centers for Disease Control and Prevention (KCDC) (KCDC, 2020) (Table 1). The epicenter of the South Korean COVID-19 outbreak has been identified in Daegu, a city of 2.5 million people, approximately 150 miles South East of Seoul. The rapid spread of COVID-19 in South Korea has been attributed to one case linked to a superspreading

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Table 1
The total number of confirmed and suspected cases as of Mar 6, 2020, as well as the case and fatality rate distribution by gender and age (KCDC, 2020).

Total	Confirmed cases				Suspected cases		
	Subtotal	Discharged	Isolated	Deceased	Subtotal	Being tested	Tested negative
164,740	6284	108	6,134	42	158,456	21,832	136,624

Classification		Cases (%)	Deaths (%)	Fatality rate (%)
Total		6284 (100)	42 (100)	0.7
Sex	Male	2,345 (37.3)	25 (59.5)	1.1
	Female	3,939 (62.7)	17 (40.5)	0.4
Age	0–9	45 (0.7)	–	–
	10–19	292 (4.6)	–	–
	20–29	1,877 (29.9)	–	–
	30–39	693 (11.0)	1 (2.4)	0.1
	40–49	889 (14.1)	1 (2.4)	0.1
	50–59	1,217 (19.4)	5 (11.9)	0.4
	60–69	763 (12.1)	11 (26.2)	1.4
	70–79	340 (5.4)	14 (33.3)	4.1
	Above 80	168 (2.7)	10 (23.8)	6.0

event that has led to more than 3900 secondary cases stemming from church services in the city of Daegu (Kuhn, 2020; Ryall, 2020). This has led to sustained transmission chains of COVID-19, with 55% of the cases associated with the church cluster in Daegu (Bostock, 2020).

Moreover, three other clusters have been reported, including one set in Chundo Daenam hospital in Chungdo-gun, Gyeongsanggbuk-do (118 cases), one set in the gym in Cheonan, Chungcheongnam-do (92 cases), and one Pilgrimage to Israel cluster in Gyeongsanggbuk-do (49 cases). These few clusters have become the primary driving force of the infection. A total of 33 cases were imported, while the four major clusters are composed of local cases, as described in Table 2.

The transmission of SARS-CoV-2 in Korea is exacerbated by amplified transmission in confined settings, including a hospital and a church in the city of Daegu. The hospital-based outbreak alone involves 118 individuals, including 9 hospital staff (News, 2020), which is reminiscent of past outbreaks of SARS and MERS (Chowell et al., 2015). To respond to the mounting number of cases of COVID-19, the Korean government has raised the COVID-19 alert level to the highest (Level 4) on Feb 23, 2020, to facilitate the implementation of comprehensive social distancing measures including enhanced infection control measures in hospitals, restricting public transportation, canceling of social events, and delaying the start of school activities (Kim, 2020).

While the basic reproduction number, denoted by R_0, applies at the outset of an exponentially growing epidemic in the context of an entirely susceptible population and in the absence of public health measures and behavior changes, the effective reproduction number (R_t) quantifies the time-dependent transmission potential. This key epidemiological parameter tracks the average number of secondary cases generated per case as the outbreak progresses over time. Steady values of R_t above 1 indicate sustained disease transmission, whereas values of R_t <1 do not support sustained transmission, and the number of new cases is expected to follow a declining trend. In this report, using a mathematical model parameterized with case series of the COVID-19 outbreak in Korea, we investigated the transmission potential and severity of COVID-19 in Korea using preliminary data of local and imported cases reported up until Feb 26, 2020.

Methods

Data

We obtained the daily series of confirmed cases of COVID-19 in South Korea from Jan 20, 2020, to Feb 26, 2020, that are publicly available from the Korea Centers for Disease Control and Prevention (KCDC) (KCDC, 2020). Our data includes the dates of reporting for all confirmed cases, the dates of symptom onsets for the first 28 reported cases, and whether the case is autochthonous (local transmission) or imported. We also summarize the case clusters comprising one or more cases according to the source of infection, according to the field investigations conducted by the KCDC (KCDC, 2020). Accordingly, four major clusters were identified. The total number of confirmed and suspected cases as of Mar 6, 2020, as well as the crude case and fatality rate distribution by gender and age, are presented in Table 1.

