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Original Article

Is There Any Relationship Between the Number of COVID-19 Tests by Country with the Income Inequality of Countries? A Comparison with Income Inequality Metrics

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Abstract

OBJECTIVE: Coronavirus diseases 2019 test numbers vary from country to country. The present study aims to investigate whether there is a relationship between the number of coronavirus diseases 2019 tests by country with the income inequality of countries.

MATERIAL AND METHODS: The association between the number of coronavirus diseases 2019 tests and income inequality metrics was evaluated in 197 countries. Income inequality metrics consisted of the gross domestic product per capita, Gini index, the P80/P20 ratio, human development index ranking, and poverty rate. The share of the tests that gave positive results (positive rate) and fatality rates was calculated by countries.

RESULTS: There was a strong positive correlation between the number of coronavirus diseases 2019 tests per million people and the number of coronavirus diseases 2019 patients per million people (rho = 0.697, $P < .001$). A significant correlation was observed between the number of coronavirus diseases 2019 tests and all income inequality metrics ($P < .001$). The strongest positive correlation with the number of coronavirus diseases 2019 tests was between gross domestic product per capita (rho = 0.775), while the strongest negative correlation with the number of coronavirus diseases 2019 tests was between human development index ranking (rho = −0.836). The multiple regression analysis showed that age ($P = .01$), gross domestic product per capita ($P < .001$), and human development index ranking were independent factors affecting the number of coronavirus diseases 2019 tests per million people (adjusted $R^2 = 0.301$). The fatality rate was associated with the number of coronavirus diseases 2019 tests ($P = .01$).

CONCLUSION: Income inequalities in countries are associated with the number of coronavirus diseases 2019 tests. For this reason, many deaths from coronavirus diseases 2019 may have gone overlooked in countries with poor-income inequality metrics.

KEYWORDS: SARS-CoV-2, polymerase chain reaction testing, countries, income inequality metrics
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INTRODUCTION

Worldwide, more than 90 million people have caught the coronavirus diseases 2019 (COVID-19) by January 2021.[1] The COVID-19 polymerase chain reaction (PCR) test is accepted as the golden standard method for confirming COVID-19. However, the number of test-positive cases depends on the timing of the outbreak and public health policies between countries.[2] Thus, it is difficult to interpret basic differences in the number of cases between continents. It is known that countries need to do more testing to be able to properly monitor the spread of the virus. Moreover, the number of conducted COVID-19 tests may affect the number of test-positive cases.[3] Health care workers rely on the results to guide patients' medical treatment. On the other hand, individuals rely on test results to decide on whether to self-isolate. Therefore, the small number of tests causes real patients to be ignored, and consequently, the transmission chain cannot be broken and the burden on the health system increases.

It is well-known that the majority of COVID-19-related deaths have occurred in the community where testing capacity is lacking.[4] A lot of patients who died in countries are not able to test, despite presenting with typical symptoms of COVID-19. Therefore, it can be said that COVID-19 cases were under-reported because testing was rarely done, not because COVID-19 was rare. The social quality of the state, the level of democracy, the level of income inequality, poverty and education level, racial/ethnic minority ratio, and the immigrant/refugee population ratio are known to contribute to this.[5] The class inequality of COVID-19 has shown itself both between regions and countries.[6] Both the number of tests per million people (pmp) and non-pharmaceutical public health practices differ from country to country. As an illustration, in South Sudan, where the per capita income is 302 dollars, the number of PCR tests performed pmp is 7000, whereas, in Luxembourg, where the per capita income is 114 000 dollars, this number is 2.7 million (385 times more tests).[7]

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Table 1. The Definitions Regarding Income Inequality Metrics

