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Sustained excess all-cause mortality post COVID-19 in 21 countries: an ecological investigation

Chryso Th. Pallari[1], Souzana Achilleos[1], Annalisa Quattrocchi[1], Mohammad R. Rahmanian Haghighi[1,2], Minh Tam Phan[1], Andreas Artemiou[3], Catherine M. Bennett[4], Joseph Cuthbertson[5], Claudia Zimmermann[6], Eva Schernhammer[6], Catharina Vernemmen[7], Serge Nganda Mekogo[7], Jackeline C.P. Lobato[8], Laylla Macedo[9], Maria Athanasiadou[10], Laust H. Mortensen[11], Julia A. Critchley[12], Lucy P. Goldsmith[13], Gleb Denissov[14], Nolwenn Le Meur[15], Levan Kandelaki[16], Nino Chikhladze[17], Kostas Athanasakis[18], Binyamin Binyaminy[19], Tamar Maor[19], Enza Caruso[20], Giuseppe Ambrosio[21], Cyndy Martial[22], Marie Chan Sun[23], Terje P. Hagen[24], Manuel Barron[25], Mario Chong[26], Błażej Łyszczarz[27], Ivan Erzen[28], José Antonio Cernuda Martínez[29], Pedro Arcos González[29], Bo Burstrom[30], Wenjing Tao[30], Qian Huang[31], Antonis Polemitis[32], Andreas Charalambous[33], Christiana A. Demetriou[1,]*

[1]Primary Care and Population Health, University of Nicosia Medical School, Nicosia, Cyprus
[2]Centre for Health Economics Research and Modelling Infectious Diseases, Vaccine and Infectious Disease Institute, University of Antwerp, Antwerpen, Belgium
[3]Information Technologies, University of Limassol, Nicosia, Cyprus
[4]Institute for Health Transformation, Deakin University, Burwood, Australia
[5]School of Medicine, University of Notre Dame, Notre Dame, IN, Australia
[6]Department of Epidemiology, Center for Public Health, Medical University of Vienna, Vienna, Austria
[7]Sciensano, Epidemiology of Infectious Diseases, Brussels, Belgium
[8]Department of Epidemiology and Biostatistics, Institute of Collective Health (ISC), Fluminense Federal University Niterói, Niterói, Brazil
[9]Institute of Studies in Collective Health, Federal University of Rio de Janeiro, Rio de Janeiro, RJ, Brazil
[10]Health Monitoring Unit, Government of the Republic of Cyprus Ministry of Health, Nicosia, Cyprus
[11]Department of Public Health, Section of Social Medicine, University of Copenhagen, Denmark
[12]Population Health Research Institute, School of Medical and Health Sciences, City St George's, University of London, London, United Kingdom
[13]Division of Health Services Research and Management, School of Health and Psychological Sciences, City St George's, University of London, London, United Kingdom
[14]Department of Registers, National Institute for Health Development, Tallinn, Estonia
[15]University of Rennes, Ecole des Hautes Etudes en Sante Publique, CNRS, Inserm, Arènes, Rennes, Bretagne, France
[16]National Center for Disease Control and Public Health, Head of the Population Registry Division of Department of Medical Statistics, Tbilisi, Georgia
[17]Faculty of Medicine, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia
[18]Department of Public Health Policy, University of West Attica, Egaleo, Attica, Greece
[19]State of Israel Ministry of Health, Israel Center of Disease Control, Ramat Gan, Israel
[20]Department of Political Sciences, University of Perugia, Perugia, Umbria, Italy
[21]Division of Cardiology and CERICLET, Department of Medicine, University of Perugia, Perugia, Umbria, Italy
[22]Demography/Census Unit, Statistics Mauritius, Port Louis, Mauritius
[23]Faculty of Medicine and Health Sciences, Department of Medicine, University of Mauritius, Reduit, Moka, Mauritius
[24]Institute of Health and Society, Department of Health Management and Health Economics, University of Oslo (UiO), Oslo, Norway
[25]Department of Economics, Universidad del Pacifico, Lima, Peru
[26]Department of Engineering, Universidad del Pacifico, Lima, Peru
[27]Department of Health Economics, Nicolaus Copernicus University in Toruń, Bydgoszcz, Kujawsko-Pomorskie, Poland
[28]Public Health School, National Institute of Public Health, Ljubljana, Slovenia
[29]Faculty of Medicine and Health Sciences, Unit for Research in Emergency and Disaster, University of Oviedo, Oviedo, Asturias, Spain
[30]Global Public Health, Karolinska Institute, Stockholm, Stockholm, Sweden
[31]Center for Rural Health and Research, East Tennessee State University, Johnson City, TN, United States

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[32]University of Nicosia, Nicosia, Cyprus
[33]University of Nicosia Medical School, Nicosia, Cyprus

*Corresponding author. Department of Primary Care and Population Health, University of Nicosia Medical School, 21 Ilia Papakyriacou, 2414 Engomi, Nicosia, Cyprus. E-mail: demetriou.chri@unic.ac.cy

Abstract

Background: Despite widespread vaccination efforts, significant excess mortality continued in various countries following the COVID-19 pandemic. This study aims to estimate excess mortality during 2022 in 21 countries and regions, and to examine the relationship of governmental control measures and vaccination rates with excess mortality during 2021–2 at an ecological level.