Imputing the date of onset

To estimate the growth rate of the epidemic, it is ideal to characterize the epidemic curve according to dates of symptoms onset rather than dates of reporting. For the COVID-19 data in Korea, the symptom onset dates are available for only the first 28 reported cases. Moreover, all of the dates of symptoms onset are

Table 2
Characteristics of the largest COVID-19 clusters in South Korea as of Mar 8, 2020.

Cluster name	Cluster location	Cluster size	Reporting date for the first case linked to cluster	Reporting date for the last case linked to cluster
Shinchunji Church of Jesus	81, Daemyeong-ro, Nam-gu, Daegu, Republic of Korea	4482	2/18/2020	3/08/2020
Chundo Daenam hospital	79-7, Cheonghwa-ro, Hwayang-eup, Cheongdo-gun, Gyeongsangbuk-do, Republic of Korea	118	2/20/2020	2/29/2020
Cluster related to the gym in Cheonan	667, Dujeong-dong, Seobuk-gu, Cheonan-si, Chungcheongnam-do, Republic of Korea	92	2/25/2020	3/08/2020
Pilgrimage to Israel	31, Guncheong-gil, Uiseong-eup, Uiseong-gun, Gyeongsangbuk-do, Republic of Korea	49	2/22/2020	3/02/2020

available for the imported cases. Therefore, we utilize this empirical distribution of reporting delays from the onset to diagnosis to impute the missing dates of onset for the remainder of the cases with missing data. For this purpose, we reconstruct 300 epidemic curves by dates of symptoms onset from which we derive a mean incidence curve of local case incidence and drop the last three data points from the analysis to adjust for reporting delays in our real-time analysis (Tariq et al., 2019).

Estimation of reproduction number from daily case incidence

We assess the effective reproduction number, R_t, which quantifies the time-dependent variations in the average number of secondary cases generated per case during an outbreak due to intrinsic factors (decline in susceptible individuals) and extrinsic factors (behavior changes, cultural factors, and the implementation of public health measures) (Anderson and May, 1991; Chowell et al., 2015; Nishiura et al., 2010). Using the Korean incidence curves for imported and local cases, we estimate the evolution of R_t for COVID-19 in Korea. First, we characterize daily local case incidence using a generalized growth model (GGM) (Viboud et al., 2016). This model describes the growth profile via two parameters: the growth rate parameter (r) and the scaling of the growth rate parameter (p). The model captures diverse epidemic profiles ranging from constant incidence ($p = 0$), sub-exponential or polynomial growth ($0 < p < 1$), and exponential growth ($p = 1$) (Viboud et al., 2016). The generation interval is assumed to follow a gamma distribution with a mean of 4.41 days and a standard deviation of 3.17 days (Nishiura et al., 2020; You et al., 2020).

Next, to estimate the most recent estimate of R_t, we simulate the progression of incident cases from GGM and apply the discretized probability distribution (ρ_i) of the generation interval using the renewal equation (Nishiura and Chowell, 2009; Nishiura and Chowell, 2014; Paine et al., 2010) given by

$$R_{t_i} = \frac{I_i}{\sum_{j=0}^{i} (I_{i-j} + \alpha\ J_{i-j})\rho_i}.$$

In the renewal equation, we denote the local incidence at calendar time t_i by I_i, and the raw incidence of imported cases at calendar time t_i by J_i. The parameter $0 \leq \alpha \leq 1$ quantifies the relative contribution of imported cases to secondary disease transmission (Nishiura and Roberts, 2010). The denominator represents the total number of cases that contribute to the incidence cases at time t_i. Next, we estimate R_t for 300 simulated curves assuming a Poisson error structure to derive the uncertainty bounds around the curve of R_t (Chowell, 2017).

Results

Reconstructed incidence of COVID-19

The reconstructed daily incidence curve of COVID-19 after imputing the onset dates for the Korean cases is shown in Figure 1. Between Jan 20 and Feb 18, 2020, an average of two new cases were reported each day, whereas, between February 19–26, 2020, 154 new cases were reported on average each day.

