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The Impact of Social Inequalities, Aging Populations, and Vaccination Disparities on COVID-19 Mortality Burden Worldwide

Grace A. O'Neill[1]*, Patrick J. Byrne[1], Fiona M. Doyle[1]

[1]Department of Psychology and Health, School of Applied Psychology, University College Cork, Cork, Ireland.

***E-mail** ✉ grace.oneill@outlook.com

Abstract

Since its emergence, COVID-19 has placed severe strain on societies worldwide, with deaths occurring more frequently among older adults and people with chronic health conditions. Marked international differences in infection outcomes and case fatality rates (CFRs) have prompted investigation into the role of demographic and social conditions in shaping COVID-19 mortality. This study assessed how population age structure, disparities in human development, healthcare resources, and pandemic response measures contribute to cross-national and regional variation in COVID-19 CFRs. A cross-sectional analysis was performed using publicly available secondary data compiled from multiple global databases. Countries were grouped by region to examine differences in COVID-19 CFRs and to evaluate the extent to which selected sociodemographic characteristics and mitigation indicators explained observed regional patterns. COVID-19 CFRs differed considerably across world regions, alongside pronounced variation in the examined indicators. The highest average CFR was observed in South America (1.97% ± 0.74), whereas Oceania exhibited the lowest (0.26% ± 0.11). African regions consistently showed the weakest performance in terms of vaccination coverage, pandemic readiness, and related measures. Regression analysis identified population median age, vaccination coverage, and the Inequality-Adjusted Human Development Index (IHDI) as significant determinants of COVID-19 fatality rates. Higher median age and greater developmental inequality were associated with increased CFRs, while higher vaccination uptake was linked to reduced mortality. Differences in COVID-19 fatality rates across regions are closely tied to demographic composition, social inequality, and the effectiveness of pandemic control strategies. Countries with older populations, greater inequality in human development, and limited vaccination coverage experience disproportionately higher COVID-19 mortality.

Keywords: Social inequalities, COVID-19, Vaccination, Aging populations

Introduction

The outbreak of Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), first identified toward the end of 2019 and widely known as COVID-19 [1], rapidly escalated into a global pandemic, profoundly disrupting social, economic, and health systems worldwide [2, 3]. Despite extensive efforts by public health authorities to curb transmission through established interventions, including vaccination campaigns, the virus has continued to spread across populations, resulting in mounting death tolls and placing unprecedented pressure on healthcare systems globally [4, 5].

Although scientific understanding of COVID-19 continues to evolve as new evidence emerges [6], a consistent pattern has been observed in terms of disease severity and mortality. Older adults and individuals with pre-existing health conditions—such as obesity, diabetes, and cardiovascular disease—have been shown to experience disproportionately worse outcomes following infection [7, 8]. Given this heightened vulnerability among older age groups, it is reasonable to expect that countries with younger population structures may exhibit lower COVID-19 case fatality rates (CFRs) than those with more aged populations.

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As the pandemic has progressed and more comprehensive data have become available, pronounced differences in COVID-19 incidence and mortality have been documented both within and between countries with diverse socioeconomic profiles and health system capacities. These disparities have driven increased scholarly interest in examining how social determinants and healthcare infrastructure shape COVID-19 outcomes [2, 6, 9-12]. For example, a study published in 2020 reported significant relationships between COVID-19 CFRs and indicators such as gross domestic product (GDP) per capita, physician density, and health expenditure, suggesting that lower-income countries could face higher fatality rates [9]. Similarly, other researchers have projected poorer COVID-19 outcomes in settings characterized by weak health infrastructure and limited system capacity [10]. Evidence from the United States has also demonstrated elevated CFRs in economically disadvantaged neighborhoods [11]. Conversely, another contemporary study attributed Africa's relatively low reported COVID-19 CFRs to its younger population profile and lower life expectancy, resulting in a smaller proportion of elderly individuals [12].

Against this background, the present study examined the influence of pandemic preparedness, critical care availability, COVID-19 vaccination coverage, population median age, and inequality in human development on country-level COVID-19 CFRs worldwide. In addition, regional analyses were conducted to illustrate geographic patterns and differences in fatality rates across global regions.