Methods: Excess mortality for 2022 was estimated by analysing weekly mortality data from January 2020 to December 2022 across 21 countries and regions participating in the C-MOR consortium. This was achieved by comparing the observed age-standardized mortality rates per 100 000 population to a baseline derived from historical data (2015–19). Governmental control measures and vaccination efforts were investigated for their association with weekly excess mortality during 2021–2 in multilevel models with country as a random effect.

Results: All 21 countries experienced excess mortality in 2022, ranging from 8.6 (Peru) to 116.2 (Georgia) per 100 000 population, noting that rates were not directly comparable across countries. Many countries had higher excess mortality in 2022 compared with previous years. Mauritius showed a significant excess mortality for the first time in 2022. The proportion of COVID-19 deaths relative to total deaths decreased in 2022 for most countries, except Australia. Governmental control measures and vaccinations were associated with reduced excess mortality in 2021 and 2022, respectively.

Conclusion: The study reveals sustained excess mortality throughout 2022. Excess deaths were mainly non-COVID-19-related, likely due to displaced mortality or to broader long-term impacts of the pandemic response. Governmental control policies and vaccination efforts were associated with lower excess mortality. These findings provide critical insights into pandemic mortality dynamics and emphasize the need for continued vigilance and adaptive public health strategies.

Keywords: COVID-19, excess mortality, vaccination, governmental control measures, indirect mortality, all-cause mortality.

Key Messages

- The findings reveal significant excess mortality in 2022 across most countries, with notable variations by region and demographic group, highlighting continued pandemic-related health impacts.
- Excess deaths during 2022 were mainly non-COVID-19-related and could be partly attributed to displaced mortality or to broader long-term impacts of the pandemic response.
- Governmental control policies in 2021 and vaccination efforts in 2022 were associated with lower excess mortality during these pandemic years.

Introduction

Over 4 years since COVID-19 emerged and despite rapid vaccine development,[1] the long-term pandemic mortality impact and its determining factors remain only partially understood.[2]

Calculating excess all-cause mortality by comparing observed and expected deaths during a specified time period[3] provides valuable insights into the direct and indirect impacts of the COVID-19 pandemic, including mortality associated with overwhelmed healthcare systems and other pandemic adverse effects.[3] While many studies have focused on specific countries or regions to examine excess mortality,4–7 they often relied on provisional public data, the consistency of which was affected by the frequency of updates.[8,9]

Understanding how government responses and vaccination efforts influenced the global pandemic toll is crucial.[1,10] Vaccines have played a pivotal role in reducing COVID-19 mortality and preventing healthcare system overload by decreasing infections and severe cases.11–13 However, overwhelmed healthcare systems and strict measures reduced healthcare access and worsened health outcomes, while pandemic-related lifestyle and mental health implications possibly contributed to excess deaths during and after the pandemic.[14] Further, a study of 31 European countries found that those with successful protective measures during the pandemic experienced higher mortality rates after restrictions were lifted—a phenomenon termed the reverse harvesting effect.[15] The widespread relaxation of restrictions, economic reopening, and increased vaccination rates in 2022 altered healthcare systems, thus affecting excess-mortality patterns and warranting close examination of this period.

Building on previous estimates of excess all-cause mortality in 24 countries for 2020–1,[10] this study examines excess mortality in 2022 (total, sex-specific, and age-specific) by analysing weekly mortality data across 2020–2 from 21 C-MOR consortium countries.[8,16] We also analysed the relationship between government control measures, with a focus on vaccination, and excess mortality during 2021–2. These findings aim to aid policymakers in addressing ongoing healthcare challenges from the COVID-19 pandemic and in improving responses to similar future public health emergencies.

Methods

Data acquisition

Data availability was the sole criterion for inclusion in the study and 21 C-MOR consortium countries and/or regions provided mortality data for this ecological study. The participating countries or regions were Australia, Austria, Brazil, Belgium, Cyprus, Denmark, England and Wales, Estonia, France, Georgia, Greece, Israel, Italy, Mauritius, Northern Ireland, Norway, Peru, Poland, Slovenia, Spain, Sweden, and the USA. Total, sex-specific, and age-specific weekly all-cause mortality data for 2015–22 were obtained from national vital statistics databases (Supplementary Table S1). Data were compiled in mid-2023 to account for reporting delays[9,17] and allow reporting authorities sufficient time to consolidate and enhance the quality of the data.[18]

Moreover, weekly COVID-19 deaths were obtained for each country for all three of the years of 2020–2 from national vital statistics databases. For the countries that were unable to provide COVID-19 deaths, data were acquired from the online database "Our World In Data."[19]

Data on total vaccinations by manufacturer for each country in 2021 and 2022 were obtained from "Our World In Data."[19] Vaccine doses per 100 000 population, including primary and booster doses, were calculated weekly. For other infection control measures, data on eight governmental policy measures under "Closure and Containment" were sourced from the Oxford COVID-19 Government Response Tracker.[20] These measures were ordinal categorical variables, with weekly values estimated as the mode of daily indicators. Additionally, the weekly average stringency index of government measures[20] and COVID-19 incidence per 100 000 population were analysed for their association with excess mortality. Descriptions and sources of these variables are available in Supplementary Tables S2 and S3.

