Joint External Evaluations as Predictors of Excess Mortality During the COVID-19 Pandemic

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Abstract

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As the world enters the interpandemic period, it is essential that global health leaders accelerate preparedness and resilience against the next pandemic, building upon hard-fought COVID-19 experiences. To adequately prepare for the next pandemic, global health leaders must discriminate between effective and ineffective measures using universally applicable metrics and compensate for disparities in disease detection and reporting systems. World Health Organization (WHO)-led Joined External Evaluations (JEE) are conducted collaboratively between recognized experts and nations requesting the evaluation. This study intends to understand whether JEEs can serve as predictors for the ultimate outcome from pandemics, excess morality, or whether non-technical factors must be incorporated into a more comprehensive prediction of pandemic preparedness that allows counties opportunities to address specific weaknesses.

The authors used 103 publicly available JEE reports conducted during 2016 through 2019 and WHO estimates of excess mortality for 2020 and 2021 to regression modeling of technical indicators, their sums in a given technical area, and the sums of the Prevent, Detect, and Respond domains.

Estimated excess deaths among high- and low-income countries were both significantly lower than those of middle-income countries but did not differ significantly from one another. No preparedness domain, technical area, or individual indicator correlated with decreased mortality across all countries or across all income strata, although the technical area of "National legislation, policy, and financing" and the indicator "Mechanisms for responding to zoonoses and potential zoonoses are established and functional" both correlated with higher excess mortality during the pandemic.

Currently, Joint External Evaluations are likely competent vehicles to gauge countries' assessment of their progress towards meeting metrics that WHO states are important in improving preparedness against emerging health threats and pandemics as lain out in the IHR (2005). Variability in death registry completeness likely played a large role in the incongruous findings. Expanding the aperture of technical assessments to include bedrock aspects of pandemic preparedness systems such as supply chains and public trust, approaching pandemic preparedness as a global community, and improving vital statistics capture can lay the foundation for measurable indicators that ideally correlate with earlier detection and successful pandemic response.

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Table of Contents

Introduction	1
Literature Review	5
Methods	7
Results	10
Discussion	18
References	25

Introduction

As the world enters the interpandemic period, it is essential that global health leaders accelerate preparedness and resilience against the next pandemic building upon hard-fought COVID-19 experiences. Likely between October and November 2019, the People's Republic of China began to experience the first cases of viral infection with what would become known as Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2) and its clinical manifestation Coronavirus Infectious Disease-19 (COVID-19).[i] In late December 2019, after hospitals in Wuhan had identified cases with similar pathologies, the Wuhan Municipal Health Commission in Hubei Province, People's Republic of China publicly reported the first cases of severe respiratory disease of unknown etiology.[ii] [iii] [iv] Within days, Chinese researchers had reported the presence of a novel coronavirus in patients affected by this condition.[v] By January 19, the Washington Department of Health reported to the U.S. Centers for Disease Control (CDC) and Prevention a person with recent onset cough and fever, after travel to Wuhan, China. By January 20, CDC laboratories detected 2019-nCoV by real-time reverse-transcriptase–polymerase-chain-reaction (rRT-PCR), making this the first laboratory-confirmed COVID-19 case in the U.S.[vi] Within weeks the virus had spread to multiple continents and on March 11, 2020 World Health Organization (WHO) Director General Tedros Ghebreyesus declared that the COVID-19 pandemic had begun.[vii] Three years later, on May 5, 2023, after more than 700 million confirmed cases, the Director General declared that the COVID-19 pandemic had evolved into a persistent but no longer emergency health threat. [viii] [ix] WHO estimates that by the start of 2022, the world had suffered almost 5.5 million reported COVID-19 deaths and over 14.8 million excess deaths from all causes.[x] [xi] The inevitable yet difficult-to-predict nature of pandemics requires consistent global expenditure of time and treasure to prepare for events that might occur once every generation or, as the world has experienced, once a decade so far this century. Even before the May 2023 declaration, the global health community has begun evaluating the world's response to the COVID-19 pandemic and searching for ways to prepare for or prevent the next. In August 2020, Aitken et al. analyzed Global Health Security Index (GHSI) scores, which measure technical and policy preparedness against infectious diseases, against daily confirmed COVID-19 cases and deaths.[xii] They found that increased proficiency, as measured by the GHSI, correlated with higher numbers of both. Authors in that study recommended against technical capacities assessments of individual countries in favor of looking at global health systemically. In late 2021, Duong et al. expanded the search for technical capacities that could explain COVID-19 cases and deaths beyond GHSI scores to JEE scores, the International Health Regulation (2005, IHR) Self-Assessment Annual Reports, Universal Health Coverage Service Coverage Index, and the Worldwide Governance Indicator that found no significant correlation with pre-pandemic assessments and confirmed cases or deaths after a few months into the pandemic.[xiii] Missing among most pre-pandemic assessments was the resilience of the healthcare system and the framework in which that system operates. Studies have developed frameworks for assessing systemic resilience in preparing for the next pandemic including hospital bed occupancy rates, intensive care unit capacity per capita as indicators of readiness to address pandemic-related illnesses and border controls, and movement restrictions as methods to slow pandemic spread within a country.[xiv] [xv] While universal healthcare has various interpretations, the specific act of providing health insurance to all individuals within the United States could save hundreds of thousands of lives.[xvi] Some factors were found to correlate with increased COVID-19 infection rates but cannot be addressed through preparedness measures such as population density and altitude.[xvii]

With vast global disparities in healthcare systems, resources, and technical capability to acquire and share data, how can public health gauge successful pandemic response and resilience and assess what factors contributed to them? Popular metrics of success are the number of cases and the number of deaths officially reported through IHR channels using National Focal Points.[xviii] While this provides a measure of standardization, it still leaves unaddressed the notion that all countries tally cases and deaths in the same manner using the same criteria and are physically able to capture cases and deaths through a quality reporting system. As nearly all diseases exist along a severity spectrum, public health officials accept that mild or asymptomatic cases will be vastly undercounted. In countries with underdeveloped or under-resourced healthcare systems, hospitalizations and intensive care unit (ICU) admissions cannot serve as accurate proxies of severe infections. The lack of hospital or ICU beds results in a proportionally smaller number of admissions, which creates a surveillance artifact suggesting that the disease is relatively less severe in those countries. This leaves reported case numbers as unreliable global metrics for retrospective analyses and prospective planning.

