Comparison of pandemic excess mortality in 2020-2021 across different empirical calculations

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ABSTRACT (250 words)
Different modeling approaches can be used to calculate excess deaths for the COVID-19 pandemic period. We compared 6 calculations of excess deaths (4 previously published and two new ones that we performed with and without age-adjustment) for 2020-2021. With each approach, we calculated excess deaths metrics and the ratio R of excess deaths over recorded COVID-19 deaths. The main analysis focused on 33 high-income countries with weekly deaths in the Human Mortality Database (HMD at mortality.org) and reliable death registration. Secondary analyses compared calculations for other countries, whenever available. Across the 33 high-income countries, excess deaths were 2.0-2.8 million without age-adjustment, and 1.6-2.1 million with age-adjustment with large differences across countries. In our analyses after age-adjustment, 8 of 33 countries had no overall excess deaths; there was a death deficit in children; and 0.478 million (29.7%) of the excess deaths were in people <65 years old. In countries like France, Germany, Italy, and Spain excess death estimates differed 2 to 4-fold between highest and lowest figures. The R values' range exceeded 0.3 in all 33 countries. In 16 of 33 countries, the range of R exceeded 1. In 25 of 33 countries some calculations suggest R>1 (excess deaths exceeding COVID-19 deaths) while others suggest R<1 (excess deaths smaller than COVID-19 deaths). Inferred data from 4 evaluations for 42 countries and from 3 evaluations for another 98 countries are very tenuous Estimates of excess deaths are analysis-dependent and age-adjustment is important to consider. Excess deaths may be lower than previously calculated.

SIGNIFICANCE STATEMENT

Excess deaths are a key metric for assessing the impact of a pandemic. They reflect the composite impact of deaths from infection, from indirect pandemic effects, and from the measures taken. Different modeling approaches can be used to calculate excess deaths for the COVID-19 pandemic. Here, we compare four previous calculations of excess deaths and two new ones that we performed with and without adjusting for changing age structure in the estimation. Proper age-adjustment results in substantial reduction in estimates of excess deaths for 2020-2021. While results from different calculation methods are correlated, the absolute differences in estimated excess deaths are very high in most countries. Extrapolations to countries without reliable death registration is extremely tenuous.

INTRODUCTION

Many studies estimate excess deaths in specific locations, countries, regions, or worldwide during the COVID-19 pandemic.[1-4] Excess deaths reflect a composite of deaths from SARS-CoV-2 infection plus indirect effects of the pandemic (e.g. health system strain) and measures taken.[5,6] It has been argued[7,8] that excess deaths are a more appropriate measure of impact than recorded COVID-19 deaths. Recorded COVID-19 deaths may be under- or over-counted in different time periods and locations[5] and do not capture indirect effects of the pandemic and the measures taken. However, excess deaths calculations require modeling of the expected deaths that entails many assumptions and analytical choices. To obtain excess deaths estimates one needs to define a control (reference) pre-pandemic period, use some model for extrapolating expected deaths in the pandemic period and compare them against observed deaths. There are many different possibilities on how to select the pre-pandemic reference period and on how to model data and extrapolations.[9,10] A major analytical decision is whether to account for changes in the age structure of the population over time. With an aging population (particularly in high-income countries), mortality rates may increase over time, countering the anticipated decrease in mortality from better healthcare and overall human progress. These changes may be better addressed by considering age structure[9,11-13] rather than simply relying on regression trends of overall population data regardless of age.

Another pivotal dilemma in excess death calculations is what sources of data to use; and which countries are considered to have sufficiently reliable data. Death registration is sub-standard in most countries around the world: many deaths remain unrecorded.[14,15] Information on causes of death has flaws even in the most developed countries[16,17] while the pandemic generated new death coding challenges.[18] Changes in deaths over time may be confounded by changes in death registration and recorded COVID-19 deaths depend on coding. Even population counts have uncertainty and this applies also to age-stratified estimates from different sources using different imputations to estimate age-stratified population for recent years. Even in high-income countries, most of them have not had a formal census performed for many years. Finally, several highly visible studies that attempted to calculate excess mortality world-wide,[1-4] first estimated excess mortality in countries with trustworthy death data on all-cause mortality; then, they extrapolated across other countries worldwide, using the profile of various characteristics in these countries versus those with trustworthy data. Consequently, proper calculation of excess mortality in countries with most trustworthy mortality data has critical importance even for worldwide estimates.

Here, we compare the results of different evaluations that have attempted to calculate global excess mortality during the COVID-19 pandemic in 2020-2021.[1-4] We focus primarily on high-income countries with the most reliable death registration systems and discuss the implications for extrapolations to a global level. We compared 4 widely publicized excess death calculations published in eLife, Economist, the Lancet, and by the World Health Organization (WHO)[1-4,19,20] and included also our calculations. Our calculations explicitly explored what difference it would make to model deaths using separate death and population data for age strata. Besides raw excess mortality estimates, we focused on the ratio of excess mortality over recorded COVID-19 deaths. This ratio is critical in understanding whether excess mortality confers more information compared with just focusing on routinely recorded COVID-19 deaths. Ideally, one would like to see consistency in this ratio regardless of modeling and analytical choices, while large inconsistency would put the added value of excess mortality calculations in question.

RESULTS

Characteristics of the compared excess death calculations

Table 1 summarizes the main features of the compared excess death calculations. As shown, the evaluations differed substantially in defining the reference period, the choice of analytical model, exclusions, use of adjustments, eligibility criteria, data sources, extrapolations and imputations. The Economist methods used complex machine learning not described in very broad terms; the WHO and Lancet methods were convoluted and not all can be easily reproduced.

Comparison of excess deaths metrics in 33 countries with most-reliable data

33 countries were included in the main analysis, selected because they were high-income according to the World Bank, and they had detailed available weekly data on observed deaths in the three pre-pandemic years and also during 2020-2021 (Table 2). These countries had a total population of almost 1 billion and almost 20 million deaths in 2020-2021, of which 9.5% were recorded as COVID-19 deaths. The total of calculated excess deaths in these 33 countries ranged from 2.0 million (eLife) to 2.8 million (Lancet), with WHO (2.1 million) and Economist (2.2 million) being closer to eLife. Our own calculations without age adjustment gave a similar total (2.3 million), but with age-adjustment the excess deaths were only 1.6 million.

There were very large differences across countries and this was evident also when excess deaths were estimated as a proportion above the observed deaths, E_p (Supplementary Table 1), deaths per million population, E_m (Supplementary Table 2) and ratio of excess deaths over recorded COVID-19 deaths, R (Table 3) metrics. Australia, New Zealand, and in some analyses also Iceland showed no excess deaths at all, even without age-adjustment. With age-adjustment, however, in our calculations several other countries such as Norway, Finland, Denmark, Sweden, and South Korea also showed no excess deaths. In the WHO age-adjusted calculations, no excess deaths were seen in Australia, New Zealand, Iceland, and Norway. Among countries with excess deaths in all analyses, the excess death estimate differed by 2-4 times between the highest (non-age-adjusted) and lowest (age-adjusted) estimates in countries like France, Germany, Italy, and Spain. Age-adjustment led to modest reductions of estimates for the USA.

The pairwise correlations between eLife, Economist, WHO and our two calculations (with and without age-adjustments) were consistently extremely high for R (all r>=0.977). The same picture was seen largely for these 5 calculations for E_p (all r>=0.930) and for E_m (all r>=0.951). The Lancet calculations had modestly lower correlation with the other 4 evaluations (range r=0.808-0.841 for R, range r=0.835-0.919 for E_p, 0.917-0.958 for E_m). The correlations for R between different evaluations, however, were modest/poor when Australia and New Zealand (that were outliers with very negative values of R) were excluded, (range -0.386 to 0.657). The two other metrics E_p (range, 0.794-0.989) and E_m (range 0.904-0.996) show good correlation values even when these outliers are excluded.

Even when correlations were high, given the substantial differences in the absolute estimates of excess deaths with the different calculations in each country, the range of R values was always large (Table 3). The R values' range always exceeded 0.3 in all 33 countries. In 16 of 33 countries, the range of R across different evaluations exceeded 1, i.e. it was as large as the number of recorded COVID-19 deaths itself. 6 countries had consistently R >1, i.e. more excess deaths than recorded COVID-19 deaths, with all empirical evaluations. Conversely, only 2 countries, Australia and New Zealand had consistently R<1. The large majority of countries (25 of 33) had some calculations suggesting R>1 (i.e. excess deaths greater than COVID-19 deaths) and others suggesting R<1 (excess deaths smaller than COVID-19 deaths).

