COVID-19 in South Korea: epidemiological and spatiotemporal patterns of the spread and the role of aggressive diagnostic tests in the early phase

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Abstract

Background: South Korea experienced the novel coronavirus disease (COVID-19) outbreak in the early period; thus data from this country could provide significant implications for global mitigation strategies. This study reports how COVID-19 has spread in South Korea and examines the effects of rapid widespread diagnostic testing on the spread of the disease in the early epidemic phase.

Methods: We collected daily data on the number of confirmed cases, tests and deaths due to COVID-19 from 20 January to 13 April 2020. We estimated the spread pattern with a logistic growth model, calculated the daily reproduction number (Rt) and examined the fatality pattern of COVID-19.

Results: From the start date of the epidemic in Korea (18 February 2020), the time to peak and plateau were 15.2 and 25 days, respectively. The initial Rt was 3.9 [95% credible interval (CI) 3.7 to 4.2] and declined to <1 after 2 weeks. The initial epidemic doubling time was 3.8 days (3.4 to 4.2 days). The aggressive testing in the early days of the epidemic was associated with reduction in transmission speed of COVID-19. In addition, as of 13 April, the case fatality rate of COVID-19 in Korea was 2.1%, suggesting a positive effect of the targeted treatment policy for severe patients and medical resources.

Conclusions: Our findings provide important information for establishing and revising action plans based on testing strategies and severe patient care systems, needed to address the unprecedented pandemic.
Introduction

A rapid increase in atypical pneumonia cases caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) was first observed in Wuhan, China, in Dec 2019. Since then, the novel coronavirus disease, named COVID-19, has rapidly spread to over 200 countries, areas and territories. The World Health Organization (WHO) declared the COVID-19 pandemic on March 11. South Korea (hereafter, Korea) has been affected by the COVID-19 epidemic, with more than 10,000 confirmed cases reported through April 2020. The first case in Korea was identified on 20 January 2020, and 27 cases were observed sporadically through 17 February. However, the spread exploded with the mass infection on 18 February, stemming from a ‘Shinchunji’ church service in the city of Daegu (with a population of about 2.5 million and the epicentre of COVID-19 in Korea), which marked the start of the nationwide epidemic in Korea.

Because Korea experienced the COVID-19 outbreak earlier than other countries, sharing information regarding epidemiological features and intervention strategies can aid the development and implementation of policies to prevent further devastation from the pandemic. Several international media outlets and governments have highlighted the ‘aggressive testing’ strategy that Korea implemented in the early stage of the epidemic and its consequences, leading to a drastic reduction in the spread and the lower fatality rate of COVID-19. However, despite growing evidence, studies that investigated the Korean case are sparse. Most have addressed the epidemic in a specific region, such as Wuhan, or at the country level, with limited information on differences in epidemiological patterns depending on regional or demographic characteristics. Further, a lack of quantified evidence of the effect of diagnostic tests in the early phase has been reported, although early testing, diagnosis and subsequent quarantine are acknowledged as the basic principles to reduce transmission rates.

This study investigates the epidemiological and spatiotemporal patterns of the COVID-19 spread in Korea. We examine whether ‘aggressive testing’ in the early days of the epidemic contributed to a reduction in the spread of disease. We also explore whether improved patient care guidelines and medical resource mobilization influenced reducing the fatality rate.

Materials and Methods

Data

Study area and population

We analysed nationwide data in Korea, collected until 13 April 2020, including all eight metropolitan/special cities and nine provinces (hereafter, regions). The study area was classified into three sub-areas: Daegu (the epicentre), neighbouring areas around Daegu (Gyeongsang provinces, Busan and Ulsan) and other areas (not classified as Daegu and neighbouring areas).
COVID-19 case data
We collected daily time-series counts of the cumulative confirmed cases and deaths in Korea from 20 January to 13 April 2020, by extracting from press releases of the Korea Centers for Disease Control and Prevention (KCDC). The 382 cases confirmed at the airports and immediately quarantined were excluded in this study.5 The definition of COVID-19 cases in Korea is displayed in Table 1. The data were stratified based on age (0–19 years (y), 20–39 y, 40–59 y, 60–79 y, 80+ y) and sex. In addition, the data included the number of local and overseas imported cases; however, this classification was only provided from 25 March onwards and was not provided by age group and sex.

