Covid-19 mortality is associated with test number and government effectiveness

Li-Lin Liang

Department of Business Management, National Sun Yat-sen University, Kaohsiung, Taiwan

Ching-Hung Tseng

Germark Biotechnology Co., Ltd., Taichung, Taiwan

Hsiu J. Ho

Institute of Biomedical Informatics, National Yang-Ming University, Taipei, Taiwan

Chun-Ying Wu (✉ cywu4@ym.edu.tw)

Institute of Biomedical Informatics, Institute of Public Health, Institute of Clinical Medicine, Faculty of Medicine, National Yang-Ming University, Taipei, Taiwan; Division of Translational Research, Taipei Veterans General Hospital, Taipei, Taiwan; Department of Public Health, China Medical University, Taichung, Taiwan

Research Article

Keywords: Covid-19, mortality rate, multivariable linear regression model

Posted Date: May 11th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-28218/v1>

License: © ⓘ This work is licensed under a Creative Commons Attribution 4.0 International License.

[Read Full License](#)

Version of Record: A version of this preprint was published at Scientific Reports on July 24th, 2020. See the published version at <https://doi.org/10.1038/s41598-020-68862-x>.

Abstract

Objectives: A question central to the Covid-19 pandemic is why the Covid-19 mortality rate varies so greatly across countries. This study aims to investigate factors associated with cross-country variation in Covid-19 mortality.

Methods: Covid-19 mortality rate was calculated as number of deaths per 100 Covid-19 cases. To identify factors associated with Covid-19 mortality rate, a multivariable linear regression model was applied to a cross-sectional dataset comprising 78 countries and 1,790,550 patients infected by Covid-19. We retrieved data from the Worldometer website and the Worldwide Governance Indicators and World Development Indicators databases.

Results: Covid-19 mortality rate was negatively associated with Covid-19 test number per 1,000 population (RR=0.97; 95% CI 0.96 to 0.99, P=0.013) and government effectiveness indicator (RR=0.96; 95% CI 0.93 to 0.98, P=0.001). Covid-19 mortality rate was positively associated with number of critical cases per 100 Covid-19 cases, Covid-19 case number per 10,000 population, proportion of population aged 65 or older and proportion of deaths attributable to communicable diseases in previous years (all with P<0.05). Predicted mortality rates were highly associated with observed mortality rates ($r = 0.74$; P<0.001).

Conclusions: Multiple factors were associated with Covid-19 mortality rates. Increasing Covid-19 testing and improving government effectiveness may have the potential to attenuate Covid-19 mortality.

Authors Li-Lin Liang and Chun-Ying Wu contributed equally to this work.

Introduction

Since the first report of the severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), causing coronavirus disease 2019 (Covid-19) [1,2], more than 1.8 million people have been infected and more than 110,000 have died worldwide as of April 12, 2020. The highly contagious Covid-19 has led to large numbers of infections, health care system overload, and lockdowns in many countries [3,4]. The spread of Covid-19 to more than 100 countries met the criteria of a pandemic [5].

A question central to the Covid-19 pandemic is why the Covid-19 mortality rate varies so greatly across countries, from over 10% in Italy and the United Kingdom to less than 0.1% in Latvia and New Zealand. Such wide variation implies that there are factors other than patient characteristics that determine Covid-19 mortality, such as government response.

Patient-level studies have shown that Covid-19 mortality can be explained by age, obesity, and underlying diseases, such as hypertension, diabetes, and coronary heart disease, etc [6–8], as well as

clinical symptoms, complications, hospital care, previous immunity and virus mutations [9,10]. These findings help health professionals to identify high-risk patients.

However, this evidence alone may not be sufficient to support effective policies for reducing Covid–19 mortality.