*Effective reproduction number (**R_t**) from daily case incidence*

Under the empirical reporting delay distribution from early Korean cases with available dates of onset, the intrinsic growth rate (r) was estimated at 0.6 (95% CI: 0.6, 0.7) and the scaling of growth parameter (p) was estimated at 0.8 (95% CI: 0.7, 0.8), indicating sub-exponential growth dynamics of COVID-19 in Korea (Figure 2, Table 3). The mean reproduction number R_t was estimated at 1.5

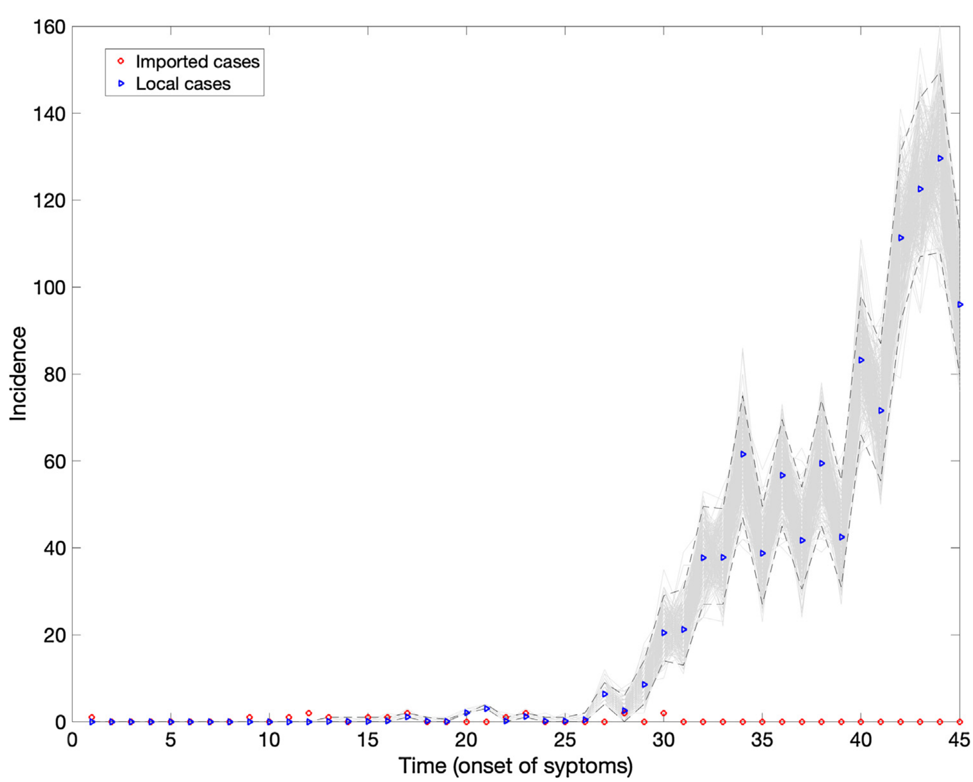

Figure 1. Reconstructed epidemic curve for the local Korean COVID-19 cases by the dates of onset as of February 26, 2020. The blue triangles represent the local cases, red triangles represent the imported cases and the gray curves correspond to the uncertainty in the local cases because of missing onset dates.