Statistical analysis

The same methodology as previously used[10] was employed for calculating mortality rates and estimating excess mortality,. Crude mortality rates (CMRs) were first calculated for the total population and sex-specific by using population estimates from the World Bank,[21] the UK Office for National Statistics,[22] and Eurostat.[23] Age-specific mortality rates (ASpMRs) and weekly (directly) age-standardized mortality rates (ASMRs) were then calculated by using the aggregated age groups provided by each country. These age groups are detailed in Supplementary Table S4 followed by the equations used for the calculation of CMRs, ASpMRs, and ASMRs.

Total and sex-specific weekly excess mortality for 2022 was calculated by comparing the observed weekly 2022 ASMR (per 100 000 population) against the expected weekly ASMR in 2022, estimated based on a time-series regression analysis of historical data (2015– 19) as previously described.[8,10,24–26] Likewise, age-specific weekly excess mortality for 2022 was calculated by comparing the observed weekly 2022 CMR (per 100 000 population) against the expected weekly CMR in 2022, estimated based on historical data (2015–19).

The regression models were built on complete weeks; truncated weeks—usually as a result of the different death counts observed around Christmas and New Year[27]—were excluded, as shown in Supplementary Table S5. Sex-specific excess mortality for 2022 could not be calculated for Northern Ireland due to the lack of sex-specific all-cause mortality data and thus Northern Ireland was not included in this analysis. Also, sex-specific weekly all-cause mortality for Peru was collected from 2017 to 2022.

The weekly comparison of observed and expected mortality rates is visually depicted by using z-scores. Z-scores ranging from −2 to +2 are considered "normal," whereas a z-score of >4 is considered a substantial increase.[28,29]

To estimate the excess mortality for 2022, the cumulative expected mortality rate was subtracted from the observed rate. By using a time-series regression model, 95% confidence intervals (CIs) were calculated. The 95% CIs were also estimated by using the time-series regression model. The P-score—defined as the ratio of the cumulative excess to the cumulative expected mortality, expressed as a percentage—was calculated for 2022, for the total population, by sex, and for age groups <65, 65+, <70 and 70+years.

To understand the relationship between the weekly number of vaccine doses (primary and booster), governmental control measures, and weekly excess mortality, multilevel models were employed, as detailed in the Supplementary Methods.

All analyses were performed by using R Statistical Software, version 2024.04.2 + 764 (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Weekly comparisons—total population and by sex and age group in 2020–2

Weekly excess-mortality results between 2020 and 2022 are presented in the Supplementary Results section, Supplementary Figures S2–S5, and Supplementary Table S6. Briefly, in 2022, all countries showed a substantial increase in the ASMR for the total population, ranging from 1 to 10 weeks. The excess-mortality duration among the countries varied between 1–12 weeks and between 1 and 8 weeks, for males and females, respectively. Lastly, excess mortality was higher in the older age groups investigated (65+ and 70+years).

Cumulative excess mortality in 2022

Figure 1 illustrates the cumulative excess all-cause mortality for 2020, 2021, and 2022. Supplementary Table S7 shows the cumulative observed and expected all-cause ASMRs for 2022, while Supplementary Table S8 shows the difference between the cumulative observed and expected all-cause ASMRs for 2020 and 2021. Supplementary Table S9 provides data for all three of the years 2020, 2021, and 2022 combined. It is important to note that countries report aggregated mortality data in different age groups, so calculated ASMRs are not directly comparable.

All participating countries presented substantial excess cumulative mortality in 2022. Notably, Australia, Austria, Cyprus, Denmark, Israel, Italy, Norway, Spain, and Sweden experienced a higher excess mortality in 2022 than in 2021, whereas Australia, Cyprus, Denmark, Israel, Mauritius, and Norway experienced the highest excess mortality in 2022. Additionally, all countries except Mauritius demonstrated a substantial increase in yearly all-cause mortality across the 3 years combined.

Supplementary Table S10 details the yearly cumulative mortality rate differences by sex for 2022. In 2022, all countries showed significant excess cumulative mortality for both males and females. Figure 2 (2021 and 2022) and Supplementary Table S11 show the male-to-female cumulative excess ASMR ratios. Generally, males were more affected, with females being more affected than males in Cyprus in 2022 and in Australia, Denmark, and Mauritius in 2021.

Supplementary Table S12 demonstrates the cumulative CMR differences (observed–expected) by age group for the year 2022. Age-specific excess all-cause mortality was higher in the older age groups of 65+ and 70+years than in those in the younger age groups for both years.

