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Short Communication

Global coronavirus disease 2019: What has daily cumulative index taught us?

Chih-Cheng Lai[a], Cheng-Yi Wang[b], Ya-Hui Wang[c], Po-Ren Hsueh[d,*]

[a] Department of Internal Medicine, Kaohsiung Veterans General Hospital, Tainan Branch, Tainan, Tawain
[b] Department of Internal Medicine, Cardinal Tien Hospital and School of Medicine, College of Medicine, Fu Jen Catholic University, New Taipei City, Taiwan
[c] Medical Research Center, Cardinal Tien Hospital and School of Medicine, College of Medicine, Fu Jen Catholic University, New Taipei City, Taiwan
[d] Departments of Laboratory Medicine and Internal Medicine, National Taiwan University Hospital, National Taiwan University College of Medicine, Taipei, Taiwan

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ABSTRACT

In addition to the absolute case number, a rapid increase in the number of COVID-19 cases within a short time results in insufficiency of healthcare systems and further negatively affects patient outcomes. This study was conducted to investigate the association between the outcomes of COVID-19 patients and daily cumulative index (DCI), which was defined as the average daily number of new cases of COVID-19 and calculated by cumulative cases/number of days between the first reported case and March 6, 2020, by country. Spearman's rank correlation analyses were conducted to evaluate the relationship between mortality, incidence, and DCI. In this study, DCI was positively correlated with incidence (adjusted risk ratio [aRR] = 1.01, 95% confidence interval [CI] = 1.00-1.02, $P < 0.01$). Higher correlation was observed between mortality and DCI (mortality rate: r = 0.397, $P = 0.018$; mortality per 1 000 000 people: r = 0.0.428, $P = 0.004$) than between disease incidence and DCI. DCI remained statistically significantly associated with mortality per 1 000 000 people after adjustment of Health Care Index (aRR = 1.02, 95% CI = 1.01-1.03, $P < 0.001$) or Healthcare Access and Quality Index (aRR = 1.02, 95% CI = 1.01-1.04, $P < 0.01$. Reducing DCI through strict infection control measures can help slow the number of new COVID-19 cases and further improve outcomes in COVID-19 patients.

1. Introduction

Since the first case of coronavirus disease 2019 (COVID-19) caused by severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2; previously known as 2019-nCoV) emerged in Wuhan, China at the end of 2019, the number of COVID-19 cases has increased exponentially across the whole of China and has become a global pandemic [1-6]. Up to March 6, 2020, there was a total of 98 129 global cases, and 3380 deaths were reported [7]. Although most of the cases and deaths occurred in China, the increasing trend of incidence and mortality in China seems to have stabilized. In contrast, a dramatic increase in the number of COVID-19 cases has been reported in Europe, the United States, the Republic of Korea, and Iran since the end of February. Based on the earlier experience in Hubei, China [8], the rapid escalation in the number of new COVID-19 cases may lead to an insufficiency of healthcare resources and further negatively affect patient outcomes. A similar association can be observed worldwide; therefore, this analysis was conducted to find a possible association between the outcome of mortality and the case number of COVID-19.

To prevent the spread of COVID-19 and its associated morbidity and mortality, early detection and appropriate management of patients with COVID-19 are necessary. These tasks are time- and resource-consuming for the healthcare system and staff. For example, to collect specimens for SARS-CoV-2 detection from a suspected COVID-19 case, a healthcare worker needs to wear personal protective equipment (PPE) in an isolation room. To treat a patient with COVID-19, a hospital needs to provide adequate manpower and equipment. Thus, it can be expected that a large increase in the number of new COVID-19 cases can cause a huge burden on healthcare resources and possible burnout of healthcare staff. In addition to the absolute case number, we hypothesize that a rapid increase in the number of new COVID-19 cases within a short time can result in insufficiency of the healthcare system and further negatively affect patient outcomes.

* Corresponding author. Departments of Laboratory Medicine and Internal Medicine, National Taiwan University Hospital, No. 7 Chung-Shan S. Road, Taipei 100, Taiwan.
E-mail address: hsporen@ntu.edu.tw (P.-R. Hsueh).

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Table 1
Characteristics of 93 countries/territories with reported cases of coronavirus disease 2019 (COVID-19) as of 6 March 2020 [7].