Income Inequality Metrics	Definitions
Gross domestic product[11]	The total monetary or market value of all the finished goods and services produced within a country's borders in a specific time period
Gross domestic product per capita[11]	Breaks down a country's economic output per person and is calculated by dividing the GDP of a country by its population
P80/P20 ratio[11]	The ratio of the household income at the 80th percentile (i.e., 20% below the wealthiest household) to the household income at the 20th percentile (i.e., 20% above the lowest income household)
Gini coefficient (index)[12]	A measure of statistical dispersion intended to represent the income inequality or wealth inequality within a nation or any other group of people
Human development index[13]	The geometric mean of normalized indices for each of the 3 dimensions that were a long and healthy life, being knowledgeable, and having a decent standard of living
Human development index ranking[13]	A list of countries by inequality-adjusted human development index
Extreme poverty rate[14]	People living on less than $1.25 a day

To the best of our knowledge, there is no study investigating the relationship between income inequality metrics and the number of COVID-19 tests, the number of COVID-19 deaths/patients pmp, and mortality among COVID-19 patients.[8,9] In the present study, the effect of income inequality on the number of COVID-19 tests in countries was investigated with income inequality metrics.

MATERIAL AND METHODS

Total numbers of PCR-positive cases and deaths by COVID-19 reported from all countries (n = 211) worldwide were downloaded from the webpage of the World Health Organization (WHO) on January 10, 2021.[10] Because the total number of tests is often volatile from time to time, it was accepted as 10 months rolling average. Countries with a total number of tests pmp (n = 14) unknown were excluded in the present study. Since countries have performed different testing policies and have a different number of populations, aiming to investigate the state of the current COVID-19 by analyzing the number of test-positive cases alone may lead to bias. Thus, it has been also focused in the current study on changes in the number of test-positive patients and deaths adjusted by the population of each country and considering the timing of the pandemic. The number of population-adjusted total test-positive cases and the number of population-adjusted total deaths were calculated for a population of a million. However, it should be noted that the number of test-positive cases analyzed in this study was smaller than the number of infected people and was observed only after the hidden phase.

The rate of PCR tests among the population (named as examination rate) and the rate of COVID-19-related deaths among the population caught COVID-19 (named as fatality rate) were also calculated. The fatality rate was defined as the number of deaths in persons who tested positive for severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) divided by the number of SARS-CoV-2 cases.

Also, the share of tests that gave positive results (positive rate) and how many tests were performed to find one case of COVID-19 were determined.

Income Inequality Metrics Used in the Present Study

The definitions regarding income inequality metrics are shown in Table 1.

Speculatively, it was suggested that, in developed countries, strict compliance to social distancing is better achieved. Therefore, the gross domestic product (GDP) and GDP per capita of each country were accepted as predictor variables in the present study.

Besides, several variables have been analyzed to determine the effect of income distribution inequality in countries on COVID-19. One of the approaches developed to examine income distribution is to compare the shares of the groups in the population with the highest income and lowest income in the total income. In this comparison, the income of the richest 20% of the population is proportioned to the income of the poorest 20% that is called the P80/P20 ratio. It is accepted that as this ratio increases, the income inequality in the country increases.

Another indicator that measures the inequality in income distribution is the Gini coefficient. This coefficient varies between 0 and 1, and the coefficient is 0 in the case of complete income equality and 1 in the case of complete income inequality. In other words, the closer the Gini coefficient is to 1, the results indicate income inequality.

MAIN POINTS

- The number of coronavirus diseases 2019 (COVID-19) patients detected increases in line with the increase in the number of COVID-19 tests.
- Income inequality in countries determines the number of COVID-19 tests.
- Countries with poor-income inequality metrics may have experienced more COVID 19 deaths.

In this study, the P80/P20 ratios[11] published by the United Nations Development Program (UNDP) for all countries of the world every year, and the Gini index[12] published by The World Bank for all world countries were used.

Moreover, the human development index (HDI) and HDI ranking, which are other indicators of inequality, were examined in the study. A list of countries by inequality-adjusted human development index was published by the UNDP in its 2019 Human Development Report.[13]

The extreme poverty rate, another indication of inequality within and between countries, was obtained from UNDP and The World Bank database.[14,15]

In case there is no data for the year 2020 for each data set, the most recently published data were taken into consideration.