Table 4 shows the break-down of excess deaths per age stratum in each country for our age-adjusted analyses. In total, 0.478 of the 1.609 million excess deaths were in people <65 years old (29.7%), but the percentage varied widely across countries. 30 of 33 countries had death deficit for children 0-14 years old (all, except for Iceland, Luxembourg, and Netherland that also had minimal excess deaths in children) and overall across all 33 countries there was a death deficit of 7,737 deaths for children 0-14 years old. 10 countries had death deficit even for people <65 years old. Conversely, for 4 countries, more than 25% of the excess deaths was in people <65 years old (Canada 45.5%, USA 41.6%, Chile 37.8%, UK 28.7%).

Other countries

eLife, Economist, Lancet, and WHO had estimates of excess deaths in 42 additional countries (Supplementary Table 3). These countries had a total population of almost 1.4 billion, the total reported COVID-19 deaths were almost 2.3 million and the excess death estimates were about double with all 4 evaluations (4.7 million per eLife, 4.8 million per Economist, 5.5 million per Lancet, 4.4 million per WHO) with higher correlations between eLife, Economist and WHO and more modest correlations with Lancet for all three excess death metrics. For several countries, differences across evaluations were very large. Two countries had death deficits by some evaluations, but not with others (Singapore range -1,770 to 1,776 and Japan range -19,469 to 111,000).

Another 98 countries (total population 5.3 billion) had excess death values obtained only per Economist, Lancet and WHO (Supplementary Table 4) for a total of 10.7, 9.8, and 7.9 million, respectively (6-9 times higher than recorded COVID-19 deaths). The correlation of the calculations was modest for all three metrics (r=0.499-0.570, r=0.552-0.662, r=0.530-0.801 for E_p, E_m, and R, respectively). Very large differences across different calculations for the same country were very common. For 11 countries, there was an estimated death deficit based on some calculation but not with all 3. For China, the range was extreme (452,669 excess deaths per Economist; -52,064 deficit per WHO).

DISCUSSION

Across 33 high-income countries with total population of approximately 1 billion and highly thorough death registration, different empirical estimates of excess deaths in 2020-2021 ranged widely from 1.6 million, i.e. substantially fewer than the 1.9 million recorded COVID-19 deaths, to 2.8 million, almost a million more. Countries with highest estimates of excess deaths were more or less the same in all evaluations; and countries with the most favorable picture performed well across the different evaluations. However, large differences emerged in the magnitude of the estimates for each country. The largest divergence was produced by whether age adjustment was used in calculating excess deaths. Age-adjusted estimates were lower. They are more appropriate, since COVID-19 has impressive age-related risk gradient for death.[20,21] Modest changes in age structure, in particular with aging populations, may produce major differences in estimates. With age-adjustment, several high-income countries showed no or minimal excess deaths; and for many others, the estimates of excess deaths markedly decreased. However, even age-adjusted excess death estimates differed substantially depending on the choice of data source for age-stratified population in the recent years as well as modeling choices.

Our age-adjusted analyses also revealed large differences across countries in the proportion of excess deaths accounted by non-elderly age strata. A few countries had more than a quarter of the excess deaths in people <65 years old. There are several possible factors that may explain this pattern. Adverse risk profile of the non-elderly populations, including high prevalence of obesity; inequalities and disadvantaged populations without good health care; and increased fatalities due to opioid overdose and other non-COVID-9 causes of excess death may explain in part the USA pattern. Also for Canada, USA and UK, many deaths in elderly people may have occurred in long-term care residents with very limited life expectancy. Deaths from SARS-CoV-2 among patients with limited life expectancy result in no excess deaths if the time window assessed after their infection is shorter than their life expectancy.[23]

The ratio R of excess deaths over recorded COVID-19 deaths varied substantially across different evaluations. Only 5 countries in Eastern Europe and USA had consistently R >1, i.e. more excess deaths than recorded COVID-19 deaths. Conversely, only Australia and New Zealand had consistently R<1. R values varied widely for all countries. In most countries, the uncertainty in the range of excess death estimates exceeded the number of recorded COVID-19 deaths itself. This large variability questions to what extent excess deaths can give much better insights on the total pandemic toll than COVID-19 recorded deaths.[7] Excess death calculations are dependent on how they are calculated. In some cases, like Eastern Europe, they can tell that COVID-19 deaths have been undercounted and/or the numbers of other deaths have escalated during the pandemic. However, they cannot differentiate the relative contribution of these two factors nor can they give a precise estimate of either or their combination. In a few countries with limited SARS-CoV-2 deaths they can be reassuring that indirect pandemic effects and measures did not escalate fatalities, at least during 2020-2021. However, for most countries, excess death calculations are so model-dependent that they should be seen with great caution.

Besides the high-income countries with meticulous weekly death registration data, excess death calculations for the rest of the world are very tenuous exercises. For 42 countries where eLife, Economist, Lancet and WHO generated estimates, on average excess deaths were ~2-times the COVID-19 recorded deaths and among another 98 countries where Economist and Lancet provided estimates, overall R was 6-9. However, given the low reliability of the data, the immense uncertainty surrounding these estimates cannot be overstated. More importantly, these calculations offer no causal insights. Excess deaths may be due to the virus, the indirect pandemic effects, or/and disruptive measures taken, even more so in countries with very frail healthcare systems, widespread poverty, and/or even high rates of hunger. The 2020-2021 crisis may have indeed resulted in many deaths, but causes may be very complex.

For some of these additional countries, calculations were run based on available mortality data. Even then, in most cases death registration is unreliable and the impact of changes in death registration during the pandemic compound any calculation. Perhaps age-adjustment would also lead to different estimates in these countries, as for the 33 most data-reliable countries. Even for these 33 countries, population estimates (including age-stratified population counts) are projected with different methods and typically no formal population census has been performed for several years. This adds further uncertainty to excess death calculations that are highly susceptible to minor differences especially in the population of elderly strata. For most countries, excess death calculations are indirectly imputed from the countries with mortality data. The methods employed by the Economist are not described in sufficient detail to allow probing validity and reproducibility. Lancet and WHO calculations provide more elaboration, mostly proving their complexity. The uncertainty in excess death estimates apparently far exceeds the width of published confidence intervals.

Hence, extrapolations from the 33 main analysis countries to other countries need to be extremely cautious. Among the total excess deaths, deaths due specifically to viral infection in the other countries may be proportionally far less. Other countries have far smaller percentage of elderly people and very few nursing home residents. Conversely, they have far more frail health systems, societies, and economies. Therefore, probably indirect effects of the pandemic and measures were perhaps more important contributors to total excess deaths than SARS-CoV-2 infection.

Nepomuceno et al. have also assessed the impact of different analytical choices on excess death calculations for 2020.[8] They find modest differences among different approaches in countries with reliable death registration. Age-stratification has been also to be important in previous assessments for specific countries.[24,25] Germany is a classic example. Our age-adjusted estimate is 55,000 excess deaths, while without age-adjustment we calculated 129,000 excess deaths and Lancet calculated 203,000 excess deaths – compared with 111,000 COVID-19 reported deaths. Baum[23] calculated only 22,000 excess deaths after age adjustment, while Koenig[24] without age adjustment found more excess deaths than recorded COVID-19 deaths. In Germany, the number of people aged >80 years increased from 4.6 million in 2016 to 5.8 million in 2020, so consideration of age is crucial.[11] Further diversity stems from whether modeling anticipates increasing life expectancy (decreasing mortality rate) over time.[11] However, this approach may calculate spuriously high excess deaths: calculations assume a desired mortality rate lower than even attained in reality in the past. Medical and overall progress cannot guarantee continuing to decrease overall mortality in high-income countries, especially in old, frail people. In fact, care of such people may have deteriorated over time (e.g. with privatization and deterioration of long-term care) and the pandemic brought this to light.[26] Moreover, data from much longer-term periods of observation suggest multiple, overlapping, complex long-term trends in winter mortality.[27] Finally, some other models may diverge in their calculations, if they exclude certain periods. E.g., the popular Euromomo model using a Serfling model in its core but excludes weeks of high influenza activity from the modeling: thus it generates high excess death estimates.[28]

Some other caveats should be discussed. First, finer adjustment for age (e.g. in more narrow age bins), and more comprehensive adjustment for other factors (e.g. gender, frailty, long-term care facility residence, comorbidities) may be able to offer even more accurate estimates of excess deaths. Second, even in countries with reliable data, some deaths are registered with delays, although with >4 months after the end of 2021 our main analyses for the 33 countries should not be affected much. Third, there can be debate on whether/how natural disasters and wars should be excluded. Fourth, long-term effects of both the pandemic and measures taken on healthcare, other aspects of health, education, society, and economy remain uncaptured in the 2020-2021 window. Comparisons of different approaches to excess death calculations should continue for longer periods of follow-up, also in the post-pandemic endemic phase. The boundaries between pandemic and endemic phase can be debated.[29] Regardless, the relative performance of different countries and their excess death ranking may change substantially over time. Sixth, analyzing specific causes of death may be informative, but suffers from major misclassification even in high-income countries.