COVID-19 testing data
We collected daily reports of the number of diagnostic tests from the KCDC from 30 January to 13 April 2020, which were available only at a national level. During this period a total of 518,743 tests were performed, of which 2.0% were positive. Detailed information about the diagnostic test is reported in Table 1.

Medical indicators
We collected regional-level data for five medical indicators that could relate to the capacity for treatment of severe COVID-19 patients and thus are potentially linked to COVID-19 mortality. These indicators were the numbers of: available hospital beds; beds in the intensive care unit (ICU); negative pressure beds plus extracorporeal membrane oxygenation (ECMO); and numbers of hospitals equipped with the ECMO. More detailed information on data collection and variable selection can be found in the Supplementary materials (Supplementary Methods 1, available as Supplementary data at IJE online).

Statistical modelling
Growth curve estimation
We applied a logistic growth model to estimate cumulative confirmed cases on day \( t \) (\( C_{\text{mod}, t} \)). The logistic growth model can detect both starting and plateau points of an epidemic and assumes a ‘saturation effect’ indicating that the size of the at-risk population decreases due to public health interventions, changes in behaviour and quarantine.12
Parameters from the logistic model were used to derive the empirical distribution of the $C_{mod, t}$ and daily new confirmed cases ($P_{mod, t} = C_{mod, t} - C_{mod, t-1}$) using Monte Carlo simulation, which assumes a multivariate normal distribution.\(^{13}\)

**Durations to peak and plateau points**
We defined two time points related to transmission patterns over time: peaks and plateaus. We defined 18 February 2020 as the start date of the epidemic (the 31st case; the first confirmed case in Daegu, although this might not represent when the virus or disease was first present in Daegu). The peak was then defined as the day $t$ when $P_{mod}$ was the highest after 18 February, and the plateau point as the first day when $P_{mod}$ was smaller than average $P_{mod}$ from the start date of the epidemic until 13 April, the end date of the study, i.e. the first date of $t$ for which $P_{mod, t} < (C_{mod, Apr. 13} - C_{mod, Feb. 18}) / \text{[number of dates between 18 February and 13 April]}$. This point can be interpreted as an indication of maximum growth and therefore a plateau.\(^{14}\) Finally, we calculated the number of days from the start of the epidemic to each peak and plateau point. The empirical means and confidence intervals (eCI) for each duration were estimated by Monte Carlo simulation.

**Daily reproduction numbers**
We estimated the daily reproduction number ($R_d$, interpreted as the daily $R_0$) following Cori et al.\(^{15}\) The reproduction number changes as intervention policies are implemented, thus the real-time reproduction numbers can guide control plans and provide insight into the effectiveness of intervention policies.\(^{15,16}\) $R_d$ was calculated based on a combination of the observed daily confirmed cases and the distribution of the serial interval (the time interval between infection and subsequent transmission), then smoothed using a 7-day time window.\(^{17}\) The serial interval was assumed to follow a gamma distribution with a mean of 4.98 days and a standard deviation of 3.22 days\(^1\); sensitivity analysis was conducted based on other parameters suggested from earlier studies.\(^{18,19}\) Imported cases were included in the $R_d$ calculation but not considered in the age- and sex-specific calculations, due to data limitations. All analyses were conducted using the EpiEstim R software package.\(^{15}\)

**Doubling time**
The epidemic doubling time was calculated to assess the dynamic features of the COVID-19 transmission. $C_{mod}$ was used to calculate the 7-day rolling doubling time from 18 February 2020 to the end date of the study (13 April 2020). The eCIs of the doubling time were estimated by Monte Carlo simulation.

