Role of the Funder/Sponsor: The funders had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; or decision to submit the manuscript for publication.

1. Inflation Reduction Act of 2022, HR 5376, 117th Cong (2021-2022). Accessed September 30, 2022. https://www.congress.gov/bill/117th-congress/house-bill/5376/text

2. Hernandez I, San-Juan-Rodriguez A, Good CB, Gellad WF. Changes in list prices, net prices, and discounts for branded drugs in the US, 2007-2018. *JAMA*. 2020;323(9):854-862. doi:10.1001/jama.2020.1012

3. Centers for Medicare & Medicaid Services. Medicare Part B spending by drug. Accessed September 30, 2022. https://data.cms.gov/summary-statistics-on-use-and-payments/medicare-medicaid-spending-by-drug/medicare-part-b-spending-by-drug

4. Centers for Medicare & Medicaid Services. ASP drug pricing files. Accessed September 30, 2022. https://www.cms.gov/medicare/medicare-part-b-drug-average-sales-price/2020-asp-drug-pricing-files

5. Cubanski J, Neuman T. *Prices Increased Faster Than Inflation for Half of All Drugs Covered by Medicare in 2020*. Kaiser Family Foundation. Published February 25, 2022. Accessed September 30, 2022. https://www.kff.org/medicare/issue-brief/prices-increased-faster-than-inflation-for-half-of-all-drugs-covered-by-medicare-in-2020/

6. Freed M, Fuglesten Biniek J, Damico A, Neuman T. *Medicare Advantage in 2022: Enrollment, Update, and Key Trends*. Kaiser Family Foundation. Published August 25, 2022. Accessed September 30, 2022. https://www.kff.org/medicare/issue-brief/medicare-advantage-in-2022-enrollment-update-and-key-trends

COVID-19 and Excess All-Cause Mortality in the US and 20 Comparison Countries, June 2021-March 2022

The US experienced high COVID-19 death rates and higher excess all-cause mortality compared with peer countries during 2020.[1] However, an important question is how cross-national differences in mortality shifted during 2021 and 2022 with both widespread availability of vaccination and new variants. We compared COVID-19 and excess all-cause mortality in the US, the 10 most- and least-vaccinated states, and 20 peer Organization for Economic Co-operation and Development (OECD) countries during the Delta and winter Omicron waves.

Supplemental content

Methods | Using previous methodology, we compared the US overall, the 10 most- and least-vaccinated states, and the 20 OECD countries with 2021 population exceeding 5 million and greater than $25 000 per capita gross domestic product (Supplement 1).[1] US COVID-19 mortality, all-cause mortality, and vaccination data were obtained from the US Centers for Disease Control and Prevention.[2] For other countries, COVID-19 mortality data were obtained from the World Health Organization, all-cause mortality data from OECD databases, and vaccination data from Our World in Data (Supplement 1).[3-5] Some mortality data from 2021 and 2022 were provisional.

Each location's COVID-19 mortality rate per capita was calculated over 2 periods: (1) Delta from June 27, 2021 (week 26), to December 25, 2021 (week 51), and (2) Omicron from December 26, 2021 (week 52), to March 26, 2022 (week 12). We estimated excess all-cause mortality by comparing mortality in each period with mortality in 2015-2019, fitting underlying trends using prepandemic, out-of-sample validation (Supplement 1).[6]

For each period, we calculated the difference in US deaths if mortality rates of other locations were realized. We used regression models to statistically compare rates across locations (Supplement 1), with significance set at $P < .005$ for 2-sided tests to account for multiple testing. Analyses were conducted in R version 4.0.2 (R Foundation for Statistical Computing). The study was deemed not human subjects research by the Brown University institutional review board.