Materials and Methods

Study variables and data collection

The primary outcome variable for this study was the COVID-19 case fatality rate (CFR), defined as the proportion of confirmed COVID-19 deaths relative to the total number of confirmed COVID-19 cases, expressed as a percentage. Country-specific CFRs were calculated using data from the World Health Organization (WHO) COVID-19 database as of January 26, 2022 [13].

Population median age was included as a key demographic variable, with 2021 country-level data obtained from Worldometer [14]. In addition, four explanatory variables were selected to capture pandemic preparedness, healthcare capacity, mitigation efforts, and social inequality. These included the Global Health Security Index (GHSI) as a measure of national pandemic preparedness, intensive care unit (ICU) bed capacity as an indicator of critical care availability, full COVID-19 vaccination rate per 100 population (Vac/100), and the Inequality-Adjusted Human Development Index (IHDI). Data for GHSI were sourced from the Johns Hopkins Center for Health Security [15], ICU bed capacity from a compilation of multiple international sources [16], vaccination rates from the WHO COVID-19 dashboard dated January 26, 2022 [17], and IHDI values from the United Nations Development Programme (UNDP) [18].

Median age represents a summary measure of a population's age distribution, identifying the age that divides the population into two equal halves—one younger and one older [19]. Given existing evidence demonstrating increased COVID-19 mortality among older individuals [7, 8], population median age was incorporated to assess the relationship between age structure and COVID-19 CFRs at both national and regional levels.

The Global Health Security Index is a comprehensive benchmarking tool designed to evaluate a country's capacity to prevent, detect, and respond to infectious disease threats, including pandemics such as COVID-19. Introduced in 2019, the GHSI combines multiple dimensions of health security, encompassing health system robustness, surveillance and reporting capabilities, and rapid response mechanisms aimed at controlling disease spread [15].

In response to the COVID-19 pandemic, multiple vaccines have been developed and deployed globally. A growing body of evidence indicates that full vaccination substantially reduces disease severity and mortality associated with COVID-19 [20, 21]. However, vaccination coverage remains highly uneven across and within countries [13], largely due to disparities in vaccine access and distribution. To account for these differences, vaccination rate per 100 population (Vac/100) was included to evaluate its association with national COVID-19 CFRs.

The Inequality-Adjusted Human Development Index (IHDI) was incorporated to capture the impact of unequal distribution of human development outcomes on COVID-19 mortality. The IHDI modifies the Human Development Index (HDI) by accounting for disparities in health (measured by life expectancy at birth), education (mean and expected years of schooling), and income (gross national income per capita) within populations [22]. In light of evidence showing that

COVID-19 mortality has disproportionately affected socioeconomically disadvantaged, marginalized, and minority populations in the United States [23], this study sought to explore whether similar patterns are observable at the global level.

Finally, ICU bed capacity per 100,000 population was included as an indicator of a country's ability to manage severe and life-threatening COVID-19 cases. Because critical illness from COVID-19 often requires specialized intensive care to improve survival and recovery, it was hypothesized that greater ICU capacity at the national level would be associated with lower COVID-19 CFRs.

Data analysis

The assembled dataset was first screened for completeness, after which any country lacking information for one or more study variables was excluded. An additional preliminary screening focused on identifying extreme CFR values, and countries identified as outliers were removed. From an initial pool of 190 countries, 74 were excluded because they either reported no confirmed COVID-19 cases or deaths or had incomplete data across the explanatory variables. This process yielded 116 eligible countries. Further inspection identified six countries with CFR values exceeding 5—Ecuador (5.04), Egypt (5.44), Sudan (6.10), Mexico (6.50), Peru (6.94), and Yemen (18.85)—which were removed from subsequent analyses. The final analytical sample therefore consisted of 110 countries.

To guide the selection of appropriate statistical methods, the distributional properties of all variables were examined. Skewness estimates ranged from 1.605 for ICU bed capacity per 100,000 population to −0.408 for vaccination rate per 100 population, while kurtosis values varied between 2.915 for ICU bed capacity per 100,000 population and −1.312 for median age. All values fell within acceptable limits for normality as defined by Hair *et al*. [24]. These results were consistent with visual assessments of histogram distributions. On this basis, parametric statistical techniques were applied in the main analyses.

Summary statistics, including means and standard deviations, were then calculated for the outcome variable and all predictors. Prior to regression modeling, the dataset was evaluated for multicollinearity. Variance inflation factor (VIF) values ranged from 6.99 for IHDI to 1.70 for ICU beds per 100,000 population. As these values were below the commonly accepted cutoff of 10 [25], multiple linear regression analysis was performed to examine the extent to which the selected variables explained variation in global COVID-19 CFRs.

