Effect of Nonpharmaceutical Interventions on Transmission of Severe Acute Respiratory Syndrome Coronavirus 2, South Korea, 2020

Sukhyun Ryu, Seikh Taslim Ali, Cheolsun Jang, Baekjin Kim, Benjamin J. Cowling

We analyzed transmission of coronavirus disease outside of the Daegu-Gyeongsangbuk provincial region in South Korea. We estimated that nonpharmaceutical measures reduced transmissibility by a maximum of 33% without resorting to a strict lockdown strategy. To optimize epidemic control, continuous efforts to monitor the transmissibility are needed.

Infection with severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was identified in South Korea on January 20, 2020 (*1*). By April 21, 2020, a total of 10,683 cases of coronavirus disease (COVID-19) in South Korea had been confirmed and 237 persons had died (*2*) (Figure 1, panel A). A large number of COVID-19 cases and deaths resulted from superspreading events in the Daegu-Gyeongsangbuk provincial region of South Korea (Figure 1, panel B). On February 23, 2020, during the early phase of the outbreak as the number of COVID-19 cases increased, public health authorities in South Korea raised the infectious disease alert to its highest level (*3*). Subsequently, enhanced screening and testing in the community (operation of drive-through screening centers and designation of private hospitals where COVID-19 screening testing was available) were implemented (*4*,*5*).

On April 19, 2020, public health authorities in South Korea started to relax social distancing measures, which had been implemented on March 21, 2020; as of April 21, 2020, the COVID-19 epidemic in South Korea had been contained. Recent studies have examined how public health interventions can contain COVID-19 outbreaks (*6*,*7*). However, in the absence of information on public health measures against transmission of SARS-CoV-2 in South Korea, we estimated the transmissibility of SARS-CoV-2 and evaluated the effects of the public health measures implemented outside the Daegu-Gyeongsangbuk provincial region in South Korea.

The Study

We collected data published by local public health authorities in South Korea, including the city or provincial departments of public health. The data comprised date of exposure; date of illness onset; and the source of infection, including contact history and demographic characteristics (e.g., patient birth year and sex). We extracted these line list data of cases by using an electronic data-extraction form. We divided the study into 2 periods, before and after the declaration of highest public alert: period 1 (January 20–February 23, 2020) and period 2 (February 24–April 21, 2020). We restricted our analysis to all other regions in South Korea that excluded Daegu-Gyeongsangbuk provincial region, where there were superspreading events and the data have not been made publicly available (*8*). Over the entire 3-month study period (January 20–April 21, 2020), data were collected for 2,023 cases, which accounted for 98% of the 2,066 reported cases from the South Korea Ministry of Health and Welfare.

The median case-patient age was 42 (range 1–102) years, and 820 (41%) case-patients were male (Table). We analyzed the statistical differences in patient age and sex between periods 1 and 2 by using the χ^2 test but did not identify any significant differences. The proportion of cases imported from Daegu-Gyeongsangbuk provincial regions was 31% in period 1 and

