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Calculating Excess Mortality Rates Due to COVID-19

A Flash Review

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Calculating Excess Mortality Rates Due to COVID-19: A Flash Review[1][2][3]

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Mesh Terms and Keywords

COVID-19, SARS-CoV-2, Excess Mortality

Question

This flash review aims to provide an overview of the methods used to define and operationalize COVID-19 excess deaths. COVID-19-related excess deaths are defined as the difference between the observed and the expected number of deaths during the COVID-19 pandemic period. The reason for calculating COVID-19 excess deaths is to provide a more accurate estimate of the number of lives that were lost due to the pandemic. Although the number of deaths by COVID-19 disease has been reported by health authorities, the true effects of the pandemic may be different. The primary reason for this difference is due to the indirect effects of the disease such as missed or delayed medical interventions caused by the shortages or an overburdened healthcare system, and other social or behavioural changes such as fewer traffic-related incidents or changes in substance use. Also, the absence of post-mortem testing among those who have died before they could receive a diagnostic confirmation, variations in death registration systems regarding the definition of COVID-19 death, and reporting other comorbidities as the cause of death when the deceased suffered from other pre-existing conditions may result in underreporting of this estimate.[1,2]

In this flash review, we answer the question: What are the most appropriate methods for calculating the COVID-19 excess mortality rate with special attention to the Canadian context? Different methods of calculating this estimate are provided in detail.

Review/search strategy

A search was made on PubMed using the terms (“excess mortality” OR “excess deaths”) AND (“COVID-19” OR “coronavirus” OR “SARS-CoV-2”). The search was limited to publications after 2019. PubMed search keywords: ("COVID-19"[Mesh] OR "SARS-CoV-2"[Mesh]) AND "Mortality"[Mesh] AND "Excess". Also, grey literature and snowball searches were performed to identify relevant publications conducted by North American health organizations. Articles found in PubMed, grey literature, and snowball searches were added to the reference manager (Zotero).

In the next step, a title/abstract screening was performed to identify articles that met the inclusion criteria. Studies were selected at this stage that were research articles, reports, or fact sheets in the English Language, publicly available, and conducted in any of the founding OECD member countries which includes: Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom, and the United States.

The full-text screening was carried out to select studies that provided a detailed description of their analysis and calculated the mortality rate for the whole population of their study. The following items were charted for each item: title, first author, publication type and year, journal, the population of interest, data source, control/standardization, pre-COVID and COVID mortality date range, a summary of study methodology to calculate excess mortality, and the justification for using the methodology of selected studies.

Findings

Of 281 articles identified in PubMed, 24 met the inclusion criteria in the title and abstract screening step, and 19 articles were included in the final review after the full-text screening. Two studies were identified in the snowball search and four were found in the grey literature search. A summary of the selected studies' and their methodologies is presented in Tables 1 and 2 at the end of this flash review.

Studies stated factors suggesting that official data may underestimate measures of COVID-19 death. Compared to studies conducted in one country, ones conducted in multiple countries may have been more impacted by the underestimation of this estimate. Therefore, most reviewed studies preferred using the all-cause mortality rate rather than the COVID-19 mortality rate to calculate COVID-19 excess death. All-cause mortality has the advantage of avoiding problems caused by the considerable variation in definitions of what comprises a COVID-19 death between different regions or countries and other possible causes of underestimating these estimates.[3–13]

Based on the reviewed studies, two main methods were used to calculate expected mortality: first, to calculate an average of the mortality rates in the prior five years and compare the deaths rate related to the previous five years with the COVID-19 period deaths rate. In this method, it is assumed that the population is constant throughout the year.[5,11,14] Second, to model the mortality rate in the pandemic years based on the previous year's mortality rates accounting for changes in year-to-year mortality rates and population growth.[3,4,6,7,10,13,15–17]

Achilleos et al. studied excess all-cause mortality and COVID-19-related mortality in 22 countries. To calculate the expected mortality rate in this study, both methods were used. In the first method, the average year-to-date mortality rate between 2015 and 2019 for each country was considered the expected mortality rate, and the 2020 year-to-date mortality rate was considered the observed mortality rate. The overall and sex-stratified mortality rates were used to calculate the difference in mortality rates for 2015-2019 and 2020. In the second method, Poisson regression was used to model the expected number of deaths for 2020. Also, a Generalized Linear Model was used to adjust for secular trends, yearly, and half-yearly seasonal cycles. Counts with a 95% confidence interval of observed and expected deaths were calculated to estimate the count and 95% CI of excess death along with the ratio of observed/expected death. The authors also discussed that by using two methodologies, an agreement in cases of increase or decrease in mortality is shown. Also, it allowed researchers to validate the first method which was to subtract the average 2015-2019 mortality rate from the observed mortality rate in 2020.