Acknowledging these caveats, our analyses map the magnitude and uncertainty of excess deaths during 2020-2021. In countries with reliable data, age-adjustment suggests that excess deaths is lower than what has been previously published in calculations without age-adjustment. Excess death calculations convey some broad picture, especially for countries that fared very well or very poorly. Large differences in the impact of a pandemic across countries has been seen also in previous pandemics[30,31] for reasons that often remain largely unexplained. In depth assessments with death certificate audits, medical record audits, and autopsies may yield more granular insights about deaths and their causes, but these approaches also have limitations and feasibility challenges. For most countries worldwide, the tremendous uncertainty in the sparse data and indirect inferences should be mostly a call for improving the completeness and accuracy of death registration and investment in more rigorous demography infrastructures in the future.

MATERIALS AND METHODS

Compared published excess mortality estimates

We considered four previously published pandemic excess mortality evaluations[1-4,18,19] that have calculated both country-specific and global estimates and which use diverse methods to extrapolate from pre-pandemic reference periods to the pandemic period.

Karlinsky and Kobak published their evaluation in eLife in mid-2021;[1] the Economist team released their estimates in late 2021;[2] the COVID-19 Excess Mortality Collaborators published their estimates in the Lancet in early 2022 considering the two-year period 2020-2021;[3] and WHO released in May 2022 its updated estimates covering the same two year period 2020-2021. We call these four evaluations for convenience eLife, Economist, Lancet, and WHO respectively. Both the eLife and Economist models allow updating of excess mortality estimates over time and we have used the Our World in Data resource[18,19] that includes such updates. We used the estimates of excess mortality for the 2020-2021 two-year period for all 4 evaluations to maximize comparability. The three evaluations used also different sources for capturing the recorded numbers of COVID-19 deaths, which resulted in mostly minor discrepancies. Again, to maximize comparability, we used the same set of recorded numbers of COVID-19 for comparing against the excess mortality estimates of each evaluation: this set is identical to the set used by the Lancet evaluation, with the exception of Spain and UK where the Lancet numbers of recorded deaths were too high by 10% and 16%, respectively (perhaps due to clerical error) and where we used the Johns Hopkins data instead.[32]

The reported cumulative counts of COVID-19 deaths are taken from the Johns Hopkins Repository as reported by Our World in Data. The same values are reported by two of the four methods we use: eLife and Economist. Lancet reported values in https://ghdx.healthdata.org/sites/default/files/record-attached-files/IHME_EM_COVID_19_2020_2021_DATA_Y2022M03D10.CSV are sometimes quite different. Specifically for Spain, United Kingdom, Kazakhstan, Mexico, Russia, Georgia & Tajikistan where discrepancies are over 10% and some times as large as 115% (Russia is 651,000 in Lancet and 302,671 in OWID).

For each of the 4 evaluations, we extracted information on the following methodological features: reference period selected; modeling of reference period (static average, linear, spline, Poisson seasonality, other); exclusion of heat waves, wars, natural disasters, other; unit of modeling data (week, month, quarter, other); pandemic time period covered in the original publication/release; source of data for all-cause mortality; source of data for COVID-19 deaths used in original analysis; age and/or gender adjustment in calculations of excess deaths (if yes, how); any other adjustment in the calculations (if yes, specify); eligibility criteria and number of countries modeled directly; eligibility criteria and number of countries inferred from the directly modeled countries; and how these were inferred. Details on the data sources and modeling methods for these 4 evaluations can be found in references 1-4, 18 and 19.

Evaluation considering age strata in the calculations

We performed also our own calculation of excess deaths focused on considering the impact of age-adjustment on the calculations. We considered three pre-pandemic years (2017 to 2019) as the reference period. We used the following age strata: 0-14, 15-64, 65-75, 75-85, and >85 years old. For each age stratum, we obtained the average mortality, the number of deaths per million for the population of the specific age stratum. Then we extrapolated to the two pandemic years, again correcting for the population size in the specific age stratum. Finally, expected deaths were summed across the population strata. An illustrative worked example of the age-adjusted calculations is shown in Figure 1 using the data for Germany. This analytical approach corrects for changes in total population of a country over time, as well as changes in the proportion of elderly people. If the total population and/or the proportion of older people is increasing in recent years over time, the expected deaths by the age-adjusted scheme will be more compared to analyses that do not consider population changes and age-stratification. The inverse will happen, if the total population and/or the proportion of older people is decreasing in recent years over time. We used the Human Mortality Database (https://www.mortality.org),[33] specifically the Short Term Mortality Fluctuations file (https://www.mortality.org/Public/STMF/Outputs/stmf.csv) that includes weekly all-cause deaths and mortality values allowing the population size to be calculated as their ratio for each week.

Some clarifications are required for these analyses. First, on the calculation of the Weekly Population from the weekly Death Count and Weekly Mortality given in the MDH file stmf.csv. As Population = Death/Mortality, when Death = 0, Mortality = 0, so that Population is not defined. In these cases, we get the Population value from adjacent weeks with non-zero Death in the same year. Another problem is that some years, like 2015 & 2020 have an extra week 53, a leap week. This is because 52 weeks is 364 days whereas an average year is 365.25 days (a leap year every fourth year adds an extra day). Since mortality data are reported weekly, these years would get an apparent extra week of deaths. To correct this issue, we consider a standard year to be 365.25/7 = 52.1786 weeks and distribute weekly counts uniformly into years. Thus 2017 gets all its 52 week plus 0.1786 of week 1 of 2018. Year 2018 loses 0.1786 of week 1 and needs to get an additional 2*0.1786 of week 1 of 2019, and so on. In this way all the five years 2017 to 2021 are adjusted to have 52.1786 weeks.

We averaged the mortality values for each age-stratum over the reference years. We did not exclude any deaths or periods due to heat waves or other natural or man-made events, since it is subjective to arbitrate which ones should be excluded; moreover, we wanted to compare the COVID-19 pandemic with three recent years that had not raised any concerns about undue levels of deaths. We also repeated the excess death calculations using the same exact process but without considering age-strata.

We used population data, including also age-strata, from mortality.org.[34,35] for consistency across all evaluations in calculating excess deaths per million even though different evaluations had used different sources originally, e.g. WHO had used population data from the World Population Prospects 2019 with projections.[36]

Countries considered in main comparison

We focused our primary comparison on countries that have excellent death registration, are high income, and include data with weekly deaths in the Human Mortality database. These countries have the most reliable evidence to allow proper excess death calculations and changes in deaths over time cannot be due to changes in death registration (e.g. either improvements in death registration during the pandemic as countries put more resources on capturing information or worsening of death registration during the pandemic due to the pandemonium and acute death peaks). We defined high-income countries by World Bank criteria.[37] The Short Term Mortality Fluctuations file in the Human Mortality database includes detailed weekly deaths for the period 2017-2019 and also for the pandemic years 2020-2021 on 35 countries, all of which except Bulgaria and Russia are high-income, thus 33 countries were included in the main analyses. Of note, Canada and Australia did not have data for the entire 2 years of 2020-2021 and we performed calculations that cover the available time periods.

Excess death metrics of interest

We calculated excess deaths for the full two years 2020-2021 for each country, E. We expressed them also as percentage above the expected deaths, E_p and as excess deaths per million E_m. E.g. if 60,000 deaths happened in 2020-2021 in one country of 4,000,000 people and 50,000 were expected, the percentage E_P is (60,000-50,000)/50,000=12% and E_m is (60,000-50,000)/4,000,000=2,500 per million. As the main metric of interest, we used the ratio of estimated excess mortality E divided by the number of officially recorded COVID-19 deaths during 2020-2021, hence called the excess ratio R. E.g. R=1.20 means that the estimated excess mortality is 20% higher than the officially recorded COVID-19 deaths and R=0.90 means that the estimated excess mortality is 10% lower than the officially recorded COVID-19 deaths.