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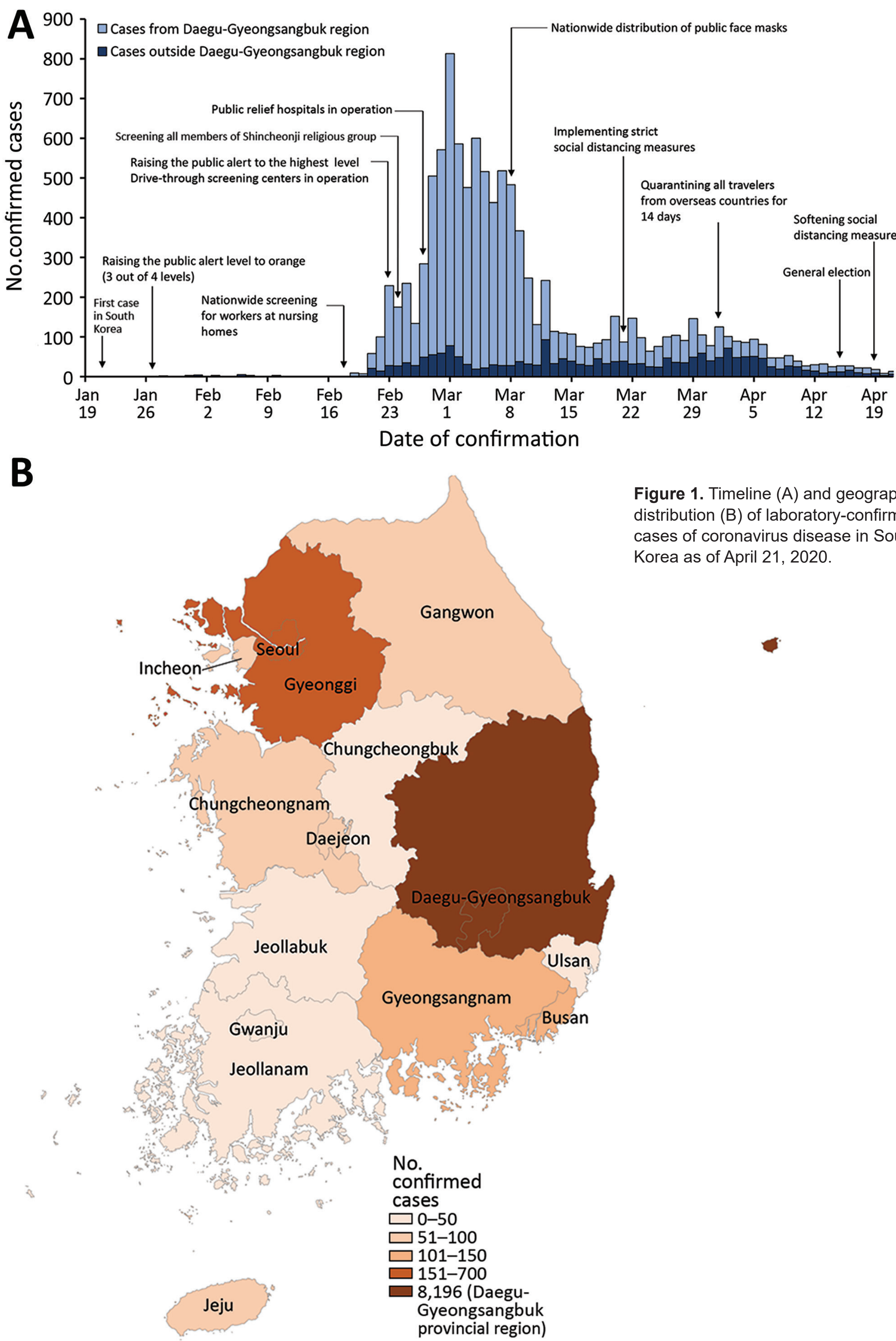

Figure 1. Timeline (A) and geographic distribution (B) of laboratory-confirmed cases of coronavirus disease in South Korea as of April 21, 2020.

Table. Demographic characteristics of 2,023 persons with confirmed cases of coronavirus disease, from publicly available data on April 21, 2020, South Korea, outside of Daegu-Gyeongsangbuk provincial region*

Characteristic	All, no. (%)	Period 1, no. (%)†	Period 2, no. (%)‡
Age group, y			
0–19	123 (6)	11 (5)	112 (6)
20–39	715 (35)	104 (50)	611 (34)
40–59	619 (31)	50 (24)	569 (31)
60–79	295 (15)	37 (18)	258 (14)
$\geq$80y	50 (3)	6 (3)	44 (2)
Unknown	221 (11)	0	221(12)
Sex			
M	820 (41)	107 (56)	713 (39)
F	953 (47)	100 (43)	853 (47)
Unknown	250 (12)	1 (1)	249 (14)
Type of transmission§			
Local	892 (44)	116 (55)	776 (43)
Imported from Daegu-Gyeongsangbuk	155 (8)	65 (31)	90 (5)
Imported from abroad	552 (27)	16 (8)	536 (30)
Cases occurring in large clusters	424 (21)	11 (5)	413 (23)

*Assignment to period was based on date of symptom onset. If cases were asymptomatic or date of symptom onset date was not reported, we used the date of case confirmation.
†Jan 20–Feb 23, 2020; n = 208.
‡Feb 24–Apr 21, 2020; n = 1,815.
§Source of infection is provided for all cases; if not identified, we considered the case to have occurred by local transmission.

decreased to 5% in period 2. However, during the same periods, the proportion of cases imported from abroad and cases occurring in large clusters increased from 8% to 30% and from 5% to 23%.

