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Excess deaths in the United States during the first year of COVID-19

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ABSTRACT

Accurately determining the number of excess deaths caused by the COVID-19 pandemic is hard. The most important challenge is determining the counterfactual count of baseline deaths that would have occurred in its absence. Flexible estimation methods were used here to provide this baseline number and plausibility of the resulting estimates was evaluated by examining how changes between baseline and actual prior year deaths compared to historical year-over-year changes during the previous decade. Similar comparisons were used to examine the reasonableness of excess death estimates obtained in prior research. Total, group-specific and cause-specific excess deaths in the U.S. from March 2020 through February 2021 were calculated using publicly available data covering all deaths from March 2009 through December 2020 and provisional data for January 2021 and February 2021. The estimates indicate that there were 649,411 (95% CI: 600,133 to 698,689) excess deaths in the U.S. from 3/20–2/21, a 23% (95% CI: 21%–25%) increase over baseline, with 82.9% (95% CI: 77.0% - 89.7%) of these attributed directly to COVID-19. There were substantial differences across population groups and causes in the ratio of actual-to-baseline deaths, and in the contribution of COVID-19 to excess mortality. Prior research has probably often underestimated baseline mortality and so overstated both excess deaths and the percentage of them attributed to non-COVID-19 causes.

1. Introduction

Determining the death toll of the coronavirus (COVID-19) pandemic is hard. In its early stages, testing was sporadic, and some mortality was probably attributed to other causes (Gill and DeJoseph, 2020), with misclassification possibly continuing as the epidemic progressed. Some deaths probably also occurred indirectly, such as those due to reductions in emergency department or hospital visits transpiring because the health care system was stressed beyond capacity or individuals avoided medical care to reduce exposure to the virus (Baum and Schwartz, 2020; Jeffery et al., 2020; Solomon et al., 2020). Conversely, mortality from other sources may have declined. For example, social distancing might have reduced deaths from transmissible diseases such as influenza and pneumonia below levels that otherwise would have been expected (Jones, 2020).

The standard method for addressing these combined effects is to calculate excess deaths, here estimated as the difference between actual deaths and the counterfactual baseline count anticipated if the COVID-19 pandemic had not occurred. Excess deaths have been computed across a wide variety of settings including measuring the effects of obesity, HIV, hurricanes and heatwaves (Flegal et al., 2005; Buehler et al., 1990; Santos-Lozada and Howard, 2018; Nitschke et al., 2011), as well as for COVID-19 (Woolf et al., 2020a; Weinberger et al., 2020; Woolf et al., 2020b; Rossen et al., 2020; Faust et al., 2021; Woolf et al., 2021; Rossen et al., 2021; Institute for Health Metrics and Evaluation, 2021; Sanmarchi et al., 2021).

A key challenge is determining the baseline count to which observed mortality is compared. In the context of COVID-19, multiple methods have been employed and no single procedure is necessarily universally preferable. For instance, approaches used to compute excess deaths over short periods (e.g. weeks) or for limited geographic areas (like states) may be less well suited to calculating excess national deaths over a full year.

Prior investigations have typically modeled deaths over arbitrarily determined prior periods and used the specifications with the best fit among the models tested to estimate baseline deaths. However, the

Abbreviations: CI, Confidence interval; COVID-19, SARS-CoV-2 virus; RMSE, Root mean square error; U.S., United States.

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plausibility of the resulting counterfactual fatality counts has not been assessed. The current study develops a simple criterion for examining the credibility of such methods that involves investigating how the relationship between estimated baseline deaths and actual mortality occurring over the same period one-year earlier compares to historical changes in year-over-year fatality counts. The results suggest that earlier studies are likely to have frequently overestimated excess U.S. deaths during the COVID-19 pandemic, and also the share of these deaths attributed to non-COVID causes. New procedures are next used to provide estimates of excess mortality from March 2020 through February 2021, the first year of significant COVID-19 mortality in the United States. (A few COVID-19 deaths occurred during the first two months of 2020 and the virus may have entered the country as early as December 2019 (Althoff et al., 2021)).

2. Data

Information on deaths from 2009 through 2020 were obtained from the Centers for Disease Control (CDC) and Prevention *Multiple Cause of Death (MCOD)* data, downloaded from *CDC Wonder* (Centers for Disease Control and Prevention, 2022). Data were utilized on cause of death, using four-digit *International Classification of Diseases, Tenth Revision* (ICD-10) codes, age, race/ethnicity, gender, and year of death. Since final data from January 2021 through February 2022 were not available at the time of this study, provisional data for these months, updated on May 1, 2022, was obtained from *CDC Wonder (*Centers for Disease Control and Prevention, 2018*)*. The provisional and final data provide comparable information, except for differences in the coding of race/ethnicity. The earlier estimates of excess deaths, examined below, used data from the CDC, *Provisional Death Counts for Coronavirus Disease (COVID-19)* series (National Center for Health Statistics, 2021), and two of these data sets (Centers for Disease Control and Prevention, 2022b; Centers for Disease Control and Prevention, 2020-2021) were used for this portion of the analysis. The online appendix supplies additional details.