	Cumulative case no.	Death no.	Incidence per 1 000 000 population	Case fatality rate (%)	Death per 1 000 000 population	Daily cumulative index
Asia						
China	80552	3042	55.97	3.78	2.11	1220.48
Republic of Korea	6284	42	122.57	0.67	0.82	136.61
Japan	349	6	2.76	1.72	0.05	6.84
Singapore	117	0	20.00	0.00	0.00	2.79
Hong Kong SAR	104	2	13.87	1.92	0.27	2.42
Australia	57	2	2.24	3.51	0.08	1.39
Malaysia	55	0	1.70	0.00	0.00	1.38
Thailand	47	1	0.67	2.13	0.01	0.89
Taiwan	45	1	1.89	2.22	0.04	1.02
India	30	0	0.02	0.00	0.00	0.83
Vietnam	16	0	0.16	0.00	0.00	0.38
Macau SAR	10	0	15.40	0.00	0.00	0.23
Philippines	5	1	0.05	20.00	0.01	0.14
New Zealand	4	0	0.83	0.00	0.00	0.57
Indonesia	2	0	0.01	0.00	0.00	0.50
Cambodia	1	0	0.06	0.00	0.00	0.03
Nepal	1	0	0.03	0.00	0.00	0.02
Sri Lanka	1	0	0.05	0.00	0.00	0.03
Bhutan	1	0	1.30	0.00	0.00	NA
Americas						
United States	148	10	0.45	6.76	0.03	3.44
Canada	45	0	1.19	0.00	0.00	1.15
Ecuador	13	0	0.74	0.00	0.00	3.25
Brazil	7	0	0.03	0.00	0.00	0.88
Mexico	5	0	0.04	0.00	0.00	0.83
Saint Martin	2	0	51.73	0.00	0.00	2.00
Argentina	1	0	0.02	0.00	0.00	0.50
Chile	1	0	0.05	0.00	0.00	0.50
Dominican Republic	1	0	0.09	0.00	0.00	0.25
Saint Barthelemy	1	0	101.25	0.00	0.00	1.00
Europe						
Italy	3858	148	63.81	3.84	2.45	110.23
Germany	534	0	6.37	0.00	0.00	14.05
France	420	6	6.43	1.43	0.09	10.24
Spain	257	3	5.50	1.17	0.06	7.56
United Kingdom	118	0	1.74	0.00	0.00	3.47
Switzerland	86	1	9.94	1.16	0.12	9.56
Norway	86	0	15.86	0.00	0.00	10.75
Netherland	82	0	47.86	0.00	0.00	11.71
Sweden	61	0	6.04	0.00	0.00	1.79
Belgium	50	0	4.31	0.00	0.00	1.67
Austria	47	0	5.22	0.00	0.00	5.22
Greece	32	0	3.07	0.00	0.00	4.00
Iceland	26	0	76.19	0.00	0.00	6.50
San Marino	21	0	618.90	0.00	0.00	3.50
Denmark	18	0	3.11	0.00	0.00	2.25
Israel	15	0	1.73	0.00	0.00	1.15
Ireland	14	0	2.84	0.00	0.00	2.80
Finland	12	0	2.17	0.00	0.00	0.33
Czechia	12	0	1.12	0.00	0.00	3.00
Croatia	10	0	2.44	0.00	0.00	1.11
Georgia	9	0	2.26	0.00	0.00	1.13
Portugal	9	0	0.88	0.00	0.00	3.00
Romania	6	0	0.31	0.00	0.00	0.75
Belarus	6	0	0.63	0.00	0.00	0.86
Slovenia	6	0	2.89	0.00	0.00	6.00
Russian federation	4	0	0.03	0.00	0.00	0.12
Estonia	3	0	2.26	0.00	0.00	0.38
Azerbaijan	3	0	0.30	0.00	0.00	0.60
Hungary	2	0	0.21	0.00	0.00	2.00
Bosnia and Herzegovina	2	0	0.61	0.00	0.00	2.00
North Macedonia	1	0	0.48	0.00	0.00	0.13
Monaco	1	0	25.48	0.00	0.00	0.20
Poland	1	0	0.03	0.00	0.00	0.50
Ukraine	1	0	0.02	0.00	0.00	0.50
Andorra	1	0	12.94	0.00	0.00	0.33
Armenia	1	0	0.34	0.00	0.00	0.25
Latvia	1	0	0.53	0.00	0.00	0.33
Lithuania	1	0	0.37	0.00	0.00	0.14

(*continued on next page*)

Table 1 (*continued*)