We analyzed the time interval between illness onset and laboratory confirmation for 818 symptomatic case-patients. We estimated the mean time interval from symptom onset to confirmation of COVID-19 during periods 1 and 2 by fitting 3 parametric distributions (Weibull, gamma, and log-normal) and based our selection of best fit on the Akaike information criterion (*9*). We found the log-normal distribution to be the best fit for this time interval, with a mean of 4.6 (95% CI 0.0–12.4) for period 1 and a substantial reduction to 3.4 (0.0–9.0) for period 2 (Appendix, https://wwwnc.cdc.gov/EID/article/26/10/20-1886-App1.pdf).

To estimate the incubation period, we analyzed data from 181 case-patients for whom precise contact history with other confirmed case-patients was known. The incubation period was estimated by fitting 3 parametric distributions and best fitted by the log-normal distribution; the overall estimated median incubation period was 4.7 (95% CI 0.1–15.6) days (Appendix). We identified 44 clusters of infection and 79 case-patients who had had clear exposure to only 1 index case-patient among these clusters (Appendix). Overall, serial intervals were negative for 8 of the 79 transmission pairs. We estimated the serial interval distribution by fitting a normal distribution to all 79 observations (*10*). We estimated a mean (± SD) serial interval to be 3.9 (± 4.2) days (Appendix).

In mid-February 2020, the number of cases rapidly increased; the largest proportion of cases was among persons who had been infected in Daegu-Gyeongsangbuk provincial region and traveled to other regions of South Korea (Figure 2, panel A). To investigate the effectiveness of nonpharmaceutical interventions implemented in South Korea (Appendix), we estimated the instantaneous effective reproduction number (R_t), a real-time measure of transmission intensity, from daily onset of cases and our estimated serial interval distribution by using the EpiEstim package in R (*11*,*12*). R_t is defined as the mean number of secondary infections per primary case with illness onset at time *t*; R_t<1 indicates that the epidemic is under control.

We present the daily estimates of R_t from February 16, 2020, because the stable estimate of R_t was not available due to the low number of confirmed cases (Figure 2, panel B). At the end of period 1, on February 21, mean R_t peaked at 2.53 (95% credible interval [CrI] 1.90–3.25) and then started to decline faster to <1 by February 29. R_t further declined and remained at <1 during the rest of period 2, indicating the potential effect of nonpharmaceutical interventions implemented over time (Figure 2, panel B). Specifically, mean R_t was 2.03 (CrI 1.89–2.17) before the 1-week period when the declared public alert was at the highest level and reduced to 1.37 (CrI 1.27–1.47) in the following 1-week period, corresponding to a 32.59% (95% CI 23.78%–41.41%) reduction in transmissibility. Similarly, along with the high public alert, the implementation of strict social distancing measures on March 12, 2020, was