Figure 3 and Supplementary Table S13 illustrate variations in the reporting and categorization of COVID-19 deaths and overall crude mortality. Despite the total number of deaths

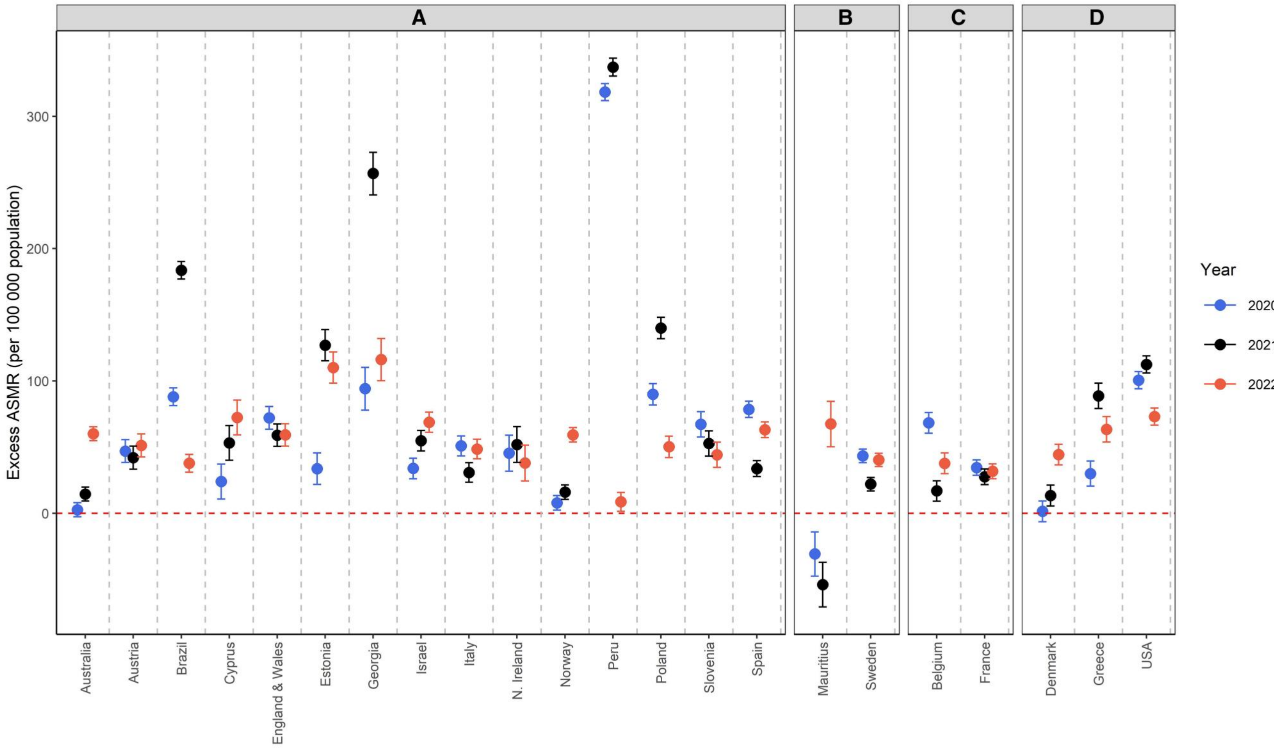

Figure 1. Cumulative excess age-standardized mortality rate for total population for 2020, 2021, and 2022. Plot letters correspond to the age groups in which countries have provided data and therefore the age groups used for age standardization: (A) age groups <15, 15–44, 45–64, 65+years; (B) age groups <20, 20–49, 50–69, 70+ years; (C) age groups <45, 45–64, 65+years; (D) age groups <15, 15–64, 65+years. The magnitude of excess mortality is not directly comparable between countries reporting mortality data in different age groups.

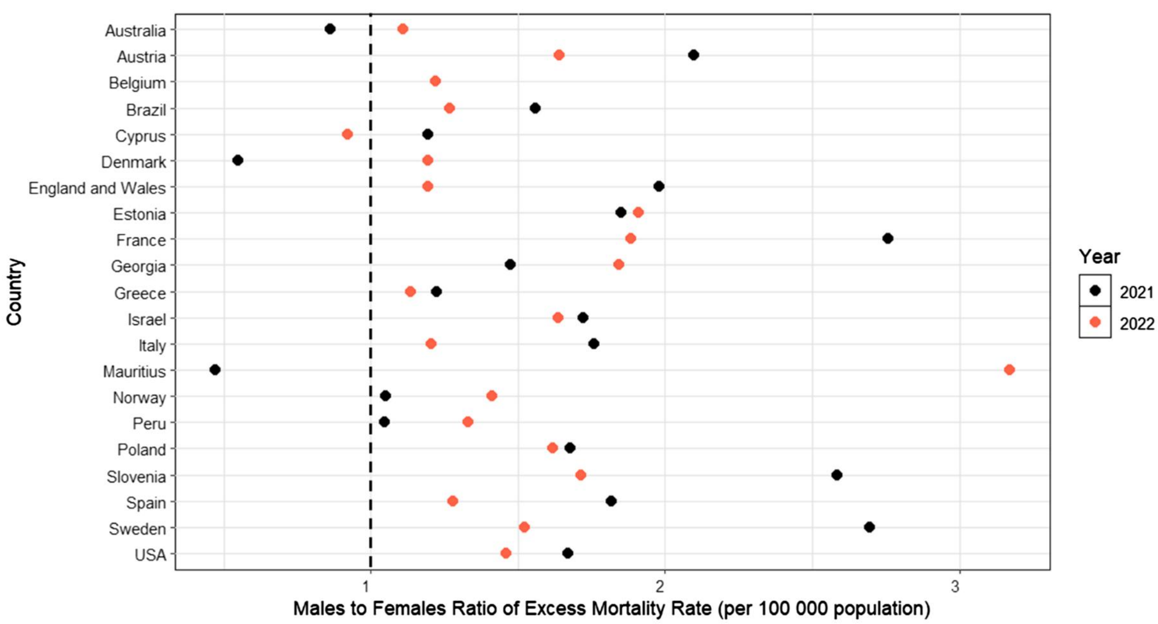

Figure 2. Male-to-female cumulative excess age-standardized mortality rate ratios for 2021 and 2022. The 2021 rate ratio for Belgium is 13.4, which is beyond the *x*-axis limit and therefore is not depicted. Values of >1 denote a higher excess mortality in males compared with females.