Analyses

We calculated the total number of excess deaths across the eligible countries with each of the different calculation methods, and as compared with the total recorded COVID-19 deaths. We also calculated the Pearson correlation coefficients of excess death metrics across the eligible countries based on the different calculation methods (a full list of correlation coefficient estimates appears in Supplementary Table 5).

We noted in how many of the 33 eligible countries the different calculations of excess deaths had consistently R above 1 or R below 1 (i.e. they all agreed that excess deaths were more than the recorded COVID-19 deaths or they all agreed that excess deaths were less than the recorded COVID-19 deaths); and in how many countries had R values that were all within a range of 0.3 between the highest and lowest estimate (a higher range means that divergence in the excess death estimates exceeds 30% of the recorded COVID-19 deaths); and within a range of 1 (a higher range means that the divergence in the excess death estimates exceeds the number of recorded COVID-19 deaths itself).

For the remaining, non-eligible countries, we evaluated excess death metrics and their comparison across different evaluations as exploratory analyses.

All analyses were done independently by two analysts (ML and FZ) and then compared notes with arbitration (including discussion with the third author, JPAI) for any disagreements until both analysts obtained the same results.

Data availability

All data are in the manuscript, tables, and supplementary tables and in the publicly available databases listed in Supplementary Links to Data

Table 1. Main features of the construction of the compared evaluations of excess deaths

	eLife	Lancet	Economist	WHO	Levitt
Reference period years	2015-2019	2010 (or earliest available)-February 2020	Unclear, not mentioned	2015–2019 (countries with monthly historical data); 2000–2019 (country with annual historical data)	2017-2019
Modeling of reference period	Linear fit	Ensemble of 6 models (weighted): 4 using splines with different placement of the last knot, one Poisson, and one taking 2019 only	Machine learning. Mix of boosted Gradient, Random Forest and Bootstrapping.	Sum of an annual trend (thin-plated spline) and a within-year seasonal variation (cyclic cubic spline)	Static average
Exclusions	Heat waves	Heat waves	Unclear, not mentioned	Not mentioned	No
Time unit of modeling data	Weekly (preferred) or monthly or quarterly	Weekly or monthly	Weekly for most, some monthly	Monthly	Weekly
Pandemic time period covered in the original publication/release	Varies per country, mostly 2020 to mid-2021, exact start in 2020 depends on availability of weekly (week 10), monthly (March), or quarterly (January) data	2020-2021 (acknowledged potential problem with late registration for last weeks/months)	2020 to late 2021	2020-2021 (had also released early estimates for 2020)	2020-2021
Pandemic time period covered in the current comparative analysis	2020-2021	2020-2021	2020-2021	2020-2021	2020-2021
Source of data for all-cause mortality	Human Mortality Database, others	World Mortality Database, Human Mortality Database, European Statistical Office	World Mortality Database, Human Mortality Database, others	Eurostat, Human Mortality Database, World Mortality Database	Human Mortality Database
Source of data for COVID-19 deaths used in original paper	Johns Hopkins	Apparently Johns Hopkins (although too high for Spain and UK)	Unclear	Not used	Johns Hopkins

Source of data for COVID-19 deaths used in the current comparative analysis	Johns Hopkins	Johns Hopkins	Johns Hopkins		Johns Hopkins
Age adjustment	No	No (authors stated that they may adjust for age in future work)	No	Yes (excess deaths summed across 7 age strata)	Yes (excess deaths summed across 5 age strata), also done without age-adjustment
Gender adjustment in calculations	No	No	No	Yes	No
Any other adjustment	No	Under-registration corrected for countries with <95% death registration	Probably no (unclear)	No	No
Eligibility criteria for countries modeled directly	Weekly, monthly or quarterly data available for at least one pre-pandemic year and for pandemic period	Weekly or monthly data available for any pre-pandemic years and for pandemic period	Data availability (unclear about details)	Data availability (Age and sex specific death for 2020 aggregated to 5-year age bands), excluding the countries that have experienced conflict, small population numbers, incomplete deaths and/or erratic/implausible age-pattern	Weekly data available in Human Mortality Database from 2017 onwards
Number of countries modeled directly	103 in the publication. 77 with data to December 2021	74 countries and territories in the publication	78 countries apparently had mortality data, but it seems that all countries were included in the machine learning	50	36
Eligibility criteria for countries inferred from the directly modeled countries	None	All countries considered	Unclear	All countries. All data for 2021 were inferred	None
Number of countries inferred from the directly modeled countries	None	Remaining world	Remaining world	Remaining world	None
How were they	Not applicable	LASSO regression,	Machine learning as	K-mean clustering. Countries are	Not Applicable

inferred?		selected 15 covariates related to pandemic (e.g. seroprevalence) and to background population health metrics (e.g. Healthcare Access and Quality Index)	above; totally impossible to reproduce based on thinly presented information, 121 indicators considered	divided into 5 clusters with different values of, Human Development Index Mean age at death, Crude excess rate	

Table 2. Excess death estimates for 2020-2021 according to 6 evaluations in the 33 eligible countries*

Country	2021 Population (millions) from HMD**	Two Years Actual All-Cause Death from HMD	Two Year Excess Death per eLife	Two Year Excess Death per Economist	Two Year Excess Death per Lancet	Two Year Excess Death per WHO	Two Year Excess Death per Levitt Age-Adjusted	Two Year Excess Death per Levitt Not Age-Adjusted
Australia	24.547	277,603	-11,639	-9,500	-18,100	-14,258	-14,460	-2,116
Austria	8.935	180,363	15,261	16,877	18,300	11,941	13,007	15,343
Belgium	11.494	239,201	20,613	23,364	32,800	17,919	13,958	19,036
Canada	36.108	586,135	13,474	23,548	43,700	22,018	21,829	37,938
Chile	17.960	263,154	38,894	38,094	37,200	38,698	31,640	45,021
Croatia	4.051	119,871	16,826	19,186	22,900	17,178	12,205	16,050
Czechia	10.730	269,137	41,480	43,942	49,100	37,040	34,079	43,262
Denmark	5.864	111,772	913	2,453	10,400	3,716	-3,157	2,390
Estonia	1.332	34,559	3,172	3,774	5,630	3,374	2,675	3,346
Finland	5.548	112,800	2,662	4,469	8,780	2,858	-716	4,345
France	65.467	1,297,407	78,910	97,390	155,000	81,849	57,767	96,831
Germany	82.533	2,005,701	88,446	113,242	203,000	194,987	54,740	128,557
Greece	10.711	274,725	24,177	25,269	25,400	19,394	20,515	29,551
Hungary	9.762	296,496	35,811	41,714	53,800	36,499	27,813	36,090
Iceland	0.362	4,640	50	-35	-314	-10	-142	11
Israel	9.293	99,437	7,203	7,967	9,280	6,178	3,201	5,421
Italy	59.630	1,454,193	167,816	190,872	259,000	160,800	115,690	166,373
Latvia	1.906	63,088	6,979	7,851	12,400	7,668	6,046	7,023
Lithuania	2.802	90,523	16,008	17,396	20,000	17,253	11,283	12,274
Luxembourg	0.635	9,106	57	314	1,070	69	109	171
Netherlands	17.479	339,242	28,495	33,017	45,500	29,213	17,969	32,020
New Zealand	5.013	67,586	-2,787	-2,566	-872	-2,678	-4,118	-1,826
Norway	5.408	82,491	1,101	1,986	742	-100	-2,994	-182
Poland	38.482	998,284	157,247	171,806	214,000	157,531	149,722	182,454
Portugal	10.323	248,658	20,677	24,530	40,400	20,449	16,286	25,602
Slovakia	5.480	131,782	24,131	25,538	25,400	24,320	18,662	23,786
Slovenia	2.103	47,090	4,953	5,492	6,980	5,584	3,944	5,617

South Korea	51.631	621,862	7,529	6,967	4,630	6,289	-30,286	33,417
Spain	47.511	948,016	102,991	115,685	162,000	103,935	68,720	95,964
Sweden	10.408	184,326	9,926	11,976	18,100	11,253	-367	3,666
Switzerland	8.688	146,969	11,394	13,539	15,500	8,247	5,640	10,139
United Kingdom	67.145	1,353,941	136,795	148,889	169,000	148,896	87,307	125,716
United States	329.995	6,849,500	961,032	1,017,655	1,130,000	932,460	871,295	1,116,088
TOTALS	969.336	19,809,658	2,030,597	2,242,701	2,780,726	2,110,570	1,609,862	2,319,376

HMD , Human Mortality Database short-term mortality fluctuation file stmf.csv downloaded from https://www.mortality.org/Public/STMF/Outputs/stmf.csv on 1-May-2022.