Community, symptom-based surveillance relied on the presence of non-specific viral symptoms, which could be attributed to a number of infections, especially during winter months.[xix] During the first two Northern Hemisphere typical seasons of the pandemic, countries saw very little influenza and so the symptom-based surveillance could have been relatively reliable.[xx] However, the 2022-2023 influenza season was severe and accompanied by a significant increase in pediatric respiratory syncytial virus cases, which would confound any attempt at symptom-based COVID-19 surveillance in this period.[xxi] [xxii] [xxiii] Throughout the pandemic, countries used shifting case definitions to count COVID-19 cases and therefore deaths, which caused case number spikes and troughs as inclusion criteria loosened and tightened over time.[xxiv] [xxv] As home diagnostics become more prevalent and the need for centralized testing decreases, the proportion of milder cases captured through surveillance systems will proportionally drop, reducing the overall case count while leaving the hospitalized and fatal case counts untouched resulting in a perceived increase in the proportion of severe cases.[xxvi] These artificial discontinuities in surveillance data highlight the need for a metric unaffected by the shifting sands of diagnostic availability or public health surveillance capacity. They also highlight the need for improved global surveillance capabilities, if individual case reporting will be used for resource allocation, enhanced public health activities, and measures of pandemic response success. There is also the question of whether in a pandemic, where global exposure is a valid assumption, counting each case is required or whether local trends in severe or fatal cases should be sufficient to forecast needs and move personnel, equipment, and other resources in time to appropriately respond.

When evaluating pandemic preparedness, response, and resilience, mortality is a barometer of success or failure with disease-specific mortality the pinnacle metric. However, capturing disease-specific mortality is fraught with challenges. Staggering global variability in vital records standards, capacities, and policies and specifically with COVID-19 disease diagnostics and case definitions make disease-specific mortality a suboptimal variable for epidemiologic investigations. However, all-cause mortality assumes that the number of deaths above the historic mean for a country during the study period, when adjusted for conflict and natural disasters, are inferred to reflect the condition or event under study. This allows for the capture of the wider effects of the pandemic, which should be considered when gauging the efficacy of preparedness and resilience efforts. As just-in-time logistics intentionally keep on-hand stocks low and stretched-thin healthcare systems provide care with minimal staffing reserve, perturbations in supply chains or baseline processes will impact downstream operations, including the timely receipt of personal protective equipment, the postponement of preventative care services, and interruptions to chemotherapy, all of which could lead to an increase in all-cause mortality but would not be captured as directly related to COVID-19. The economic ramifications of the COVID-19 pandemic also led to increased mortality from populations unable to afford healthcare and increased prices of nutritious foods.[xxvii] During the first year of the pandemic, it was estimated that 141 million additional people in Asia and Africa could no longer afford a healthy diet and that 128,000 children would die due to secondary effects from the pandemic in 2020 alone.[xxviii] [xxix] Thus, excess all-cause mortality allows for a more complete assessment of a pandemic's human cost.

A key challenge is to identify metrics to objectively assess which aspects of national healthcare systems correlated with higher or lower number of excess deaths during the pandemic period. Joint External Evaluations (JEE) are conducted under the auspices of the World Health Organization (WHO) at the request of a government in collaboration with independent global health experts and host governments.[xxx] The JEE provides an assessment of technical capabilities for detection, assessment, notification and response found in the International Health Regulations (2005).[xxxi] According to WHO, the IHR (2005) are intended to "detect, prevent, protect against, control and provide a public health response to the international spread of disease in ways that are commensurate with and restricted to public health risks, and which avoid unnecessary interference with international traffic and trade."[xxxii] While not specific to pandemics, the JEE covers technical capacities in aspects of preparedness, response, and resiliency key to successfully navigating a pandemic. During 2016 through 2019, 104 countries participated in the JEE process, with 22 high-income, 56 middle-income, and 25 low-income countries, allowing for a more representative picture of global capacity and impacts, and one country evaluated as part of a two-country JEE was excluded because of incomplete information specific to that country. The JEE process categorizes technical capacities into four broad domains: Prevent, Detect, Respond, and Other, which contains points of entry, as well as chemical and radiation preparedness.

By using a universally agreed-upon metrics and relatively objective capacity indicators, this study hopes to assess whether the identified technical capacities alone are sufficient to successfully mitigate the worst effects of a pandemic. This analysis will also inform the international community about other necessary considerations for future preparedness and response strategies.