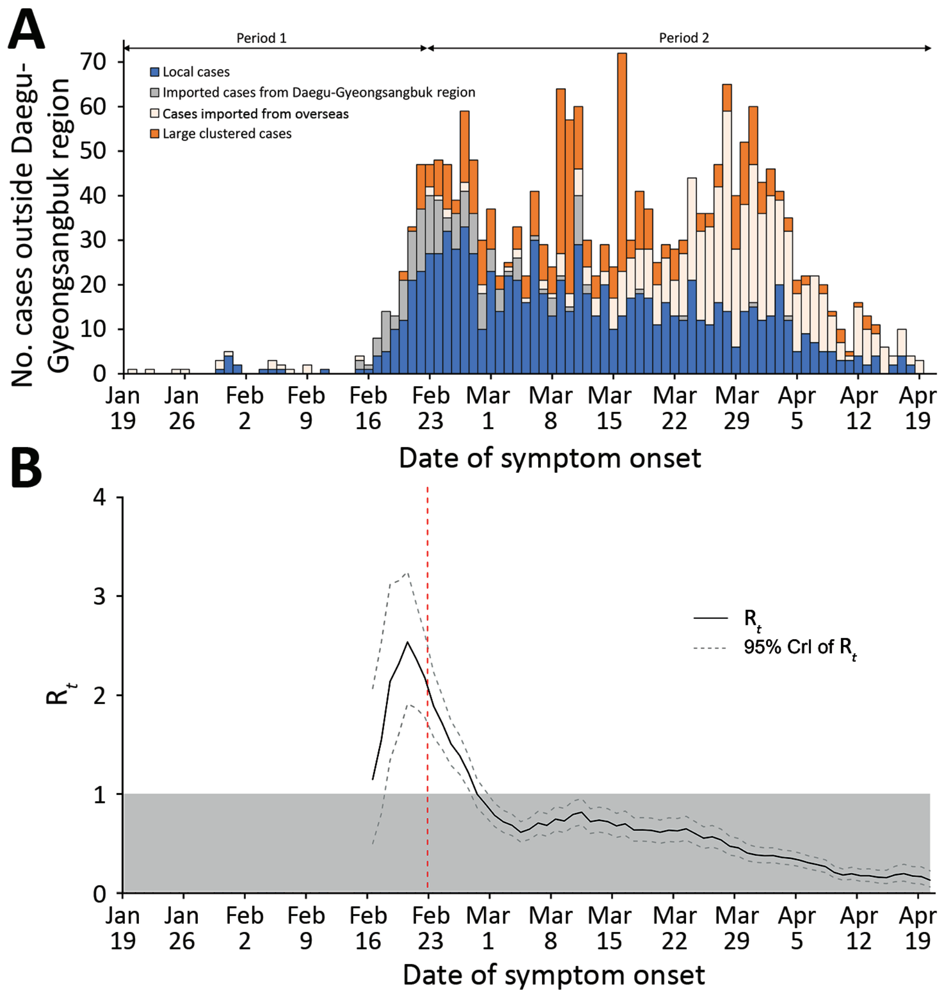

Figure 2. Incidence and estimated daily effective reproductive number (R_t) of coronavirus disease in regions outside of Daegu-Gyeongsanbuk provincial region, South Korea, as of April 21, 2020. A) The epidemic curve shows the daily number of patients with confirmed cases and symptom onset. For case-patients who did not report any symptoms on the date of case confirmation (n = 1,205 cases; 60% of total), the date of confirmation was plotted instead. B) Daily estimated R_t and 95% CrI of R_t; shading indicates the area below the epidemic threshold of $R_t = 1$. The vertical dashed line indicates the start of the highest public alert on February 23, 2020. CrI, credible interval.

associated with an R_t reduction of an additional 9.75% (95% CI 7.23%–12.29%).

Conclusions

Combined nonpharmaceutical interventions, including enhanced screening and quarantining of persons with suspected and confirmed cases and social distancing measures, were implemented over time. Our results suggest that those interventions, without a lockdown, reduced the transmissibility of SARS-CoV-2 in regions outside of the Daegu-Gyeongsangbuk provincial region, in South Korea.

Our study has some limitations. First, in our analysis of the changes of transmissibility of SARS-CoV-2, we did not include the large clustered cases reported as superspreading events because in these large clusters, the reporting date may not be a good proxy for the date of infection and would overestimate R_t (*13*). Second, it is uncertain how many cases were still undetected. This proportion may potentially mislead the actual time trends of number of infections in the population. Third, we based our estimation of time delay on self-reported data, which are not free from reporting (recall) bias. Fourth, government-generated data, including dates of symptom onset, were not available; therefore, we retrieved online case reports, which could have resulted in some inaccuracies in the information used in our analyses. However, the daily numbers of confirmed cases from the collected line list we used was similar to the numbers in the official daily reports (Appendix).

Our findings suggest that the nonpharmaceutical interventions implemented in South Korea during the COVID-19 outbreak effectively reduced virus transmissibility and suppressed local spread. However, the population of South Korea is still susceptible to further outbreaks or epidemic waves. Because social distancing measures will be relaxed while opportunities for importation of infections from abroad continue, ongoing monitoring of the effective reproductive number can provide relevant information to help policymakers control a potential second wave of COVID-19.

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About the Author

Dr. Ryu is an assistant professor of preventive medicine at Konyang University, Daejeon, South Korea. His research interests include infectious disease epidemiology with a focus on public health interventions.