Data is given for full two-year period 1-Jan-2020 to 31-Dec-2021 for all countries except for Australia to 2021 week 48 and Canada to 2021 week 48. Because we use a standard year of 365.25 days (52.1786 weeks), the two years 2020 & 2021 are 104.357 weeks. The HMD Total Deaths, Expected Deaths and Excess Deaths for Australia and Canada are all smaller than they would be if data for these two locations were no delayed.

Data in the HMD are summed over weeks available. This means that both the Total Deaths and Population are incomplete for Australia (to week 47) and Canada (to week 48).

Table 3. Ratio of excess deaths over recorded COVID-19 deaths for 33 countries

Country	Reported COVID-19 Deaths from OWID	Excess Death/Reported per eLife	Excess Death/Reported Economist	Excess Death/Reported per Lancet	Excess Death/Reported per WHO	Excess Death/Reported Age-Adjusted	Excess Death/Reported per Levitt Not Age-Adjusted
Australia	2,253	-5.17	-4.22	-8.03	-6.33	-6.42	-0.94
Austria	13,733	1.11	1.23	1.33	0.87	0.95	1.12
Belgium	28,331	0.73	0.82	1.16	0.63	0.49	0.67
Canada	30,570	0.44	0.77	1.43	0.72	0.71	1.24
Chile	39,115	0.99	0.97	0.95	0.99	0.81	1.15
Croatia	12,538	1.34	1.53	1.83	1.37	0.97	1.28
Czechia	36,129	1.15	1.22	1.36	1.03	0.94	1.20
Denmark	3,267	0.28	0.75	3.18	1.14	-0.97	0.73
Estonia	1,932	1.64	1.95	2.91	1.75	1.38	1.73
Finland	1,714	1.55	2.61	5.12	1.67	-0.42	2.53
France	123,805	0.64	0.79	1.25	0.66	0.47	0.78
Germany	111,925	0.79	1.01	1.81	1.74	0.49	1.15
Greece	20,790	1.16	1.22	1.22	0.93	0.99	1.42
Hungary	39,186	0.91	1.06	1.37	0.93	0.71	0.92
Iceland	37	1.35	-0.95	-8.49	-0.27	-3.82	0.29
Israel	8,243	0.87	0.97	1.13	0.75	0.39	0.66
Italy	137,402	1.22	1.39	1.88	1.17	0.84	1.21
Latvia	4,570	1.53	1.72	2.71	1.68	1.32	1.54
Lithuania	7,387	2.17	2.35	2.71	2.34	1.53	1.66
Luxembourg	915	0.06	0.34	1.17	0.08	0.12	0.19
Netherlands	20,999	1.36	1.57	2.17	1.39	0.86	1.52
New Zealand	51	-54.65	-50.31	-17.10	-52.51	-80.75	-35.81
Norway	1,305	0.84	1.52	0.57	-0.08	-2.29	-0.14
Poland	97,054	1.62	1.77	2.20	1.62	1.54	1.88
Portugal	18,955	1.09	1.29	2.13	1.08	0.86	1.35
Slovakia	16,635	1.45	1.54	1.53	1.46	1.12	1.43
Slovenia	5,589	0.89	0.98	1.25	1.00	0.71	1.01

South Korea	5,625	1.34	1.24	0.82	1.12	-5.38	5.94
Spain	89,405	1.15	1.29	1.81	1.16	0.77	1.07
Sweden	15,310	0.65	0.78	1.18	0.74	-0.02	0.24
Switzerland	12,217	0.93	1.11	1.27	0.68	0.46	0.83
United Kingdom	148,737	0.92	1.00	1.14	1.00	0.59	0.85
United States	827,887	1.16	1.23	1.36	1.13	1.05	1.35
TOTAL OR MEDIANS	1,883,611	1.09	1.22	1.36	1.00	0.71	1.15

OWID refers to Our World in Data master COVID-19 file down loaded from https://covid.ourworldindata.org/data/owid-covid-data.csv on 22-Apr-2022.

Table 4. Excess deaths per age strata in the 33 countries of the main analysis*

Country	Mean HMD 2020 & 2021 Population (millions)	Excess deaths in 0-14 years	Excess deaths in 15-64 years	Excess deaths in 65-74 years	Excess deaths in 75-84 years	Excess deaths in >85 years	Excess death for all ages	Percentage of excess deaths <65 years old
Australia	24.547	-151	-1,196	-1,802	-5,485	-5,825	-14,460	No excess
Austria	8.935	-55	1,812	1,449	5,673	4,129	13,007	13.5%
Belgium	11.494	-307	675	2,707	4,071	6,812	13,958	2.6%
Canada	36.108	1,113	8,894	4,429	4,558	2,835	21,829	45.8%
Chile	17.960	-857	12,810	7,551	7,592	4,545	31,640	37.8%
Croatia	4.051	-25	1,192	3,639	4,196	3,203	12,206	9.6%
Czechia	10.730	-144	4,261	9,906	11,614	8,442	34,079	12.1%
Denmark	5.864	-21	-882	-194	-1,643	-417	-3,157	No excess
Estonia	1.332	-9	530	538	741	875	2,675	19.5%
Finland	5.548	-35	-350	308	-652	12	-716	No excess
France	65.467	-562	-3,076	13,541	8,666	39,198	57,767	No excess
Germany	82.533	-143	12,197	10,066	34,161	-1,541	54,740	22.0%
Greece	10.711	-70	3,569	4,710	3,500	8,805	20,515	17.1%
Hungary	9.762	-94	4,593	10,362	8,676	4,277	27,813	16.2%
Iceland	0.362	19	6	-14	-139	-14	-142	**
Israel	9.293	-269	203	1,168	668	1,431	3,201	-2.1%
Italy	59.630	-568	12,066	21,888	40,081	42,223	115,690	9.9%
Latvia	1.906	-49	1,082	1,248	2,254	1,511	6,046	17.1%
Lithuania	2.802	-56	2,584	2,403	3,567	2,785	11,283	22.4%
Luxembourg	0.635	40	-58	-64	1	189	109	No excess
Netherlands	17.479	14	1,241	3,566	7,175	5,973	17,969	7.0%
New Zealand	5.013	-62	-512	-797	-1,301	-1,446	-4,118	No excess
Norway	5.408	-63	-452	-433	-1,540	-506	-2,994	No excess
Poland	38.482	-574	19,293	47,295	39,417	44,291	149,722	12.5%
Portugal	10.323	-110	1,959	2,877	4,277	7,283	16,286	11.4%
Slovakia	5.480	-36	3,467	6,293	6,211	2,728	18,663	18.4%

Slovenia	2.103	-13	-49	691	1,418	1,897	3,944	No excess
South_Korea	51.631	-774	-431	-7,474	-10,335	-11,272	-30,286	No excess
Spain	47.511	-203	9,788	13,194	14,342	31,598	68,720	13.9%
Sweden	10.408	-41	-682	2	-422	776	-367	No excess
Switzerland	8.688	-16	175	492	1,075	3,914	5,640	2.8%
United_Kingdom	67.145	-762	25,852	19,276	20,476	22,465	87,307	28.7%
United_States	329.995	-2,858	365,676	216,688	169,623	122,167	871,295	41.6%
TOTAL	969.336	-7,737	486,236	395,508	382,515	353,341	1,609,862	29.7%

**No excess overall, small excess in >65 years old.

Supplementary Table 1: Excess deaths as percentage of the observed deaths in the 33 countries during 2020-2021