**Effects of aggressive testing**
In this study, we defined ‘aggressive testing’ as a combination of rapid and widespread testing. Since KCDC has conducted full case investigations for any space with confirmed infections and testing on all potentially infected people with overlapping moving patterns and routines within a few days of the outbreak, we determined that testing policies in Korea were implemented quickly and showed degrees of fluidity and scalability. Therefore we describe the Korean testing policies as ‘aggressive’. More detailed information on interventions in Korea indicating the rapid and widespread testing are provided in Supplementary Method 2, available as Supplementary data at IJE online.

We hypothesized that an increase in testing was associated with reduced transmission of COVID-19. To examine this hypothesis, we estimated the association between the daily number of tests and changes in the number of daily confirmed cases ($P_{mod, t} - P_{mod, t-1}$; i.e. the speed of transmission) using a distributed lag model. In this analysis, we restricted data to the early period of the epidemic defined as the first 4 weeks from the start date of the epidemic, because the daily number of tests was maintained at around 10 000 per day during the first 4 weeks and decreased afterwards, along with the stabilization in new confirmed cases. We used a natural cubic spline with two equally spaced knots on the log scale to consider the lagged effect of testing up to 14 lag days. For sensitivity analysis, we changed modelling specifications to examine the consistency of the results. Also, we assessed the association between the number of tests and daily $R_d$ with a 7-day moving average as a predictor variable.

**Fatalities**
We compared daily changes in the proportion of new deaths relative to the cumulative confirmed cases before and after revision of the COVID-19 response guidance announced by the KCDC on 1 March 2020 (COVID-19 Action Procedures, 7th edition),\(^{20}\) using two-sample $t$ tests. Before the revision, all confirmed patients were hospitalized. However, the exponentially growing number of new cases created challenges in securing hospital beds, and therefore the KCDC modified its directive to hospitalize only severe cases. Patients with mild symptoms were transferred to a temporary care centre and treated under quarantine. We repeated the $t$ test by areas, age groups and sex.

Second, we examined how the medical resources for each region were associated with the case fatality rates (CFRs) using weighted regression models. We considered population, sex ratio, the percentage of people aged $\geq$ 60 years, gross regional domestic product (GRDP) per capita and age-sex standardized smoking prevalence as
confounders. Detailed information on data collection and frameworks of the regression model are described in the Supplementary data (Supplementary Method 3, available as Supplementary data at IJE online).

Results

Figure 1 displays the time trend of daily confirmed cases in Korea and the timing of major interventions implemented by the KCDC and Korean government. Full lists of the interventions and major epidemic events with timelines are provided in Supplementary Tables S3 and S4, available as Supplementary data at IJE online. Through 13 April, a total of 10,155 confirmed COVID-19 cases were reported in Korea, with 6819 (67.1% of the total cases) in Daegu, 1619 (15.9%) in areas neighbouring Daegu and 1717 (16.9%) in other areas. Detailed descriptive information is provided in the Supplementary Table S5, available as Supplementary data at IJE online.

Figure 2A shows the time trend of cumulative cases from the date of the first diagnosed case in Korea. Figure 2B displays daily confirmed cases with imported cases from 25 March and shows that over 60% of confirmed cases were imported after 1 April. Figure 2C displays geographical distributions of the numbers of cumulative cases on 13 April. The fitted logistic growth model for cumulative cases is displayed in Figure 2D. The R² of the model was 0.99. Figure 2E shows the daily reproduction number (Rₜ), which was initially 3.9 [95% credible interval (CI) 3.7 to 4.2] and declined to <1 after 14 days.

The results of sensitivity analysis for Rₜ are reported in Supplementary Figure S1, available as Supplementary data at IJE online, and the results were influenced by the mean value of the serial interval. Figure 2F shows the epidemic doubling time; the initial doubling time was 3.8 days (95% eCI 3.4 to 4.2 days). The logistic growth curves and Rₜs for each region are displayed in Supplementary Figures S2 and S3, available as Supplementary data at IJE online.

Table 2 shows information on the national spread pattern of COVID-19. The number of days from the start date of the epidemic to peak and plateau was 15.2 (95% eCI 15 to 16 days) and 25.8 (95% eCI 25 to 26 days), respectively. Daily confirmed cases at peak and plateau were estimated as 537.8 and 167.0, respectively, and Rₜ was 2.2 at peak and 0.5 at plateau point.