appearing similar across the 3 years (2020–2), in some countries, there was a noticeable increase in reported COVID-19 deaths in 2021 with a simultaneous decrease in non-COVID-19 deaths during the same year, suggesting a possible overdetection of cases and overreporting of deaths as COVID-19 deaths. This is not surprising given the test availability and meticulous testing procedures, particularly in hospitals, which increased the likelihood of COVID-19 detection and deaths being coded as COVID-19 deaths. Additionally, the data indicate that, in many countries, non-COVID-19 death

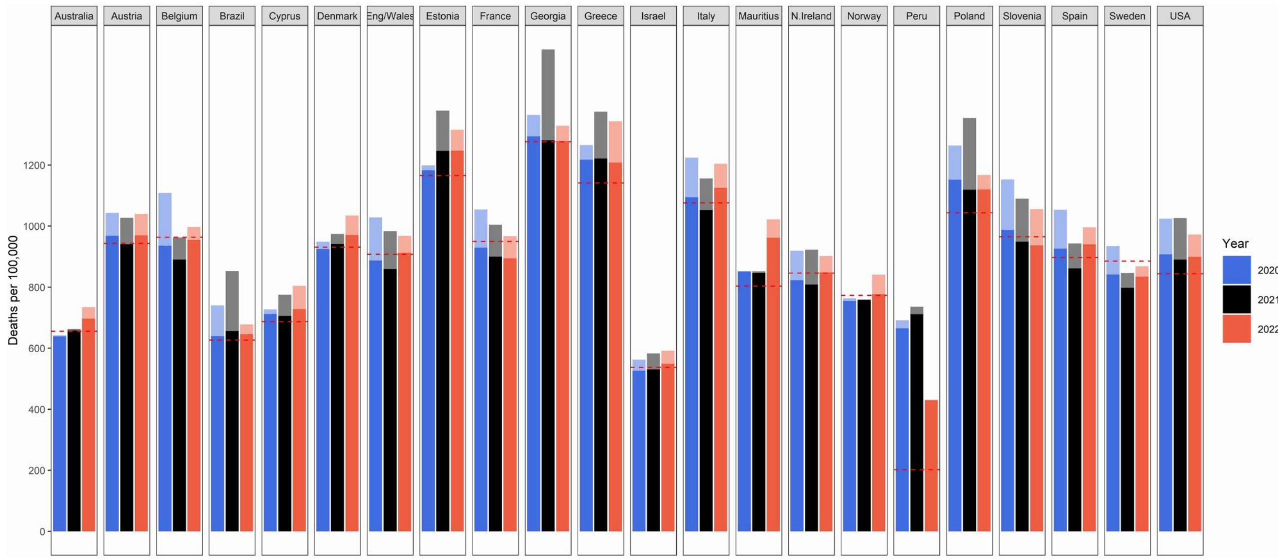

Figure 3. Country-specific overall CMRs for 2020–2, separated as other causes of death vs COVID-19 deaths. The lighter-colored portion of each bar illustrates COVID-19 deaths. Vertical lines show country-specific baseline (expected) mortality calculated as the average of crude all-cause death rates between years 2015 and 2019.

rates returned to or surpassed the 2020 levels in 2022, which may reflect changes in detection and reporting practices during 2022.

Impact of vaccination and other governmental policies on excess mortality

We developed year-specific multilevel models to examine the influence of total vaccinations on excess mortality. These models also examined the weekly incidence of reported COVID-19 cases, overall stringency of governmental control measures, and weekly non-COVID-19 mortality. The random-effect estimates for each country introduced variation in the model, with intraclass correlation coefficients of 0.63 for 2021 and 0.55 for 2022. In both mixed models, non-COVID-19 mortality was most strongly associated with excess mortality, negatively for 2021 ($\beta_{2021} = -2.21$, $P < 0.001$) and positively for 2022($\beta_{2022} = 1.24$, $P < 0.001$). Total vaccinations per 100 population were independently negatively associated with excess mortality in 2022 ($\beta_{2022} = -0.49$, $P = 0.005$). The stringency of control measures was negatively associated with excess mortality in 2021, but weakly positively in 2022 ($\beta_{2021} = -0.62$, $P < 0.001$, and $\beta_{2022} = 0.16$, $P = 0.031$) (Table 1).

Supplementary Figures S6–10 and Supplementary Table S14 with its description show the results of regression analyses to examine the relationship between the number of vaccine doses administered and excess mortality, for various vaccines, in the years 2021 and 2022. Briefly, only Pfizer/BioNTech (2021: $\beta = -0.00200$, $P < 0.001$ and 2022: $\beta = -0.00162$, $P < 0.001$) and Moderna (2021: $\beta = -0.00326$, $P = 0.023$ and 2022: $\beta = -0.00152$, $P = 0.0778$) vaccines showed negative relationships with cumulative excess mortality in both 2021 and 2022.