Total mortality counts were computed as were those by sex, race/ethnicity, age, and the following causes: COVID-19; heart disease; malignant neoplasms (cancer); cerebrovascular disease (stroke); Alzheimer's disease; diabetes; chronic lower respiratory disease (respiratory); influenza or pneumonia (flu/pneumonia); kidney disease; motor vehicle accidents (vehicle); drug overdoses; intentional self-harm (suicide); and assault (homicide). Appendix Table A1 indicates the ICD-10 codes corresponding to each of these causes. For brevity, white, black, and other race individuals below refer to non-Hispanic persons.

3. Methods

3.1. Year-over-year changes in deaths

Observed counts for all deaths and for specified groups and causes were calculated for each month from 3/09–2/21, with adjustments for the extra February day in leap years. The data were then aggregated over 12-month March to February periods, hereafter referred to as "years" and denoted by the year with the majority of months (e.g. 2020 indicates 3/20–2/21).

Historical year-over-year percentage changes in the mortality counts were computed as:

$$\Delta D_{it} = \frac{D_{it} - D_{it-1}}{D_{it-1}} \times 100\%, \tag{1}$$

for D_{it} the number of deaths overall or specified group or cause i, in year t, and measured from 2010 to 2019.

3.2. Prior estimates

Estimates of excess deaths and the share attributed to COVID-19 were obtained from four prior studies (Woolf et al., 2021; Rossen et al., 2021; Institute for Health Metrics and Evaluation, 2021; Sanmarchi et al., 2021) that covered at least the 3/1/20–12/31/20 period. Two of these (Woolf et al., 2021; Rossen et al., 2021) built upon methods developed in prior analyses examining shorter periods (Woolf et al., 2020a; Weinberger et al., 2020; Woolf et al., 2020b; Rossen et al., 2020), so that problems identified here also apply to those earlier investigations. All four studies provided estimates of excess deaths but two (Woolf et al., 2021; Sanmarchi et al., 2021) did not supply information on baseline mortality. For these, total deaths were calculated using the data sources described above, with baseline deaths then computed as the difference between total and excess fatalities.

The implied change in baseline deaths versus lagged mortality counts was next computed, where the latter refer to those occurring over the timespan 12-months earlier than the original study. The 12-month lag period was set to start and end on the same day of the week as in the original study and contained the same number of days. For instance, when considering excess deaths from 3/1/20–1//2/21, the lag period was 3/3/19–1/4/20.

Ninety-five percent confidence intervals (95% CI), or estimate bounds, were calculated, to the extent possible given the information supplied in the original analyses. Further adjustments were sometimes required to provide comparable estimates, as detailed in the appendix.

3.3. New estimates

New estimates of excess deaths from 3/1/20–2/28/21 were obtained using the following procedure.

First, year-over-year changes in monthly total death counts were calculated. These revealed substantial excess volatility in January deaths, versus other months. For instance, the standard deviation in the year-over-year monthly changes from 2009 to 2019 was almost five times as high in January as the average of the other eleven months, with particularly large January fluctuations for deaths from heart disease, lower respiratory causes and flu/pneumonia (Appendix Table A2).

Adjusted counts were computed using a procedure that removed the January volatility but preserved the overall number of deaths occurring over the full 11-year (2009–2019) period. Specifically, with deaths in (March through February) year t and group or cause i again denoted by D_{it}, define corresponding counts with January deaths excluded as D_{it}' and calculate the ratio of the average annual number of fatalities from 2009 to 2019 to the corresponding 11-month (excluding January) total as:

$$Ratio_i = \left(\frac{\sum_{t=2009}^{2019} D_{it}}{\sum_{t=2009}^{2019} D_{it}'} \right) \Big/ 11. \tag{2}$$

The adjusted mortality count, was then calculated as

$$D_{it}^{adj} = D_{it}' \times Ratio_i. \tag{3}$$

D_{it}^{adj} preserves the total number of deaths from 2009 to 2019 but removes the volatility from January year-over-year changes.

Next, the adjusted mortality counts, overall and separately by group and cause, were regressed on linear and quadratic time trends for periods beginning between 2009 and 2015 and ending in 2019; 2015 was the latest starting year considered to ensure that the estimation model contained a minimum of five years. A root mean square error based goodness-of-fit criterion was used to determine the optimal starting year and choice of linear versus quadratic trend. This procedure was flexible in allowing the determinants of mortality trends to be heterogenous across groups and sources.

Baseline deaths were then estimated using the preferred regression specification, with the trend variables set to their 2020-year values and 95% CI's computed using the standard error of the regression predicted value. Finally, excess deaths were calculated as the difference between actual 2020 mortality and the estimated baseline count. The appendix provides further details.

As a sensitivity check excess deaths were also computed based on observed mortality counts, without adjusting for excess January volatility.

3.4. Plausibility

Plausibility of the excess death estimates, both from prior studies and the original analysis presented here, was evaluated by examining how the implied year-over-year change in estimated COVID-19 period baseline deaths, versus actual fatalities during the same period one-year earlier, compared to the average and range of historical changes in year-over-year deaths from 2009 to 2019. Close accordance between the baseline versus one-year lagged mortality change with typical historical patterns of year-over-year growth suggest that the estimation models provided reasonable results. The appendix supplies additional details on these methods.