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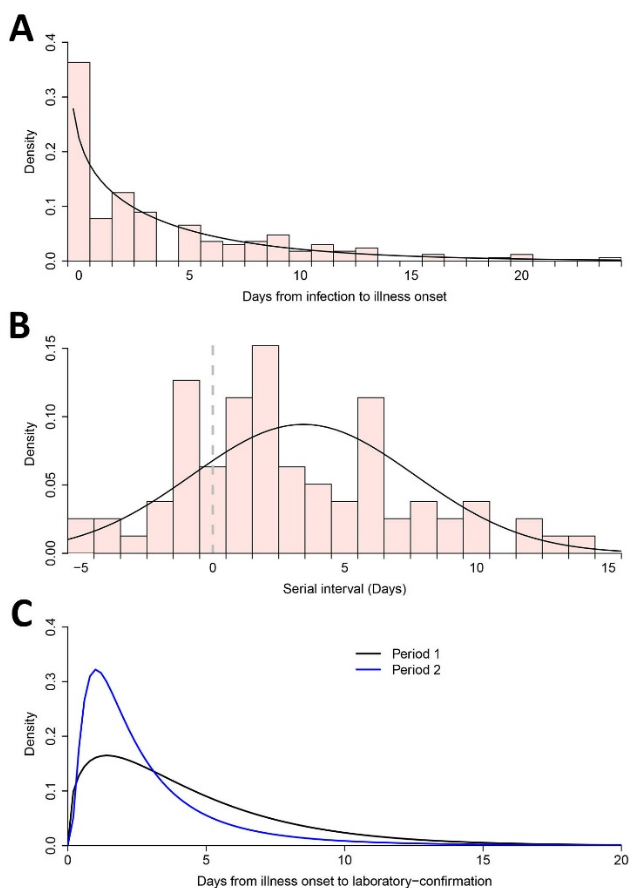
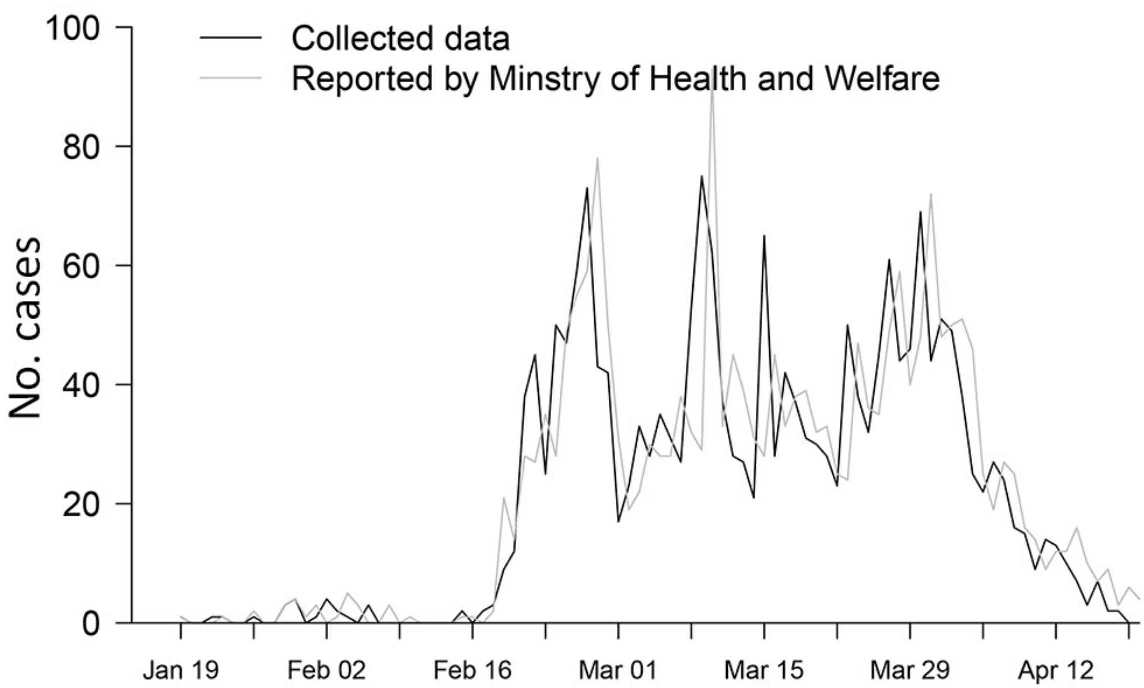
Appendix



Appendix Figure 1. Estimates of epidemiological distributions, COVID-19, South Korea. A) Distribution of incubation period among 181 laboratory-confirmed cases. The line is best fitted by a gamma distribution.