Although a number of studies used Poisson regression to estimate expected mortality rate, Gibertoni et al.[6] preferred using linear regression over Poisson regression to estimate the expected mortality among Italian municipalities. Authors stated that since in 3% of the municipalities there were irregular patterns of mortality in the five years used for the prediction, that caused failures in providing affordable estimates for small municipalities.

To calculate COVID-19 excess mortality rate, studies control/standardize for different factors. Age- and sex-specific mortality rates were used by most studies in calculating COVID-19 excess mortality in addition to the overall mortality rates since control/standardization for age and sex have shown to affect mortality patterns.[5,6,9–11,16,17] Among other factors controlled by studies, one study considered underlying conditions to estimate excess mortality in patients living with different underlying conditions.[18] Two studies considered temporal and spatial analysis in their methodology. The reason for including time and space was stated as to optimize the observation of epidemic behaviour, considering the effect of location proximity and time closeness.[10,17] One study considered racial factors [9] and one study included ethnic factors and area deprivation indicators [19] to control for the COVID-19 excess mortality patterns among different races and social classes of their population of interest. Also, sensitivity analysis was performed by a number of studies to consider the changes in year-to-year mortality rates and life expectancy in calculating the expected number of deaths. [13,20]

To report COVID-19 excess mortality rate, both death counts and mortality rates were used by the reviewed studies. Mcgrail reported COVID-19 excess mortality as a percentage of observed mortality. The author stated that this method allows for comparisons across areas with different population sizes.[21]

In addition to review studies conducted in other countries, an in-depth review of Canadian studies was performed to provide a summary of the methodologies used by Canadian authorities and researchers to calculate COVID-19 excess mortality. The Public Health Agency of Canada has published a fact sheet entitled: "COVID-19 and deaths in older Canadians: Excess mortality and the impacts of age and comorbidity". According to this fact sheet, there was higher excess mortality among older adults and people living with comorbidities in Canadian provinces in 2020. In this study, the excess mortality was calculated by comparing the death counts for 2020 to the average weekly number of deaths in 2015 to 2019 reported by Statistics Canada. Also, Age groups' excess death counts were calculated and graphed. [22]

McGrail conducted a study entitled: "Excess mortality, COVID-19 and health care systems in Canada". This study used publicly available data to explore excess mortality related to COVID-19 in the Canadian provinces from March 2020 to October 2021 to assess the population-wide effects of the pandemic and variations across Canada. To calculate observed deaths, weekly data on total mortality and expected death numbers were obtained from Statistics Canada. The author stated that province-specific statistical modelling, controlling for age and sex was used by Statistics Canada to compute the number of deaths that would have occurred in the absence of the pandemic, accounting for year-over-year population growth and aging. However, avoidable death changes such as decreased motor vehicle accidents were not considered in the method used by Statistics Canada. The author also stated that other factors influencing the mortality rate during the pandemic needed to be considered in Stat Canada methodology such as increased overdose emergencies, changes in drug supply, and unexpected heat waves.

Mcgrail's study used week-by-week mortality patterns to prevent masking the trends in mortality by overall rates. As mentioned above, excess mortality was calculated as a percentage of total observed mortality, to allow for comparisons across provinces with very different population sizes. Data on COVID-19 death numbers were obtained from the "COVID-19 in Canada" dashboard to calculate COVID-19 deaths as a percentage of total excess deaths. Excess and COVID-19 mortality proportions were also calculated per 100 000 population by province, overall and by week. This study recommended considering public health factors influencing mortality such as heat waves and fewer motor vehicle accidents during the pandemic to have a more accurate estimate of the expected mortality. [21]

<u>The Statistics Canada method</u>

Statistics Canada provided an estimation of excess mortality in Canada from 1 Jan 2020 to 4 July 2020. To estimate the expected number of deaths, a quasi-Poisson regression model adopted from Farrington et al.[23] was fitted to the weekly all-cause mortality data for 2016 – 2019. This data included published death data for 2016 - 2018 from the Canadian Vital Statistics Death Database and provisional death counts for 2019 coming from the National Routing System

(NRS). Expected death counts were produced for 2020 up to July 4^{th}, estimated using the following model of year-to-year seasonal patterns of death counts:[24]

$$log\ \mu_t = \alpha + \beta t + \gamma_{c(t)} \quad (1)$$

where μ_t is the expected death counts in week t, β is the coefficient corresponding to the linear time trend, and $\gamma_{c(t)}$ is the seasonal factor for the week t in which $c(t)$ shows the period of the year that includes week t.