Results | The US reported 370 298 COVID-19 deaths (112 per 100 000) during the Delta and Omicron waves (61/100 000 and 51/100 000, respectively). COVID-19 deaths per capita in the US overall and in both state subgroups significantly exceeded those of all peer countries during the study period (**Table 1**). However, there were significantly fewer COVID-19 deaths in the top 10 states by vaccination uptake (73% coverage) at 75 deaths/100 000 compared with the bottom 10 (52% coverage) at 146 per 100 000 ($P < .001$).

US excess all-cause mortality exceeded COVID-19 mortality at 145/100 000 and exceeded peer countries in all periods, as did excess all-cause mortality in the least-vaccinated states (**Table 2**). However, the 10 most-vaccinated states had excess all-cause mortality comparable with or less than that of several peer countries over Delta and Omicron combined (eg, Denmark, Germany, the Netherlands, Austria, Italy, Finland). While excess all-cause mortality in the top 10 states significantly exceeded that of many comparators during Omicron, excess all-cause mortality was significantly less than COVID-19 mortality for the top 10 states during this wave (29 vs 47 per 100 000, $P < .001$).

From June 27, 2021, to March 26, 2022, the US would have averted 122 304 deaths if COVID-19 mortality matched that of the 10 most-vaccinated states and 266 700 deaths if US excess all-cause mortality rate matched that of the 10 most-vaccinated states. If the US matched the rates of other peer countries, averted deaths would have been substantially higher in most cases (range, 154 622-357 899 for COVID-19 mortality; 209 924-465 747 for all-cause mortality).

Discussion | The US continued to experience significantly higher COVID-19 and excess all-cause mortality compared with peer countries during 2021 and early 2022, a difference accounting for 150 000 to 470 000 deaths. This difference was muted in the 10 states with highest vaccination coverage; remaining gaps may be explained by greater vaccination uptake in peer countries, better vaccination targeting to older age groups, and differences in health and social infrastructure.

This study also highlights the value of excess mortality in understanding effects of COVID-19. Excess all-cause mortality began to fall below COVID-19 mortality in several countries and highly vaccinated states during Omicron, perhaps owing to reductions in non–COVID-19 deaths. However, cross-location differences may also reflect differences in COVID-19 death coding.

Limitations include use of some provisional mortality estimates and lack of adjustment by age and comorbidities. Nevertheless, unadjusted estimates remain important, because a country's response to COVID-19 should reflect

Table 1. COVID-19 Mortality in the US and Comparison Countries

Country	Vaccination rate, %	COVID-19 mortality per 100 000			Potential US deaths averted, No. (%)		
		Delta	Omicron	Total	Delta	Omicron	Total
New Zealand	75	0.5	3.3	3.7	200 663 (99)	157 236 (94)	357 899 (97)
Japan	80	3	7.4	10.4	192 278 (95)	143 443 (85)	335 721 (91)
Australia	76	4.9	14.2	19.2	185 819 (92)	120 894 (72)	306 713 (83)
Republic of Korea	82	6.1	18.2	24.3	181 927 (90)	107 650 (64)	289 577 (78)
The Netherlands	67	16.6	7.9	24.5	147 061 (73)	141 898 (84)	288 959 (78)
Norway	73	10	18.6	28.7	168 899 (84)	106 280 (63)	275 179 (74)
Canada	77	10.2	20.2	30.4	168 351 (83)	101 049 (60)	269 401 (73)
Switzerland	67	16.4	15.5	31.9	147 757 (73)	116 511 (69)	264 268 (71)
Sweden	70	6.3	31.3	37.6	181 286 (90)	64 167 (38)	245 453 (66)
Ireland	78	20.5	17.2	37.7	134 206 (66)	110 857 (66)	245 063 (66)
France	74	14.6	27.6	42.2	153 765 (76)	76 453 (45)	230 218 (62)
Israel	64	19.4	24.9	44.3	137 898 (68)	85 326 (51)	223 224 (60)
Spain	80	17.7	26.7	44.5	143 348 (71)	79 372 (47)	222 720 (60)
Finland	74	12	35.2	47.2	162 449 (80)	51 097 (30)	213 546 (58)
Belgium	76	25.3	22.5	47.7	118 390 (59)	93 526 (56)	211 916 (57)
Denmark	78	10.9	41.2	52.2	166 026 (82)	31 182 (19)	197 208 (53)
Germany	71	29.6	22.7	52.3	104 041 (51)	92 750 (55)	196 792 (53)
Italy	76	15.2	39	54.2	151 867 (75)	38 609 (23)	190 476 (51)
UK	71	30.1	28.9	59	102 324 (51)	72 176 (43)	174 500 (47)
Austria	74	40.4	24.6	65	68 040 (34)	86 582 (52)	154 622 (42)
US							
10 most-vaccinated states	73	28.1	46.6	74.7	108 916 (54)	13 388 (8)	122 304 (33)
Overall	63	60.9	50.6	111.6			
10 least-vaccinated states	52	86.6	59.4	146	−85 080 (−42)	−29 058 (−17)	−114 138 (−31)