With respect to governmental policies, Supplementary Figures S11–S18 show the percentage of weeks in each year (2020–2) for which a specific stringency level of each policy was applied in each country. For most policies, higher stringency levels were more common in previous years than in 2022.

The relationship between each governmental policy measure (3-week lag) and excess mortality, accounting for total vaccinations and non-COVID-19 mortality, are shown in Figure 4 (unadjusted models are presented in Supplementary Figure S19). In 2021, all policy measures—with the exception of the strictest levels of school closing, restrictions on gatherings, closing of public transport, and stay-at-home requirements—were negatively associated with excess mortality. On the other hand, in 2022, most measures were positively associated with excess mortality, with the exception of the lowest stringency levels for school closing, public transport closing, and international travel controls.

Discussion

Patterns of excess mortality

All countries except Mauritius showed significant excess cumulative total and sex-specific mortality rates for 2022 and over the combined period of 2020–2. This trend aligns with the ongoing impact of COVID-19 also evidenced elsewhere.[15,30,31] The excess mortality in 2022 may be partly due to the "reverse harvesting effect," in which vulnerable individuals, protected during the pandemic, were more likely to die after protective measures were lifted.[15] Variability in death certificate completion and coding[31] may have attributed these deaths to COVID-19 or other infectious diseases or underlying conditions.[32] Australian data support this explanation, showing substantial excess mortality from COVID-19 in 2022 after the lifting of strict protection measures.[33]

On the other hand, excess mortality in 2022 can be partly attributed to the indirect effects of the pandemic. Overburdened healthcare systems, care access disruptions, and adverse lifestyle and mental health impacts[14,34–37] contributed to excess mortality even post pandemic. For instance, Brazil and Peru experienced significant excess mortality in 2022, reflecting ongoing challenges in managing health impacts despite vaccination efforts.38–40 Sex- and age-group-specific results are discussed along with the relevant tables (Supplementary Tables S10–S12).

The interplay between COVID-19 deaths and excess mortality highlights differences in national responses and

Table 1. Multilevel model results on the association between pandemic-related variables and weekly excess mortality (z-scores) during 2021 and 2022

	2021[a]			2022[a]		
Predictors	**Estimates**	**CI**	***P***	**Estimates**	**CI**	***P***
(Intercept)	2.04	0.94 to 3.15	**<0.001**	1.91	1.13 to 2.68	**<0.001**
Weekly incidence of COVID-19 (3-wk lag)	0.57	0.39 to 0.75	**<0.001**	–0.04	–0.23 to 0.15	0.664
Total vaccinations per 100 population (3-week lag)	0.02	–0.19 to 0.22	0.869	–0.49	–0.83 to –0.15	**0.005**
Stringency of control measures (3-week lag)	–0.62	–0.83 to –0.40	**<0.001**	0.16	0.02 to 0.31	**0.031**
Weekly non-COVID-19 mortality (per 100 000 population)	–2.21	–2.84 to –1.57	**<0.001**	1.24	0.79 to 1.69	**<0.001**
Random effects		**2021**			**2022**	
σ^2		3.74			2.51	
ICC		0.63			0.55	
$N_{\mathrm{data\$location}}$		20			20	
Observations		1028			988	
Marginal R^2/Conditional R^2		0.311/0.743			0.287/0.677	

[a] Kazakhstan and Peru were excluded from this analysis due to a completeness of vital registration systems of <90%, which affects the excess-mortality estimates.

healthcare outcomes. While most countries maintained a consistent total number of deaths over the 3 years, Brazil, Georgia, and Poland experienced significant increases in total deaths in 2021, largely due to COVID-19, suggesting a potentially inadequate response to the pandemic. In 2022, deaths in these countries returned to 2020 or lower levels, potentially indicating a "harvesting effect" after the 2021 peak.

Impact of vaccination

While acknowledging a potential residual risk of ecological fallacy, the findings from this study underscore the importance of vaccination in mitigating excess mortality during the COVID-19 pandemic. During 2021, the multilevel models on age-standardized excess mortality, which accounted for cross-country variability, did not evidence a mitigating effect of vaccination efforts on weekly excess mortality. This finding may be attributed to the still insufficient coverage of a substantial percentage of the population in many countries, the prioritization of older and more vulnerable populations, and the prevalence of the more virulent Delta strain during 2021, all of which may have overshadowed the benefit of vaccines in reducing excess mortality in 2021 within countries. In addition, our data evidenced a strong, negative, significant correlation between vaccination rates and the stringency index in 2021 ($r = -0.6719$; $P < 0.0001$), as, within countries, there was a relaxing of control measures as vaccination coverage increased. Therefore, vaccination benefits may have been offset by the rollback of control measures. However, the population-level effectiveness of COVID-19 vaccination is evident in studies that have shown an increasing share of deaths among 0- to 69-year-olds during the first months of vaccinations in countries that prioritized vaccination among the elderly.[41] Also, cross-country comparisons evidenced a negative association between mRNA vaccine coverage and excess mortality in 2021. During 2021, large numbers of vaccinations with Pfizer/BioNTech and Moderna vaccines can be considered as indicative of a successful pandemic response by countries with better healthcare system access and quality (with few exceptions, such as the UK and Austria, who invested in AstraZeneca as the first vaccine to come to market). Over and above vaccine effectiveness, this phenomenon, observed also elsewhere,[15] is also a likely explanation for the negative relationship seen between total mRNA vaccinations and cumulative mortality across countries in 2021. On the contrary, in 2022, the mitigating effect of total vaccinations on excess mortality was obvious at both the weekly level (multilevel model) and the yearly cumulative level across countries. This finding aligns with studies showing the high effectiveness of Pfizer/BioNTech and Moderna vaccines in reducing COVID-19-related infection severity, hospitalizations, and mortality.[42,43]