COVID-19 spread patterns in Korea differed by area as well as by age and sex. Figure 3 displays the logistic growth curves and Rₜs by area, age and sex. Figure 3 displays the logistic growth curves and Rₜs were estimated as 1.8 and 2.2, respectively. Area showed distinctively slower growth patterns, reaching plateau about 3 weeks later. The initial Rₜs of the three areas were similar (Daegu: 4.2, Daegu: 4.2, and others: 3.8); however, the duration over which Rₜ stably decreased to <1 was longer in other areas than in Daegu and neighbouring areas. The spread was greater and faster in the younger age groups, with older groups showing flatter and slower growth patterns. The number of cumulative cases and initial Rₜ were greater in females than in males.
Figure 4 presents the associations of number of tests with changes in daily confirmed cases and with $R_t$ during the first 4 weeks of the epidemic. We found that a higher number of tests was associated with a reduced number of new daily cases. Specifically, an increase of 1000 tests was associated with an overall decrease by 14.5 new cases (95% CI 10.4 to 18.8) over 14 lag days. The estimate was generally consistent with the results with changes in modelling specifications (Supplementary Table S6, available as Supplementary data at IJE online). We also found that an increase in testing was associated with a decrease in $R_t$ within 2–3 weeks, as $R_t$ was reduced by up to 0.65 (95% CI 0.25 to 0.71) per 1000 tests in about 2 weeks.

The temporal and regional trends of fatalities are displayed in Figure 5. Figure 5A shows the daily death counts. By 13 April 2020 a total of 217 deaths had occurred in Korea, 147 of which occurred in Daegu, in areas neighbouring Daegu 54 and only 16 in other areas. Among the total deaths, 199 deaths occurred in people aged 60+ y. As of 13 April, the CFR in the total population was 2.1% and was higher in Daegu and neighbouring areas than elsewhere (Supplementary Table S5). Figure 5B presents daily percentages of deaths relative to the numbers of cumulative confirmed cases during the study period. After the first day of the epidemic, the average death percentage was 0.44% before the revision of the COVID-19 response guidance (1 March), after which it decreased to 0.05% ($P$-value = 0.08). Furthermore, the reduction was observed in all areas (from 0.04% in other areas to 3.41% in neighbouring areas), age groups (0.01% in 80+ y to 1.3% in 60–79 y) and for men (0.67%) and women (0.1%). Figure 5C shows fatality rates by regions. Higher availability of medical resources was generally associated with lower CFR at the regional level (Table 3).

**Discussion**

This study investigated the epidemiological features of the COVID-19 outbreak in Korea. Increased testing was related to reductions in transmission and reproduction numbers, and the availability of medical interventions and resources for severe patients was related to a reduction in CFR.
The initial $R_t$ we estimated at 3.9 nationally and 4.2 for Daegu. These values are generally similar to those in European countries, for which initial $R_t$ were reported with range of 3.0 to 5.0, and generally lower than those reported for Wuhan (2.2 to 2.7) and other provinces in China (1.1 to 1.7). Our data showed that the initial $R_t$ in Korea differed by age and sex: higher initial $R_t$s were observed in younger age groups (<60 y) than in older groups (60+ y) and females compared with males. These results were due to the high fraction of women and younger people in Shinchunji; such patterns may be highly linked to the characteristics of specific mass infection events in the early epidemic phase.

Unlike reports from other countries in which the initial $R_t$ lasted for more than 1–2 weeks, the Korean data show a steady and rapid decline over time (with an $R_t$ < 1 after 2 weeks from the start date of the epidemic) and a relatively short duration between peak and plateau (about 10 days). Our results indicate that the aggressive testing approach that was implemented early in the epidemic partly contributed to the rapid reduction of the spread of COVID-19. In addition, we postulate that the higher