Other Variables Used in the Present Study

By countries, the mean age, the rate of people over 65 years of age, smoking rate, cardiovascular disease-related mortality rate, diabetes mellitus (DM) prevalence, life expectancy, and the number of hospital beds per thousand people were examined.

Statistical Analysis

The data were entered into the Statistical Package for Social Sciences 23.0 (IBM SPSS Corp.; Armonk, NY, USA) package program. Descriptive statistics were used to summarize pertinent study information. Variables were characterized using mean, maximum (max), and minimum (min) values, and percentages were used for qualitative variables. Correlation analysis between numerical variables was performed by Spearman's correlation test, and correlation coefficient (rho) was calculated. If the correlation coefficient was negative, it was accepted as an inverse relationship between 2 variables (an increase in one and a decrease in the other), whereas, if it is positive, it was accepted as a straight relationship (an increase in one and an increase in the other) between the 2 variables. If the rho coefficient is between 0.01 and 0.19, 0.20 and 0.29, 0.30 and 0.39, 0.40 and 0.69, or is ≥0.70, it was accepted as "negligible relationship, weak relationship, moderate relationship, strong relationship, very strong relationship," respectively. Moreover, multivariate regression analysis was done for the relationship between the income inequality metrics with the number of COVID-19 tests per million people. In the present study, since there may be high correlations between the income inequality metrics, multiple regression analysis was performed separately for each income metric. A P value of <.05 was considered statistically significant.

RESULTS

One hundred ninety-seven countries were included in the present study. The numbers and rates of COVID-19 test and COVID-19-related results are shown in Table 2. The mean number of the COVID-19 tests pmp was 335.329, whereas the mean number of PCR-positive patients in pmp was 18.761. An average of 335 people pmp around the world had died because of COVID-19. Examination rate was 33.6% (min: 0.5%, max: 425.4%) whereas the mortality rate of patients with COVID-19 was calculated as 1.8% (min: 0%, max: 28.8%).

The share of test-positive cases differed significantly from country to country (P < .001) (Figure 1). The positivity rate was 9.6% on average (min: 0.4%, max: 65.4%). The worldwide performed test median per case was 12.6. While this number remained below 3.5 in countries such as Argentina, Mexico, Bolivia, Costa Rica, Ecuador, and Brazil, it was over 500 in countries such as China, Vietnam, New Zealand, and Hong Kong.

The relationships between the number of COVID-19 tests and the variables were shown in Table 3. There was a strong positive correlation between the number of COVID-19 tests and GDP per capita (rho = 0.775, P < .001), whereas there was a strong negative correlation between HDI ranking and the number of COVID-19 tests (rho = −0.836, P < .001). Increase in the countries' Gini coefficient, extreme poverty rate, and P80/P20 ratio was associated with a decrease in the number of COVID-19 tests pmp (negative correlation). The number of COVID-19 tests pmp was moderately correlated with the age and the rate of the population over 65 years of age (rho = 0.715 and rho = 0.636, respectively). The number of COVID-19 PCR tests pmp was weakly associated with smoking rate, and GDP (rho = 0.197 and rho = 0.197, respectively). In the multiple regression analysis, age (P = .01), GPD per capita (P < .001), and HDI ranking were found to be independent factors affecting the number of COVID-19 PCR tests pmp (adjusted R^2 = 0.301).

Table 2. The Numbers and Rates of COVID-19 Test and COVID-19-related Results

Variables	Mean ± SE	Median Values (IQR)
The COVID-19 tests pmp, n	345 815 ± 43 406	149 192 (371 174)
PCR-positive patients in pmp, n	19 828 ± 1586	12223 (29391)
People who died from COVID-19 in pmp, n	335.1 ± 29.8	157.0 (448.2)
Examination rate, %	33.6 ± 4.1	14.2 (33.6)
The mortality rate of patients with COVID-19, %	1.8 ± 0.1	1.5 (1.4)
The positivity rate, %	9.6 ± 0.6	7.9 (11.0)
The performed test per case, n	85.6 ± 18.4	12.6 (34.0)

Pmp; per million people, n; number, SE; Standard error, IQR; interquartile range; PCR, polymerase chain reaction.