	Cumulative case no.	Death no.	Incidence per 1 000 000 population	Case fatality rate (%)	Death per 1 000 000 population	Daily cumulative index
Luxembourg	1	0	1.60	0.00	0.00	0.25
Liechtenstein	1	0	26.23	0.00	0.00	1.00
Gibraltar	1	0	29.68	0.00	0.00	1.00
Serbia	1	0	0.11	0.00	0.00	NA
Eastern Mediterranean						
Iran	3513	107	41.82	3.05	1.27	234.20
Kuwait	58	0	13.58	0.00	0.00	5.27
Bahrain	49	0	28.80	0.00	0.00	4.90
Iraq	36	2	0.90	5.56	0.05	3.60
United Arab Emirates	27	0	2.73	0.00	0.00	0.73
Oman	16	0	3.13	0.00	0.00	1.60
Lebanon	16	0	2.34	0.00	0.00	1.23
Qatar	8	0	2.78	0.00	0.00	1.60
Saudi Arabi	8	0	0.23	0.00	0.00	2.67
Occupied Palestinian territory	7	0	NA	0.00	NA	7.00
Pakistan	5	0	0.02	0.00	0.00	0.63
Egypt	3	0	0.03	0.00	0.00	0.15
Morocco	2	0	0.05	0.00	0.00	0.67
Afghanistan	1	0	0.03	0.00	0.00	0.10
Jordan	1	0	0.10	0.00	0.00	0.33
Tunisia	1	0	0.08	0.00	0.00	0.33
Africa						
Algeria	12	0	0.27	0.00	0.00	1.33
Senegal	4	0	0.24	0.00	0.00	1.33
Nigeria	1	0	0.00	0.00	0.00	0.14
Cameroon	1	0	0.04	0.00	0.00	NA
South African	1	0	0.02	0.00	0.00	NA
International conveyance	696	6	NA	0.86	NA	23.20

NA, not applicable.

2. Materials and Methods

Daily cumulative index (DCI) was defined as the average daily number of new cases of COVID-19 and calculated by cumulative cases/number of days between the first reported case and March 6, 2020. As the quality and availability of the healthcare system varies in each country, and this may also affect patient outcomes, two additional indexes, the Health Care Index (HCI) (https://www.numbeo.com/health-care/rankings_by_country.jsp. Access on March 6, 2020) and Healthcare Access and Quality Index (HAQI) [9,10], were used to represent the performance of the healthcare system in each country in this analysis. The HCI is based on surveys from visitors of one open website. The indices are updated continuously and the Health Care Index 2020 version was used in this study [10]. The HAQI uses 32 scaled cause values, which comprised vaccine-preventable diseases; infectious diseases and maternal and child health; non-communicable diseases, including cancers, cardiovascular diseases; and other non-communicable diseases, such as diabetes; and gastrointestinal conditions, and provides an overall score of 0-100 of personal healthcare access and quality by location over time [9]. The most recent version, used in this study, comprises the data from 2016. Spearman's rank correlation analyses were conducted to evaluate the relationship between mortality, incidence, and DCI. A negative binomial regression model was used to estimate the risk ratio (RR) and 95% confidence interval (CI) between DCI and incidence. Statistical analyses were performed using the SAS software version 9.4 (SAS Institute Inc., Cary, NC). A P value of < 0.05 indicated statistical significance in all analyses.

3. Results

To date, China has the highest number of COVID-19 cases (n = 80 552), followed by the Republic of Korea (n = 6284), Italy (n = 3858), and Iran (n = 3513) (Table 1). However, the incidence per 1 000 000 population was the highest in San Marino (618.90), followed by the Republic of Korea (122.57) and Saint Barthelemy (101.25) (Table 1). The incidence in China, Italy, and Iran was 55.97, 63.81, and 41.82, respectively. China had the most deaths (n = 3042), followed by Italy (n = 148), Iran (n = 107), and the Republic of Korea (n = 42) (Table 1). The overall case fatality rate was the highest in the Philippines (20.00%), the United States (6.76%), Iraq (5.56%), Italy (3.84%), and China (3.78%) (Table 1). In addition, Italy had the most deaths per 1 000 000 people (2.45), followed by China (2.11), Iran (1.27), and the Republic of Korea (0.82) (Table 1). During the study period, DCI was the highest in China (1220.48), followed by Iran (234.20), the Republic of Korea (136.61), and Italy (110.23) (Table 1). Moreover, the international conveyance Diamond Princess had 696 cases and 6 deaths. Thus, the overall case fatality rate was 0.86% and the DCI was 23.20.