This gap in Covid–19 research has been addressed by several studies. Some scholars have discussed the effectiveness of governments' policies, such as quarantine or lockdown, in slowing the spread of Covid–19 [3,11]. Others have suggested that projecting hospital utilization during the Covid–19 outbreak is necessary to assure the adequacy of resources to treat large numbers of patients [12]. A recent study analyzed the association between

Covid–19 mortality and health care resource availability [13]. In addition, increasing Covid–19 testing has been advocated to attenuate its spreading [14].

The resulting pieces of evidence have not been assembled or applied to explanations of country variations in Covid–19 mortalities. Countries vary widely in terms of capacities to prevent, detect and respond to disease outbreaks [15,16]. We aim to explore country-level factors associated with Covid–19 mortalities. Specifically, we examined whether a key strategy, Covid–19 testing, can reduce Covid–19 mortalities. We also examined whether the severity of Covid–19 outbreak, as measured by the critical case rate and case number explains high numbers of Covid–19 mortalities. Furthermore, we investigated whether government effectiveness, or the government's capacity to formulate and implement sound policies to tackle the crisis, can reduce Covid–19 mortality.

Methods

Study design and data sources:

For this worldwide cross-sectional study, we used data from open access databases. We retrieved Covid–19 related data from the website “Worldometer: coronavirus”[17]. This website has compiled data from several important resources, such as the World Health Organization, U.S. Centers for Diseases Control and Prevention, and Computational Health Informatics Program of Harvard University. Covid–19 case numbers, death numbers, critical case numbers, and test numbers from more than 100 countries have been reported. This database is updated daily. We identified 1,790,550 Covid–19 cases with 109,654 deaths at 10:00 GMT on April 12, 2020 from the Worldometer database.

Government effectiveness information was retrieved from the Worldwide Governance Indicators (WGI) website [18]. Information regarding other country-level factors, i.e. bed number, age structure and disease patterns, was retrieved from the World Bank's World Development Indicators (WDI)[19]. WDI was widely used in cross-country studies on health policy [20,21]. The most recent year for which country data was available was 2018. After merging Covid–19 data with country-level data, the study sample consisted of totally 1,634,060 Covid–19 infected patients with 101,864 deaths in 78 countries. Countries were

excluded from this analysis, if data was not available from public sources. The sample countries are shown in Supplementary table 1.

Variables definitions:

Covid-19 mortality rate was defined as the number of deaths per 100 Covid-19 cases.

Since the distribution of Covid-19 deaths was right skewed, we log-transformed the variable to make the data conform more closely to the normal distribution and to improve the model fit. The Covid-19 related factors were the test number per 1,000 population, case number per 10,000 population, and the critical case rate. We used a smaller unit (per 1,000 population) for the test number than for the case number (per 10,000 population) to make the values of these two variables more comparable. The critical case rate was calculated by dividing the number of critical cases by the number of Covid-19 infected cases.

Government effectiveness was measured by the government effectiveness scores developed by the WGI project [18]. These scores were obtained from assessment of the quality of public and civil services and policy formulation and implementation, and the government commitment to such policies. The scores ranged from -2.50 to 2.50, with a lower value indicating a lower level of effectiveness [22]. We multiplied the scores by 10.

Population age structure and disease patterns were measured respectively, by the percentage of the population aged 65 or older, and the percentage of all-cause deaths attributable to communicable diseases. The range of communicable diseases was all diseases excluding non-communicable diseases such as cancer and diabetes mellitus. The number of beds was measured per 1,000 population.

Linear regression analyses

To examine the association of Covid-19 mortality rates with selected variables, we performed both univariable and multivariable linear regressions. The ordinary least squares method was used and the R-squared value was obtained to determine the explanatory power of the model. R-squared value measured the proportion of the variance of Covid-19 mortality rates jointly explained by the included covariates.

Other factors that may explain cross-country variation in Covid-19 mortality rates, including economic development, health expenditures and population mobility, were also analyzed. We added several variables to capture these factors (see Supplementary table 2). However, none of the coefficients for those variables was statistically significant.