Results and Discussion

Global distribution of CFR

A global mapping of COVID-19 CFRs was generated for 190 countries to illustrate geographic variation in fatality rates **(Figure 1).** CFR values between 0 and 0.5% were observed in 33 countries, while 38 countries recorded CFRs between 0.51% and 1%. The largest group, comprising 64 countries, fell within the 1.01–2% range, whereas 44 countries exhibited CFRs between 2.01% and 4%. An additional 11 countries reported CFRs exceeding 4%.

At the lower end of the spectrum, Greenland and Iceland recorded particularly low CFRs of 0.04% and 0.07%, respectively, reflecting minimal mortality relative to confirmed infections. In contrast, Yemen emerged as a clear outlier with a CFR of 18.85%. Elevated CFRs were also observed in Mexico, Peru, and Sudan, each exceeding 6%.

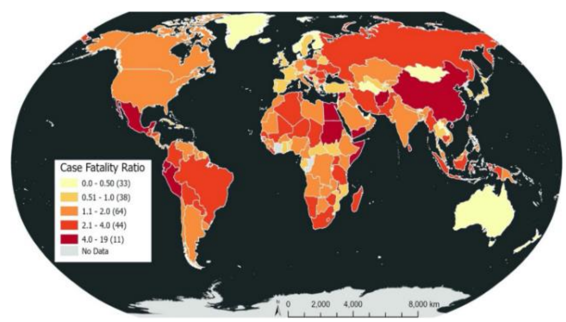

Figure 1. Global choropleth representation of COVID-19 case fatality rates (CFRs) across 190 countries (values in parentheses indicate the number of countries within each CFR category)

Descriptive analysis

The descriptive statistics presented in **Tables 1 and 2** are based on a final analytical sample of 110 countries distributed across global regions, including 26 countries from Africa, 27 from Asia, 32 from Europe, 13 from North and Central America, 10 from South America, and 2 from Oceania. At the global level, the mean COVID-19 CFR across all included countries was 1.544% of reported cases. Iceland exhibited the lowest observed CFR at 0.075%, while Bosnia and Herzegovina recorded the highest value at 4.215%.

Regional comparisons revealed notable variation in fatality rates. South America recorded the highest average CFR at 1.973%, whereas Oceania demonstrated the lowest mean CFR at 0.264%.

Table 1. Summary statistics for selected socioeconomic and COVID-19 CFR indicators

Variable	Mean	Sample Size (N)	Standard Deviation	Maximum	Minimum
Population Median Age (years)	32.03	110	9.087	47.3	15.8
Case Fatality Rate (CFR, %)	1.544	110	0.910	4.215	0.075
ICU Beds per 100,000 Population	6.89	110	7.09	34.7	0.1
Inequality-Adjusted Human Development Index (IHDI)	0.640	110	0.183	0.899	0.303
Global Health Security Index (GHSI)	44.657	110	13.519	75.9	20.9
Vaccinations per 100 People	48.597	110	25.935	88.102	0.696

Median Age, Case Fatality Rate (CFR), Inequality-adjusted Human Development Index (IHDI), Global Health Security Index (GHSI), ICU Beds Per 100,000 Population (ICU), Vaccination rate (Vac/100)

Table 2. Regional descriptive statistics for COVID-19 case fatality rate and key indicators

Variable	Statistic	Africa [26]	Asia [27]	Europe [28]	North and Central America [13]	South America [10]	Oceania [2]
Population Median Age (years)	Mean	22.211	30.889	41.624	30.308	30.538	38.300
	Standard Deviation	6.794	6.720	2.670	6.431	3.593	0.566
Vaccinations per 100 People	Mean	21.782	51.099	62.600	52.204	59.332	79.395
	Standard Deviation	23.295	23.011	16.594	20.127	19.734	1.247
Global Health Security Index (GHSI)	Mean	32.637	44.567	54.706	43.131	41.025	66.800
	Standard Deviation	7.445	11.648	9.000	15.529	12.414	6.081
ICU Beds per 100,000 Population	Mean	1.681	6.481	11.206	6.000	9.613	6.400
	Standard Deviation	2.612	6.919	6.067	9.280	7.669	3.818
Case Fatality Rate (CFR, %)	Mean	1.804	1.488	1.310	1.654	1.973	0.264
	Standard Deviation	0.779	0.961	0.980	0.780	0.742	0.107
Inequality-Adjusted Human Development Index (IHDI)	Mean	0.434	0.641	0.818	0.601	0.636	0.772
	Standard Deviation	0.125	0.140	0.062	0.141	0.117	0.124