Countries are ordered by total COVID-19 mortality rate from June 27, 2021-March 26, 2022. This includes the Delta (June 27, 2021-December 25, 2021) and winter Omicron (December 26, 2021-March 26, 2022) periods. Vaccination rates reflect the population percentage with 2 or more doses as of January 2022. States include the 50 states and District of Columbia. Potential deaths averted were calculated assuming that the full US had the per capita COVID-19 mortality rate of the specified country/states during the period of interest. All comparisons between the US and other countries were statistically significant in all periods, as were comparisons between the 10 most-vaccinated and 10 least-vaccinated states and comparisons between state subgroups and other countries ($P < .001$).

risks in its population rather than a hypothetical standardized population.

These findings highlight that the US continued to lag peer countries in COVID-19 and excess all-cause mortality, albeit with lower mortality in highly vaccinated states.

Alyssa Bilinski, PhD
Kathryn Thompson, MHA
Ezekiel Emanuel, MD, PhD

Author Affiliations: Department of Health Services, Policy, and Practice, Brown School of Public Health, Providence, Rhode Island (Bilinski, Thompson); Department of Medical Ethics and Health Policy, University of Pennsylvania Perelman School of Medicine, Philadelphia (Emanuel).

Accepted for Publication: November 7, 2022.

Published Online: November 18, 2022. doi:10.1001/jama.2022.21795

Corresponding Author: Alyssa Bilinski, PhD, Department of Health Services, Policy, and Practice, Brown School of Public Health, 121 S Main St, Office 828, Providence, RI 02903 (alyssa_bilinski@brown.edu).

Author Contributions: Dr Bilinski had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Concept and design: Bilinski, Emanuel.
Acquisition, analysis, or interpretation of data: Bilinski, Thompson.
Drafting of the manuscript: All authors.
Critical revision of the manuscript for important intellectual content: All authors.
Statistical analysis: Bilinski, Thompson.

Conflict of Interest Disclosures: Dr Bilinski reported receiving grants from the Centers for Disease Control and Prevention though the Council of State and Territorial Epidemiologists (NU38OT000297). Dr Emanuel reported serving as a paid or unpaid speaker for United Health Group, Blue Cross Blue Shield Dana Point, Center for Global Development, CBI/Informa, American Academy of Arts and Sciences, University of California San Francisco, UCSF Medicine Grand Rounds, Vagelos College of Physicians & Surgeons, UNESCO, NCCN Academy for Excellence & Leadership, National Institutes of Health, ASPO, NCAC BC/BS, Penn-Cellicon Valley 2021, Activity Based Funding Conference, Leonard Davis Institute, Penn Medical Alumni Weekend, National Health Equity Summit, The Galien Foundation, Temple Shalom Chicago, Perry World House Graduate Association, AIFA-Italian Medicine Agency, Penn Rising Scholar Success Academy, Rainbow Push Coalition, Infectious Diseases Society of America, Rise Health, VinFuture, Wellsky, Brown University Warren Alpert Medical School, 19th Annual Signature Foundation Health Policy Forum, Healthcare Leaders of New York, 21st Population Health Colloquium, MedImpact, Village MD, University of Syndney, Massachusetts Association of Health Plans, Virta Health, Tel Aviv University, American Philosophical Society, Princeton University, Philadelphia Committee on Foreign Relations, Health Action Alliance, Yale University, Hartford Medical Society, American Board of Pediatric Dentistry,