We conducted the Breusch-Pagan test for the null hypothesis that the variance in the potential distribution of the disturbance term in the regression model is constant for all sample countries. The test rejected the hypothesis, indicating that the least squares estimator is inefficient. To overcome this

problem, we used standard errors that are robust to unequal variances, known as heteroscedasticity. All analyses were performed using Stata 16 software (StataCorp Inc.).

Validation study

The validity of our regression model was examined by comparing the observed Covid–19 mortality rates with the predicted mortality rates for individual countries. We drew a graph with observed and predicted mortality rates on the two axes. If the model fit well, we expected to see the data points scattered around the 45-degree cross line on the graph.

Results

Descriptive statistics and univariable regression analysis

Table 1 summarizes the Covid–19 mortality rates and regression covariates. For the 78 studied countries, the mean Covid–19 mortality rate was 3.42% (95% CI 2.76 to 4.08%). The mean Covid–19 test number per 1,000 population was 9.54 (95% CI 6.16 to 12.91); the mean Covid–19 case number per 10,000 population was 6.91 (95% CI 4.61 to 9.20); and the mean critical case rate was 2.41% (95% CI 1.97 to 2.85). Moreover, the mean government effectiveness score was 0.56 (95% CI 0.37 to 0.75); the mean proportion of the population aged 65 or older was 13.24% (95% CI 11.91 to 14.57%); the mean bed number per 1,000 population was 3.87 (95% CI 3.34 to 4.40); and the mean communicable disease death rate was 15.72% (95% CI 13.33 to 18.11).

On univariable regression analysis, R-squared values (the explanatory power) were 0.14 for the critical case rate, 0.13 for the test number, 0.05 for the population aged 65 or older, and 0.04 for the government effectiveness indicator. Figures 1A and 1B show that Covid–19 mortality rates are positively associated with critical case rates (correlation coefficient, $r = 0.30$, $P = 0.007$) and the proportion of the population aged 65 or older ($r = 0.23$; $P = 0.044$). Figures 1C and 1D show Covid–19 mortality rates are negatively associated with test numbers ($r = -0.38$, $P < 0.001$) and the government effectiveness ($r = -0.20$, $P = 0.076$), respectively.

Multivariable regression analyses

Results of multivariable regression analyses for predicting Covid–19 mortality rates are shown in Table 2. Among the Covid–19 related factors, one additional Covid–19 screening test per 1,000 population was associated with a 3% reduction in mortality risk ($RR = 0.97$; 95% CI 0.96 to 0.99, $P = 0.013$). Moreover, one additional Covid–19 case per 10,000 population was associated with a 4% increase in mortality risk ($RR = 1.04$; 95% CI 1.02 to 1.07, $P = 0.001$) and one additional percentage point in the critical case rate was associated with a 11% increase in mortality risk ($RR = 1.10$; 95% CI 1.02 to 1.19, $P = 0.016$).

Among the country related factors, we found that a percentage point increase in the population aged 65 or older is associated with a 9% increase in mortality risk (RR = 1.09, 95% CI 1.05 to 1.14, $P < 0.001$). One additional bed per 1,000 population was associated with a 7% reduction in mortality risk, but the coefficient was not statistically significant (RR = 0.93; 95% CI 0.85 to 1.01, $P = 0.084$). A 0.1 increase in government effectiveness score was associated with a 4% reduction in mortality risk (RR = 0.96; 95% CI 0.93 to 0.98, $P = 0.001$), while a one percentage point increase in communicable disease rate was associated with a 2% increase in mortality risk (RR = 1.02; 95% CI 1.01 to 1.04, $P = 0.009$).

Multivariable regression with interaction term

To improve the prediction accuracy, we added an interaction term, positive test rate, to the regression model (Table 3). The positive test rate was calculated by dividing the number of Covid-19 cases by the number of Covid-19 tests, both measured at per 1,000 population. We found that positive test rate significantly improves prediction accuracy, with the R-squared value increasing from 0.49 to 0.55. An increase of one percentage point in positive test rate was associated with a 4% increase in mortality rate (RR = 1.04; 95% CI 1.02 to 1.05; $P < 0.001$). The inclusion of the positive test rate made test number and case number insignificant, indicating the strong interaction effect between them.