Case Fatality Rate (CFR), Standard Deviation (SD), Inequality-adjusted Human Development Index (IHDI), Median Age, Vaccination rate (Vac/100), ICU Beds per 100,000 Population (ICU), Global Health Security Index (GHSI)

Analysis of population age structure indicated that the global mean median age was approximately 32.2 years, with a standard deviation of about 9.1 years. Uganda was identified as having the youngest population, with a median age of 15.8 years, whereas Japan had the oldest population, recording a median age of 47.3 years. At the regional level, Africa exhibited the lowest median age at 22.2 years, while Europe had the highest regional median age of 41.6 years.

Assessment of pandemic preparedness using the Global Health Security Index (GHSI) showed a global mean score of 44.657, with a standard deviation of 13.519. Venezuela recorded the lowest GHSI score at 20.9, in contrast to the United States, which achieved the highest score of 75.9. Regionally, Africa had the lowest average GHSI value at 32.6, while Oceania recorded the highest regional average of 66.8. With respect to inequality in human development, the global mean IHDI score was 0.640, with a standard deviation of 0.183. Comoros had the lowest IHDI value at 0.303, while Norway recorded the highest score of 0.899. Consistent with these findings, Africa had the lowest regional IHDI average at 0.434, whereas Europe recorded the highest at 0.818.

Global COVID-19 vaccination coverage averaged 48.597 fully vaccinated individuals per 100 population, with a standard deviation of 25.935. Haiti reported the lowest vaccination rate at 0.696 per 100 population, while Chile recorded the highest at 88.102. Regional comparisons indicated that Oceania had the highest mean vaccination coverage at 79.395 per 100 population, whereas Africa recorded the lowest regional average at 21.782.

Regarding critical care capacity, the global mean number of ICU beds was 6.89 per 100,000 population, with a standard deviation of 7.09. Malawi reported the lowest ICU bed availability at 0.1 per 100,000 population, while the United States had the highest availability at 34.7 per 100,000 population. At the regional level, Africa recorded the lowest average ICU bed capacity at 1.68 per 100,000 population, whereas Europe exhibited the highest capacity.

Inferential analysis

Inferential findings from the final Ordinary Least Squares (OLS) regression model are summarized in **Table 3.** The model, which regressed COVID-19 CFR on median age, IHDI, ICU bed capacity, vaccination rate per 100 population, and GHSI, was statistically significant ($F(5, 104) = 7.907$, $p < 0.001$), with an R^2 value of 27.5%. This indicates that the combined set of explanatory variables accounted for 27.5% of the observed variation in global COVID-19 CFRs.

Among the predictors included in the model, IHDI, population median age, and vaccination rate per 100 population emerged as statistically significant determinants of COVID-19 CFR. The direction of these associations suggests that greater inequality in human development and older population age structures are linked to higher fatality rates, while higher vaccination coverage is associated with reduced COVID-19 mortality. **Figure 2** presents a plot of regression residuals against fitted CFR values, demonstrating no discernible regional pattern in residual dispersion.

Table 3. Final multiple regression model predicting COVID-19 case fatality rate

Variable	B [95% CI]
Population Median Age	0.073 [0.033 to 0.113]*
Intercept	2.257 [1.576 to 2.937]
ICU Beds per 100,000 Population	0.001 [−0.026 to 0.029]
Vaccinations per 100 People	−3.389 [−5.570 to −1.208]*
Global Health Security Index (GHSI)	−0.005 [−0.024 to 0.014]
Inequality-Adjusted Human Development Index (IHDI)	−0.014 [−0.023 to −0.004]*
F Statistic	7.907
R^2	0.275
P-Value	< 0.001

Inequality-adjusted Human Development Index (IHDI), Global Health Security Index (GHSI), Median Age, Vaccination rate (Vac/100), ICU Beds Per 100,000 Population (ICU)