All analyses were conducted in 2021 and 2022 using STATA Statistical Software: Release 17.

4. Results

4.1. Year-over-year changes

Fig. 1 shows the year-over-year percentage change in total deaths over 12-month periods from 2009 to 2019, and corresponding results adjusted to eliminate excess January volatility. Annual deaths increased from 2.44 million in 2009 to 2.86 million in 2019 and mortality growth averaged 1.70% per year but with considerable variability. The standard deviation of the 12-month change was 1.70% (not shown), with minimum and maximum changes of −1.22% and 3.63%. Positive year-over-year growth occurred in eight of ten years, with reductions exceeding 0.6% happening just once, from 2017 to 2018. Average growth in adjusted fatalities counts was virtually the same as the unadjusted change (1.63%) but the standard deviation was reduced by almost 40% (to 1.05%), with rising year-over-year adjusted mortality observed in nine of ten years, and annual increases of 1.8%–3.0% in seven.

These patterns imply that positive year-over-year mortality growth is the norm and that baseline death estimates lower than those 12-months earlier are probably unreliable.

4.2. Prior estimates

Table 1 summarizes estimates of excess COVID-19 mortality from four earlier studies (Woolf et al., 2021; Rossen et al., 2021; Institute for

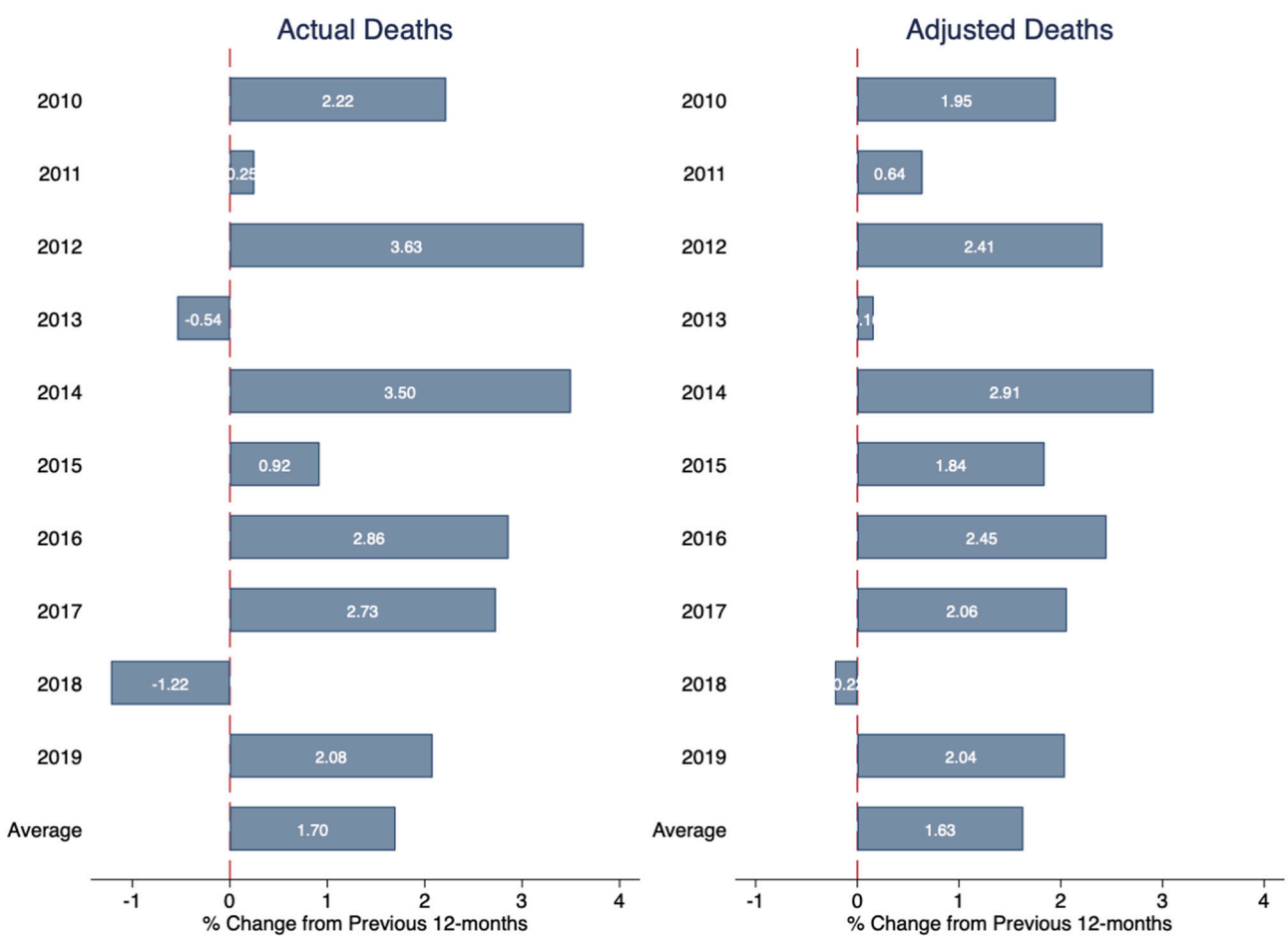

Fig. 1. Changes in U.S. Deaths for 12-Month Periods Starting on March 1.
Note: Figure shows percentage changes in deaths for 12-month periods beginning in March 1 of specified year, relative to deaths in the prior 12 months. Deaths were computed using the mortality data, with adjustments to the counts made for February deaths in leap years. Adjusted deaths were calculated by taking actual deaths for 11 months of the (March through February) year, with January fatalities excluded, then multiplying this by the average ratio of all deaths to the 11-month counts over the entire, 2009–2019 year period, as described in METHODS. The standard deviation in the annual change in deaths is 1.70% using the actual data and 1.05% with the adjusted data.