Country	HMD All-Cause Death in 2020 plus 2021	Per eLife	Per Economist	Per Lancet	Per WHO	Per Levitt Age-Adjusted	Per Levitt Not Age-Adjusted
Australia	277,603	-4.2%	-3.4%	-6.5%	-5.1%	-5.2%	-0.8%
Austria	180,363	8.5%	9.4%	10.1%	6.6%	7.2%	8.5%
Belgium	239,201	8.6%	9.8%	13.7%	7.5%	5.8%	8.0%
Canada	586,135	2.3%	4.0%	7.5%	3.8%	3.7%	6.5%
Chile	263,154	14.8%	14.5%	14.1%	14.7%	12.0%	17.1%
Croatia	119,871	14.0%	16.0%	19.1%	14.3%	10.2%	13.4%
Czechia	269,137	15.4%	16.3%	18.2%	13.8%	12.7%	16.1%
Denmark	111,772	0.8%	2.2%	9.3%	3.3%	-2.8%	2.1%
Estonia	34,559	9.2%	10.9%	16.3%	9.8%	7.7%	9.7%
Finland	112,800	2.4%	4.0%	7.8%	2.5%	-0.6%	3.9%
France	1,297,407	6.1%	7.5%	11.9%	6.3%	4.5%	7.5%
Germany	2,005,701	4.4%	5.6%	10.1%	9.7%	2.7%	6.4%
Greece	274,725	8.8%	9.2%	9.2%	7.1%	7.5%	10.8%
Hungary	296,496	12.1%	14.1%	18.1%	12.3%	9.4%	12.2%
Iceland	4,640	1.1%	-0.8%	-6.8%	-0.2%	-3.0%	0.2%
Israel	99,437	7.2%	8.0%	9.3%	6.2%	3.2%	5.5%
Italy	1,454,193	11.5%	13.1%	17.8%	11.1%	8.0%	11.4%
Latvia	63,088	11.1%	12.4%	19.7%	12.2%	9.6%	11.1%
Lithuania	90,523	17.7%	19.2%	22.1%	19.1%	12.5%	13.6%
Luxembourg	9,106	0.6%	3.4%	11.8%	0.8%	1.2%	1.9%
Netherlands	339,242	8.4%	9.7%	13.4%	8.6%	5.3%	9.4%
New Zealand	67,586	-4.1%	-3.8%	-1.3%	-4.0%	-6.1%	-2.7%
Norway	82,491	1.3%	2.4%	0.9%	-0.1%	-3.6%	-0.2%
Poland	998,284	15.8%	17.2%	21.4%	15.8%	15.0%	18.3%
Portugal	248,658	8.3%	9.9%	16.2%	8.2%	6.5%	10.3%
Slovakia	131,782	18.3%	19.4%	19.3%	18.5%	14.2%	18.0%

Slovenia	47,090	10.5%	11.7%	14.8%	11.9%	8.4%	11.9%
South Korea	621,862	1.2%	1.1%	0.7%	1.0%	-4.9%	5.4%
Spain	948,016	10.9%	12.2%	17.1%	11.0%	7.2%	10.1%
Sweden	184,326	5.4%	6.5%	9.8%	6.1%	-0.2%	2.0%
Switzerland	146,969	7.8%	9.2%	10.5%	5.6%	3.8%	6.9%
United Kingdom	1,353,941	10.1%	11.0%	12.5%	11.0%	6.4%	9.3%
United States	6,849,500	14.0%	14.9%	16.5%	13.6%	12.7%	16.3%
TOTAL OR AVERAGES	19,809,658	7.9%	9.0%	11.7%	8.0%	5.2%	8.5%

Supplementary Table 2: Excess deaths per million population in the 33 countries during 2020-2021*

Country	Mean 2020 & 2021 Population (millions) from HMD**	Excess Death per eLife	Excess Death per Economist	Excess Death per Lancet	WHO	Excess Death per Levitt Age-Adjusted	Excess Death per Levitt Not Age-Adjusted
Australia	24.547	-474	-387	-737	-581	-589	-86
Austria	8.935	1,708	1,889	2,048	1,336	1,456	1,717
Belgium	11.494	1,793	2,033	2,854	1,559	1,214	1,656
Canada	36.108	373	652	1,210	610	605	1,051
Chile	17.960	2,166	2,121	2,071	2,155	1,762	2,507
Croatia	4.051	4,154	4,736	5,653	4,240	3,013	3,962
Czechia	10.730	3,866	4,095	4,576	3,452	3,176	4,032
Denmark	5.864	156	418	1,774	634	-538	408
Estonia	1.332	2,381	2,833	4,227	2,533	2,008	2,512
Finland	5.548	480	806	1,583	515	-129	783
France	65.467	1,205	1,488	2,368	1,250	882	1,479
Germany	82.533	1,072	1,372	2,460	2,363	663	1,558
Greece	10.711	2,257	2,359	2,371	1,811	1,915	2,759
Hungary	9.762	3,668	4,273	5,511	3,739	2,849	3,697
Iceland	0.362	138	-97	-867	-28	-391	30
Israel	9.293	775	857	999	665	344	583
Italy	59.630	2,814	3,201	4,343	2,697	1,940	2,790
Latvia	1.906	3,662	4,119	6,506	4,023	3,172	3,685
Lithuania	2.802	5,713	6,208	7,138	6,157	4,027	4,380
Luxembourg	0.635	90	494	1,685	109	171	270
Netherlands	17.479	1,630	1,889	2,603	1,671	1,028	1,832
New Zealand	5.013	-556	-512	-174	-534	-821	-364
Norway	5.408	204	367	137	-18	-554	-34
Poland	38.482	4,086	4,465	5,561	4,094	3,891	4,741
Portugal	10.323	2,003	2,376	3,914	1,981	1,578	2,480

Slovakia	5.480	4,403	4,660	4,635	4,438	3,406	4,341
Slovenia	2.103	2,355	2,612	3,319	2,655	1,876	2,671
South Korea	51.631	146	135	90	122	-587	647
Spain	47.511	2,168	2,435	3,410	2,188	1,446	2,020
Sweden	10.408	954	1,151	1,739	1,081	-35	352
Switzerland	8.688	1,311	1,558	1,784	949	649	1,167
United Kingdom	67.145	2,037	2,217	2,517	2,218	1,300	1,872
United States	329.995	2,912	3,084	3,424	2,826	2,640	3,382
TOTAL OR AVERAGE	969.336	1,868	2,118	2,749	1,906	1,314	1,966

Supplementary Table 3: Excess deaths in 42 countries with available calculations from eLife, Economist, Lancet, and WHO

Country	2021 Population (millions) from WPR	Reported COVID-19 Deaths (OWID)	Excess Death per eLife	Excess Death per Economist	Excess Death per Lancet	Excess Death per WHO
Albania	2.873	3,217	14,655	15,514	17,300	12,688
Armenia	2.968	7,972	19,882	14,023	20,600	19,663
Azerbaijan	10.223	8,358	39,829	39,505	53,500	57,006
Bolivia	11.833	19,680	55,330	54,059	161,000	88,029
Bosnia and Herzegovina	3.263	13,442	19,123	21,019	20,900	15,719
Brazil	213.993	619,334	698,346	696,006	792,000	681,266
Bulgaria	6.897	30,955	58,061	61,754	82,500	57,495
Colombia	51.266	129,942	165,781	165,571	179,000	164,745
Cyprus	1.216	638	783	725	809	1,011
Ecuador	17.888	33,681	66,620	67,917	112,000	80,867
Egypt	104.258	21,752	275,979	296,179	265,000	251,101
Guatemala	18.250	16,107	43,111	43,389	51,100	49,393
Iran	85.029	131,606	251,283	258,514	274,000	232,153
Ireland	4.983	5,912	2,954	3,900	1,170	2,920
Japan	126.051	18,389	-13,147	15,873	111,000	-19,469
Kazakhstan	18.995	18,211	80,686	81,946	49,000	76,214
Kyrgyzstan	6.628	2,802	14,532	13,906	22,600	12,313
Lebanon	6.769	9,119	15,149	14,111	36,100	18,518
Malta	0.443	476	405	500	735	477
Mauritius	1.273	786	1,097	1,315	659	942
Mexico	130.262	299,428	606,476	616,288	798,000	626,219
Moldova	4.024	10,275	15,702	16,491	16,500	18,158
Monaco	0.040	38	134	164	53	64
Mongolia	3.329	2,059	721	1,088	5,600	6
Montenegro	0.628	2,411	2,632	3,534	4,080	3,910