Since the initial Statistics Canada analysis was conducted simultaneously as the pandemic death counts were reported, contemporaneous death counts had to be adjusted for reporting delays. A Poisson regression model was used to, in effect, "nowcast" weekly counts of death that occurred in weeks 20 Dec 2019 - 22 March 2020 and 22 March - 4 July 2020 based on distribution of reporting delays estimated from death records in each period.[24] Insofar as our objective is to estimate excess deaths retrospectively, then data will have been fully reported and these kinds of nowcasting adjustments are unnecessary.

Finally, the expected weekly number of excess deaths was subtracted from the observed weekly death counts adjusted for the reporting delays during the pandemic period to calculate excess death counts. To calculate the 95% prediction intervals of calculated estimates, variances of the two models were combined.

Conclusions and recommendations

Excess mortality is defined as the difference between the observed and expected number of deaths during a period. Calculating excess mortality in the COVID-19 pandemic period helps to better identify the true effects of the pandemic, in particular the lives lost due to the indirect effects of the pandemic. To calculate excess mortality different methodologies can be used. In this flash review, common methods of calculating excess mortality were reviewed and summarized.

Two main methods considered by the studies to calculate the expected death rate were: first, to calculate an average of the five previous years' mortality counts, and second, to fit a model to the previous year's mortality data. Both methodologies are useful depending on the availability of the data. However, the second method provides the researcher with the opportunity to account for the changes in year-to-year mortality rates and population growth. Canadian studies have used both methods to estimate COVID-19 excess mortality. In the study conducted by the Public Health Agency of Canada the first method was used.[22] Statistics Canada and Mcgrail used the second method to calculate COVID-19 excess mortality rate. [1,21]

It is also recommended to calculate all-cause mortality since it provides more accurate estimates compared to COVID-19 death as it is not affected by variations in the definition of COVID-19 death among different health jurisdictions, underreporting, or undiagnosed cases. Controlling for age and sex, calculating age- and sex-specific mortality rates in addition to the overall mortality rates is recommended.

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Table 1. Results of PubMed, grey literature, ans snowball searches for COVID-19.