Table 1
Summary of Results for Selected Prior Studies.

Study	Time period	Actual-baseline death ratio (95% CI) [lower bound][a]	Excess deaths attributed to COVID-19, % (95% CI), [upper bound] [b]	Baseline vs. actual deaths 12-months earlier: % Δ (95% CI) [upper bound] [c]
Sanmarchi et al. (Sanmarchi et al., 2021)	2/26/20–12/31/20 [d]	1.187 (1.172 to 1.203)	83.2 (77.7 to 89.6) [e]	0.86 (−0.48 to 2.20)
Rossen et al. (Rossen et al., 2021)	1/26/20–2/27/21	1.212 [1.169]	75.4 [88.3]	−1.01 [2.63]
Woolf et al. (Woolf et al., 2021) [f]	3/1/20–1/2/21	1.229 (1.229 to 1.230)	72.4 (72.2 to 72.5)	−1.00 (−1.04 to −0.96)
IHME (Institute for Health Metrics and Evaluation, 2021)	3/1/20–4/24/21 [g]	1.306	63.4	−10.16

[a] Excess and observed deaths calculated in original study.
[b] COVID-19 fatalities include cases where it was identified as the underlying or a contributing cause of death.
[c] Baseline deaths were provided by the authors of some studies and computed for others, as described in online appendix. Deaths 12-months earlier were computed as part of the current analysis in all cases.
[d] Time period for calculating baseline and prior deaths was slightly modified from original study as discussed in online appendix.
[e] Original study provided COVID-19 underlying cause of death numbers. These were converted to multiple cause of death estimates, as described in online appendix.
[f] North Carolina excluded from analysis.
[g] Time period was not provided in original study and so was estimated as discussed in the online appendix.

Health Metrics and Evaluation, 2021; Sanmarchi et al., 2021). Observed deaths were 19%–31% above baseline values. The primary or point estimates indicate that the share of excess mortality attributed to COVID-19, ranged from 63%–75% in three investigations (Woolf et al., 2021; Rossen et al., 2021; Institute for Health Metrics and Evaluation, 2021) and was 83% in the fourth (Sanmarchi et al., 2021). The Woolf et al. study (Woolf et al., 2021) has extremely narrow 95% CI's, as do widely cited prior investigations (Woolf et al., 2020a; Weinberger et al., 2020; Woolf et al., 2020b) using similar methods. The CI's or bounds were also fairly tight in the other studies that provided them (Rossen et al., 2021; Sanmarchi et al., 2021). These small confidence intervals and bounds suggest modeling shortcomings, given the substantial variability of actual year-over-year mortality counts documented above.

The last column of Table 1 shows the implied change in baseline deaths versus actual fatalities for the same period 12-months earlier. For three studies (Woolf et al., 2021; Rossen et al., 2021; Institute for Health Metrics and Evaluation, 2021), the primary estimates indicated lower baseline than one-year lagged mortality, in contrast to the positive historical growth observed for eight of the ten years from 2010 to 2019. Baseline deaths in one investigation (Sanmarchi et al., 2021) were 0.86% (95% CI, −0.48%-2.20%) higher than actual deaths one-year earlier and the upper-bound for another (Rossen et al., 2021) showed positive year-over-year growth. These two analyses also attributed the highest share of excess deaths directly to COVID-19, as expected since the denominator over which these shares were calculated was lower. The negative change in baseline versus prior year deaths from one study (Institute for Health Metrics and Evaluation, 2021) far exceeded the largest historical decrease observed over any of the prior 10 years.

4.3. Original estimates

Table 2 and Fig. 2 summarize original estimates of excess deaths; Appendix Table A4 provides additional details. There were 649,4911 (95% CI: 600,133-698,689) excess deaths from 3/1/20–2/28/21, 23% (95% CI: 21%–25%) above the baseline. COVID-19 was as an underlying or contributing cause in 538,215 fatalities, or 82.9% (95% CI: 77.0%–89.7%) of excess mortality.

Gender differences in the ratio of observed versus baseline deaths were fairly modest while race disparities were larger. White people had the highest absolute number of excess deaths, but these represented a smaller percentage increase over baseline than for other groups: the ratio was 1.17 (95% CI: 1.15–1.19) for white individuals compared with 1.33 to 1.51 (with similar sized 95% CI's) for black, Hispanic, and other nonwhite persons. Among white people, 87.3% (95% CI: 78.9%–97.8%) of excess deaths were attributed to COVID-19, with considerably lower percentages for black (67.8%, 95% CI: 63.4%–72.9%) and other nonwhite individuals (76.4%, 95% CI: 74.3%–78.5%).