North Macedonia	2.083	7,960	14,242	15,407	20,200	15,358
Oman	5.223	4,116	4,205	4,332	12,300	11,502
Panama	4.382	7,428	7,498	7,375	10,200	7,643
Paraguay	7.220	16,624	19,863	19,481	22,500	19,817
Peru	33.359	202,690	217,194	209,350	349,000	289,667
Philippines	111.047	51,504	204,234	223,349	184,000	185,255
Qatar	2.931	618	920	913	1,560	1,538
Romania	19.128	58,752	108,159	115,973	119,000	106,912
Russia	145.912	302,671	1,080,748	1,090,178	1,070,000	1,072,326
San Marino	0.034	100	133	135	118	169
Serbia	8.698	12,714	50,973	52,167	37,400	55,643
Singapore	5.897	828	1,766	1,156	-1,770	1,477
South Africa	60.042	91,145	246,097	243,575	302,000	238,670
Thailand	69.951	21,698	63,120	60,679	35,200	15,303
Ukraine	43.467	102,088	178,896	191,797	181,000	198,226
Uruguay	3.485	6,170	3,023	3,213	9,820	3,108
Uzbekistan	33.936	1,485	35,729	34,662	69,100	44,888
TOTALS	1390.176	2,295,181	4,672,924	4,777,033	5,496,834	4,718,910

Supplementary Table 4: Excess deaths in 98 countries with available calculations from Economist, Lancet and WHO

Country	2021 Population (millions) from worldpopulationreview.com	Reported COVID-19 Deaths (OWID)	Excess Death per Economist	Excess Death per Lancet	Excess Death per WHO
Afghanistan	39.835	7,356	62,635	192,000	44,532
Algeria	44.617	6,276	83,476	54,400	69,588
Andorra	0.077	140	160	328	372
Angola	33.934	1,770	37,525	64,000	22,687
Antigua and Barbuda	0.099	119	72	43	-28
Argentina	45.606	117,169	142,053	142,000	89,881
Bahrain	1.748	1,394	2,628	3,920	666
Bangladesh	166.303	28,072	478,621	413,000	140,764
Barbados	0.288	260	54	553	-355
Belarus	9.443	5,578	59,666	85,600	48,893
Belize	0.405	602	790	982	698
Benin	12.451	161	5,227	8,250	11,853
Bhutan	0.780	3	148	108	-396
Botswana	2.397	2,444	8,467	17,200	7,413
Burkina Faso	21.497	318	32,841	21,400	22,157
Burundi	12.255	38	17,774	4,310	9,335
Cambodia	16.946	3,012	13,648	17,500	12,518
Cameroon	27.224	1,851	41,325	41,300	35,321
Cape Verde	0.562	352	1,303	659	924
Central African Republic	4.920	101	532	14,100	6,248
Chad	16.915	181	43,072	15,200	19,250
China	1444.216	4,636	452,669	17,900	-52,064
Comoros	0.888	157	1,001	1,480	725
Costa Rica	5.139	7,353	6,833	6,220	9,650
Cuba	11.318	8,322	14,507	26,600	18,157
Djibouti	1.002	189	5,574	3,850	1,769

Dominica	0.072	47	41	149	12
Dominican Republic	10.954	4,247	5,208	20,800	11,872
El Salvador	6.518	3,824	21,848	26,900	17,035
Equatorial Guinea	1.450	175	467	2,770	1,718
Eritrea	3.601	76	-1,018	7,210	2,413
Eswatini	1.172	1,303	5,053	13,600	3,820
Ethiopia	117.876	6,937	160,509	208,000	103,497
Fiji	0.903	698	765	1,480	-114
Gabon	2.279	288	4,058	3,980	1,601
Georgia	3.980	13,800	21,238	44,300	24,464
Ghana	31.732	1,295	21,998	35,900	20,909
Grenada	0.113	200	98	255	-266
Guinea	13.497	391	9,705	26,700	12,531
Guinea-Bissau	2.015	149	2,336	4,350	2,842
Guyana	0.790	1,054	2,071	2,690	2,810
Haiti	11.542	766	14,552	27,900	9,612
Honduras	10.063	10,433	27,364	55,400	22,662
India	1393.409	481,486	4,896,948	4,070,000	4,740,891
Indonesia	276.362	144,094	694,553	736,000	1,028,564
Iraq	41.179	24,158	257,540	183,000	66,734
Jamaica	2.973	2,473	2,816	6,460	3,593
Jordan	10.269	12,653	21,564	27,000	11,928
Kenya	54.986	5,378	87,165	171,000	12,350
Kuwait	4.329	2,468	7,528	3,560	4,241
Laos	7.379	372	9,772	4,640	1,755
Lesotho	2.159	665	2,789	17,800	3,983
Liberia	5.180	287	5,229	7,970	4,044
Libya	6.959	5,710	25,523	36,700	7,859
Madagascar	28.427	1,027	31,115	65,100	25,581
Malawi	19.648	2,364	23,285	54,900	17,114
Malaysia	32.776	31,487	9,867	48,100	7,534
Maldives	0.544	262	684	296	246
Mali	20.856	660	23,896	33,500	27,311
Mauritania	4.775	866	8,573	7,990	6,948
Morocco	37.345	14,849	63,507	157,000	34,751

Mozambique	32.163	2,006	51,667	78,100	42,728
Myanmar	54.806	19,268	126,922	101,000	44,189
Namibia	2.587	3,633	9,425	18,000	7,753
Nepal	29.675	11,594	102,094	123,000	32,512
Nicaragua	6.702	217	16,550	33,400	12,095
Niger	25.131	275	52,602	18,100	34,341
Nigeria	211.401	3,030	194,192	163,000	186,434
Pakistan	225.200	28,933	786,089	664,000	230,439
Papua New Guinea	5.223	590	-2,248	15,600	761
Rwanda	9.119	1,350	23,061	21,900	5,403
Saint Kitts and Nevis	13.277	28	53	30	-208
Saint Lucia	0.054	295	558	501	369
Saint Vincent and the Grenadines	0.184	81	94	234	495
Saudi Arabia	0.111	8,877	82,910	32,900	17,550
Senegal	35.341	1,890	10,838	38,600	16,504
Seychelles	17.196	134	-12	116	7
Sierra Leone	0.099	123	2,696	7,570	7,886
Somalia	8.141	1,333	24,572	89,000	35,460
South Sudan	16.360	135	28,655	14,700	9,167
Sri Lanka	11.381	14,979	30,530	12,900	-8,830
Sudan	21.497	3,331	293,181	83,600	38,000
Suriname	44.909	1,189	1,845	2,590	726
Syria	0.592	2,897	14,808	27,100	7,315
Tajikistan	18.276	125	14,927	29,400	13,009
Tanzania	9.750	737	56,541	132,000	40,029
Togo	61.498	248	8,719	9,030	-6,988
Trinidad and Tobago	8.478	2,869	3,533	5,130	2,030
Tunisia	1.403	25,569	27,913	72,500	23,822
Turkey	11.936	82,361	326,000	185,000	264,040
Uganda	85.043	3,294	55,399	73,500	20,518
United Arab Emirates	47.124	2,164	10,069	9,340	2,330
Vanuatu	9.991	1	-86	35	-76
Venezuela	0.314	5,328	54,398	164,000	22,324
Vietnam	28.705	32,394	143,991	72,300	-6,210
Yemen	98.169	1,984	53,341	65,600	33,793

Zambia	30.491	3,734	30,811	81,300	23,553
Zimbabwe	18.921	5,004	39,912	80,900	18,631

Supplementary Table 5: Correlation coefficients for various excess death metrics (as shown in Table 3, supplementary Table 1, supplementary Table 2, supplementary Table 3, and supplementary Table 4) between the different evaluations

R (Table 3)	33 countries					
	eLife	Economist	Lancet	WHO	Levitt Age-adjusted	Levitt Non-age-adjusted
eLife		0.999	0.818	0.999	0.994	0.989
Economist			0.839	0.999	0.995	0.989
Lancet				0.841	0.829	0.808
WHO					0.994	0.988
Levitt Age-adjusted						0.977

R (Table 3)	New Zealand and Australia excluded					
	eLife	Economist	Lancet	WHO	Levitt Age-adjusted	Levitt Non-age-adjusted
eLife		0.603	0.075	0.636	0.117	0.450
Economist			0.805	0.772	0.405	0.394
Lancet				0.657	0.519	0.243
WHO					0.474	0.453
Levitt Age-adjusted						-0.368