B) Distribution of serial interval among 79 cases in 44 clusters. The line indicates a fitted normal distribution. C) Distribution of symptom onset to laboratory-confirmation divided by two periods of the epidemic in South Korea. The black line is the estimate during period-1(before February 23, 2020), and the blue line is the estimate during period-2 (on or after February 24, 2020). Both lines indicate a fitted log-normal distribution.



Appendix Figure 2. Daily number of laboratory-confirmed cases from the collected data and reported data by the Korean Ministry of Health and Welfare outside of Daegu-Gyeongsangbuk provincial region in South Korea. The black line indicates the collected data used in this study, and the gray line indicates the daily number of confirmed cases reported from the central government in South Korea.

Appendix Table 1. The dates of symptom onset among 79 cases in 44 clusters of infection. We retrieved the line-list data of the cases by using electronic data-extraction form (MS excel software). The column of this excel spread sheet presents the variables, including the date of exposure, date of illness onset, source of infection, demographic characteristics including birth year and gender of the cases.

Number of cluster	Index case	Symptom onset	Sex	Age	Source ID from local public health authorities
1	1	February 18, 2020	Female	26	Busan #11
1	0	February 19, 2020	Male	29	Busan #39
1	0	February 23, 2020	Female	32	Busan #56
2	1	February 21, 2020	Female	57	Busan #2
2	0	February 20, 2020	Female	25	Busan #5
2	0	February 21, 2020	Female	82	Busan #6
2	0	February 22, 2020	Female	44	Busan #25
2	0	February 29, 2020	Female	83	Busan #87
3	1	February 21, 2020	Male	19	Busan #15
3	0	February 26, 2020	Male	16	Busan #62
3	0	February 28, 2020	Male	19	Busan #82
4	1	February 21, 2020	Female	25	Busan #59
4	0	February 26, 2020	Male	25	Busan #65
4	0	February 24, 2020	Female	51	Busan #58
5	1	February 17, 2020	Male	25	Busan #13
5	0	February 20, 2020	Female	56	Busan #20
6	1	February 22, 2020	Female	62	Busan #78
6	0	March 1, 2020	Female	36	Busan #81
7	1	February 17, 2020	Female	28	Busan #36
7	0	February 23, 2020	Male	27	Busan #54
7	0	February 26, 2020	Female	18	Busan #70
7	0	March 2, 2020	Female	40	Busan #85
8	1	February 28, 2020	Male	79	Busan #71
8	0	March 9, 2020	Male	50	Busan #92
8	0	March 12, 2020	Male	50	Busan #98
9	1	March 6, 2020	Female	68	Busan #100

Number of cluster	Index case	Symptom onset	Sex	Age	Source ID from local public health authorities
9	0	March 9, 2020	Male	73	Busan #97
10	1	February 19, 2020	Male	25	Busan #57
10	0	February 23, 2020	Female	65	Busan #60
11	1	February 6, 2020	Female	82	Seoul #14
11	0	February 15, 2020	Male	82	Seoul #13
12	1	February 27, 2020	Female	42	Seoul #140
12	0	February 29, 2020	Female	61	Seoul #164
13	1	February 24, 2020	Female	60	Seoul #38
13	0	March 6, 2020	Male	65	Seoul #117
14	1	March 12, 2020	Male	26	Seoul #266
14	0	March 19, 2020	Female	29	Seoul #297
14	0	March 18, 2020	Female	55	Seoul #298
15	1	March 11, 2020	Female	30	Ulsan #29
15	0	March 12, 2020	Male	30	Ulsan #30
16	1	March 16, 2020	Female	30	Ulsan #31
16	0	March 16, 2020	Male	30	Ulsan #36
17	1	March 17, 2020	Female	26	Seoul #304
17	0	March 20, 2020	Male	61	Seoul #320
18	1	March 19, 2020	Female	4	Seoul #311
18	0	March 22, 2020	Female	38	Seoul #314
19	1	February 27, 2020	Female	55	Suwon #13
19	0	February 29, 2020	Male	42	Suwon #16
20	1	March 7, 2020	Male	24	Suwon #17
20	0	March 9, 2020	Male	10	Suwon #18
21	1	March 20, 2020	Male	20s	Suwon #23
21	0	March 22, 2020	Male	50s	Suwon #24
21	0	March 22, 2020	Female	20s	Suwon #26
22	1	March 27, 2020	Female	55	Suwon #44
22	0	March 31, 2020	Male	42	Suwon #45
23	1	March 21, 2020	Female	30	Yongin #41
23	0	March 22, 2020	Male	57	Yongin #43
24	1	March 14, 2020	Male	49	Yongin #29
24	0	March 19, 2020	Female	49	Yongin #27