Actual-to-baseline death ratios were fairly comparable for 25–44, 45–64 and ≥ 65 year olds, ranging from 1.21 to 1.31, with 95% CI's between 1.20 and 1.40, but with a considerably lower 1.15 (95% CI: 1.07–1.23) ratio for persons younger than 25. Over 90% of excess deaths of seniors were attributed to COVID-19, but with monotonically decreasing shares at younger ages.

Among non-COVID causes, heart disease had the largest absolute number of excess fatalities (31,382; 95% CI: 27,794-35,870) but this represented a smaller actual-to-baseline death ratio (1.05, 95% CI: 1.04–1.05) than for diabetes or Alzheimer's disease. There were no excess cancer deaths and lower respiratory disease mortality was 5% (95% CI: 1%–8%) below baseline, with a similar but less precisely estimated reduction for influenza/pneumonia.

Excess mortality from external causes was often large in percentage terms. The actual-to-baseline death ratio was 1.17 (95% CI: 1.09–1.26) for motor vehicle fatalities, 1.36 (95% CI: 1.19–1.59) for drug overdoses, and 1.45 (95% CI: 1.28–1.66) for homicides. Conversely, suicides were 8% (95% CI: 7%–10%) below baseline.

Excess deaths calculated without adjusting for excess January volatility were generally fairly similar to the adjusted computations, but were frequently slightly larger and had considerably wider 95% CI's. For instance, the estimated number of overall excess deaths was 665,086 (95% CI: 581,516-748,656) compared to the main estimate of 649,311 (95% CI: 600,133-698,689). However, the unadjusted estimates were almost always within the 95% CI of the adjusted number (Appendix Table A7).

4.4. Success predicting baseline deaths

Plausibility of the new excess death estimates just described was examined by investigating whether the baseline changes, versus 12-months earlier, were consistent with historical year-over-year changes. Results, summarized in Appendix Table A5 and Fig. A1, show that the range of historical mortality changes was substantial in percentage terms for all groups and causes, and sometimes extremely large. For example, year-over-year changes ranged from −5.7%-3.2% for <25 year olds, −20.9%-14.9% for influenza/pneumonia, −2.8%-23.0% for drug fatalities, and − 4.6%-11.0% for homicides.

Estimated baseline changes were usually compatible with historical changes. The 95% CI's always overlapped the range of prior year-over-year growth, and usually included the average change from 2009 to 2019. These results provide support for the methods used here to estimate the excess deaths. There were six cases (25–44 year olds, Alzheimer's disease, lower respiratory disease, drug overdoses, vehicle fatalities, and homicides) where the baseline death counts were >1.0%, below lagged numbers, while the average year-over-year historical increase was at least 1.0%, and one (persons <25) where both were

Table 2
Actual, Baseline, Excess and COVID-19 Deaths, March 2020 to February 2021: All Individuals and Selected Demographic Groups and Causes.

Group/cause	Actual deaths # [a]	Baseline deaths (95% CI)[b]	Excess deaths, # (95% CI) [c]	COVID-19 deaths, # [d]
All	3,530,039	2,880,628 (2,831,350 to 2,929,906)	649,411 (600,133 to 698,689)	538,215
Male	1,856,870	1,496,731 (1,474,500 to 1,518,962)	360,139 (337,908 to 382,370)	294,654
Female	1,673,169	1,383,815 (1,355,115 to 1,412,515)	289,354 (260,654 to 318,054)	243,561
White [e]	2,570,623	2,194,820 (2,154,584 to 2,235,056)	375,803 (335,568 to 416,039)	328,073
Black [e]	474,435	355,814 (347,522 to 364,106)	118,621 (110,329 to 126,913)	80,425
Hispanic	337,656	223,147 (221,119 to 225,175)	114,509 (112,481 to 116,537)	99,002
Other [e]	138,243	100,405 (99,362 to 101,448)	37,838 (36,795 to 38,881)	28,901
Age: <25	64,864	56,554 (52,681 to 60,428)	8310 (4436 to 12,183)	1026
Age: 25–44	185,131	140,984 (132,262 to 149,706)	44,147 (35,425 to 52,869)	12,827
Age: 45–64	659,736	524,787 (514,993 to 534,582)	134,949 (125,154 to 144,743)	90,578
Age: ≥ 65	2,620,197	2,166,951 (2,145,231 to 2,188,670)	453,246 (431,527 to 474,966)	433,779
Heart	700,775	668,943 (664,905 to 672,981)	31,832 (27,794 to 35,870)	
Cancer	598,662	601,543 (600,086 to 602,999)	−2881 (−4337 to −1424)	
Stroke	161,600	150,951 (147,733 to 154,168)	10,649 (7432 to 13,867)	
Alzheimer's	135,430	116,445 (110,879 to 122,011)	18,985 (13,419 to 24,551)	
Diabetes	104,943	90,411 (89,077 to 91,745)	14,532 (13,198 to 15,866)	
Lower respiratory	146,491	153,706 (148,757 to 158,655)	−7215 (−12,164 to −2266)	
Influenza/ pneumonia	48,405	50,359 (45,358 to 55,360)	−1954 (−6955 to 3047)	
Kidney	52,775	52,234 (51,687 to 52,780)	541 (−5 to 1088)	
Vehicle	42,754	36,641 (33,890 to 39,393)	6113 (3361 to 8864)	
Drugs	99,671	73,223 (62,570 to 83,875)	26,448 (15,796 to 37,101)	
Suicide	45,727	49,957 (49,084 to 50,829)	−4230 (−5102 to −3357)	
Homicide	25,371	17,563 (15,307 to 19,819)	7808 (5552 to 10,064)	