Table 2
Risk ratios (RR) between daily cumulative index (DCI) and incidence, as analysed using negative binominal regression models.

	Crude RR (95% CI)	Adjusted RR (95% CI)[a]	Adjusted RR (95% CI)[b]
DCI	1.00 (1.00-1.01)	1.01 (1.00-1.02)***	1.01 (1.00-1.02)**
$0 < DCI \leq 0.625$	Reference	Reference	Reference
$0.625 < DCI \leq 2.25$	3.54 (1.30-9.69)*	4.95 (2.41-10.32)***	6.85 (3.01-15.6)***
$DCI > 2.25$	50.2 (19.6-128.8)***	44.8 (21.3-94.2)***	78.8 (35.3-175.8)***

CI, confidence interval.
* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$.
[a] Adjusted by Healthcare Index.
[b] Adjusted by Healthcare Access and Quality Index.

Initially, DCI was found to be positively correlated with disease incidence (adjusted risk ratio [aRR] = 1.01, 95% CI = 1.00-1.02, $P < 0.01$) and higher DCI was associated with higher disease incidence (Table 2). In addition, both HCI and HAQI were positively correlated with incidence (HCI: aRR = 1.06, 95% CI = 1.02-1.11, $P < 0.01$; HAQI: aRR = 1.10, 95% CI = 1.07-1.12, $P < 0.001$). Further-