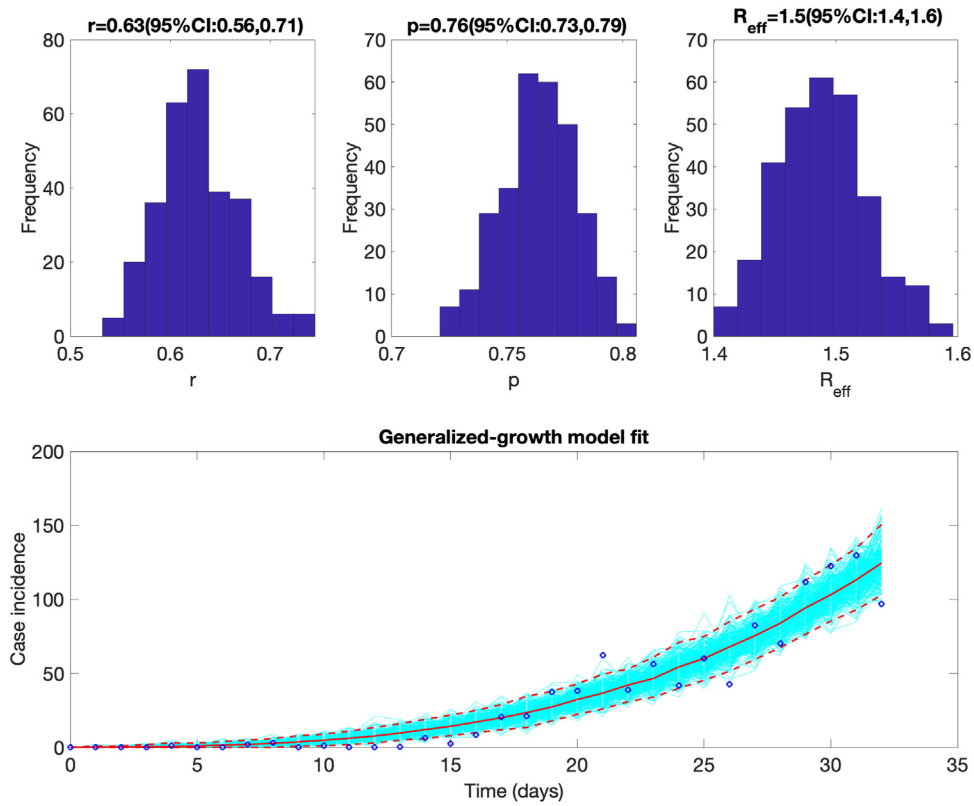

Figure 2. The mean reproduction number with 95% CI estimated by adjusting for the imported cases with $\alpha = 0.15$. Estimates for growth rate (r) and the scaling of the growth rate parameter (p) are also provided. The plot at the bottom depicts the fit of the Generalized Growth Model to the Korean data assuming Poisson error structure as of February 26, 2020.

Table 3
Mean estimates and the corresponding 95% confidence intervals for the effective reproduction number, growth rate, and the scaling of growth parameter during the early growth phase as of Feb 26, 2020.

Parameters	Estimated values
Reproduction number	1.5 (95% CI:1.4,1.6)
Growth rate, r	0.6 (95% CI:0.6,0.7)
Scaling of growth parameter, p	0.8 (95% CI:0.7,0.8)

(95% CI: 1.4, 1.6) as of Feb 26, 2020. Our estimates of R_t are not sensitive to changes in the parameter that modulates the contribution of the imported cases to transmission (α).

The crude case fatality rate

The crude case fatality rate is higher among males (1.1%) compared to females (0.4%) and increases with older age, from 0.1% among those 30–39 yrs to 6% among those > = 80 yrs as of Mar 6, 2020.

Transmission clusters

The spatial distribution of the Korean clusters is shown in Figure 3, and the characteristics of each cluster are presented in Table 2 as of Mar 8, 2020.

Shincheonji Church of Jesus cluster

As of Mar 8, 2020, 4482 confirmed cases of COVID-19 are linked to this cluster, according to the KCDC (KCDC, 2020). This largest cluster is associated with the Shincheonji Church of Jesus, with the first case (the 31^{st} patient in the country) confirmed on Feb 18. It is unclear how this case contracted the illness, as she does not present a recent history of travel or contact with another infected patient. However, before becoming a symptomatic case of COVID-19, she visited the hospital in Cheongdo after a minor car accident. After becoming a symptomatic case of COVID-19, she attended the Shincheonji Church of Jesus in Daegu twice. According to the KCDC, the patient had contact with 166 people, primarily at the Shincheonji Church and the hospital in Cheongdo; all those with whom the patient had contact, now placed themselves into self-quarantine. The Shincheonji church of Jesus has temporarily closed its facilities and halted the church activities as of Feb 18, 2020.

Chungdo Daenam hospital cluster

This cluster comprising 118 local cases and seven deaths is associated with Chungdo Daenam hospital, where South Korea's first coronavirus-associated case fatality occurred. Of the 118 cases, 92 were confirmed on Feb 22, 2020 (KCDC, 2020). A 63-year-old man who died of pneumonia at the hospital on Feb 19 was posthumously tested positive for COVID-19. On Feb 21, another patient at Daenam Hospital died from COVID-19, followed by another death on Feb 23. The confirmed cases were mainly from the psychiatric ward and include nine medical staff persons. The exact route of the infection is not yet known.