Table 2. Excess All-Cause Mortality in the US and Comparison Countries

Country	Vaccination rate, %	Excess all-cause mortality per 100 000			Potential US deaths averted, No. (%)		
		Delta	Omicron	Total	Delta	Omicron	Total
New Zealand	75	−7.6	12.7	5.1	354 910 (108)	110 837 (72)	465 747 (96)
Sweden	70	20.8	11.6	32.4	260 705 (79)	114 455 (75)	375 159 (78)
Belgium	76	36.1	−2.2	33.9	209 740 (64)	160 481 (105)	370 221 (77)
France	74	26.4	10.8	37.2	241 932 (73)	117 271 (77)	359 203 (74)
Canada	77	24.5	13	37.5	248 446 (75)	109 860 (72)	358 306 (74)
Australia	76	9.6	28.6	38.1	297 871 (90)	58 315 (38)	356 186 (74)
Switzerland	67	35.3	3.8	39.1	212 401 (64)	140 586 (92)	352 987 (73)
Spain	80	39.2	3.3	42.5	199 500 (61)	142 251 (93)	341 752 (71)
UK	71	53.2	−4.2	49	153 074 (46)	167 074 (109)	320 148 (66)
Israel	64	29.7	27.8	57.4	231 156 (70)	60 978 (40)	292 134 (61)
Norway	73	45.7	12.4	58.1	177 988 (54)	111 819 (73)	289 807 (60)
Denmark	78	45.7	14.3	60	178 016 (54)	105 494 (69)	283 510 (59)
Germany	71	62.8	0.2	63.1	121 191 (37)	152 333 (99)	273 524 (57)
The Netherlands	67	65.4	−1.8	63.6	112 691 (34)	159 037 (104)	271 728 (56)
10 most-vaccinated US states	73	36.4	28.7	65.1	208 703 (63)	57 997 (38)	266 700 (55)
Italy	76	50.3	20.9	71.2	162 666 (49)	83 790 (55)	246 456 (51)
Austria	74	65.4	7.5	72.9	112 625 (34)	128 245 (84)	240 871 (50)
Finland	74	54.6	27.6	82.2	148 495 (45)	61 429 (40)	209 924 (43)
US overall	63	99.3	46.1	145.5			
10 least-vaccinated US states	52	136	57.3	193.3	−121 749 (−37)	−37 173 (−24)	−158 922 (−33)

Countries are ordered by total excess all-cause mortality rate from June 27, 2021-March 26, 2022. This includes the Delta (June 27, 2021-December 25, 2021) and winter Omicron periods (December 26, 2021-March 26, 2022) periods. Vaccination rates reflect the population percentage with 2 or more doses as of January 2022. States include the 50 states and District of Columbia. Potential deaths averted were calculated assuming that the full US had the all-cause mortality rate of the specified country/states during the period of interest. All comparisons between the US overall and other countries were statistically significant in all periods ($P < .005$), as were comparisons between the 10 most-vaccinated and least-vaccinated states and comparisons between the 10 least-vaccinated states and all other countries ($P < .001$).