*Significant at 95% CI

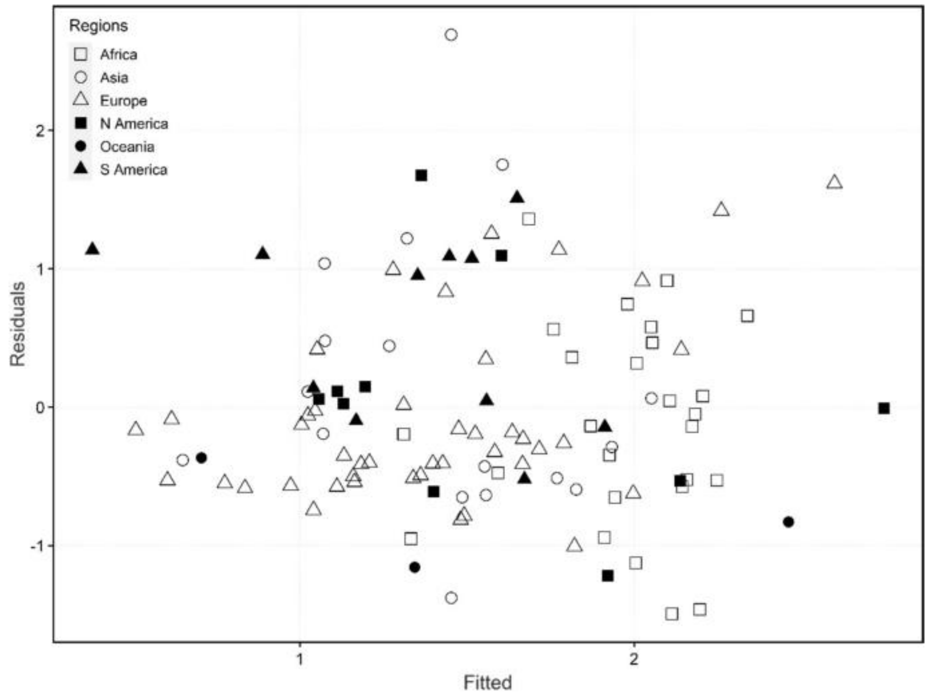

Figure 2. Residual plot of the regression model

Differences in countries' existing socioeconomic conditions and health system capacities are likely to shape their ability to respond effectively to the COVID-19 pandemic and may help explain observed variation in case fatality rates (CFRs) across nations and regions. Early investigations conducted at the beginning of the pandemic identified or predicted associations between COVID-19 CFRs and factors such as population age structure, life expectancy, gross domestic product (GDP) per capita, healthcare spending, hospital bed availability, and physician density [9, 12, 25, 26]. Building on this prior work, the present study used more recent COVID-19 data to examine how inequality in human development, median population age, pandemic preparedness, vaccination coverage, and critical care capacity relate to COVID-19 CFRs at both global and regional levels. Regional comparisons were additionally undertaken to emphasize geographic differences in fatality patterns. Particular attention was given to understanding the roles of socioeconomic inequality, as measured by the IHDI, and vaccination rates, given their relevance to equity and disease prevention. Importantly, the use of current data enabled a comparison between observed fatality outcomes and projections made during the early stages of the pandemic.

Descriptive findings indicated that countries in the African region consistently recorded the lowest values across all selected indicators. Despite this, the highest average CFR was observed in South America, with Africa following closely behind. Both Africa and South America exhibited lower mean population ages compared to Europe and Oceania, supporting the notion that less economically developed regions tend to have younger demographic profiles than more developed regions. Similarly, Africa and Asia reported lower average scores for pandemic preparedness (GHSI) and COVID-19 vaccination coverage relative to Europe and North and Central America, underscoring the need for innovative and context-specific public health strategies in resource-limited settings.

Observed regional differences in GHSI, IHDI, ICU bed availability, and vaccination coverage likely reflect longstanding disparities in socioeconomic development and healthcare infrastructure. These disparities suggest that countries in lower-resourced regions may face structural disadvantages that limit their ability to respond effectively to public health emergencies such as COVID-19, thereby increasing vulnerability to higher mortality. Examination of the choropleth map of CFRs **(Figure 1)** revealed substantial variation across countries in all regions, without a consistent or uniform regional pattern. This lack of clear clustering was also evident in maps generated using only countries included in the regression analysis. Such findings highlight the heterogeneity within regions, particularly with respect to demographic composition, and suggest that within-region differences—such as variation in population median age—may influence regional comparisons.