Cluster related to the gym in Cheonan

In the central cities of Cheonan, 92 COVID-19 patients were associated with a Zumba dance class after an instructor became the 5th confirmed case in Cheonan on Feb 25, 2020. According to the provincial government of South Chungcheong Province, everyone who attended the class in Cheonan was tested, and 27 cases were

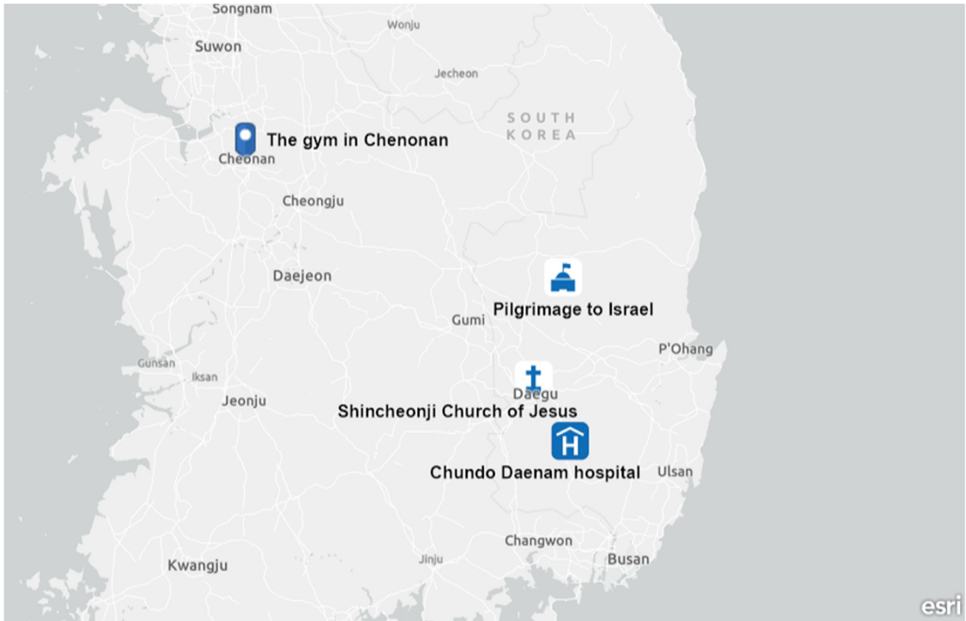

Figure 3. Map depicting the spatial distribution of the four largest clusters of COVID-19 in Korea as of March 8, 2020.

confirmed on Feb 28, 2020, with most of the cases being women in their 30's and 40's (KCDC, 2020). As of Mar 8, 2020, a total of 92 individuals were infected, including Zumba instructors and students, as well as their families and acquaintances (KCDC, 2020).

Pilgrimage tour to Israel related cluster

This cluster comprised 49 cases as of Mar 8, 2020. This cluster was identified when 31 Catholic pilgrims visited Israel between Feb 8, 2020, and Feb 16, 2020, and were subsequently confirmed to have COVID-19 (2020). Eleven individuals were diagnosed on Feb 17, 2020; twenty others were confirmed positive between February 21–25, 2020, and immediately quarantined. Of the 31 infected pilgrims, 19 came from Euiseong County, North Gyeongsang Province, while one patient, a tour guide, came from Seoul. Health authorities have traced multiple contacts by the cases of this cluster, and additional cases were confirmed after that, raising concerns about the potential risk of secondary infections.

Discussion

This is the first study to report estimates of the transmission potential of COVID-19 in Korea based on the trajectory of the epidemic, which was reconstructed by using the dates of onset of the first reported cases in Korea. The estimates of R clearly indicate the sustained transmission of the novel coronavirus in Korea; the case fatality rate appears to be higher among males and older populations (Table 1). Moreover, the imported cases contribute little to secondary disease transmission in Korea, as a majority of these cases occurred in the early phase of the epidemic, with the most recent imported case reported on Feb 9, 2020. These findings support the range of social distancing interventions that the Korean government put in place to bring the outbreak under control as soon as possible.

Our estimates of the reproduction number can be compared with earlier estimates reported for the epidemic in China, where the estimates of R lie in the range 2–7.1 (Lai et al., 2020; Li et al., 2020; Mizumoto et al., 2020; Read et al., 2020; Special Expert Group for Control of the Epidemic of Novel Coronavirus Pneumonia of the Chinese Preventive Medicine A, 2020; Wu et al., 2020; Zhang et al., 2020; Zhou et al., 2020). Moreover, the mean R reached values as high as ~11 for the outbreak that unfolded aboard the Princess Cruises ship during January–February 2020 (Mizumoto and Chowell, 2020). In contrast, a recent study on Singapore's COVID-19 transmission dynamics reported lower estimates for R_t (1.1, 95% CI: 1.1, 1.3) as of Feb 19, 2020, reflecting a significant impact of the control interventions that were implemented in Singapore (Tariq et al., 2020). The estimates of the scaling of growth parameter (p) in our study indicate sub-exponential growth dynamics of COVID-19 in Korea. This aligns well with the sub-exponential growth patterns of COVID-19 in Singapore and all Chinese provinces except Hubei (Roosa et al., 2020; Tariq et al., 2020).