[a] Actual deaths reported using data from Centers for Disease Control and Prevention, as described in METHODS.
[b] Estimate of deaths from march 2020 – February 2021 that would have occurred in the absence of the COVID-19 pandemic, calculated as described in METHODS.
[c] Excess deaths computed as difference between actual and baseline deaths.
[d] Includes deaths with COVID-19 identified as the underlying or a contributing cause of death.
[e] Excludes Hispanics.

negative but the former considerably more so than the latter (−3.9% versus −0.9%). These resulted from strong negative trend squared coefficients in the preferred baseline regression models and raise the possibility that excess deaths may be overstated in these cases.

5. Discussion

Excess mortality provides important information for understanding consequences of the COVID-19 pandemic (Zylke and Bauchner, 2020; Bauchner and Fontanarosa, 2020; Garber, 2021) but it is difficult to estimate and the results are dependent on the procedures used to calculate the baseline deaths that would have occurred without the pandemic. This study evaluated excess death estimates obtained from prior research and provides new calculations of excess mortality from 3/1/20–2/28/21.

An important finding is that previous investigations have probably understated baseline deaths and, consequently, overestimated both excess mortality and the share attributed to non-COVID-19 causes. Key evidence for this is that the implied baseline death estimates were frequently lower than actual mortality one year earlier, whereas such year-over-year decreases have rarely occurred. Instead deaths typically increased over time, but with considerable year-over-year variability. This also implies that confidence intervals on excess deaths will be substantial and that estimates yielding small 95% CI's are dubious.

The overstatement of excess deaths in earlier studies should not be surprising to the extent they did not adequately adjust for factors such as population growth and aging that increased baseline death counts. Prior research demonstrates that failure to account for shifting age structure and population size results in exactly this source of upwards bias (Shiels et al., 2021a). There may also be group-specific or location-specific determinants of baseline deaths that vary over time in ways that have not been sufficiently captured.

New estimates of excess deaths from 3/1/20–2/28/21, the first year of COVID-19 in the U.S., were provided above, with a goodness-of-fit criteria used to determine the preferred model, which varied across groups and causes of death. Changes in baseline deaths, relative to actual prior year counts, obtained using this method were largely consistent with historical patterns of mortality growth and the results frequently suggested higher shares of excess deaths attributed to COVID-19 than in most prior research.

The procedure included an adjustment for excess volatility in mortality observed during January which, relative to unadjusted estimates, often modestly reduced estimated excess deaths but also more substantially tightened the confidence intervals. A substantial portion of the excess January volatility it was almost certainly related to the varying severity of flu seasons, which affected deaths from influenza and related diseases such as pneumonia in ways consistent with observed January fluctuations (Centers for Disease Control and Prevention, 2021), and have also been linked to heart disease mortality (Bhugra et al., 2021).

In its first year of the COVID-19 pandemic, there were an estimated 649,611 (95% CI, 600,133-698,689) excess U.S. deaths, a 23% (95% CI: 21%–25%) rise over baseline. The percentage increases were relatively small for non-Hispanic white persons and those <25, consistent with prior research (Rossen et al., 2020; Woolf et al., 2021; Kathail and Chin, 2020). Although seniors did not have particularly large percentage growth, the absolute number of excess deaths was by far the greatest for them (453,246, 95% CI: 431,257-474,966).

Eighty-three percent of excess deaths were attributed to COVID-19, but with a wide 95% CI (77.0%–89.7%), reflecting the substantial historical variability in year-over-year mortality counts. There are two likely reasons why the COVID-19 share of excess deaths was higher than in most prior research (Woolf et al., 2020a; Weinberger et al., 2020; Woolf et al., 2020b; Rossen et al., 2020; Woolf et al., 2021; Rossen et al., 2021; Institute for Health Metrics and Evaluation, 2021). First, detection of COVID-19 involvement may have been poor early in the epidemic, due to disruptions in the medical system and broader economy (Stuart, 2020), which was important for studies focused on the early pandemic periods. Second, the understatement of baseline deaths in most previous analyses mechanically induced a lower estimated COVID-19 share of excess mortality.

Excess deaths from non-COVID-19 sources remain important.