| Time points (t) | Time from initial outbreak (days) | Daily cases | $R_t$ | Doubling time (days) |
|----------------|----------------------------------|------------|------|----------------------|
| National       | After a week                      | –          | 244.9 (226.7 to 263.3) | 3.9 (3.7 to 4.2) | 3.8 (3.4 to 4.2) |
|                | Peak                             | 15.2 (15 to 16) | 537.8 (495.9 to 583.6) | 2.2 (2.1 to 2.2) | 4.8 (4.3 to 5.3) |
|                | Plateau                          | 25.8 (25 to 26) | 167.0 (152.5 to 184.0) | 0.5 (0.4 to 0.5) | 17.4 (16.2 to 18.9) |
| Areas          | Daegu                            | –          | 174.1 (161.4 to 185.5) | 4.2 (3.8 to 4.5) | 2.9 (2.6 to 3.1) |
|                | Peak                             | 14.3 (14 to 15) | 483.1 (455.2 to 512.7) | 2.7 (2.6 to 2.8) | 3.4 (3.1 to 3.7) |
|                | Plateau                          | 23.4 (23 to 24) | 120.3 (103.9 to 133.6) | 0.6 (0.6 to 0.7) | 11.3 (10.7 to 11.9) |
| Neighbouring   | After a week                      | –          | 52.8 (50.3 to 55.4) | 3.5 (3.2 to 4.0) | 3.6 (3.3 to 3.9) |
|                | Peak                             | 13.5 (13 to 14) | 93.1 (87.4 to 99.3) | 1.7 (1.5 to 1.8) | 4.6 (4.2 to 5.0) |
|                | Plateau                          | 23.7 (23 to 24) | 26.6 (24.2 to 26.7) | 0.6 (0.5 to 0.6) | 16.9 (15.9 to 18.0) |
| Others         | After a week                      | –          | 14.0 (13.4 to 14.5) | 3.8 (3.0 to 4.7) | 9.2 (8.7 to 9.8) |
|                | Peak                             | 32.3 (31 to 33) | 44.7 (43.3 to 46.2) | 0.9 (0.8 to 1.0) | 14.1 (13.5 to 14.7) |
|                | Plateau                          | 46.3 (45 to 48) | 29.9 (28.8 to 30.8) | 0.5 (0.4 to 0.6) | 29.0 (27.5 to 30.8) |
| Age groups     | 0–19 y                            | –          | 11.5 (10.3 to 12.7) | 6.8 (4.5 to 9.7) | 4.2 (3.7 to 4.7) |
|                | Peak                             | 17.9 (17 to 18) | 32.6 (29.9 to 35.7) | 1.6 (1.4 to 1.8) | 5.6 (4.9 to 6.4) |
|                | Plateau                          | 28.8 (28 to 30) | 11.3 (10.4 to 12.3) | 0.4 (0.3 to 0.5) | 19.1 (17.5 to 21.0) |
|                | 20–39 y                           | –          | 101.7 (91.0 to 111.4) | 4.6 (4.1 to 5.2) | 3.4 (3.0 to 3.9) |
|                | Peak                             | 14.7 (14 to 15) | 227.1 (203.7 to 254.0) | 2.2 (2.1 to 2.3) | 4.4 (3.8 to 5.1) |
|                | Plateau                          | 24.5 (24 to 25) | 64.5 (57.7 to 71.2) | 0.4 (0.4 to 0.5) | 16.7 (15.0 to 18.6) |
|                | 40–59 y                           | –          | 85.5 (80.1 to 90.9) | 3.8 (3.4 to 4.2) | 4.0 (3.6 to 4.4) |