Validation of the prediction model

To validate the robustness of our prediction model, we examined the association between the predicted mortality rates and the observed mortality rates for each country (Figure 2). The X axis was the observed mortality rate and the Y axis was the predicted mortality rate. The predicted mortality rates were significantly and positively correlated with the observed mortality rates ($r = 0.74$, $P < 0.001$).

Discussion

To the best of our knowledge, this is the first country level study to systematically examine the factors related to Covid-19 mortality. We found that Covid-19 test number is negatively associated with mortality rates. The effectiveness of population screening for Covid-19 infection to reduce mortality risk is currently being debated. Those supporting screening suggest the beneficial effect of identifying asymptomatic patients to attenuate Covid-19 spread. Opponents argue that reduced mortality risk is mainly due to increased detection of asymptomatic patients. In the present study, we found that one additional test per 1,000 population is associated with a 3% reduction in mortality rate, even after adjusting for case number, critical case rate, and other country-related factors.

We also found that Covid-19 case number and critical case rate are positively associated with mortality risks. This is consistent with the real-world observations that high case numbers and high critical rates have led to health care system overload in several countries. Covid-19 infected patients need greater health care resources, such as isolation rooms and health care faculties and facilities. The availability of

health care resources has been reported to be associated with Covid–19 mortality [13]. Attenuating increases in case number and critical case rate may help to increase Covid–19 patient survival rates.

Recent Covid–19 clinical studies have reported associations for mortality with old age and multiple comorbidities [6,7,23]. We confirmed these observations. Countries with higher proportions of people aged 65 or older had significantly higher mortality rates. In the present study, bed number was not significantly associated with Covid–19 mortality rate. Although one additional bed number per 1,000 population was negatively associated with a 7% reduction in risk of mortality, this association was not significant. A potential reason for this non-significance is the wide variation in bed vacancy rates and bed types. However, this information was not available from the WDI database. The influence of other stronger factors, such as critical case rate, test number, and government effectiveness, may have also contributed to the non-significance. An alternative explanation is that several countries have constructed temporary hospitals to increase bed numbers, not recorded in the WGI database, which may have affected the importance of bed number as a predictor of mortality rates.

Government effectiveness is a measure of good governance, which is essential to long-term development outcomes [24]. In the present study, we demonstrated that for short-term crises such as the Covid–19 outbreak, government effectiveness remains critical, as it related to the formulation and implementation of quarantine and screening policies, as well as quality of public health services in managing and treating patients. In addition, we found that communicable disease death rate, an indicator of the ability of the countries to prevent and treat infectious diseases, is positively associated with Covid–19 mortalities.

Positive test rate is a combination of the effects of case number and test number. A higher positive test rate implies under-screening with some asymptomatic patients going undiagnosed. These asymptomatic patients may increase the risk of Covid–19 spread and case number. Moreover, not counting these asymptomatic patients leads to over-reporting of critical case rates and mortality rates. These factors may explain the positive association between positive test rate and mortality rate.

There are several limitations to the present study. First, this study is based on Covid–19 cases reported by countries. Inaccurate reporting and the rapid increases in cases may have influenced the predictive power of our model. However, the trends in the prognostic factors for predicting mortality rates may not have changed. Second, the lack of completeness of the database limits our analyses in certain countries, for example test numbers in China and critical case numbers in India. Third, the Covid–19 related factors used in the present study are from country-level data, not patient-level data. If worldwide patient-level data is made available for analyses, the prediction accuracy will further improve. Fourth, we selected only a limited number of factors that potentially determine the Covid–19 mortality in a country.