Literature Review

A study by Jain et al., 2022 performed regression modeling to compare countries' overall JEE scores with national infectious diseases and COVID-19-specific deaths. They found timeframe-dependent positive correlation of JEE scores with increased COVID-19-specific mortality up to six months into the pandemic that ceased to be statistically significant at and beyond that time point.[xxxiii] They found, however, that overall infectious disease mortality rate declined with increasing JEE score during that timeframe, which suggests that dynamics other than the technical capabilities measured by the JEE could factor into COVID-19 mortality. Haider et al., 2020 separately assessed JEE as well as GHSI scores with COVID-19-related mortality as well as time to detection of first COVID-19 case.[xxxiv] In that study, neither JEE nor GHSI scores significantly correlated with COVID-19 mortality. When dozens of countries requested U.S. Government assistance to confront the pandemic, Nguyen et al. (2021) asked CDC country offices to assess host nation pandemic response using JEE scores. That study described a poor correlation of JEE scores in countries requesting U.S. assistance with those same countries' response measures in the first months of the pandemic.[xxxv] Maruta et al. (2021) found that African countries' preparedness, as measured by JEE scores, were found to have statistically significantly increased COVID-19 cases compared to African countries with lower JEE scores.[xxxvi] Aitken et al., 2020 used GHSI scores, which closely correlated to JEE scores, to assess early pandemic response success and found that higher scoring countries had higher numbers of COVID-19 cases, suggesting that data capture capability likely plays a key role in these findings and should be taken into account when assessing subjective success.[xxxvii] Duong et al., 2022 looked at GHSI and State Party Annual Reporting (SPAR) scores and reported no significant correlation between these scores and COVID-19 mortality after 2 months into the pandemic.[xxxviii] This and the findings by Jain et al. regarding time-limited effects of JEE scores suggests that over time non-technical factors play an increasing role in countries ability to prevent COVID-19-related mortality.

Methods

This study correlated excess COVID-19 deaths modelled by WHO for the period of 2020-2021, with findings from 103 publicly available JEEs conducted between March 2016 and November 2019.

More specifically, the analysis used rates of excess deaths due to all causes per 100,000 population during the period of 2020–2021 inclusive as reported by WHO, based on modelled estimates, and most recently updated on May 19, 2023.[xxxix] These numbers were derived from WHO country consultation with Member States in January - March 2023. The consultation reviewed draft estimates, data sources, and methods. Countries provided primary data sources, inputs, and other feedback to include all causes of mortality, except those caused by armed conflict or natural disasters as calculated by the United Nations Population Division.[xl] [xli] Accounting for those distinct events leaves the direct and indirect effects of COVID-19 as the most likely cause of significant mortality increases globally.

We abstracted JEE scores from 103 unique publicly available JEEs performed between March 2016 and November 2019 inclusive. [xlii] A duplicate JEE was excluded from the analysis and only data for Switzerland was extracted from the joint Switzerland/Lichtenstein JEE. A key assumption of this study is that technical capacity remained unchanged despite up to three years since evaluation and the challenges of the pandemic through the end of 2021.

The multiple versions of the JEE tool used over the years presented challenges during analysis. Between 2016 and 2019, WHO introduced various JEE versions with unique variables only assessed across a small minority of countries. WHO released the most recent JEE tool in June 2022 (Appendix B). As fewer than 25 countries were evaluated on these capacities and to retain as many countries in the analysis as possible, we excluded variables P1.3 "*Financing is available for the implementation of IHR capacities*", P1.4 "*A financing mechanism and funds are available for the timely response to public health emergencies*", P5.2 "*Mechanisms are established and functioning for the response and management of food safety emergencies*", D4.4 "*A field epidemiology training program (FETP) or other applied epidemiology training program in place*", and R4.3 "*Case management procedures implemented for IHR-relevant hazards*". This left 48 capacities for analysis. Of these 48, P4.3 "*In-service trainings are available*", D2.4" *Syndromic surveillance systems*", and R2.4 "*Case management procedures implemented for IHR relevant hazards*" were not assessed in approximately a quarter of the countries. To include those capacities in the analysis, the mean of the other scores in those technical areas were substituted for those variables.

When assessing the three preparedness domains measured by the JEE: Prevent, Detect, and Respond as well as those indicators grouped as Other (Chemical Emergencies, Radiation Events, and Points of Entry), we used the sums of the individual indicator scores within those domains by country. The highest possible Prevent domain score for a country was 75, given the 15 Prevent indicators and the highest JEE score of 5. Similarly, the highest possible Detect domain score was 65, given its 13 indicators, 70 for Respond, and 30 for the Other grouping. We similarly summed the indicators in each of 19 technical areas to analyze the work in those capabilities.

As technical capacities might be insufficient to explain lower excess death rates, we also included national gross domestic product (GDP) from World Bank data as a proxy of the sum of resources available to a country to fight the pandemic.[xliii] To assess the impact of healthcare policies at a national level, we added the WHO Universal Healthcare Coverage (UHC) score as a marker for a healthcare system's overall capacity to provide care to its entire population at baseline.[xliv][xlv]

To account for differences in global income and capacity levels, we divided countries into "High Income Country" (HIC), "Middle Income Country" (MIC), and "Low" income (LIC) categories, based on available data from the World Bank.[xlvi] We further divided "Middle" income countries into "High Middle" and "Low Middle" income categories based on the same source.

We manually entered all data into Microsoft Excel for Mac 2019 and used SAS 9.4 for statistical analyses. As several countries reported negative excess mortality during the study period, we could not perform log transformation and so relied on linear regression analysis. We performed multiple linear regression models with excess mortality rate as the dependent variable. We used PROC UNIVARIATE to obtain mean and standard deviation of key variables by income level.