Number of cluster	Index case	Symptom onset	Sex	Age	Source ID from local public health authorities
24	0	March 27, 2020	Female	77	Yongin #47
25	1	March 20, 2020	Female	68	Yongin #34
25	0	March 21, 2020	Male	44	Yongin #35
25	0	March 26, 2020	Female	44	Yongin #44
26	1	March 25, 2020	Not available	20s	Uijeongbu #18
26	0	March 30, 2020	Not available	20s	Uijeongbu #19
26	0	April 1, 2020	Not available	50s	Uijeongbu #22
27	1	February 20, 2020	Female	40s	Sejong #2
27	0	February 22, 2020	Female	40s	Sejong #6
27	0	February 27, 2020	Female	20s	Sejong #3
27	0	February 22, 2020	Female	50s	Sejong #4
27	0	March 1, 2020	Female	40s	Sejong #5
28	1	February 21, 2020	Female	47	Gyeongnam #5
28	0	February 18, 2020	Male	21	Gyeongnam #7
28	0	February 24, 2020	Male	16	Gyeongnam #29
28	0	February 25, 2020	Male	41	Gyeongnam #42
29	1	April 2, 2020	Female	39	Gyeongnam #109
29	0	April 4, 2020	Male	9	Gyeongnam #110
30	1	February 23, 2020	Female	72	Namyangju #2
30	0	February 23, 2020	Male	77	Namyangju #3
31	1	March 28, 2020	Female	20s	Jeju #9
31	0	April 1, 2020	Male	30s	Jeju #11
32	1	April 9, 2020	Male	60s	Guri #5
32	0	April 6, 2020	Female	61	Pocheon #12
32	0	April 12, 2020	Female	60s	Pocheon #14
33	1	March 23, 2020	Female	46	Pyeongtaek #19
33	0	March 22, 2020	Female	78	Pyeongtaek #26
33	0	March 25, 2020	Male	79	Pyeongtaek #27
33	0	March 23, 2020	Female	34	Pyeongtaek #28
33	0	March 26, 2020	Female	32	Pyeongtaek #29
33	0	April 3, 2020	Male	47	Pyeongtaek #35
33	0	April 6, 2020	Male	54	Pyeongtaek #38
34	1	March 25, 2020	Male	9	Pyeongtaek #36

Number of cluster	Index case	Symptom onset	Sex	Age	Source ID from local public health authorities
34	0	March 19, 2020	Female	49	Pyeongtaek #39
35	1	February 24, 2020	Female	40s	Gwangmyeong #2
35	0	February 28, 2020	Male	49	Gwangmyeong #3
35	0	March 2, 2020	Male	11	Gwangmyeong #4
36	1	April 6, 2020	Not available	60s	Uijeongbu #28
36	0	April 6, 2020	Not available	60s	Uijeongbu #29
36	0	April 9, 2020	Male	60	Gwangju #15
36	0	April 9, 2020	Female	56	Gwangju #16
37	1	February 25, 2020	Female	49	Gunpo #2
37	0	March 3, 2020	Male	78	Ansan #1
37	0	March 3, 2020	Female	73	Ansan #3
38	1	March 3, 2020	Female	48	Gwangmyeong #2
38	0	February 28 2020	Male	49s	Gwangmyeong #3
38	0	March 2, 2020	Male	11	Gwangmyeong #4
39	1	February 18, 2020	Male	36	Chungbuk #2
39	0	February 18, 2020	Female	35	Chungbuk #3
39	0	March 4, 2020	Female	57	Chungbuk #14
40	1	March 8, 2020	Female	42	Chungnam #107
40	0	March 6, 2020	Male	1	Chungnam #108
41	1	March 6, 2020	Male	38	Chungnam #94
41	0	March 6, 2020	Female	32	Chungnam #95
41	0	March 6, 2020	Female	3	Chungnam #96
42	1	April 7, 2020	Female	42	Seongnam #120
42	0	April 10, 2020	Male	1	Seongnam #122
43	1	February 21, 2020	Male	21	Busan #29
43	0	February 24, 2020	Male	19	Busan #42
43	0	February 21, 2020	Female	51	Busan #43
44	1	February 21, 2020	Female	25	Busan #59
44	0	February 24, 2020	Female	51	Busan #58
44	0	February 21, 2020	Female	44	Busan #61
44	0	February 28, 2020	Female	31	Busan #63