The results on Johnson and Johnson, Oxford/AstraZeneca, and the other vaccines are discussed along with the relevant figures and Supplementary Table S14.

Role of health policies

Control measures became less stringent each year during the pandemic. Government policies had a nuanced role in addressing excess mortality, with varying impacts in 2021 and 2022. In 2021, most policy measures corresponded with a reduction in excess mortality, indicating their effectiveness in curbing virus transmission and mortality. This aligns with studies showing that stronger containment measures reduced COVID-19 deaths globally.[44,45] Interestingly, in our study, the greatest reductions in excess mortality were often seen with less stringent measures, such as recommendations and partial restrictions, rather than strict requirements. This could be partly explained by the fact that countries with less strict measures had more Intensive Care Unit (ICU) capacity or that countries with vulnerable populations (i.e. a larger percentage of older individuals) responded with stricter measures to protect their population. However, it could also suggest that community engagement and empowering individuals to protect themselves and vulnerable populations are effective strategies, especially within the context of public health capacity.[46]

In 2022, the association of most measures with excess mortality was weakened or reversed. This may reflect reverse causation, i.e. when countries struggled with excess mortality, they kept measures in place, while effective pandemic responses and high vaccination rates were accompanied by the lifting of restrictions. On the other hand, the association of some control measures with reduced mortality in 2022 should be interpreted with caution. The fast spread of the Omicron variant in 2022 and the prevalence of viral antibodies in the population as measured in seroprevalence studies[47] were associated with a reduction in excess mortality in 2022. As the Delta variant was becoming increasingly rarer, measures of moderate stringency replaced stricter control measures. Thus, the observed associations between some measures of low to moderate stringency and reduced excess mortality may be better attributed to the less virulent Omicron variant