|                | Peak                             | 15.0 (15 to 15) | 171.5 (159.3 to 185.1) | 2.1 (1.9 to 2.2) | 5.1 (4.6 to 5.6) |
|                | Plateau                          | 25.7 (25 to 26) | 54.6 (50.1 to 60.0) | 0.5 (0.5 to 0.6) | 18.3 (16.9 to 19.9) |
|                | 60–79 y                           | –          | 41.6 (39.0 to 44.2) | 3.1 (2.6 to 3.6) | 4.7 (4.2 to 5.1) |
|                | Peak                             | 16.9 (16 to 17) | 89.3 (83.1 to 96.7) | 1.6 (1.5 to 1.7) | 6.2 (5.6 to 6.9) |
|                | Plateau                          | 28.3 (28 to 29) | 33.3 (30.9 to 35.8) | 0.4 (0.4 to 0.5) | 18.9 (17.6 to 20.3) |
|                | 80+ y                             | –          | 4.9 (4.5 to 5.3) | 4.0 (1.8 to 7.0) | 5.8 (5.3 to 6.3) |
|                | Peak                             | 24.0 (23 to 25) | 17.5 (16.5 to 18.7) | 1.0 (0.8 to 1.2) | 8.4 (7.8 to 9.1) |
|                | Plateau                          | 36.4 (36 to 37) | 8.4 (7.9 to 8.9) | 1.4 (1.2 to 1.6) | 21.9 (20.6 to 23.5) |
| Sex            | Male                             | –          | 87.8 (80.9 to 94.5) | 3.4 (3.1 to 3.8) | 4.8 (4.3 to 5.4) |
|                | Peak                             | 16.8 (16 to 17) | 177.7 (162.9 to 196.9) | 1.6 (1.5 to 1.7) | 6.5 (5.7 to 7.3) |
|                | Plateau                          | 28.4 (27 to 29) | 68.1 (63.2 to 73.1) | 0.4 (0.4 to 0.5) | 19.2 (17.6 to 21.0) |
|                | Female                           | –          | 153.2 (141.3 to 164.1) | 4.3 (3.9 to 4.7) | 3.8 (3.4 to 4.2) |
|                | Peak                             | 15.1 (15 to 16) | 337.9 (310.5 to 366.7) | 2.1 (2.1 to 2.2) | 4.7 (4.2 to 5.3) |
|                | Plateau                          | 25.6 (25 to 26) | 103.2 (94.0 to 113.7) | 0.4 (0.4 to 0.4) | 17.9 (16.5 to 19.4) |
number of tests may be related to mitigation of the spread on a multi-country scale. As of 13 April, European countries and the USA had relatively lower positive rates (≥15% in Italy, the UK, Spain and the USA) and generally had higher incidences of COVID-19 (all incidence cases per 10 000: ≥12 cases), compared with Korea (positive rate: 2%, and incidence cases per 10 000: 2 cases). Other countries reported lower positive rates (Taiwan, Australia and New Zealand; positive rates: <2%, and incidence cases per 10 000: <3 cases).23 Since multiple interventions, such as mitigation measures that encourage social/physical distancing and work-at-home policies, influence the spread of infectious disease, analysis of the isolated effectiveness of active testing is limited. However, given that aggressive testing is a leading intervention policy, this international comparison can support the hypothesis that Korea’s testing strategy contributed to the decline in COVID-19 spread.