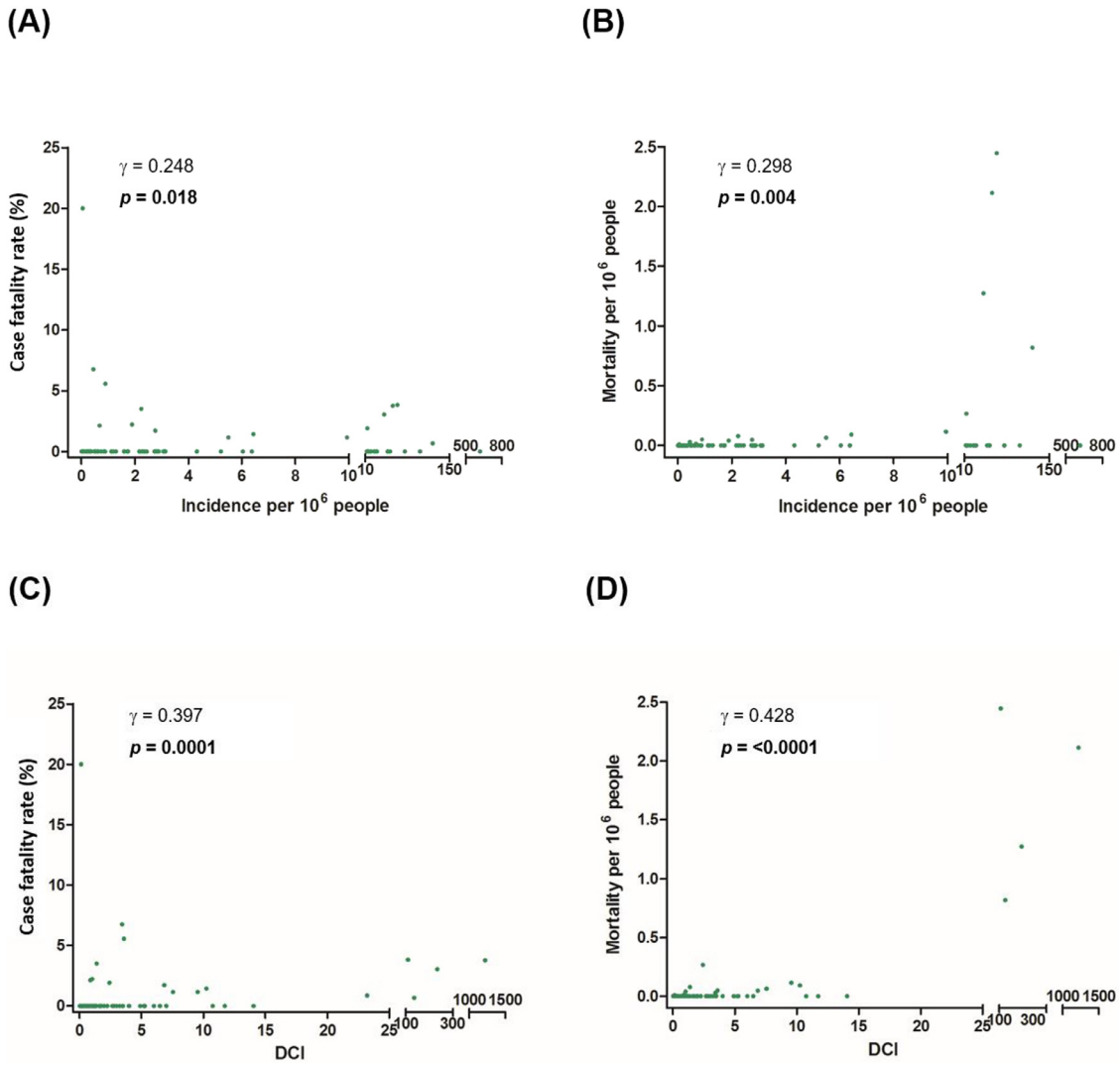

Fig. 1. Association between mortality, incidence, and daily cumulative index (DCI) of COVID-19. (A) Correlation between case fatality rate (%) and incidence (per 10^6 people) of COVID-19. (B) Correlation between mortality (per 10^6 people) and incidence (per 10^6 people) of COVID-19. (C) Correlation between case fatality rate (%) and DCI of COVID-19. (D) Correlation between mortality (per 10^6 people) and DCI of COVID-19.

more, case fatality rate and mortality per 1 000 000 people were found to be positively correlated with incidence (mortality rate: r = 0.248, P = 0.018; mortality per 1 000 000 people: r = 0.298, P = 0.004) (Figures 1A and 1B). Moreover, higher correlation was observed between mortality and DCI (case fatality rate: r = 0.397, P = 0.018; mortality per 1 000 000 people: r = 0.0.428, P = 0.004) than between disease incidence and DCI (Figures 1C and 1D). Finally, DCI remained statistically significantly associated with mortality per 1 000 000 people after adjustment of HCI (aRR = 1.02, 95% CI = 1.01-1.03, P < 0.001) or HAQI (aRR = 1.02, 95% CI = 1.01-1.04, P < 0.01).

4. Discussion

This study had several significant findings. Firstly, DCI was positively correlated with disease incidence. It is reasonable that a rapid increase in the number of cases can facilitate the spread of COVID-19 and result in even more cases. Secondly, higher level of healthcare performance was associated with higher incidence of COVID-19. This may be explained by the fact that countries with higher HCI or HAQI had better ability to detect COVID-19; thus, more cases may be identified. Finally, DCI was positively correlated with mortality and the significant association between DCI and mortality remained unchanged after adjustment of the level of healthcare performance (HCI or HCAI). Moreover, the four countries with the highest DCI – China, Iran, the Republic of Korea, and Italy – had more deaths per 1 000 000 people than other countries. The current study findings are similar to those of Ji et al. [8], in which a larger number of infections earlier in China was associated with higher mortality. Our previous study also showed that incidence and mortality rates were correlated with DCI, particularly in countries with local transmission [10]. However, the correlation with DCI observed in the present study was not as good as that in the earlier China study [8], but DCI was found to be more correlated with mortality than incidence. In addition to the absolute number of patients (incidence), the rapidly increasing number of patients (high DCI) may cause huge consumption of medical resources and may lead to shortage of healthcare availability and poor patient outcome in this COVID-19 outbreak. However, whether DCI can be applied in other settings/countries or another epidemiological scenario requires further study.

This study had several limitations. Firstly, several confounding factors, such as the infection prevention and control strategy and the capacity of diagnostic tests, can affect the incidence of COVID-19 in each country. These factors were not evaluated in this study. Secondly, the mortality of COVID-19 patients can be

affected by the underlying condition of the patients, the composition of study population and the capacity of critical care, such as the number of intensive care units, mechanical ventilators, and critical care providers. Although HCI and HAQI were used in this study to represent the quality of healthcare systems, further comprehensive study incorporating these factors is needed.

In conclusion, DCI could be a potential indicator positively correlated with the incidence and mortality of COVID-19. Reducing DCI through strict infection control measures can help slow the number of new COVID-19 cases and further improve outcomes in COVID-19 patients.

Declarations

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Competing Interests: None.

Ethical Approval: Not needed.

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