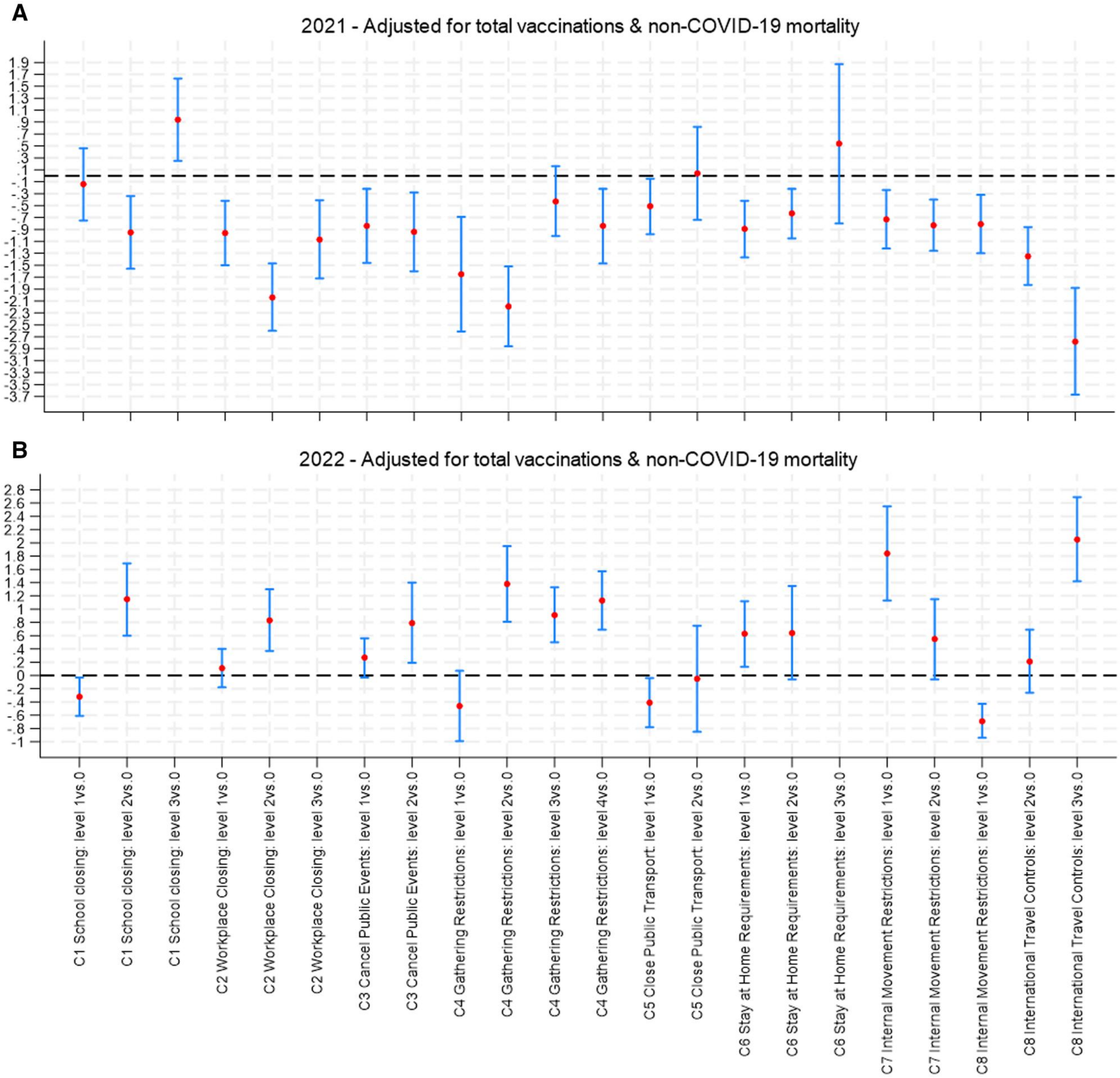

Figure 4. Multilevel model results on the relationship between individual governmental control policies (3-week lag) and excess mortality z-score in (A) 2021 and (B) 2022. Multilevel models included country as a random effect and categorical governmental control measures as fixed effects, adjusting for total vaccinations and non-COVID-19 mortality. A separate model was built for each governmental control measure. Each point represents the regressioncoefficient for each control measure level and whiskers represent the 95% CIs. Lack of regression coefficients for particular control measure levels indicates that that level was not implemented in the respective year analysed.

and the increased seroprevalence rather than the measures themselves.

Future public health and research implications

These results emphasize the importance of robust vaccination campaigns and the need for long-term evaluation of vaccine effectiveness. Equitable access to vaccines during global emergencies is crucial and can be supported by international partnerships. Importantly, our results suggest that, until health systems adapt or vaccination coverage is sufficient, government policies can mitigate future epidemics. However, instead of blanket measures of maximum stringency, involving communities and using adaptable public health strategies based on vaccination and infection rates are likely to be more effective. Future research studies should continue to explore the underlying factors contributing to excess mortality, including socioeconomic determinants, healthcare capacity, and public health policies, as well as vaccination strategies.

Strengths and limitations

This study presents a robust analysis of excess mortality across 21 countries or regions, leveraging data from national vital statistics databases spanning the years 2015–22. However, this study has several limitations, including variability in mortality data reporting and categorization among countries,[31] inconsistent age groupings affecting data comparability, potential reporting delays, and variations in data quality, especially from developing countries. Additionally, vaccination data may not accurately depict individual coverage, and missing demographic and variant prevalence data could limit understanding of excess-mortality determinants. Finally, the possibility of ecological fallacy means that population-level correlations might not reflect individual experiences, prompting cautious interpretation of the results. Further study strengths are discussed in the Supplementary Material, along with a more detailed explanation of the study limitations.

Conclusion

This ecological investigation of excess all-cause mortality highlights the lasting effect of the pandemic on all-cause mortality, both direct and indirect. Even though ASMRs are not directly comparable between countries, our findings reveal significant variations in excess mortality across countries and demographic groups, underscoring the global health inequities in health resilience and care access. Lastly, despite the potential ecological fallacy risk, the non-stringency-dependent effectiveness of control measures and the effectiveness of vaccinations in mitigating excess mortality during 2021 and 2022, respectively, highlight the need for vigilant and adaptive public health strategies to manage future public health challenges.

Ethics approval

Ethics approval to conduct the study was obtained from the Cyprus National Bioethics Committee (16/6/2020, EEBK/EΠ/2020/01.127).

Author contributions

C.T.P., S.A., A.Q., M.R.R.H., M.T.P., C.B., C.Z., E.S., J.A. C., N.L.M., G.A., and C.A.D. contributed to (i) the conception and design of the study, or acquisition of data, or analysis and interpretation of data; (ii) the drafting of the article or revising it critically for important intellectual content; and (iii) the final approval of the version to be submitted. A.A., J. C., V.C., S.N.M., J.C.P.L., L.M., M.A., L.H.M., L.P.G., G. D., L.K., N.C., K.A., B.Bi., T.M., E.C., C.M., M.C.S., T.H., M.B., M.C., B.L., I.E., J.A.C.M., P.A.G., B.Bu., W.T., Q.H., A.P., and A.C. contributed to (i) the conception and design of the study, or acquisition of data, or analysis and interpretation of data; and (ii) the final approval of the version to be submitted.

Supplementary data

Supplementary data is available at *IJE* online.

Conflict of interest: None declared.

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Data availability

The data underlying this study, beyond what are available in the article and in its online Supplementary Material, can be shared to facilitate methodologically sound proposals after signing a data-access agreement. Proposals and data requests should be directed to demetriou.chri@unic.ac.cy.

Use of artificial intelligence (AI) tools

Open AI, GPT-4o, provided through the PowerFlow application of the University of Nicosia, was used for improving the readability and conciseness of the manuscript.

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