Ep (Table S1)	33 Countries					
	eLife	Economist	Lancet	WHO	Levitt Age-adjusted	Levitt Non-age-adjusted
eLife		0.992	0.873	0.972	0.960	0.948
Economist			0.919	0.973	0.964	0.939
Lancet				0.902	0.887	0.835
WHO					0.940	0.930
Levitt Age-adjusted						0.962

Ep (Table S1)	New Zealand and Australia excluded					
	eLife	Economist	Lancet	WHO	Levitt Age-adjusted	Levitt Non-age-adjusted
eLife		0.989	0.827	0.961	0.949	0.935
Economist			0.893	0.962	0.956	0.923
Lancet				0.864	0.860	0.794
WHO					0.925	0.913
Levitt Age-adjusted						0.952

Em (Table S2)	33 Countries					
	eLife	Economist	Lancet	WHO	Levitt Age-adjusted	Levitt Non-age-adjusted
eLife		0.996	0.935	0.980	0.976	0.969
Economist			0.958	0.983	0.973	0.965
Lancet				0.950	0.925	0.917
WHO					0.953	0.951
Levitt Age-adjusted						0.985

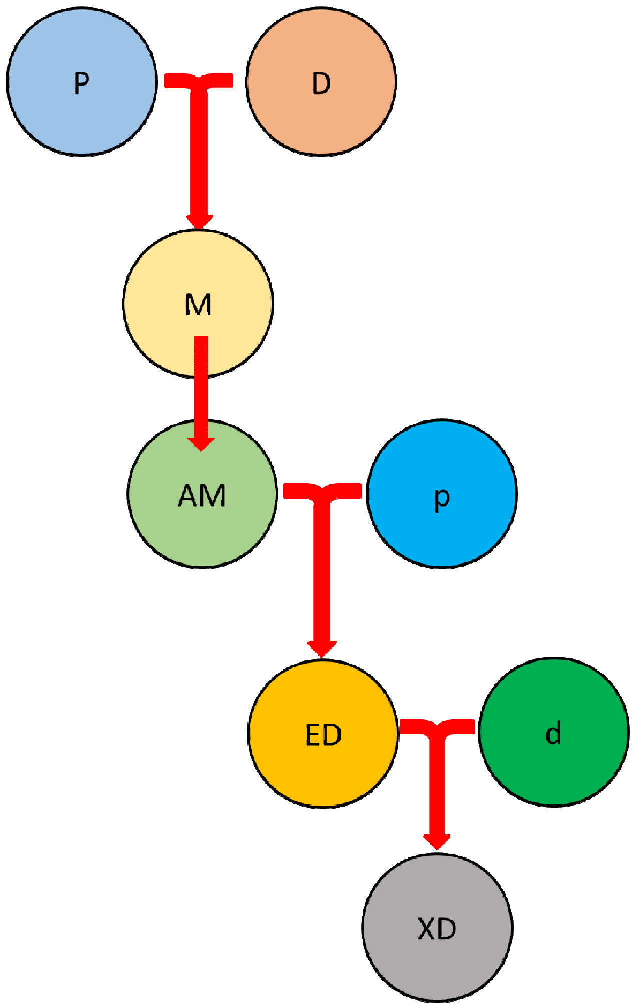
Em (Table S2)	New Zealand and Australia excluded					
	eLife	Economist	Lancet	WHO	Levitt Age-adjusted	Levitt Non-age-adjusted
eLife		0.996	0.924	0.977	0.972	0.963
Economist			0.951	0.980	0.969	0.959
Lancet				0.941	0.914	0.904
WHO					0.945	0.942
Levitt Age-adjusted						0.983
Population	0.073	0.059	0.028	0.086	0.126	0.147
Reported Deaths	0.102	0.090	0.067	0.122	0.155	0.176

Em (Table S3)	42 countries			
	eLife	Economist	Lancet	WHO
eLife		0.996	0.924	0.977
Economist			0.951	0.980
Lancet				0.941

Em (Table S4)	98 countries		
	Economist	Lancet	WHO
Economist		0.590	0.552
Lancet			0.622

Pearson correlation coefficients are calculated, in some cases excluding the outliers Australia and New Zealand

FIGURE 1.



Year	0_14	15_64	65_74	75_84	85p	Total	
(P) Population at 1st January (from mortality.org)							
2017	11,145,381	54,111,793	8,311,961	7,106,377	2,262,961	82,938,474	
2018	11,215,001	53,898,150	8,400,478	7,188,162	2,283,049	82,984,843	
2019	11,229,232	53,492,197	8,520,977	7,215,850	2,344,749	82,803,007	
(D) Total number of deceased at 31st of December (from mortality.org)							
2017	3,576	133,436	138,377	304,751	352,662	932,804	
2018	3,518	136,148	141,198	314,219	360,429	955,514	
2019	3,453	132,259	139,509	310,708	354,283	940,214	
(M) Mortality per million population : M=(D*1,000,000)/P							
2017	320.9	2465.9	16647.9	42884.2	155841.0	11246.9	
2018	313.7	2526.0	16808.3	43713.4	157871.8	11514.3	
2019	307.5	2472.5	16372.4	43059.1	151096.3	11354.8	
(AM) Average Mortality for the period 2017-2019							
2017-2019	314.0	2488.1	16609.6	43218.9	154936.4	11372.0	
(p) Population in pandemic years 2020 & 2021							
2020	11,259,695	53,063,103	8,764,763	7,076,543	2,459,432	82,623,538	
2021	11,311,321	52,598,592	9,088,830	6,854,367	2,590,048	82,443,161	
(ED) Expected death in pandemic years						**Crude**	**Adjust**
2020	3,536	132,029	145,579	305,840	381,055	**939,597**	**968,039**
2021	3,552	130,873	150,961	296,238	401,293	**937,546**	**982,917**
(D) Total number of deceased for pandemic years						**Crude**	**Adjust**
2020	3,364	133,856	145,959	317,509	383,296	983,986	983,984
2021	3,581	141,243	160,647	318,730	397,511	1,021,714	1,021,712
(XD) Age adjusted excess deaths for pandemic years						**Crude**	**Adjust**
2020	-172	1,827	380	11,669	2,241	**44,389**	**15,945**
2021	29	10,370	9,686	22,492	-3,782	**84,168**	**38,795**
2020 & 2021	-143	12,197	10,066	34,161	-1,541	**128,557**	**54,740**

Figure 1: Schematic Representation of the Calculation of Age Adjusted Excess Death. Populations and total amounts of death on a single year are used to obtain the mortality values for the reference years (2017-2019) for each of the age strata. The average of this value is taken as the reference mortality for that strata. Expected deaths for a non COVID scenario for 2020 and 2021 are obtained from the population and reference mortality data for each strata. Excess deaths are calculated as the difference between the actual deaths and the expected deaths. Expected and excess deaths for the non age adjusted case are also reported for comparison. The table reports the real values for Germany as an example. This table is provided as Excel in the Supplement so that method can be easily used on other data.

Supplementary Links to Data

HMD
1-May-2022
https://www.mortality.org/Public/STMF/Outputs/stmf.csv
Use this for 33 set Populations, Total deaths & Excess deaths in age-bands

OWID for COVID-19 reported cases and excess death by eLife method.
22-Apr-2022
https://covid.ourworldindata.org/data/owid-covid-data.csv
Use this for eLife & Reported COVID-19 Cumulative count of Death to date of Completion

WPR for estimate Deaths
14-Apr-2022
https://worldpopulationreview.com/country-rankings/death-rate-by-country
Use rateGHDE?
Expected death is 2 years (rateGHDE X pop2021)
csvData.csv

https://worldpopulationreview.com/countries
Use pop2021 in column [D]
csvData.csv

World Bank
14-Apr-2022
https://data.worldbank.org/indicator/SP.DYN.CDRT.IN?end=2017&start=2017&view=bar
API_SP.DYN.CDRT.IN_DS2_en_csv_v2_3932073.csv

Lancet
5-Apr-2022
https://ghdx.healthdata.org/sites/default/files/record-attached-files/IHME_EM_COVID_19_2020_2021_DATA_Y2022M03D10.CSV
Use for Lancet Reported deaths and Excess Death for 2020 & 2021

Economist
3-Apr-2022
https://ourworldindata.org/excess-mortality-covid#estimated-excess-mortality-from-the-economist
excess-deaths-cumulative-economist-single-entity.csv

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