Mt Sinai Ichan School of Medicine, Perelman School of Medicine, University of Minnesota, Institute for Health and Productivity Studies, Association of Academic Health Centers, Hawaii Medical Service Association and Queen's Health System, University of Pennsylvania, and Macalester College; serving as a paid or unpaid panelist for World Affairs Council, Rightway, and the Organisation for Economic Co-operation and Development; receiving travel reimbursement from Blue Cross Blue Shield Dana Point, Hartford Medical Society, Association of Academic Health Centers, Macalester College, and Oak HC/FT; serving as a paid or unpaid board member for Village MD and Oncology Analytics; serving on the advisory board of Cellares, Village MD, HIEx Health Innovation Exchange, Colton Center for Autoimmunity, JSL Health, World Health Organization COVID-19 Ethics and Governance Working Group, and Biden Transition COVID-19 Committee; serving as special advisor to the World Health Organization director general; and that he is a venture partner at Oak HC/FT and a partner at Embedded Healthcare LLC and COVID-19 Recovery Consulting. No other disclosures were reported.

Funding/Support: This study was partially funded by the Centers for Disease Control and Prevention (CDC) though the Council of State and Territorial Epidemiologists (NU38OT000297-02, Dr Bilinski) and Colton Foundation (Dr Emanuel).

Role of the Funder/Sponsor: The CDC had no role in the design and conduct of the study; collection, management, analysis, and interpretation of the data; preparation, review, or approval of the manuscript; and decision to submit the manuscript for publication.

Data Sharing Statement: See Supplement 2.

Additional Contributions: We gratefully acknowledge research assistance from Alexandra Norris, AM (Brown University). Ms Norris received compensation from grant NU38OT000297-02.

1. Bilinski A, Emanuel EJ. COVID-19 and excess all-cause mortality in the US and 18 comparison countries. *JAMA*. 2020;324(20):2100-2102. doi:10.1001/jama.2020.20717

2. Excess Deaths Associated With COVID-19. Accessed May 12, 2022. https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm

3. WHO coronavirus (COVID-19) dashboard with vaccination data. World Health Organization. Accessed October 11, 2022. http://covid19.who.int/data/

4. COVID-19 health indicators: mortality (by week). Organisation for Economic Cooperation and Development. Accessed May 12, 2022. https://stats.oecd.org/Index.aspx?DataSetCode=HEALTH_MORTALITY

5. Ritchie H, Mathieu E, Rodés-Guirao L, et al. Coronavirus (COVID-19) vaccinations. Our World in Data. Accessed October 11, 2022. https://ourworldindata.org/covid-vaccinations

6. Ruhm CJ. Excess deaths in the United States during the first year of COVID-19: NBER Working Paper 29503. National Bureau of Economic Research. Published November 2021. Accessed November 11, 2022. http://www.nber.org/papers/w29503

COMMENT & RESPONSE

Opportunities for Clinicians and Health Systems to Address Disparities in US Drug Overdose Deaths by Race and Ethnicity

To the Editor A recent Viewpoint on the increases in disparities in US drug overdose deaths by race and ethnicity called for "a multisectoral approach."[1] In addition to the solutions proposed, we think that universal access to medications for opioid use disorder (MOUD) during incarceration represents a significant opportunity to address racial and ethnic disparities in overdose deaths.

Supplemental Online Content

Bilinski A, Thompson K, Emanuel E. COVID-19 and excess all-cause mortality in the US states and 20 comparison countries, June 2021-March 2022. *JAMA*. Published November 18, 2022.
doi:10.1001/jama.2022.21795

This material has been provided by the authors to give readers additional information about their work.

Supplemental Information

COVID-19 and Excess All-Cause Mortality in the US and 20 Comparison Countries, June 2021-March 2022

Alyssa Bilinski[1] · Kathryn Thompson · Ezekiel Emanuel

Data sources

We compared the US overall and the 10 most- and least-vaccinated states to 20 Organization for Economic Co-operation and Development (OECD) countries with 2021 population exceeding 5 million (link) and greater than $25,000 per capita gross domestic product in 2021 (link).