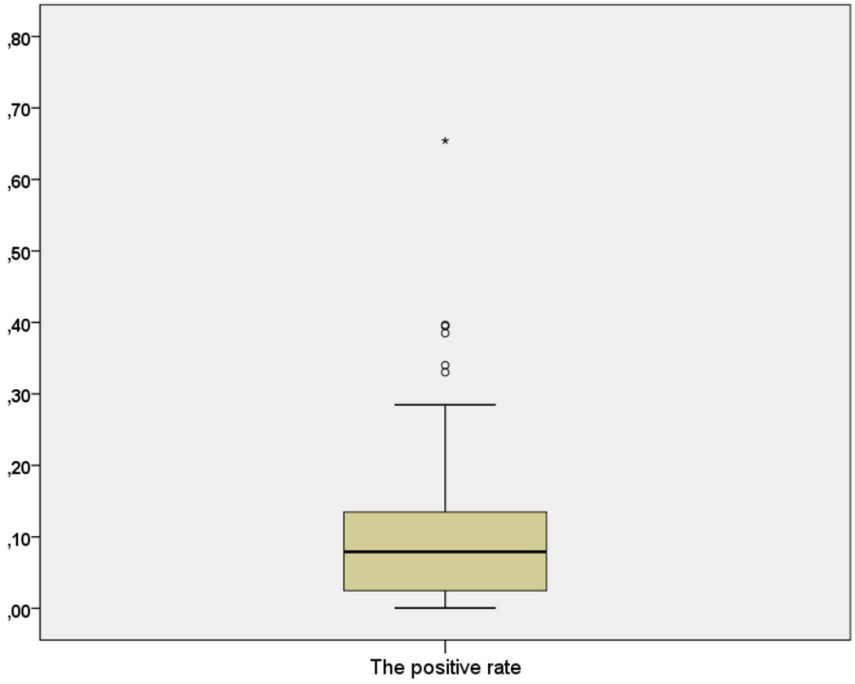

Figure 1. The analysis of number of test-positive cases by countries.

A strong positive correlation was found between the number of COVID-19 tests and the number of COVID-19 patients pmp (rho = 0.697, $P < .001$). It was observed that as the number of test increased, the number of patients increased (Figure 2).

The number of COVID-19 patients pmp was positively correlated with the mean age in countries (rho = 0.533, $P < .001$), the rate of people over 65 years (rho = 0.540, $P < .001$), smoking rate in the population (rho = 0.272, $P < .001$), cardiovascular disease (CVD)-related mortality rate (rho = 0.240, $P = .002$), DM prevalence (rho = 0.172, $P = .02$), and the number of hospital beds per thousand people (rho = 0.440, $P < .001$).

The number of COVID-19-related deaths pmp was positively significantly related with the mean age of countries, the rate of people over 65, CVD-related mortality rate, the number of hospital beds per thousand people, examination rate, GDP, GDP per capita, and life expectancy in countries, although it was negatively significant associated with the Gini coefficient, extreme poverty rate, HDI ranking, and P80/P20 ratio (Table 4).

The fatality rates in the countries were found not to be associated with any variables other than the examination rate (Table 4). There was also a weak negative correlation between examination rate and fatality rate (rho = −0.181, $P = .01$).