Title	Link	Database/ Website	Publication Type	Author(s)	Year	Journal (i.)v.:pp	Study Population	Data Sources	Controls/standardization
PubMed literature search									
Estimating excess 1-year mortality associated with the COVID-19 pandemic according to underlying conditions and age: a population-based cohort study	Link	PubMed	Research Article	Banerjee et al.	2020	Lancet 2020; 395: 1715–25	England's general population, >30years, and registered with a general practice with at list 1 year of follow-up data	Linked primary and secondary care electronic health records from England (Health Data Research UK–CALIBER)	Age (5-year age bands), sex, and underlying conditions associated mortality risk.
Rapid Estimation of Excess Mortality during the COVID-19 Pandemic in Portugal -Beyond Reported Deaths	Link	PubMed	Research Article	Vieira et al.	2020	Journal of Epidemiology and Global Health Vol. 10(3); September (2020), pp. 209–213	Portugal	Portuguese Death Certificate Information System (SICO-eVM), Directorate-General of Health daily Situation Reports.	Age and cause specific mortality rates were calculated in addition to all-cause mortality rate.
Estimation of Excess Deaths Associated With the COVID-19 Pandemic in the United States, March to May 2020	Link	PubMed	Research Article	Weinberger et al.	2020	JAMA Intern Med. 2020;180(10):1336-1344.	US states	2020 data was obtained from National Center for Health Statistics (NCHS) mortality surveillance system, 2019 data was obtained from CDC.	Mortality data was stratified by State and week. The baseline model was adjusted for seasonality, year-to-year baseline variation, influenza epidemics, and reporting delays.
Excess deaths from COVID-19 correlate with age and socio-economic status. A database study in the Stockholm region	Link	PubMed	Research Article	Strang et al.	2020	UPSALA JOURNAL OF MEDICAL SCIENCES 2020, VOL. 125, NO. 4, 297–304	County of Stockholm	Stockholm Regional Council's central data warehouse,	Age, socioeconomic status
Excess mortality from COVID-19: weekly excess death rates by age and sex for Sweden and its most affected region	Link	PubMed	Research Article	Moding et al.	2021	The European Journal of Public Health, Vol. 31, No. 1, 17–22	Sweden poplulation > 50 years	National Swedish register data and Statistics Sweden	Age, sex
Patterns of COVID-19 related excess mortality in the municipalities of Northern Italy during the first wave of the pandemic	Link	PubMed	Research Article	Gibertoni et al.	2021	Health & Place 67 (2021) 102508	Three Italian Regions: Lombardy, Veneto, Emilia-Romagna.	The Italian National Institute of Statistics (ISTAT)	Age (0–64, 65–74 and ≥ 75 years), gender
Impact of COVID-19 on excess mortality, life expectancy, and years of life lost in the United States	Link	PubMed	Report	Chan et al.	2021	PLoS ONE(Vol. 16, Issue 9)	US states	Two CDC datasets: Provisional COVID-19 Death Counts by Sex, Age, and State, and Underlying Causes of Death (1999–2019)	State, age groups (< 1 year, 1–4 years, 5–14 years, 15–24 years, 25–34 years, 35– 44 years, 45–54 years, 55–64 years, 65–74 years, 75–84 years, and 85+ years), year
Excess mortality due to Covid-19? A comparison of total mortality in 2020 with total mortality in 2016 to 2019 in Germany, Sweden, and Spain	Link	PubMed	Research Article	Kowall et al.	2021	PLoS One . 2021 Aug 3;16(8):e0255540.	Germany, Sweden, Spain	EUROSTAT database "Population (Demography, Migration And Projections)"	Age (< 20, 20–39, 40–59, 60–79, > 80 years), Week
Mortality of the COVID-19 Outbreak in Sweden in Relation to Previous Severe Disease Outbreaks	Link	PubMed	Brief Research Report	Ledberg	2021	Front. Public Health, 18 February 2021	Sweden	Swedish Book of Death, Statistics Sweden	Days
A first analysis of excess mortality in Switzerland in 2020	Link	PubMed	Research Article	Locatelli et al.	2021	PLoS ONE(Vol. 16, Issue 6)	Switzerland	the Federal Statistical Office (FSO)	Age, sex
A Bayesian spatio-temporal analysis of mortality rates in Spain: application to the COVID-19 2020 outbreak	Link	PubMed	Research Article	Saavedra et al.	2021	Population Health Metrics (2021) 19:27	Spain	Spanish official Institute of National Statistics (INE)	Spatial, sex, year, age (< 50; 50–64; 65–74; 75 and over)
Excess mortality in the United States in 2020: Forecasting and anomaly detection	Link	PubMed	Brief Report	Wiemken et al.	2021	American Journal of Infection Control 49 (2021) 1189−1190	US	Centers for Disease Control and Prevention (CDC) National Center for Health Statistics (NCHS)	-
Excess Mortality Associated With COVID-19 by Demographic Group: Evidence From Florida and Ohio	Link	PubMed	Research Article	Quast et al.	2021	Public Health Reports 2021, Vol. 136(6) 782-790	Florida and Ohio	Ohio Public Health Information Warehouse and Florida Bureau of Vital Statistics	Week, sex (male, female), age group (0-19, 20-49, 50-59, 60-69, 70-79, ≥80), and race (Black, White)
Inequalities in excess premature mortality in England during the COVID-19 pandemic: a cross-sectional analysis of cumulative excess mortality by area deprivation and ethnicity	Link	PubMed	Research Article	Barnard et al.	2021	BMJ Open 2021;11:e052646	England	Public Health England (PHE) and Office for National Statistics (ONS)	Age, deprivation quantile, ethnicity, and geographical area
Regional excess mortality during the 2020 COVID-19 pandemic in five European countries	Link	PubMed	Research Article	Konstantinoudis et al.	2022	Nature Communications (2022) 13:482	England, Greece, Italy, Spain, and Switzerland	The Office for National Statistics in England, the Hellenic Statistical Authority in Greece, the Italian National Institute of Statistics in Italy, the National Centre of Epidemiology at the Carlos III Health Institute and the Daily Monitoring Mortality System, the National Statistics Institute and Ministry of Justice in Spain, and the Federal Statistical Office in Switzerland	Age, sex, temperature, spatio-temporal units
COVID-19 mortality, excess mortality, deaths per million and infection fatality ratio, Belgium, 9 March 2020 to 28 June 2020	Link	PubMed	Surveillance	Molenberghs et al.	2022	Euro Surveill. 2022;27(7):pii=2002060	Belgium	The Belgian institute for public health	Age, sex
Excess all-cause mortality and COVID-19-related mortality: a temporal analysis in 22 countries, from January until August 2020	Link	PubMed	Research Article	Achilleos et al.	2021	International Journal of Epidemiology, Volume 51, Issue 1, February 2022, Pages 35–53	22 Countries	Publicly available or with restricted access National vital-statistics databases from each participating country	Sex
Historically High Excess Mortality During the COVID-19 Pandemic in Switzerland, Sweden, and Spain	Link	PubMed	Research Article	Staub et al.	2022	Ann Intern Med. 2022;175:523-532.	Switzerland, Sweden, Spain	Swiss Federal Statistical Office, Statistics Sweden, Spanish Statistical Office	Age, month
Estimating excess mortality due to the COVID-19 pandemic: a systematic analysis of COVID-19-related mortality, 2020–21	Link	PubMed	Research Article	COVID-19 Excess Mortality Collaborators	2022	Lancet 2022; 399: 1513–36	191 countries and territories (including 74 countries and 12 states of India), and 252 subnational units for selected countries.	Government websites, compendia developed by the World Mortality Database, the Human Mortality Database, and the European Statistical Office.	Weeks and months
Grey Literature and Snowball Search									
Excess mortality, COVID-19 and health care systems in Canada	Link	Candian Medical Association Journal (cmaj)	Research article	McGrail	2022	CMAJ May 30, 2022 194 (21) E741-E745	Canada	Statistics Canada	Age, sex
Excess mortality in Canada during the COVID-19 pandemic	Link	StatCanada	Fact sheet	Stat Canada	2020	-	Canada	Canadian Vital Statistics Death Database	Age, sex