We performed linear regression analysis to estimate the relationship between the public health capacities measured in the JEE and excess mortality during the COVID-19 pandemic.

$$Excess\ Mortality_i = \beta_0 + \beta_1 \times Health\ Capacity_i + \beta_2 \times GDP_i + \beta_3 \times UHC_i + \epsilon_i \quad (1)$$

For country *i*, *Excess Mortality* was WHO-estimated excess mortality for 2020-2021. *Health Capacity* included: 1) each assessed indicator, 2) the sum of the indicators in each technical area, and 3) the sums of the Prevent, Detect, Respond, and Other (chemical, radiological, and point of entry) preparedness domains. *GDP* was GDP per capita and *UHC* was the universal healthcare service coverage index. We applied the analysis to all 103 assessed countries and then to each of the income categories. Countries within the MIC group exhibited statistically significant positive correlation between GDP per capita and excess mortality (0.022; p=0.0470) (Table 2). Given that finding, we included GDP as a covariate for these countries' models. For countries within the LIC group, both GDP per capita and UHC index correlated with lower excess mortality (-0.084; p=0.0190 and -3.1; p=0.0135 respectively). As a result, we controlled for both GDP per capita and UHC score for LIC.

Results

Descriptive Statistics

Using World Bank categories, the 103 country-specific JEEs fell into high (22 countries), middle (56 countries), and low income (25 countries).[xlvii] For additional sub-analysis we further divided middle-income countries into Upper Middle (UMIC) and Lower Middle income (LMIC). When assessed by income category, unexpected results were found for excess mortality. Low Income countries (LIC) as a group reported statistically significantly less excess mortality than Middle Income Countries (MIC) as a whole (66.0 vs 190.2; p=0.0001) (Table 1) and when stratified (Figure 1). Low Income countries (LIC) reported significantly lower excess mortality per 100,000 population than did MIC as a whole. There was no statistically significant difference in excess mortality between HIC and LIC (p=0.349). However, the HIC group had statistically significantly higher mean scores than the MIC and LIC groups for all technical areas (Table 1, p<0.0001 for all technical areas). The MIC group similarly had statistically higher mean scores than the LIC group most technical areas (p-value range from <0.0001 to 0.0354) except for P.6 "*Biosafety and Biosecurity*" (p=0.0794), R.1 "*Emergency Response Operations*" (p=0.1446), R.4 "*Medical Countermeasures and Personnel Deployment*" (p=0.067) and R.5 "*Risk Communications*" (p=0.080).

Table 1. Descriptive statistics of preparedness domain and technical area sum scores.

		Global	HIC	MIC	UMIC	LMIC	LIC
	Excess mortality rate [Mean Deaths Per 100k] (SD)	141.0 (188.1)	100.8 (165.8)	190.2 (220.4)	294.1 (244.6)	127.9 (180.9)	66.0 (44.1)
Prevent	Sum of Prevent Indicators	Mean Score (SD)	Mean Score (SD)	Mean Score (SD)	Mean Score (SD)	Mean Score (SD)	Mean Score (SD)
	Technical Areas						
	National Legislation, Policy, and Financing	5.4 (2.5)	8.6 (1.7)	4.9 (1.8)	5.8 (2.0)	4.4 (1.5)	3.5 (1.6)
	IHR Coordination, Communication, and Advocacy	2.8 (1.3)	4.2 (0.9)	2.6 (1.1)	3.1 (1.1)	2.3 (1.0)	1.8 (0.8)
	Antimicrobial Resistance	8.4 (4.2)	14.1 (3.1)	7.7 (3.0)	8.5 (3.2)	7.2 (2.8)	5.1 (1.7)
	Zoonotic Diseases	8.9 (3.1)	11.6 (2.6)	8.8 (2.6)	9.4 (3.0)	8.4 (2.4)	6.8 (2.8)
	Food Safety	2.7 (1.3)	4.6 (0.7)	2.5 (1.0)	2.9 (1.1)	2.2 (0.8)	1.7 (0.6)
	Biosafety/Biosecurity	4.4 (2.0)	6.9 (2.0)	3.9 (1.5)	4.5 (1.8)	3.5 (1.2)	3.3 (1.2)

	Immunization	7.7 (1.7)	9.4 (0.7)	7.5 (1.6)	7.7 (2.0)	7.4 (1.4)	6.6 (1.4)
Detect	Sum of Detect Indicators	39.3 (10.2)	53.1 (8.1)	37.4 (6.6)	40.2 (6.9)	35.8 (6.0)	31.4 (6.2)
	Technical Areas						
	National Laboratory System	12.4 (3.9)	17.5 (2.5)	11.7 (2.8)	13.0 (2.5)	10.9 (2.7)	9.4 (2.6)
	Real-Time Surveillance	12.6(2.9)	15.9 (2.4)	12.2 (2.2)	12.8 (2.4)	11.8 (2.0)	10.6 (2.2)
	Reporting	5.8 (2.0)	8.7 (1.4)	5.4 (1.4)	6.1 (0.8)	5.0 (1.2)	4.3 (0.8)
	Workforce Development	8.5 (2.7)	11.0 (2.8)	8.2 (2.3)	8.4 (2.8)	8.1 (2.0)	7.0 (1.9)
Respond	Sum of Respond Indicators	36.9 (14.6)	56.0 (8.1)	33.5 (11.7)	37.7 (12.9)	30.9 (10.3)	27.8 (9.5)
	Technical Areas						
	Response Preparedness	4.6 (2.5)	8.2 (1.7)	3.9 (1.9)	4.6 (2.1)	3.5 (1.7)	3.0 (1.2)
	Emergency Response Operations	5.2 (0.4)	16.9 (3.1)	9.6 (4.4)	10.9 (5.0)	8.8 (3.9)	8.1 (4.0)
	Linking Public Health and Security Authorities	2.8 (1.3)	4.2 (0.9)	2.6 (1.1)	3.1 (0.9)	2.4 (1.1)	2.0 (1.2)
	Medical Countermeasures and Personnel Deployment	5.0 (3.0)	8.3 (2.2)	4.4 (2.6)	5.2 (2.6)	3.9 (2.5)	3.3 (2.1)
	Risk Communication	13.7 (4.3)	18.4 (2.8)	13.0 (3.7)	13.9 (4.2)	12.4 (3.2)	11.4 (3.5)
Other	Sum of Other Indicators	14.1 (7.0)	23.3 (4.9)	13.1 (5.3)	15.6 (5.2)	11.5 (4.8)	8.2 (2.9)
	Technical Areas						
	Points of Entry	4.8 (2.6)	8.2 (1.9)	4.4 (1.9)	5.2 (1.9(	3.9 (1.7)	2.6 (0.9)
	Chemical Events	4.6 (2.5)	7.8 (1.6)	4.1 (2.0)	4.9 (2.0)	3.7 (1.8)	2.8 (1.2)
	Radiological Emergencies	4.7 (2.5)	7.3 (2.1)	4.5 (2.3)	5.5 (2.3)	3.9 (2.1)	2.8 (1.3)
	Universal Healthcare Coverage	58.4 (15.6)	78.2 (8.2)	58.5 (10.8)	65.5 (7.7)	54.3 (10.3)	40.8 (7.0)
	GDP Per Capita (USD)	11277.0 (18740.3)	41478.2 (21515.3)	4128.3 (2647.6)	6904.4 (2062.9)	2462.6 (1104.5)	713.2 (243.1)