Table 3. Univariate Spearman's Rank-Order Correlation Analysis Between the Variables with the Number of COVID-19 Tests Per Million People and Multivariate Regression Analysis

	The Number of COVID-19 Tests Per Million People		Multivariate Analysis	
Variables	**rho Coefficient**	***P***	**Standardized Coefficients Beta**	***P***
Age	0.715	<.001	0.465	.01
Rate of people over 65 years of age	0.636	<.001	−0.017	.925
Smoking rate	0.197	.006	−0.053	.570
Gini coefficient	−0.366	<.001	−0.109	.925
GDP	0.197	.007	−0.121	.439
GPD per capita	0.775	<.001	0.710	<.001
Extreme poverty rate	−0.756	<.001	−0.036	.743
Life expectancy	0.759	<.001	0.058	.579
HDI ranking	−0.836	<.001	−0.866	<.001
P80/P20	−0.337	<.001	−0.025	.750

GDP, gross domestic product; HDI, human development index; P80/P20, calculated as the ratio of total income received by the 20% of the population with the highest income (the top quintile) to that received by the 20% of the population with the lowest income (the bottom quintile).

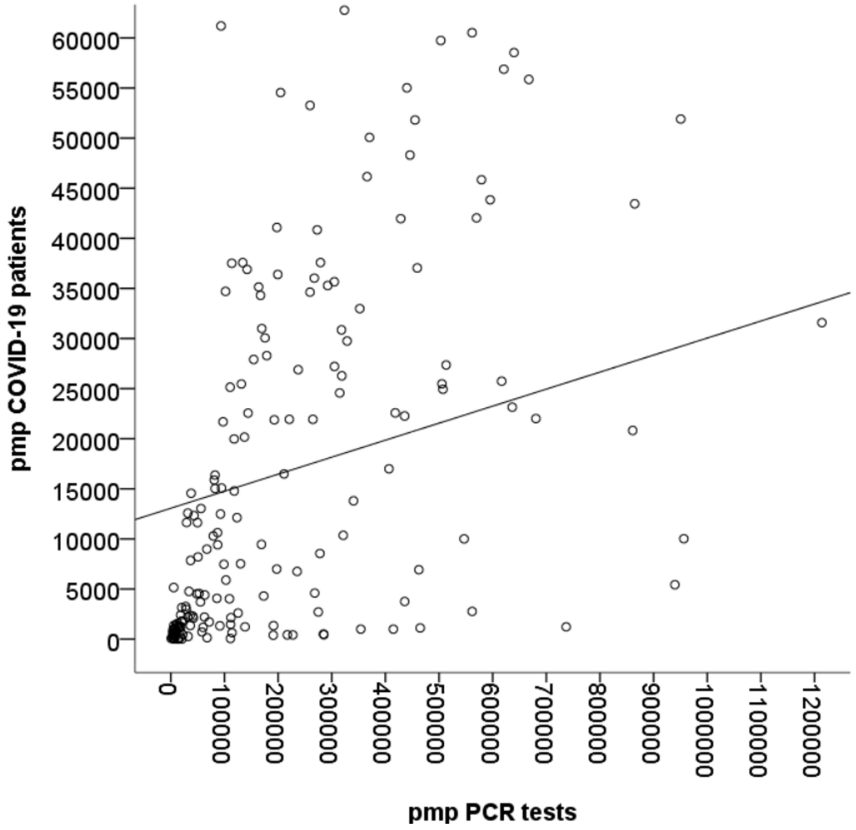

Figure 2. The correlation between the number of COVID-19 tests and the number of COVID-19 patients (rho = 0.697, $P < .001$). COVID-19, coronavirus disease 2019. pmp; per million people.

When countries are grouped as countries with a positivity rate of less than 1% (low positive rate, n = 23) and a positivity rate higher than 20% (high positive rate, n = 29), the number of COVID-19 patients pmp ($P < .001$), the number of COVID-19-related deaths pmp ($P < .001$), and fatality rate ($P < .001$) were higher in countries with a high positivity rate.

DISCUSSION

The number of confirmed patients infected with COVID-19 is what informs about the development of the pandemic. However, the confirmation of a case is based on a test. The WHO defines a confirmed case as "a person with laboratory confirmation of COVID-19 infection".[16] The focus of the current study was on using testing data to help properly interpret the data on confirmed cases and deaths. In the present study, a global data set on COVID-19 testing on the building was focused. The current study has detected a strong correlation between the number of COVID-19 tests and the number of confirmed COVID-19 cases. This means that the number of confirmed cases depends on how much a country performed tests. Without testing, there are no data and no way to understand the pandemic. It can be said that testing is a window into the pandemic and how it is spreading, and without data on who is infected by the virus, there is no way of understanding the pandemic.