Table 1. Results of PubMed, grey literature, ans snowball searches for COVID-19.

Title	Link	Database/ Website	Publication Type	Author(s)	Year	Journal (i.)v.:pp	Study Population	Data Sources	Controls/standardization
COVID-19 and deaths in older Canadians: Excess mortality and the impacts of age and comorbidity	Link	Public Health Agency of Canada(PHAC)	Fact sheet	PHAC	2021	-	Canadians 65 years old and older	Statistics Canada data	Week, age, sex
Methods for estimating the excess mortality associated with the COVID-19 pandemic	Link	World Health Organization(WHO)	Technical document	WHO	2022	-	Multiple countries	WHO routine mortality data received from countries.	Age, sex
Excess mortality during COVID-19	Link	CCODWG	Article	Our world in data website	2022	-	Multiple countries	The Human Mortality Database, the World Mortality Dataset, The Economist, and the World Health Organization	Age
Quantifying and communicating the burden of COVID-19	Link	BMC Medical Research Methodology	Research article	Cube et al.	2021	BMC Med Res Methodol (2021) 21:164	US, Germany, Italy (Lombardy)	Public estimates of excess deaths in specific states of the United States, all-cause mortality data from the German Federal Statistical Office, published mortality data of the local community Nembro, in the Lombardy, Italy.	Age

Table 2. Charting of literature search results for how they calculated excess deaths due to COVID-19 and their justification.