Future studies may explore other country-related factors to improve the prediction accuracy. Finally, acquired community immunity after the worldwide spread of Covid–19 may change the prediction accuracy. However, the results of this study can still contribute to future pandemic-related policymaking at the country level.

In conclusion, we found that higher Covid–19 mortality is associated with lower test number, higher critical case rate, higher case number, lower government effectiveness, aging population, and higher communicable disease death rate. Increasing Covid–19 test number, reducing critical case rate, and improving government effectiveness have the potential to reduce Covid–19 related mortality.

Declarations

Funding: Nil.

Competing interests: The authors have no conflicts of interest to report.

Author contributions statement: Liang and Wu formulate the research ideas, collected data, conducted analysis and wrote the manuscript. Tseng and Ho produced tables and figures.

References

1. Zhu N, Zhang D, Wang W, et al. A Novel Coronavirus from Patients with Pneumonia in China, 2019. *N Engl J Med* 2020;382:727-33.
2. Lipsitch M, Swerdlow DL, Finelli L. Defining the Epidemiology of Covid-19 - Studies Needed. *N Engl J Med* 2020;382:1194-6.
3. Iacobucci G. Covid-19: UK lockdown is "crucial" to saving lives, say doctors and scientists. *BMJ* 2020;368:m1204.
4. Pulla Covid-19: India imposes lockdown for 21 days and cases rise. *BMJ* 2020;368:m1251.
5. Remuzzi A, Remuzzi G. COVID-19 and Italy: what next? *Lancet* 2020
6. Zhou F, Yu T, Du R, et al. Clinical course and risk factors for mortality of adult inpatients with COVID-19 in Wuhan, China: a retrospective cohort. *Lancet* 2020;395:1054-62.
7. Chen T, Wu D, Chen H, et al. Clinical characteristics of 113 deceased patients with coronavirus disease 2019: retrospective study. *BMJ* 2020;368:m1091.
8. Wang D, Hu B, Hu C, et al. Clinical Characteristics of 138 Hospitalized Patients With 2019 Novel Coronavirus-Infected Pneumonia in Wuhan, China. *JAMA* 2020.
9. Rubino S, Kelvin N, Bermejo-Martin JF, Kelvin D. As COVID-19 cases, deaths and fatality rates surge in Italy, underlying causes require investigation. *J Infect Dev Ctries* 2020;14:265-7.
10. Huang C, Wang Y, Li X, et al. Clinical features of patients infected with 2019 novel coronavirus in Wuhan, China. *Lancet* 2020;395:497-506.
11. Hou C, Chen J, Zhou Y, et al. The effectiveness of the quarantine of Wuhan city against the Corona Virus Disease 2019 (COVID-19): well-mixed SEIR model analysis. *J Med Virol* 2020.
12. Moghadas SM, Shoukat A, Fitzpatrick MC, et al. Projecting hospital utilization during the COVID-19 outbreaks in the United States. *Proc Natl Acad Sci U S A* 2020.

13. Ji Y, Ma Z, Peppelenbosch MP, Pan Q. Potential association between COVID-19 mortality and health-care resource *Lancet Glob Health* 2020;8:e480.
14. Peto J. Covid-19 mass testing facilities could end the epidemic *BMJ* 2020;368:m1163.
15. Kandel N, Chungong S, Omaar A, Xing J. Health security capacities in the context of COVID-19 outbreak: an analysis of International Health Regulations annual report data from 182 countries. *Lancet* 2020;395:1047-53.
16. Bredenkamp C, Evans T, Lagrada L, Langenbrunner J, Nachuk S, Palu Emerging challenges in implementing universal health coverage in Asia. *Soc Sci Med* 2015;145:243-8.
17. 2020. at <https://www.worldometers.info/coronavirus/>?)
18. Worldwide Governance Indicators. (Accessed April 5, 2020, at <https://info.worldbank.org/governance/wgi/Home/Reports>.)
19. The World (Accessed April 5, 2020, at <https://data.worldbank.org/country>.)
20. Liang LL, Mirelman Why do some countries spend more for health? An assessment of sociopolitical determinants and international aid for government health expenditures. *Soc Sci Med* 2014;114:161-8.
21. Liang LL, Tussing The cyclicity of government health expenditure and its effects on population health. *Health Policy* 2019;123:96-103.
22. Kaufmann D, Kraay A, Mastruzzi M. The Worldwide Governance Indicators: Methodology and analytical Issues. Washington DC: The World Bank; 2010.
23. Grasselli G, Zangrillo A, Zanella A, et Baseline Characteristics and Outcomes of 1591 Patients Infected With SARS-CoV-2 Admitted to ICUs of the Lombardy Region, Italy. *JAMA* 2020.
24. Kaufmann D, Kraay A, Zoido-Lobaton Governance matters. Washington DC: The World Bank; 1999.