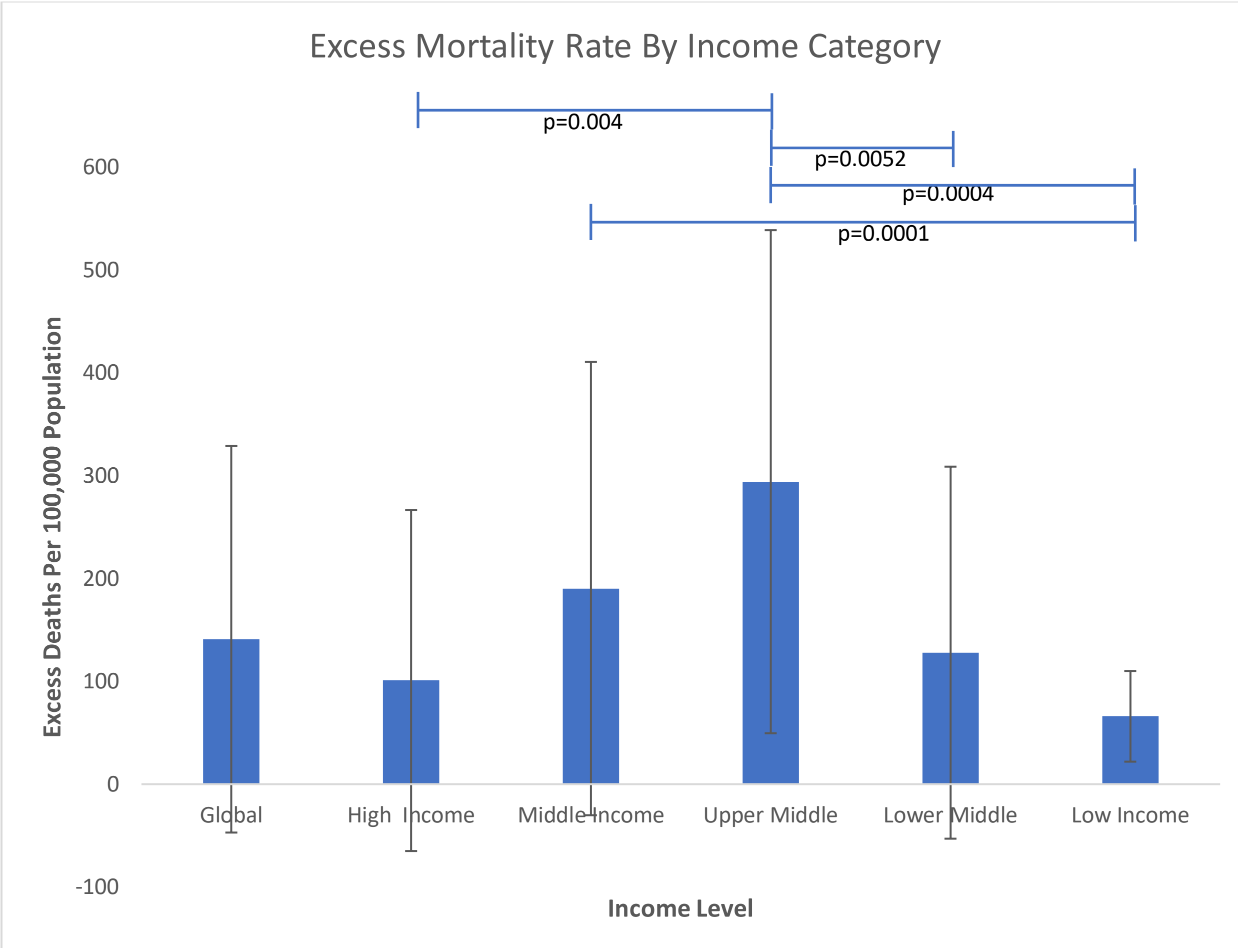

Figure 1. Excess Mortality by Income Category.

The summary of statistically significant linear regression analysis of Equation (1) results is found in Table 2.