Author(s)	Year	PreCOVID (Expected) mortality date range	COVID (observed) mortality date range	Calculation of Excess Death	Justification for the used methodology	Comments
Banerjee et al.	2020	1 Jan 1997 - 1 Jan 2017	Not provided in the article.	Observed numbers of deaths were compared with those expected based on the pre-COVID-19 mortality risks in the population. Age-stratified death rates over days in infected patients were computed. Prevalence of underlying conditions, their differing pre-COVID-19 background long-term mortality risks, or the additional risk associated with COVID-19 were excluded. Underlying conditions were defined using ICD 10th codes. Kaplan-Meier estimates of 1-year all-cause mortality at each age group were calculated. Relative risk (RR) of COVID-19 mortality compared with background mortality was computed.	Identifying the effect of chronic medical conditions on COVUD-19 excess death to consider pre-COVID-19 background long-term mortality risks related to the underlying conditions.	
Vieira et al.	2020	Average and Standard deviation of the number of daily all-cause mortality for the last 10 years between Jan 1 and April 14.	March 16 - April 14 2020	It was considered as Relevant Excess Mortality (REM) when the daily observed values exceed the estimated average value of deaths for each day plus corresponding 2 SDs or if they exceed the limits of the 95% confidence interval in the Auto Regressive Integrated Moving Average (ARIMA) model. To validate the EM calculated based on historical daily deaths, from all causes, it was compared with the estimated results obtained with an ARIMA model adjusted to the time series until April 14, 2020. The time series included the observed mortality from January 1, 2010 to March 15, 2020 and the historical average from March 16, 2020 until 14 April 2020.	Not provided in the article.	
Weinberger et al.	2020	5 Jan 2015 - 25 Jan 2020	1 March 2020 - 30 May 2020	Poisson regression model was fit to the weekly state-level death counts from 5 Jan 2015 to 25 Jan 2020. This baseline was then projected forward until May 30, 2020, to calculate expected death counts. The expected number of deaths in each week was subtracted from the observed number of deaths.	Not provided in the article.	The expected death counts were calculated using main regression model and an empirical baseline which was the mean deaths per week from previous years.
Strang et al.	2020	2016 - 2019 (Jan - May)	Jan - May 2020	95% CI, T-test, and chi-square tests were used to compare deaths proportions of observed and expected deaths ranges. Death rates for Jan to May 2020 were compared with corresponding calculated means and 95% CI for the corresponding months in 2016 - 2019.	Not provided in the article.	
Moding et al.	2021	2015 - 2019	2020	Weekly death counts for all-cause mortality by 5-year age groups and sex from 2015 to 2020 for Sweden and Stockholm region was calculated. Expected death counts was defined as the average observed weekly death counts between 2015 and 2019. Observed death counts was defined as the same measure in 2020.	All-cause mortality is the most objective and comparable way of assessing the pandemic. With relative certainty, any excess mortality in 2020 in directly or indirectly related to COVID-19. Age- and sex-specific COVID-19 fatality rate is different with the overall rates therefore, considering sex and age-specific death rates provides a more comprehensive picture of the pandemic effects on the population mortality.	
Gibertoni et al.	2021	1 - 30 April of 2015–2019	23 February - 30 April 2020	A simple linear regression was used with the observed deaths as dependent variable and year as independent (coded 0 to 4 to showing years from 2015 to 2019). The constant and slope of the model were used to estimate by extrapolation the expected number of deaths in 2020. The ratio of observed deaths in 2020 divided by 1.012 (a coefficient that corrects for 2020 being a leap year) to expected deaths in 2020 provides the relative mortality (RM) by each age/gender subgroup for each municipality. Excess mortality was then obtained by subtracting 1 from the RM and multiplying this value by 100.	Due to the lack of confirmation test for many patients who died of COVID-19 and/or reporting a pre-existing condition of the patient as the reason of death, calculating excess all-cause mortality is the most reliable way to calculate COVID-10 excess death.	Equation is provided in the article: Exp.D. = a + b*5, where x = 5 corresponds to year 2020. This study preferred using linear regression over Poisson regression to estimate the expected mortality, because in 3% of the municipalities there was irregular patterns of mortality that prevented estimation for small municipalities.
Chan et al.	2021	1999 - 2019	2020	A linear regression model was used to predict annual number of deaths from 1999 to 2019 with 95% prediction interval. This bassline was subtracted from the reported total deaths for all age groups in different sex and state subgroups.	Not provided in the article.	Equation is provided in the article