Since the first COVID-19 case was reported on Jan 20, 2020, the epidemic's trajectory showed a rapid upturn until Feb 18, 2020, when a superspreader (Case 31) was identified in the Shincheonji Church of Jesus in Daegu cluster. Since then, Korea's confirmed cases have risen tremendously. In fact, 55% of confirmed cases are linked to one cluster of infections, i.e., the Shincheonji Church of Jesus in Daegu (KCDC, 2020). Such superspreading events have been reported earlier for the 2015 MERS outbreak in South Korea (Cowling et al., 2015). Amplification of MERS in the hospital setting has been associated with diagnostic delays, which increase the window of opportunity for the generation of secondary cases (Chowell et al., 2015). This underscores the need for rapid testing, case detection, and active contact tracing to isolate infectious individuals.

Beyond Korea, substantial COVID-19 transmission has been reported in Italy, Iran, Germany, France, and aboard the Diamond cruise ship (Marcus, 2020; Woods, 2020). While the Chungdo Daenam hospital cluster and the cluster related to the Pilgrimage tour to Israel seem to have stabilized, the other two clusters are still being consolidated. Public health authorities are currently focused on containing the outbreak in the city of Daegu, the epicenter of the outbreak, and North Gyeongsang Province, where active contact tracing is being conducted. Nation-wide preventative measures are expected to reduce community transmission and ultimately bring R_t below one.

This is the first study to estimate the transmission potential and severity of COVID-19 in Korea. Our current findings suggest that there is a sustained disease transmission in the region, underscoring the need to implement a wide array of social distancing measures to rapidly contain the outbreak in Korea, mitigate the morbidity and mortality impact of the disease, and stem the number of case exportations to other nations.

Contributions

ES, AT, and GC analyzed the data. YS and WC retrieved and managed the data. ES, AT, and GC wrote the first draft of the paper. All authors contributed to the writing of this article.

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Conflict of interest

None.

Ethical approval

Not required.