Prevent

We found no statistically significant effect of the overall sum of Prevent indicators on excess mortality when using scores from all evaluated countries. For the technical area P.1 "*National legislation, policy and financing*", higher HEE scores positively correlated with higher excess mortality (coefficient 98.8; p=0.0281) (Table 2). Each unit increase of P.1 score summary correlated with almost 99,000 excess deaths during the study period. Of the technical indicators, P.4.3 “Mechanisms for responding to infectious and potential zoonotic diseases are established and functional” correlated with 36,000 excess deaths per unit increase (coefficient 36.3; p=0.0434). When looking at all evaluated countries, our results found no technical capacities where higher JEE scores correlated with lower excess mortality.

To account for differences in income and capacity levels, we conducted linear regression by income level: HIC, MIC, UMIC, LMIC, and LIC.

Among HIC, no statistically significant correlations were found between any Prevent-related measure and excess mortality.

Among MIC countries when controlling for GDP, P.3.4 “*Antimicrobial stewardship activities*”, P.5 (and its sole indicator P.5.1) “*Mechanisms for multisectoral collaboration are established to ensure rapid response to food safety emergencies and outbreaks of foodborne diseases*” (76.8; p=0.0453; 68.7; p=0.0347 respectively), P.6 “*Biosafety and Biosecurity*” and its indicator P.6.1 “*Whole-of-government biosafety and biosecurity system is in place for human, animal and agriculture facilities*” (39.5; p=0.0425 and 84.6; p=0.0390 respectively), and P.7.2 “*National vaccine access and delivery*” (72.1; p=0.0400) all statistically significantly correlated with higher excess mortality.

Among LMIC, we found P.6.2 “*Biosafety and biosecurity training and practices*” statistically significantly correlated with excess mortality (88.4; p=0.0311).

Among LIC after controlling for GDP and UHC we found no prevention measures that statistically significantly correlated with excess mortality.

Detect

When assessing the effect of the Detect domain among all evaluated countries the overall sum of Detect indicators and the sums of the technical areas had no significant correlation with excess mortality. Of the technical indicators, we only found only D.3.2 "*Reporting network and protocols in country*" to positively correlate with excess mortality (38.2; p=0.0220).

Among HIC, only D1.2 "*Specimen referral and transport system*" negatively correlated with increasing excess mortality (-127.0; p=0.0145) and no other variables or groupings positively correlated.

For MIC, after controlling for GDP we found that the overall sum of Detect technical indicators and the individual indicator D.1.3 "*Effective modern point-of-care and laboratory-based diagnostics*" correlated with increased excess mortality (10.0; p=0.0292 and 85.5; p=0.0242). The technical area D.3 "*Reporting*" and its indicator D.3.2 correlated with increased excess mortality (68.8; p=0.0015 and 153.6; p<0.0001 respectively). These last two also correlated in both the UMIC and LMIC strata (UMIC 68.8; p=0.0459 and 157.7; p=0.0097 respectively. LMIC 53.8; p=0.0332 and 121.9; p= 0.0059 respectively). In addition, the LMIC stratum saw positively correlation between the indicator D.1.2 and increased mortality (64.1; p=0.0299).

Among LIC, after controlling for GDP and UHC we found that the Detect laboratory indicator D.1.3 "*Effective modern point-of-care and laboratory-based diagnostics*" correlated with decreased excess mortality(-33.7; p=0.0062).

Respond

When assessing the effect of Respond domain and indicators among all countries, the overall sum of Respond indicators, the sums of the technical areas, and the individual technical indicators had no significant correlation with excess mortality. The same was true when assessing the effect of Respond indicators among HIC and MIC (including UMIC and LMIC strata). Among LIC, the indicator R.4.2 "*System in place for sending and receiving health personnel during a public health emergency*" correlated with higher excess mortality (13.3; p=0.0466).

Other Capacities

Globally, we found that higher Radiation Emergencies (CE) summary score and both of its indicators RE.1 "*Mechanisms established and functioning for detecting and responding to radiological and nuclear emergencies*" and RE.2 "*Enabling environment in place for management of radiation emergencies*" correlated with higher excess mortality (17.0; p=0.0195, 35.6; p=0.0148, and 29.8; p=0.0326 respectively). We also found this among MIC, when controlling for GDP (29.5; p=0.0210, 63.4; p=0.0121, and 47.6; p=0.0497 respectively). UMIC countries saw RE.1 positively correlate with excess mortality (97.0; p=0.0404).

Among HIC, LMIC, and among LIC when controlling for GDP and UHC, no Other technical area or individual indicator significantly correlated with excess mortality.

Table 2. Summary linear regression estimates for JEE summary and individual indicators. This table shows statistically significant results of linear regression analysis with estimated coefficients and p-values. Positive regression estimates indicate increased mortality associated with that higher summary or indicator score, while negative estimates indicate decreased mortality.

			Overall	HIC	MIC	UMIC	LMIC	LIC
Prevent	P.1	National legislation,	98.8; p=0.028					

		policy and financing						
	P.3.4	Optimize use of antimicrobial medicines in human and animal health and agriculture			76.8; p=0.0453	130.5; p=0.0352		
	P.4.3	Mechanisms for responding to zoonoses and potential zoonoses are established and functional	36.3; p=0.043					
	P.5 (P.5.1)	Food safety			68.7; p=0.0347			
	P.6	Biosafety and biosecurity			39.5; p=0.0425			
	P.6.1	Whole-of-government biosafety and biosecurity system is in place for human, animal and agriculture facilities			84.6; p=0.0390			
	P.6.2	Biosafety and biosecurity training and practices					88.4; p=0.031	
	P.7.2	National vaccine access and delivery			72.1; p=0.040			
Detect	Detect	Sum of All Detect Indicators			10.0; p=0.029			
	D.1.2	Specimen referral and transport system		-127.0; p=0.015			64.1; p=0.030	
	D.1.3	Effective modern point-of-care and laboratory-based diagnostics			85.5; p=0.024			-33.7; p=0.006
	D.3	Reporting			68.8; p=0.002	68.8; p=0.046	53.8; 0.033	
	D.3.2	Reporting network and protocols in country	38.2; p=0.022		153.6; p<0.0001	157.7; p=0.010	121.9; p=0.006	
Respond	R.4.2	System is in place for sending and receiving health personnel						13.3; p=0.047