Kowall et al.	2021	2016 - 2019	2020	The age-specific weekly numbers of death of 2016 to 2019 was divided to the respective age-specific mid-year population of each country to calculate the age-specific weekly mortality rates. Then, mean mortality rate of 2016 to 2019 for each age and week subgroup was calculated. The expected number of death of each week was calculated by multiplying the age-specific weekly mean mortality rates with the age-specific population of the year 2020. The 2020 weekly Standardized Mortality Ratio (SMR) with 95% CI was estimated by dividing the number of all deaths observed in that calendar week by the number of all deaths expected in that calendar week.	All-cause mortality is used to avoid variations caused by different COVID-19 definitions in countries. Also, sensitivity analysis was performed to consider the changes in life expectancy in calculating expected number of deaths.	SMR was used as the method to calculate excess death counts. A detailed explanation of the methodology was provided in the article.
Ledberg	2021	5 years prior to the onset of observed period	19 March 2020 - 31 May 2020	Serfling method: A regression model was fitted to data to predict expected death counts for the time periods related to the outbreak. Excess mortality was calculated as the difference between observed and expected death counts. The number of deaths per day was assumed to follow a Poisson distribution. time is expressed in units of days. Excess mortality was estimated as the sum of the differences between observed and expected mortality for the days of the outbreak.	In many countries a preset model-based threshold is calculated to monitor outbreaks. In the current study, the authors used the same logic to calculate excess mortality in Sweden by using the daily death counts for the time period of 1860 - 2020.	Equation is provided in the article
Locatelli et al.	2021	2019	2020	Directly standardized mortality rates (dSMR) over the years for Swiss population stratified for gender and age were calculated and compared. 2020 was considered as standard.	All-cause mortality is a robust indicator accounting for the direct and indirect effects of a pandemic. The number of deaths is divided by the population size to account for increasing number of death due to increasing population size. Standardized (or adjusted) mortality rates were used to overcome sex and age differences in mortality patterns.	Equation is provided in the article
Saavedra et al.	2021	2008 - 2019	2020	A Bayesian spatio-temporal model was developed for each of the four age groups of the population to estimate the expected number of deaths based on the 2008 to 2020 mortality rates. A special effect of outbreak in 2020 was added. Excess death was calculated as observed minus expected death counts in 2020.	With respect to previous studies, the application of spatio-temporal study methods has proven to be ideal to optimize the observation of epidemics behavior, considering the influence of location proximity and time closeness.	Equation is provided in the article
Wiemken et al.	2021	1999 - 2020	March - Dec 2020	36 Months US mortality rate was forecasted using all-cause mortality data from Jan 1999 to Feb 2020. Provisional all-cause mortality estimates from March to Dec 2020 was added to the data as the expected mortality rate. Mean and 95% Confidence Interval of the expected and observed mortality rates.	To provide updated visualizations as new data are reported and provisional mortality estimates are corrected, this study evaluate abnormal all-cause mortality counts using anomaly detection, and develop a web application to allow for real-time evaluation of excess mortality in the USA.	
Quast et al.	2021	2010 - 2019	March 21 - Dec 5 2020	A log-linear regression model was used with the relevant population as the exposure variable. The model was developed separately for each state and for all deaths and by sex, age group, and race. Ratio of observed to expected deaths was calculated as well.	Few studies have been considered racial differences in their analysis. This study aims to consider geography and race-specific differences as well as age and sex in their analysis of COVID-19 excess mortality.	Equation is provided in the article
Barnard et al.	2021	2015 - 2019	21 March 2020 - 26 February 2021	Quasi-Poisson regression models were used to estimate expected death rates. Covariates included age, gender, area deprivation, ethnicity and geographical area. To consider systematic changes in the death rates that are not reflected in the changing age structure of the population, a linear trend was included in the model.	Age, gender, area deprivation and ethnic group differences were considered in the excess mortality calculation since there are mortality differences in these specific groups.	
Konstantinoudis et al.	2022	2015 - 2019	2020	Bayesian spatiotemporal models were used to predict the expected weekly deaths by specific age and sex groups at the regional level in 5 European countries in 2020. The correlation between the predicted and observed deaths and the 95% coverage, defined as the probability that the observed deaths lie within the 95% interval estimated from the model were used to assess the agreement between the predicted and observed deaths.	Understanding spatio-temporal patterns in COVID-19 mortality helps to understand the transmission patterns and effectiveness of policies and measures to control the pandemic.	Equation is provided in the article
Molenberghs et al.	2022	2009 - 2019	9 March 2020 - 28 June 2020	Reported COVID-19 deaths in Belgium from 9 March 2020 to 28 June 2020 was compared with the expected weekly average all-cause mortality. COVID-19 death per million population and infection fatality ratio was compared between Belgium and other countries and within subgroups in Belgium.	DPM and IFR were used as mortality estimates to compare COVID-19 mortality in Belgium to countries that have a less extensive reporting strategy, in particular when the gap between excess mortality and COVID-19 mortality is large.	Equation is provided in the article