References

Adler SE. Why coronaviruses hit older adults hardest. AARP; 2020.
Anderson RM, May RM. In: Oxford, editor. Infectious Diseases of Humans. Oxford University Press; 1991.
Bostock B. South Korea is testing 200,000 members of a doomsday church linked to more than 60% of its coronavirus cases. Business Insider; 2020.
Chowell G. Fitting dynamic models to epidemic outbreaks with quantified uncertainty: a primer for parameter uncertainty, identifiability, and forecasts. Infect Dis Modell 2017;2(3):379–98.
Chowell G, Abdirizak F, Lee S, Lee J, Jung E, Nishiura H, et al. Transmission characteristics of MERS and SARS in the healthcare setting: a comparative study. BMC Med 2015;13(1):210.
Cowling BJ, Park M, Fang VJ, Wu P, Leung GM, Wu JT. Preliminary epidemiological assessment of MERS-CoV outbreak in South Korea, May to June 2015. Euro Surveill 2015;20(25):7–13.
Nishiura H, Chowell G. The effective reproduction number as a prelude to statistical estimation of time-dependent epidemic trends. Math Stat Estim Approach Epidemiol 2009;103–12 Springer D.
KCDC. The updates on COVID-19 in Korea as of Feb 25. Seoul, Korea: Korea Centers for Disease Control and Prevention; 2020.
Kim C. As Covid-19 cases rise, South Korea raises virus threat level to its maximum. Vox; 2020.
Kuhn A. Secretive church sect at the center of South Korea's coronavirus outbreak. NPR; 2020.
Lai A, Bergna A, Acciarri C, Galli M, Zehender G. Early phylogenetic estimate of the effective reproduction number Of Sars-CoV-2. J Med Virol 2020;.
Li Q, Guan X, Wu P, Wang X, Zhou L, Tong Y, et al. Early transmission dynamics in Wuhan, China, of novel coronavirus–infected pneumonia. N Engl J Med 2020;.
Marcus I. Chronology: Germany and Covid 19 ('Coronavirus'). The Berlin Spectator; 2020.
Mizumoto K, Chowell G. Transmission potential of the novel coronavirus (COVID-19) onboard the Diamond Princess Cruises Ship, 2020. medRxiv 2020;2020: 02.24.20027649.
Mizumoto K, Kagaya K, Chowell G. Early epidemiological assessment of the transmission potential and virulence of 2019 Novel Coronavirus in Wuhan City: China, 2019-2020. medRxiv 2020;2020: 02.12.20022434.
News B. Coronavirus: South Korea declares highest alert as infections surge. BBC News; 2020.
Nishiura H, Chowell G. Early transmission dynamics of Ebola virus disease (EVD), West Africa, March to August 2014. Euro Surveill 2014;19(36).
Nishiura H, Chowell G, Heesterbeek H, Wallinga J. The ideal reporting interval for an epidemic to objectively interpret the epidemiological time course. J R Soc Interface 2010;7(43):297–307.
Nishiura H, Linton NM, Akhmetzhanov AR. Serial interval of novel coronavirus (2019-nCoV) infections. medRxiv 2020;2020: 02.03.20019497.
Nishiura H, Roberts MG. Estimation of the reproduction number for 2009 pandemic influenza A(H1N1) in the presence of imported cases. Eurosurveillance 2010;15 (29):19622.
Paine S, Mercer GN, Kelly PM, Bandaranayake D, Baker MG, Huang QS, et al. Transmissibility of 2009 pandemic influenza A(H1N1) in New Zealand: effective reproduction number and influence of age, ethnicity and importations. Euro Surveill 2010;15(24).
Read JM, Bridgen JR, Cummings DA, Ho A, Jewell CP. Novel coronavirus 2019-nCoV: early estimation of epidemiological parameters and epidemic predictions. medRxiv 2020;.
Roosa K, Lee Y, Luo R, Kirpich A, Rothenberg R, Hyman JM, et al. Real-time forecasts of the COVID-19 epidemic in China from Feb 5 to Feb 24, 2020. Infect Dis Modell 2020;5:256–63.
Ryall J. Coronavirus: Surge in South Korea virus cases linked to church 'super-spreader'. The Telegraph: Telegraph Media Group Limited; 2020.
Special Expert Group for Control of the Epidemic of Novel Coronavirus Pneumonia of the Chinese Preventive Medicine A. [An update on the epidemiological characteristics of novel coronavirus pneumoniaCOVID-19]. Zhonghua liu xing bing xue za zhi = Zhonghua liuxingbingxue zazhi 2020;41(2):139–44.
Tariq A, Lee Y, Roosa K, Blumberg S, Yan P, Ma S, et al. Real-time monitoring the transmission potential of COVID-19 in Singapore, February 2020. medRxiv 2020;2020: 02.21.20026435.
Tariq A, Roosa K, Mizumoto K, Chowell G. Assessing reporting delays and the effective reproduction number: the Ebola epidemic in DRC, May 2018-January 2019. Epidemics 2019;26:128–33.
Viboud C, Simonsen L, Chowell G. A generalized-growth model to characterize the early ascending phase of infectious disease outbreaks. Epidemics 2016;15:27–37.
WHO. Coronavirus disease (COVID-2019) situation reports. 2020 Available from: https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports. [Accessed Feb 27, 2020].
Woods A. 44 new coronavirus cases reported on quarantined Diamond Princess cruise. New York Post; 2020.
Wu JT, Leung K, Leung GM. Nowcasting and forecasting the potential domestic and international spread of the 2019-nCoV outbreak originating in Wuhan, China: a modelling study. Lancet 2020;.
You C, Deng Y, Hu W, Sun J, Lin Q, Zhou F, et al. Estimation of the Time-Varying Reproduction Number of COVID-19 Outbreak in China. medRxiv 2020;2020: 02.08.20021253.
Zhang S, Diao M, Yu W, Pei L, Lin Z, Chen D. Estimation of the reproductive number of Novel Coronavirus (COVID-19) and the probable outbreak size on the Diamond Princess cruise ship: a data-driven analysis. Int J Infect Dis 2020;.
Zhou T, Liu Q, Yang Z, Liao J, Yang K, Bai W, et al. Preliminary prediction of the basic reproduction number of the Wuhan novel coronavirus 2019-nCoV. J Evid Based Med 2020;.