		during a public health emergency						
Other	RE	Radiation emergencies	17.0; p=0.020		29.5; p=0.021			
	RE.1	Mechanisms are established and functioning for detecting and responding to radiological and nuclear emergencies	35.6; p=0.0148		63.4; p=0.012	97.0; p=0.0404		
	RE.2	Enabling environment is in place for management of radiation emergencies	29.8; p=0.033		47.6; p=0.0497			
	GDP				0.022; p=0.047			-0.084; p=0.019
	UHC							-3.08; p=0.014
			n=103	n=22	n=56	n=21	n=24	n=25

Discussion

Pandemics are unforeseeable, inevitable, and by definition uncontainable. They will affect countries and communities differently, often highlighting or even exacerbating preexisting inequities. Pandemic prevention, detection, response, and resilience measures, collectively known as pandemic preparedness must be intentional, locally tailored, and globally executed to have a reasonable chance of mitigating the damage. Even the wealthiest of countries are limited in the resources that they can devote to pandemic preparedness, especially if they are expected to provide succor to countries unable or unwilling to devote adequate preparedness resources. Thus, those resources must be invested where and when they will maximize outcomes.

The question we have attempted to answer here is whether the investments in technical capacities assessed in the WHO JEE process can predict success in reducing the ultimate outcome from any disease: death. In their current state, Joint External Evaluations are likely competent vehicles to gauge countries' assessment of their progress towards meeting metrics that WHO defines as important in improving preparedness against emerging health threats and pandemics as lain out in the IHR (2005).

We have shown that none of the metrics used by WHO as measured through the JEE process consistently demonstrated a significant improvement on publicly reported excess mortality across all income strata despite HIC having statistically significantly higher JEE scores in every Domain and Technical Area than MIC or LIC. The most incongruous finding in this study is the significant correlation between higher JEE scores for radiation emergency preparedness and excess mortality as none of the evaluation criteria touch even tangentially on measures to address biological hazards. The effect was seen in the global analysis of all countries as well as the MIC. It could suggest that countries that are ready to address even radiologic emergencies, which are likely those with civilian nuclear programs, were more adept at detecting excess death during the pandemic period. This reasoning follows for the other variables that were found to positively correlate with excess mortality in the global analysis: "National Legislation, Policy, and Financing" and "Mechanisms for responding to infectious and potential zoonotic diseases are established and functional". The only two JEE indicators that correlated with lower excess mortality, one in HIC and one in LIC, related to laboratory detection. That every statistically significant variable seen in the MIC group correlated with higher excess mortality suggests that the completeness of death registry also increased with other technical capacities and likely skewed the results in the MIC group. Support for this was evidenced as technical area D.3 "*Reporting*" and indicator D3.2. "*Reporting network and protocols in country*", positively correlated with increased excess mortality in MIC and both strata, the only variables to do so. As countries' ability to detect, record, and report cases increases without concomitant capacity to prevent mortality, we should expect such an apparent mismatch. That HIC had only one indicator significantly correlate with excess mortality despite overwhelmingly higher JEE scores and lower excess mortality than MIC suggests that unmeasured factors contributed to the differences seen between those groups. The relatively lower excess mortality seen among LIC compared to MIC despite lower JEE scores, and that GDP negatively correlated with excess mortality suggests that mortality recording itself before and during the pandemic might be problematic.

To properly assess the effectiveness of a preparedness activity, one must have a standard against which to measure it. We chose excess mortality as the ultimate outcome that captured indirect effects and independent of a nation's pathogen-specific detection capabilities. While those might be true, excess mortality reliability depends on robust national vital statistics and death registration. Hospitalization is unreliable given the vast capacity differences among countries.[xlviii] Similarly, the variety of testing regimes and capacity make laboratory-confirmed cases unsuitable as a global measure of pandemic impact.[xlix] Mortality is a distinct, recordable event common across humanity and accurate excess mortality would also capture the human cost of the outbreak. Excess mortality captures those who died from the pandemic pathogen as well as those who died from deferred care for other conditions, those whose death came from secondary causes such as economic fallout, and those who died from misinformation.[l] Measuring excess mortality requires accurately capturing deaths during the pandemic and the preceding years.[li] Much of our inability to identify technical capabilities consistently correlating with improved mortality rates is likely due to the variability in death reporting during a time when public health and social support systems that are stressed at baseline were pushed beyond the breaking point. According to the United Nations, fewer than 70% of reporting jurisdictions registered 90% or more of their deaths.[lii] Of the 103 nations in our study, 34 met the recommended 90% benchmark (21 of 22 HIC and 13 of 56 MIC), 32 countries reported registering <90% of deaths (1 HIC, 23 MIC, and 8 LIC) and 37 countries had no reported data on their death registries (20 MIC and 17 LIC). The time to improve this metric is in the interpandemic period when nations can realize spillover effects from improved vital statistics capture and international programs exist to improve capture and attribution.[liii] As countries begin to see increased deaths from noncommunicable diseases, improved death capture, especially community deaths can provide information required to refocus resources towards these threats until those systems are needed to face a pandemic.[liv] [lv] The variability of mortality rates even among countries that report registering all or nearly all deaths suggest that factors other than reporting disparities are at play.