Appendix Table 2. Key non-pharmaceutical interventions in South Korea (most of the interventions)

Starting date	Interventions	Source
Travel-related measures		
February 3, 2020	Barred of entry of foreign travelers from Hubei province, China	http://overseas.mofa.go.kr/ru-ko/brd/m_7329/view.do?seq=1345588&srchFr=&srchTo=&srchWord=&srchTp=&multi_itm_seq=0&itm_seq_1=0&itm_seq_2=0
February 23, 2020	Recommended travel restriction in Daegu City - Recommended avoiding social gathering and refraining from going out in Daegu city	http://ncov.mohw.go.kr/tcmBoardView.do?contSeq=353064
March 9, 2020	Barred of entry of foreign travelers from Japan	http://overseas.mofa.go.kr/jp-ko/brd/m_1083/view.do?seq=1343492
April 1, 2020	Implemented 14-day mandatory quarantine to all travellers entering Korea from abroad	http://overseas.mofa.go.kr/nl-en/brd/m_6971/view.do?seq=761545
Case-based measures		
February 17, 2020	Implemented screening test for COVID-19 for the health care workers at all nursing home	https://www.cdc.go.kr/board/board.es?mid=a30402000000&bid=0030&act=view&list_no=366586&tag=&nPage=1
February 23, 2020	Launched nationwide drive-through screening centers - Operated 58 roadside screening sites to timely identify the infected cases in the community as of May 11, 2020	https://jkms.org/DOIx.php?id=10.3346/jkms.2020.35.e123 https://www.mohw.go.kr/react/popup_200128_4.html
February 25, 2020	Initiated screening all Sincheonji religious group members - As the Sincheonji religious group occupied a large portion of COVID-19 cases in Korea, Korean public health authorities initiated the screening program for this group members (ca. 0.2 million)	http://www.korea.kr/news/pressReleaseView.do?newsId=156377318

Starting date	Interventions	Source
February 27, 2020	Designated private hospitals as public relief hospital in nationwide - Operated 339 public relief hospitals where COVID-19 screening test is available as of May 11, 2020	http://ncov.mohw.go.kr/tcmBoardView.do?brdId=&brdGubun=&dataGubun=&ncvContSeq=353184&contSeq=353184&board_id=140&gubun=BDJ https://www.mohw.go.kr/react/popup_200128_4.html
March 9, 2020	Implemented nationwide screening the elderly at nursing home	https://www.gov.kr/portal/ntnadmNews/2120440
Community measures		
February 23, 2020	Raised the infectious disease alert to the highest level	https://www.cdc.go.kr/board/board.es?mid=a20501000000&bid=0015&act=view&list_no=366324&tag=&nPage=1
February 23, 2020	Postponed school opening for new semester - School breaks were extended nationwide until the notification by Korean Ministry of Education	https://www.moe.go.kr/boardCnts/view.do?boardID=294&boardSeq=79829&lev=0&searchType=S&statusYN=W&page=1&s=moe&m=020402&opType=N
March 9, 2020	Distributed public face masks - Evenly provided the face masks to the public through the public channels to prevent stockpiling	https://www.mfds.go.kr/brd/m_99/view.do?seq=44020&srchFr=&srchTo=&srchWord=&srchTp=&itm_seq_1=0&itm_seq_2=0&multi_itm_seq=0&company_cd=&company_nm=&page=1
March 22, 2020	Implemented social distancing measures - Recommended canceling any social event, avoiding social gathering and refraining from going out in nationwide	http://ncov.mohw.go.kr/shBoardView.do?brdId=2&brdGubun=27&ncvContSeq=1385#
April 20, 2020	Softened social distancing measures - Relaxed the measures for religious gathering, playing sports, etc.	http://www.mohw.go.kr/react/al/sal0301vw.jsp?PAR_MENU_ID=04&MENU_ID=0403&page=1&CONT_SEQ=354112