Tables

Table 1. Descriptive statistics of the factors used to predict Covid-19 mortality

Factors	Mean	SD	95% CI
Covid-19 mortality rates	3.42	2.94	2.76 – 4.08
Covid-19 related factors			
Test number per 1,000 population	9.54	14.95	6.16 – 12.91
Case number per 10,000 population	6.91	10.19	4.61 – 9.20
Critical case rate (%)	2.41	1.96	1.97 – 2.85
Country related factors			
Population aged 65 or older (%)	13.24	5.88	11.91 – 14.57
Bed number per 1,000 population	3.87	2.36	3.34 – 4.40
Government effectiveness indicator	0.56	0.84	0.37 – 0.75
Communicable disease death rate (%)	15.72	10.60	13.33 – 18.11

Table 2. Multivariable regression analysis to predict Covid-19 mortality risk

	e	95% CI	P value
Covid-19 related factors			
Test number per 1,000 population	0.97	0.96 – 0.99	0.013
Case number per 10,000 population	1.04	1.02 – 1.07	0.001
Critical case rate (%)	1.10	1.02 – 1.19	0.016
Country related factors			
Population aged 65 or older (%)	1.09	1.05 – 1.14	<0.001
Bed number per 1,000 population	0.93	0.85 – 1.01	0.084
Government effectiveness indicator*	0.96	0.93 – 0.98	0.001
Communicable disease death rate (%)	1.02	1.01 – 1.04	0.009

* Government effectiveness indicator is analyzed based on 0.1 incremental increase.

Table 3. Multivariable regression with interaction analysis for Covid-19 mortality risk

	e	95% CIP value	
Covid-19 related factors			
Test number per 1,000 population	0.99	0.97 – 1.01	0.261
Case number per 10,000 population	1.02	0.99 – 1.04	0.229
Positive test rate (%) ⁺	1.04	1.02 – 1.05	<0.001
Critical case rate (%)	1.08	1.01 – 1.16	0.033
Country related factors			
Population aged 65 or older (%)	1.09	1.05 – 1.14	<0.001
Bed numbers per 1,000 population	0.95	0.88 – 1.03	0.225
Government effectiveness indicator*	0.96	0.94 – 0.99	0.002
Communicable disease death rate (%)	1.02	1.01 – 1.04	0.002

+ Positive test rate is calculated by case number divided by test number

* Government effectiveness indicator is analyzed based on 0.1 incremental increase.

Figures

Figure 1

Cross-sectional relationship of Covid-19 mortality rate with critical case rate (A), proportion of population aged 65 or over (B), Covid-19 test number (C) and government effectiveness indicator (D) for 78 countries. Red lines are linear predictions of Covid-19 mortality rates on the corresponding covariates. The 95% confidence intervals of the fitted values are shown by grey areas (r = correlation coefficient)

Figure 2

Correlation between observed and predicted Covid-19 mortality rates for 78 countries. The 45-degree line indicates equality of observed and predicted Covid-19 mortality rates (r = correlation coefficient).

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- [Supplementarymaterial.pdf](#)