Even if we assumed that every death was captured accurately for the purposes of this study, the question remains whether the sum of individual national technical capacity alone regardless of the tool used is sufficient to gauge global pandemic preparedness. The JEE assesses the presence and proficiency of technical capacities, policy frameworks, and IHR adherence mechanisms in their normal state of operations. The COVID-19 pandemic demonstrated that our assumptions about the underpinnings without which those systems could not function should also be measured. Specifically, we saw dramatic global supply chain perturbations, public trust in governments and specifically public health officials evaporate, misinformation and disinformation successfully competed with scientific knowledge, and countries acted as individual nations that could hold the pandemic on their own rather than an integrated global community.

The COVID-19 pandemic also disrupted supply chains for vital materials including food, personal protective equipment, and even rosin for single-use laboratory plastics.[lvi] To address shortages caused by these disruptions, countries engaged in protectionist policies to ensure domestic supply. In 2021 alone, the United States invoked the Defense Production Act over 100 times to prioritize its citizens' needs.[lvii] Even the best designed and implemented technical capacity requires inputs from the international market and it is impossible to warehouse enough materiel to see a nation through a pandemic. The largest such effort, the United States Strategic National Stockpile (SNS) only keeps enough of certain critical supplies on hand to see the nation through temporary, limited interruptions until the market can resume production. As SNS funding overwhelmingly addresses just two pathogens (smallpox and anthrax), they cannot ensure the inventory matches an unknown future threat.[lviii] Thus, it is essential that production continues and goods move within and between countries to ensure that high-quality healthcare can continue in countries importing critical materials and development of countermeasures proceeds at the quickest possible pace.

Diversified supply chains offer multiple advantages. Prudent planners will assume that as countries are beholden to their citizens rather than the international community some nations will attempt to prioritize themselves ahead of others due to greater perceived need (they have more cases), greater investment (they paid for its development), or greater vulnerability (they have less capacity to deal with cases). A diversified supply chain is less disrupted when a major manufacturing hub restricts exports and redirects goods for their own use as we saw with vaccines in 2021.[lix] Second, a concentrated supply chain operates on the assumption that the producer will never experience interruptions and global logistics will never fail while a diversified supply chain is an explicit acknowledgement that the pandemic's effects will vary in time and space. Third, diversified supply chains offer the opportunity for agility in product development as new technologies and techniques are developed to better contend with the kinds of information gaps that confronted the global health community in COVID-19.[lx] Lastly, as alluded to above, global logistics all along the supply chain was severely impaired during COVID-19 even when goods were being produced.[lxi] [lxii] Diversified supply chains mean shorter logistics chains and shorter "farm to market" time overall. WHO and governments can break diversified supply chains for critical goods into measurable pieces and add to existing toolkits as a metric. However, ensuring supply chain resilience will be harder to quantify given the unknowns accompanying a pandemic.

Public distrust of public health messaging dates back centuries and has been only incompletely overcome over the years despite successes in overcoming infectious disease threats.[lxiii] [lxiv] [lxv] Despite or because infectious diseases have decreased as a leading cause of mortality in the developed world, the dangers they pose might seem more remote to persons not in the public health field.[lxvi] During COVID-19, a survey found just over half of Americans trusted the CDC and fewer than half trusted their state or local public health officials.[lxvii] Misinformation and deliberate disinformation likely succeeded to the degree it did because of the fertile ground created by this lack of trust in public health officials and others, even though a majority in the survey responded that health departments were essential. The perception of shifting advice regarding masks, societal disruptions (school closures, travel restrictions, designations of essential workers, etc.) without obvious reduction in cases, and politicization of response measures created an opening for persons with agendas and measures that was filled with messages that made people feel: safe (i.e. the pandemic wasn't real), hopeful (i.e. hydroxychloroquine can cure COVID-19), or vindicated (i.e. vaccines don't prevent COVID-

19).[lxviii] [lxix] This lack of engagement and connection with the public at large can be addressed with intentional effort by local and national leaders via a commitment to aggressive transparency and appropriate scientific and biologic humility coupled with practical advice for the individual and their families. While public communication is captured in the JEE, public connection and trust-building measures are not. These can be distilled to fundamental and globally-applicable processes for inclusion in the capabilities assessment armamentarium, but might be more indicative of connections between governments at all levels and the populations they serve.

The COVID-19 pandemic clearly demonstrated that a country addressing its own technical preparedness gaps without accounting for its geographic neighbors, supply chains, and trading and travel partners neglected the global nature of the event. Pandemics by definition are a risk to all peoples of all nations. With the exceptions of islands that can successfully close their borders, all countries will remain at risk of introduction or re-introduction as long as any country is at risk. Within eight days of the identification of SARS-CoV-2 as a novel pathogen, cases had already been reported in Thailand and Japan leaving the global community very little time to shore up preparedness efforts.[lxx] It is reasonable to assume that future pandemics will follow COVID-19's trajectory of unrecognized spread followed by explosive expansion. Addressing technical deficiencies found in assessments like the JEE is still necessary, even if it's not sufficient according to our analysis, which is why initiatives like the Global Health Security Agenda that sustainably bolster participating nations' public health capacity in the interpandemic period are so vital.[lxxi] Besides addressing technical capacities including the systems required to capture and share data, global agreements on applying the capacities: surveillance definitions, diagnostics deployment, border and travel controls, response operations, supply chains, data sharing, public communications, and countermeasure development are essential to ensuring a global coordinated response.

By expanding the aperture of technical assessments beyond health systems to include the foundational aspects of pandemic preparedness systems such as supply chains and public trust and by approaching pandemic preparedness as a global community rather than a group of nations, we can lay the groundwork of a more successful pandemic response.

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