Table 2. Charting of literature search results for how they calculated excess deaths due to COVID-19 and their justification.

Author(s)	Year	PreCOVID (Expected) mortality date range	COVID (observed) mortality date range	Calculation of Excess Death	Justification for the used methodology	Comments
Achilleos et al.	2021	2015 - 2019	January - August 2020	Observed COVID-19 deaths defining as weekly or monthly deaths were compared with the average mortality reported from 2015 - 2019 data for the same week or months. the observed death counts were also compared with the expected 2020 death rates which was estimated using Poisson regression based on historical data accounting for seasonality and long and short term trends. A Generalized Linear Model with a linear time trend was also used to adjust for secular trends and two sine and cosine terms for yearly and half-yearly seasonal cycles.	Not provided in the article.	
Staub et al.	2022	5 preceding year	multiple periods	Age-specific, monthly excess all cause deaths for Switzerland, Sweden, and Spain for 2020 and 2021 and other pandemic periods in 20th century were used. Officially reported deaths from all causes by month from the earliest available year (1877 for Switzerland, 1851 for Sweden, and 1908 for Spain) through the end of 2020 (for Sweden) and June 2021 (for Spain and Switzerland) were used. To estimate the expected values for a given year deaths and total population counts from the 5 prior years was used. Years with high pandemic mortality were excluded to estimated expected values for the following years. A Bayesian model was built to compute the expected number of death by months and age group for each year based on the 5 preceding year.	Not provided in the article.	
COVID-19 Excess Mortality Collaborators	2022	2010 - 2019	1 Jan 2020 - 31 Dec 2021	Excess mortality was calculated by subtratcing expected mortality from observed mortality, after excluding data from periods affected by late registration and anomalies such as heat waves. A database of all-cause mortality data by week and month was created. To calculate expected mortality an ensemble of six models was used. A statistical model was conducted to predicte the excess mortality rate for locations and periods where all-cause mortality data were not available, using Least absolute shrinkage and selection operator (LASSO) regression as a variable selection mechanism to assess the realtoinship between excess mortality rate and 15 covariates (COVID-19 related and background population health metrics). Also, a Baysian spline was used to estimate the weekly seasonal pattern for each location and a Poisson model was included with fixed effects on week and year.	To differentiate how much excess mortality from the pandemic is due to SARS-CoV-2 infection and how much is due to other societal, economic, or behavioural changes associated with the pandemic.	
McGrail	2022	2016 - 2020	2020 - 2021	Weekly data on total deaths obtained from statistics Canada as reported by provincial vital statistics agencies were used as observed death numbers. The numbers were adjusted to account for possible incompleteness. Province-specific statistical modeling including age and sex grouping were used to compute expected number of death accounting for year-to-year population growth and aging. Excess mortality was calculated as a percentage of total observed mortality. COVID-19 deaths were calculated as a percentage of total excess deaths. Excess and COVID-19 mortality rates were computed per 100 000 population by province, weekly and overall.	Week by week mortality patterns was used by this study to prevent masking the trends in mortality by overall rates. Excess mortality was calculated as a percentage of total observed mortality, to allow for comparisons across provinces with very different population sizes. Also, COVID-19 deaths were calculated as a percentage of total excess deaths. Excess and COVID-19 mortality rates were also calculated per 100 000 population by province, overall and by week.	
Stat Canada	2020	1 Jan 2016 - 1 Jan 2020	1 Jan 2020 - 4 July 2020	Statistical models were used to estimate death counts adjusted for incompleteness and to estimate baseline non-COVID mortality. Excess deaths are estimates by comparing adjusted counts with modeled baseline mortality. Expected number of deaths was estimated based on a quasi-Poisson regression model adopted from Farrington et al. algorithm. Also, a Poisson regression model was used to adjust observed death counts for the reporting delays.	Increasing pattern of annual death numbers and variation in the death number in a given week from year to year. Difficulty to timely collection of the observed death counts.	Methodology
PHAC	2021	2020	2016 - 2019	The average annual death for the reference period from 2016 to 2019 was used as the expected number of death in 2020. This estimate was compared with the observed number of deaths in 2020. The excess death occurred in older adults (>65) was calculated.	Not provided in the document.	
WHO	2022	2015–2019 for countries with monthly historical data, 2000–2019 for countries with annual historical data	2020 - 2021	For the countries with available monthly mortality data, Poisson regression model was developed to estimate expected death counts using 2015 - 2019 death counts. For countries with annual data, the previous model was used minus the monthly term. A negative binomial spline model was fitted to theses countries data to predict all cause mortality of 2020 and 2021. Overdispersed Poisson log-linear regression model was developed to predict the monthly ACM in countries with no data.	Different models were developed for countries with available monthly and annual data, also for countries with no data to compute all-cause mortality as expected death counts in 2020 and 2021.	Equation is provided in the document
Our world in data website	2022	2015 - 2019	2020 - 2022	An estimate produced by Ariel Karlinsky and Dmitry Kobak was used to calculate expected deaths. A regression model was fitted to the data for each region using historical data from 2015 - 2019 to project the number of deaths in 2020 - 2022. The model can capture both seasonal variations and year to year trends in mortality. P-score or the percentage difference between the reported and projected number of deaths was used to compare excess mortality between the countries.	To calculate expected mortality counts, methodology of this study has been changed from calculating five years average of the mortality counts to a fitting a regression model to the previous five years data. This change was done to consider year-to-year change in mortality patterns in calculating expected mortality.	
Cube et al.	2021	2016	2020	A search was performed to identify methods of calculating excess death. Six identified measures are: Risk difference, Risk difference per capita, P-Score, SMR, Z-Score, and population attributable fraction (PAF). PAF = (Observed - Expected) / Observed. Observed death was obtained by accumulating death counts from March to Dec 2020. Expected death counts were estimated using observed death counts in the same period in 2016.	2016 had the most similarities with 2020 in terms of Influenza activity and heat waves.	R code for estimating the population attributable fraction using the public estimated weekly excess deaths: https://static-content.springer.com/esm/art%3A10.1186%2Fs12874-021-01349-z/MediaObjects/12874_2021_1349_MOESM1_ESM.html