One important way to understand if countries are testing sufficiently is to look at the share of tests returning a positive result—known as the positive rate. The WHO suggested that a positive rate should be around 3-12% as a general benchmark of adequate testing.[17] The mean positive rate was 9.6% in all countries, and enormous differences across countries were seen. Some countries like China, Vietnam, Hong Kong, New Zealand, Australia, Cuba, and Taiwan have a positive rate of less than 1% although others such as Mexico, Argentina, Bolivia, and Brazil have positive rates of 25-50% or even more. In these countries, a case is found for every few tests conducted. In countries with a very high positive rate, it is unlikely to be testing widely enough to find all cases. As stated above, it is known that countries with a positive rate of less than 1% protect their citizens better from the pandemic than countries with positive rates of 25-50% or even more. In the present study, it was determined that countries with low-positive rates had a fewer COVID-19 patients pmp ($P < .001$), fewer COVID-19 deaths ($P < .001$), and a fewer fatality rate ($P < .001$) than those with high-positive rates.

Another way of looking at the extent of testing relative to the scale of the pandemic ask how many tests a country performs to find one COVID-19 patient. This question is simply the inverse of the present data on the positive rate. Countries that performed very few tests per confirmed case are unlikely to be testing widely enough to find all cases.[17] It has been suggested that between 10 and 30 tests per confirmed case as a general benchmark of adequate testing by the WHO. The worldwide test median per confirmed case was 12.6, and this number varied enormously between countries.

In the current study, it was determined that these differences are caused by income inequality in countries. A strong positive correlation was found between the number of

Table 4. Relationships Between the Number of COVID-19-Related Deaths pmp, Fatality Rate, and Variables

	COVID-19-Related Deaths pmp		Fatality Rate*	
Variables	rho Coefficient	*P*	rho Coefficient	*P*
Age	0.520	<.001	-0.020	.778
Rate of people over 65 years of age	0.550	<.001	0.115	.138
Smoking rate	0.289	<.001	0.154	.031
CVD mortality rate	0.180	.022	0.006	.941
DM prevalence	0.105	.173	−0.131	.101
Hospital beds (per thousand people)	0.406	<.001	−0.052	.519
Examination rate	0.539	<.001	−0.181	.011
Gini coefficient	−0.225	.006	0.037	.647
GDP	0.276	<.001	0.101	.118
GPD per capita	0.465	<.001	−0.098	.199
Extreme poverty rate	−0.458	<.001	0.075	.382
Life expectancy	0.482	<.001	−0.048	.514
HDI ranking	−0.545	<.001	0.033	.670
P80/P20	−0.236	.004	0.003	.968

*It was calculated as the number of COVID-19-related deaths/the number of COVID-19 patients.
CVD, cardiovascular disease-related; DM, diabetes mellitus prevalence; GDP, gross domestic product; HDI, human development index; P80/P20, calculated as the ratio of total income received by the 20% of the population with the highest income (the top quintile) to that received by the 20% of the population with the lowest income (the bottom quintile).

COVID-19 tests and GDP per capita whereas a strong negative correlation was detected between HDI ranking and the number of COVID-19 tests. Besides, the increase in the countries' Gini coefficient, extreme poverty rate, and P80/P20 ratio was associated with the decrease in the number of COVID-19 tests. In countries with high-income inequality, less testing has been performed. In a study that investigated the success of containment, it was concluded that the containment rate is explained by GDP alone.[9]