Regression analysis identified population median age, inequality-adjusted human development (IHDI), and vaccination rate as statistically significant predictors of COVID-19 CFR. Specifically, higher median age was associated with increased fatality rates, indicating that countries in Europe, Oceania, and North and Central America—where older populations are more prevalent—may experience higher CFRs compared to regions with younger populations, including Africa, South America, and parts of Asia. This observation aligns with previous studies reporting elevated COVID-19 mortality among older age groups across diverse settings [12, 26, 27]. A plausible explanation is the higher prevalence of chronic conditions such as diabetes, cardiovascular disease, and hypertension among older adults [29], which increases susceptibility to severe COVID-19 outcomes and death [30].

IHDI also emerged as a significant determinant of COVID-19 CFR, with results indicating that greater inequality in human development is associated with higher fatality rates. In practical terms, countries characterized by wider disparities in health, education, and income distribution tend to experience worse COVID-19 mortality outcomes, whereas more equitable societies demonstrate lower CFRs. The relevance of this finding is underscored by the structure of the IHDI, which explicitly accounts for unequal distribution of life expectancy, educational attainment, and income within populations [22]. Individuals in lower socioeconomic strata often face barriers to preventive measures and timely medical care due to financial, structural, and systemic constraints, increasing their vulnerability to severe disease. This pattern mirrors findings from earlier studies that documented disproportionately worse COVID-19 outcomes among poorer communities [11] and emphasizes the need for sustained global investment, particularly in economically disadvantaged countries.

Vaccination coverage was the third significant predictor identified in the regression model, with higher vaccination rates corresponding to lower COVID-19 CFRs. This result reinforces existing public health evidence demonstrating that COVID-19 vaccines substantially reduce the risk of severe illness, hospitalization, and death [20, 21]. Beyond confirming vaccine effectiveness, this finding highlights the central role of vaccination in controlling the pandemic at a global scale. Persistent inequalities in vaccine access and distribution across countries remain a major concern, as continued disparities may facilitate the emergence of new viral variants capable of prolonging the pandemic and intensifying its social and economic consequences [31]. Coordinated international efforts—particularly those aimed at equitable resource allocation and vaccine distribution—are therefore essential to achieving sustained pandemic control.

Given mixed findings in earlier research regarding differences in COVID-19 outcomes between urban and rural populations [28, 32], the present study also examined the potential influence of urbanization on CFRs. However, the inclusion of an urbanization variable did not materially alter the regression results. The same predictors—median age, IHDI, and vaccination rate—remained statistically significant, leading to the exclusion of urbanization from the final model.

Several limitations should be considered when interpreting these findings. Definitions and reporting practices for COVID-19–related deaths vary across countries, contributing to inconsistencies in CFR estimates [33]. Differences in resource availability may further influence reporting accuracy, as high-resource countries often have more robust systems for death certification and surveillance [27], whereas low-resource countries may underreport COVID-19 deaths due to limited testing and monitoring capacity [34]. Such factors may result in either underestimation or overestimation of CFRs. Additional challenges arise from the evolving nature of the pandemic, including shifts in dominant variants, changing public health responses, and country-specific policy priorities over time. Finally, incomplete data for some variables across certain countries limited the scope of the analysis.

Despite these limitations, the study has notable strengths. These include the use of up-to-date COVID-19 data from the World Health Organization, the restriction of analyses to countries with complete data for all variables of interest, and the incorporation of regional comparisons to highlight geographic disparities in COVID-19 CFRs.

Conclusion

The lower median age in many countries likely played a key role in reducing the expected higher COVID-19 case fatality rates (CFRs) in resource-limited nations, particularly in regions like Africa, during the initial stages of the pandemic. However, the identification of low vaccination coverage and substantial disparities in human development as strong predictors of COVID-19 CFR underscores the urgent need for coordinated, proactive international efforts to address inequities in the allocation of socioeconomic resources and COVID-19 vaccines. Such measures would strengthen the capacity of less-resourced countries to manage the current pandemic effectively and enhance their preparedness for future outbreaks, ultimately benefiting the global population. Lastly, given the evolving nature of the pandemic, additional research is essential to gain a more comprehensive understanding of the diverse factors influencing COVID-19 morbidity and mortality.

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