However, we acknowledge that the decline in $R_t$ and short durations from the start date of the epidemic to peak and plateau are unlikely to be solely attributable to aggressive testing; rather, our findings should be interpreted as a comprehensive result of a number of social and policy efforts. In particular, the following events and interventions should be considered (see Supplementary Table S3, available as Supplementary data at IJE online): first, the KCDC conducted a full case investigation of all Shinchunji members (about 200 000 persons). Moreover, the KCDC and the Korean government have strongly and repeatedly recommended a high-level social distancing strategy and the wearing of masks. On 4 March 2020, Korea announced the COVID-19 Acts, allowing prosecution of uncooperative suspected cases and suspension of entry to confirmed or suspected cases. Further, the KCDC and local governments have operated ‘Drive-Thru’ screening centres to reduce testing time and protect medical staff from cross-infection.24

Our results show that the spread and fatality patterns of COVID-19 in Korea differed between areas and age groups, which implies the benefit of differentiated prevention and mitigation strategies. Areas further away from Daegu and people aged 80+ y showed longer epidemic periods than other areas and age groups, despite having fewer cases. These findings might be linked to differences in transmission patterns centred on community and nursing hospitals for the elderly (see Supplementary Table S4). Furthermore, we found that most deaths occurred in an epicentre and neighbouring areas and older age groups. These results may contribute to prioritization of resource allocations by sub-population. We also found that treatment targeting severe patients might have contributed to the flattening of the fatality curve. As of 13 April 2020, the fatality rate in Korea (2.1%) was considerably lower than
in most Western countries. In the early stage, the rapid increase in confirmed cases resulted in a lack of resources, and thus a fast increase in deaths. The KCDC thereafter revised its treatment guidelines and our results suggest the effectiveness of this approach, particularly in the epicentre and neighbouring areas. In addition, we found that fewer medical resources were related to higher fatality rates. However, since these results were not based on an individual trial and were limited in sample size, these findings should be interpreted with caution.

This study has several limitations. First, we based our serial interval distributions, used to calculate $R_t$, in previous studies, not on the Korean cases; infectivity profiles may differ depending on interventions, cultures and living conditions. In addition, there are potential confounding variables that we were unable to account for when assessing the association between numbers of tests and spread patterns, such as the various interventions implemented during the epidemic period. Although we conjecture that many interventions were related to diagnostic testing, further studies are needed to identify potential confounders in the effects of testing on transmission.

Despite these limitations, this study has several strengths. First, using statistical modelling with data from the initial period to the stabilization period of the epidemic, we reported on the overall transmission pattern of COVID-19 in Korea. Second, the study shows that an increase in testing is associated with a decline in the transmission speed in the early phase. Third, we show differences in the spread and fatality patterns depending on areas, age and sex, which suggests the benefit of differentiated intervention policies and prioritization of medical resources.

In conclusion, our study describes the epidemiological spread patterns of COVID-19 in Korea and suggests the effectiveness of intervention policies based on aggressive
Figure 5 Fatality aspects of COVID-19 in Korea. (A) Daily death counts of COVID-19. (B) Daily percentage of new deaths compared with the number of cumulative confirmed cases. Dashed lines in Panels A and B indicate the date of the announcement of the seventh revised guidance for the COVID-19 response system. (C) Case fatality rates on 13 April 2020 for each region in Korea. The study region was divided into three areas: Daegu (the epicentre), neighbouring (areas neighbouring Daegu) and other areas. Regions are arranged in order of case fatality rate.

Table 3 Associations between medical indicators and fatality rate with the total cases at region level. Associations are expressed as changes in case fatality rate (CFR) with 95% confidence interval per unit increase in each indicator. Regional population, sex ratio, the percentage of people aged ≥ 60 years, gross regional domestic product (GRDP) per capita and age-sex standardized smoking prevalence were considered as confounders.

| Indicator                                         | Reduction in CFR(95% CI) | P-value |
|---------------------------------------------------|--------------------------|---------|
| Number of beds in the hospital (per 1000 beds)    | 0.51 (-0.03 to 1.04)     | 0.106   |
| Number of beds in intensive care unit (ICU; per bed) | 0.01 (0.00 to 0.02)     | 0.065   |
| Number of negative pressure beds (per bed)        | 0.25 (0.06 to 0.45)      | 0.038   |
| Number of hospitals equipped with the ECMO* (per hospital) | 0.47 (-0.03 to 0.98) | 0.107   |
| Number of ECMO (per machine)                      | 0.13 (0.03 to 0.23)      | 0.042   |

*ECMO machine: extracorporeal membrane oxygenation machine.
testing and policies for severe patient care. Findings in this study can offer important implications for the establishment and modification of action plans against this unprecedented worldwide pandemic.

**Supplementary Data**

Supplementary data are available at IJE online.

**Funding**

This study was funded by the Korea Ministry of Environment via the ‘Climate Change Correspondence Program’ (project number: 2014001310007).

**Acknowledgements**

We extend appreciation to Ki Ho Hong, MD, (Department of Laboratory Medicine, Seoul Medical Center, Seoul, Korea) who provided comments regarding laboratory diagnostic testing of COVID-19 in Korea. We appreciate the funding opportunity from the Korea Ministry of Environment. We also thank the KCDC, medical staff and volunteers working to end COVID-19.

**Conflict of Interest**

The authors declare they have no competing financial interests.

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