Naturally, in countries where the number of tests is low, both the number of COVID-19 patients pmp and the number of COVID-19-related deaths pmp have been lower. On the other hand, the reason for this is under-ascertainment. The absence of comparable pandemics in many African countries is notably perplexing although the pandemic has strained health systems to near-capacity in many high-income countries.[18] Under-reporting of COVID-19 deaths is a likely explanation of these patterns; however, it is difficult to measure given that vital registration systems and excess mortality data are absent in many countries.[19] The "Africa paradox" that was called why COVID-19 would not spread as efficiently in Nairobi, Accra, or Lagos as it has in New York City, London, or Mumbai has may explain with insufficient data.[20] In September, in a published report, it was estimated that only 1 in 80 deaths due to COVID-19 have likely been reported in Damascus, Syria.[21] In another report, the authors estimated there were 16 090 (95% CI: 14 300–17 990) undetected COVID-19 deaths from April to November in Khartoum, Sudan.[21] In a systematic post-mortem surveillance study in Africa, it was observed that the impact of COVID-19 in Africa has been vastly underestimated.[20,22]

It was observed that the fatality rate was not affected by the income inequality of the countries, although countries with income inequality had fewer COVID-19-related deaths than countries with less income inequality (Table 4). That made think that the disadvantaged classes such as workers, poor people, and refugees in the country could not be tested, and their COVID-19-related deaths were not recorded, that the advantageous classes could get tested and even if they live in a poor-income country, they are at risk of death only as much as those living in the rich country.

It is well known that, among the countries, it is not the richest societies that have the best health, but those which have the smallest income inequality differences between rich and poor.[23] It is suggested that income inequalities could be a predictor for the investment in, and popular support of, public services.[24] It is also known that countries that had income equality are made better use of public resources, whereas the combination of poverty and poor public health contributes to both the number of COVID-19 tests and the number of COVID-19 cases and deaths. In a study that investigated the distribution of tests for COVID-19 across income levels, it was observed that COVID-19 tests are almost perfectly distributed across income groups in New York City.[25] In Toronto, the 20 neighborhoods with the highest minority proportion and lowest household income population and the 20 neighborhoods with the lowest minority proportion and highest household income population were found to have differences in the number of tests per thousand people.[26] Countries with a more even distribution of income have a stronger sense of the public sector, with well-funded safety nets and services.[27,28] It may say that countries with poor income inequality metrics, therefore, have big network of laboratories for testing and a strong federal public health network, and these countries were accepted as successful countries in pandemic crises. They are also known to do more testing. This may suggest that countries with low levels of income inequality were simply more prepared and were in a stronger position to cope with the COVID-19 crisis.[27] There were some limitations. First, the total number of people infected with COVID-19 all over the world is not known. All it was known is the infection status of those who have been tested. Second, the indications of COVID-19 tests are not the same in each country. On the other hand, while some countries may report the number of people tested, others report the number of tests. Besides, some countries report their testing data in a way that leaves it unclear what the test count refers exactly. Third, confusion continues over whether people die "of" COVID-19 or "with" COVID-19. What defines a COVID-19 death? The answer remains still complicated, and the debate about

the COVID-related death counts continues. Many scientists still doubt the official totals. Data on excess deaths may suggest coronavirus death tolls are likely an underestimate. In April 2020, the WHO states that "a death due to COVID-19 is defined for surveillance purposes as a death resulting from a clinically compatible illness, in a probable or confirmed COVID-19 case, unless there is a clear alternative cause of death that cannot be related to COVID disease," and European Centre for Disease Prevention and Control later on also adopted these inclusion criteria in May 2020.[29,30] However, it should be noted that there are still many differences among countries about the COVID-related death definition. Although strict compliance to social distancing is better achieved in developed countries was suggested, some countries, such as Sweden, are examples that do not fit this.

In conclusion, regarding the increase in the number of COVID-19 tests, the number of COVID-19 patients detected is increasing. Income inequality in countries determines the number of COVID-19 tests. Since income inequality in countries affects COVID-19 test numbers, many COVID-19-related deaths may be overlooked in countries with poor-income inequality metrics.

Ethics Committee Approval: The Institutional Review Board of institutions approved the data analyses, and ethics committee approval was not necessary obtained for the present study as it was an internet-based study.

Informed Consent: Not applicable since the present study was an internet-based study.

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