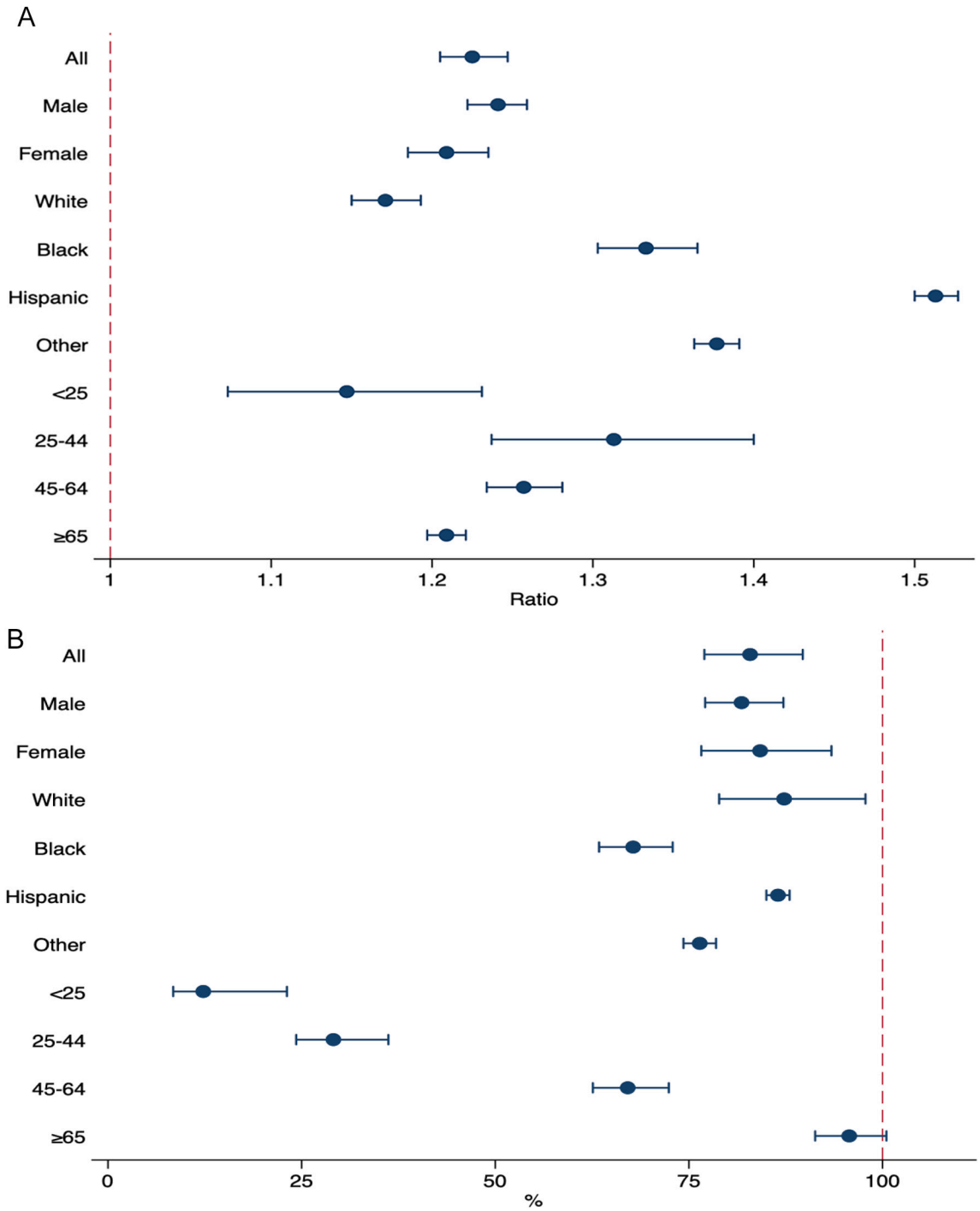

Fig. 2. Ratio of Actual vs. Baseline Deaths and Percent of Excess Deaths Involving COVID-19, by Population Group and Cause.
A. Ratio of Actual vs. Baseline Deaths, by Population Group.
B. Percent of Excess Deaths Involving COVID-19, by Population Group
C. Ratio of Actual vs. Baseline Deaths, by Cause
Note: Actual deaths were obtained from the Centers for Disease Control and Prevention Provisional Data for the period March 2020 through February 2021; baseline deaths were estimated using data from March 2009 through February 2020, as described in METHODS. Whiskers show 95% confidence intervals.

Additional heart disease fatalities were consistent with health system capacity constraints and the reluctance of some individuals to seek medical care due to fears of infection (Solomon et al., 2020; Moroni et al., 2020; Uchino et al., 2020). Despite limitations on cancer screenings early in the epidemic (Basu et al., 2021), and predictions of higher associated deaths (Sharpless, 2020), this analysis provides no evidence of excess cancer mortality through February 2021. This may reflect substantial delays between the timing of screenings or treatment and deaths, the rapid rebound in health system capacity for temporarily deprioritized procedures (Saraswathula et al., 2021), or appropriate prioritization of care for those most at risk of death. Excess diabetes fatalities could indicate its role as a comorbidity, raising risks of death

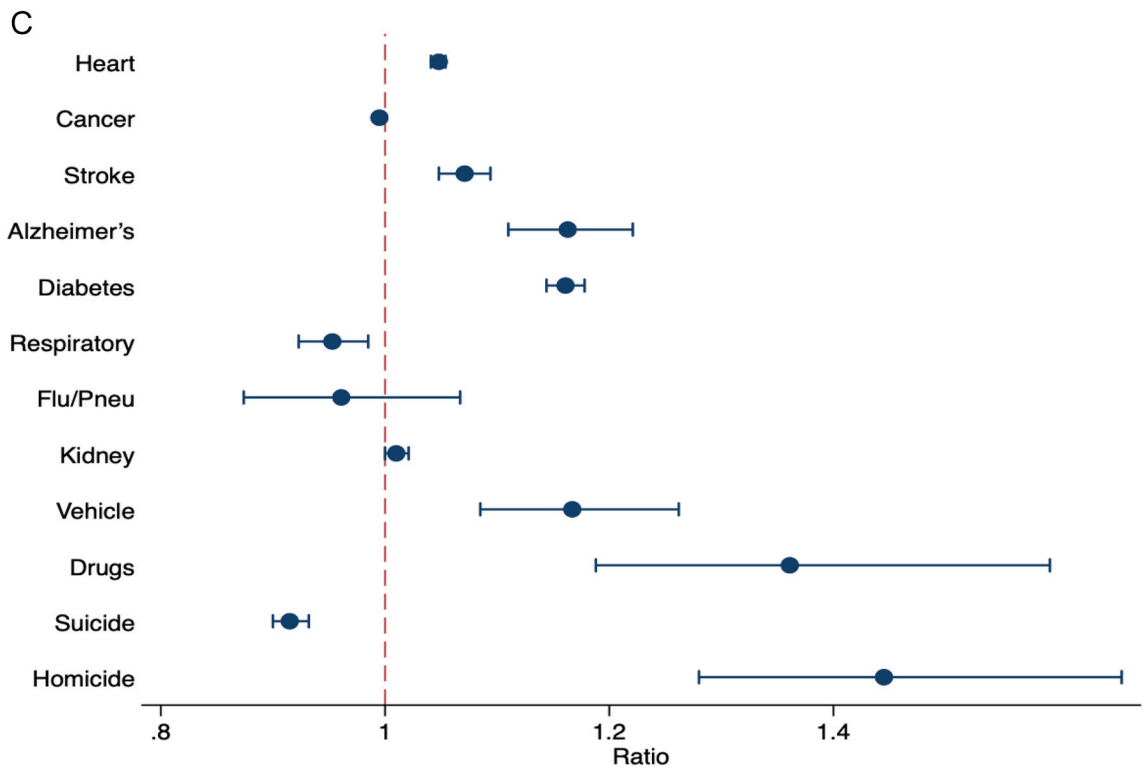

Fig. 2. (*continued*).

following COVID-19 infection, adverse effects of the virus on glycemic control, or increased difficulty in disease management during a period of social isolation and relatively limited medical support (Muniangi-Muhitu et al., 2020). Elevated Alzheimer's disease mortality may have resulted because affected individuals frequently lived in long-term care facilities, where COVID-19 deaths were common due to reductions in access to medical care, disrupted routines, social isolation, and possibly particularly adverse consequences of coronavirus infection (Brown et al., 2020; Paulin, 2020; Wan, 2020; Cronin and Evans, 2020).

Drug mortality and suicides have been described as deaths of despair (Case and Deaton, 2020), although this characterization has been questioned (Ruhm, 2019), and numerous commentators expected these fatalities to rise during the pandemic (Aronson, 2020; Gunnell et al., 2020; Petterson et al., 2020; Mulligan, 2020). While high excess mortality from drug overdoses and homicides was consistent with despair; suicides were estimated to be 7%–10% below baseline levels. Certain types of risk-taking may have increased. as reflected by the growth in vehicle fatalities even while miles driven declined (National Safety Council, 2021). Other evidence suggests that heavy drinking increased and physical activity declined (Pollard et al., 2020; Stockwell et al., 2021), although these might not be fully accounted for by the causes of death examined here.

Some results for external deaths may reflect difficulties in correctly predicting the baseline, given abrupt changes in recent trends. For instance, after rising steadily over time, suicides declined from 2018 to 2019, prior to COVID-19. Similarly, drug fatalities, fell from 2017 to 2018, after increasing for many years, although they grew again from 2018 to 2019, before the rapid COVID-19 induced increase.

These challenges point to the potential attractiveness of other methods of calculating excess deaths. For instance, some prior research has focused on age-standardized death rates (Shiels et al., 2021a; Shiels et al., 2021b), which account for changes in population aging and size. It might also be possible to directly incorporate these and other determinants of death counts into the estimation process, and it would be interesting to compare the results of such alternatives to those obtained here.

This study is subject to additional limitations. As emphasized, there is inherent uncertainty in the calculation of baseline deaths, and the share of excess mortality directly attributable to the virus may have changed over the course of the epidemic. The use of provisional mortality data may create problems. In particular, the race/ethnicity categories are more detailed than in the final data, creating potential incompatibilities. The methods developed here almost certainly improved upon earlier national estimates of excess deaths occurring over a lengthy timespan, but they may be less useful for corresponding calculations at the state-level or over shorter durations. Finally, this research did not evaluate adverse consequences other than mortality, such as increased morbidity, declining economic circumstances, and some costs of social isolation.

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Credit author statement

Christopher J. Ruhm is responsible for all aspects of this study, including conceptualization, data analysis and writing up the results.

Declaration of Competing Interest

Ruhm has served as a plaintiff's consultant in ongoing opioid litigation. This role is not related to any aspect of this study.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ypmed.2022.107174.

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