For the US, where we required sub-national data for our analyses, we obtained data from CDC files: COVID-19 mortality from "United States COVID-19 Cases and Deaths by State over Time" (link), all-cause mortality data from "Weekly Counts of Deaths by Jurisdiction and Age" (link), and vaccination data from "COVID-19 Vaccination Trends in the United States, National and Jurisdictional" (link). US population data were obtained from the Census (link, link).

For other countries, we obtained data on COVID-19 mortality from the World Health Organization (link), all-cause mortality estimates from OECD.Stat (link), and vaccination data from Our World In Data, which aggregates local estimates (link). We checked data sources by matching US CDC data to WHO and OECD mortality estimates and spot-checking OECD all-cause mortality against country-specific estimates.

COVID-19 mortality was reported daily, and we aggregated weeks beginning on Sunday ("CDC" or "epi weeks"). All-cause mortality was reported weekly. In the US, new weeks began on Sunday ("epi weeks"), but in other countries, weekly data began on Monday ("ISO weeks"). We defined delta and omicron periods based on visual inspection of mortality trends, during summer 2021 for delta and December 2022 for omicron. Because waves were tightly clustered in time, we defined the start of periods based on the earliest mortality turning point for delta and omicron across all locations of interest. Code and additional analyses are available on GitHub.

Calculations in Tables 1 and 2

Potential US deaths averted

Let r_i be the death rate of interest (reported COVID-19 deaths or excess all cause mortality) per 100,000 in country i, and d be US deaths over the period of interest. Let p be the US population in the year of interest. We estimate the difference in deaths or potential US deaths averted:

$$d - (r_i/100,000) * p$$

[1]Contact: alyssa_bilinski@brown.edu

States by Vaccination Rate

Table S1: States by 2-dose vaccination status (as of January 1, 2022). Nine of the 10 most-vaccinated states and 8 of the 10 least-vaccinated states were consistent over the full study period from June 2021 through March 2022; results were robust to including only these states in the top and bottom 10 over the full period (omitting New York from the top 10 and Indiana and North Dakota from the bottom 10) (see GitHub).

State	Rate	Rank	Set
Vermont	79.0	1	Top 10
Rhode Island	77.6	2	Top 10
Maine	77.0	3	Top 10
Connecticut	75.5	4	Top 10
Hawaii	75.3	5	Top 10
Massachusetts	75.1	6	Top 10
New York	72.7	7	Top 10
Maryland	72.0	8	Top 10
New Jersey	71.8	9	Top 10
District of Columbia	71.3	10	Top 10
Indiana	53.4	42	Bottom 10
North Dakota	53.4	42	Bottom 10
Tennessee	52.4	44	Bottom 10
Arkansas	52.3	45	Bottom 10
Georgia	52.2	46	Bottom 10
Idaho	52.0	47	Bottom 10
Louisiana	51.1	48	Bottom 10
Mississippi	49.6	49	Bottom 10
Wyoming	49.1	50	Bottom 10
Alabama	48.9	51	Bottom 10

Excess Mortality Model Selection (Table 2)

We used the following procedure to select models for estimating excess mortality, designed to address concerns about appropriately fitting secular trends raised in prior work (link). In response to this issue, some authors have fit parametric pre-pandemic trends (e.g., link, link) while others have used only 2019 as a benchmark year for counterfactual non-pandemic mortality (e.g., link). To choose functional form, we evaluated 3 possible models on pre-pandemic data: 1) a model fit only on the most recent year of data, 2) models with country-specific trends as fixed effects, and 3) models with country-specific trends random effects.

$$y_{ctk} = W_{ct} + \epsilon_{ctk} \qquad \text{fit to only the most-recent year of data} \tag{1}$$

$$y_{ctk} = W_{ct} + \beta_c^F k + \epsilon_{ctk} \tag{2}$$

$$y_{ctk} = W_{ct} + \beta_c^R k + \epsilon_{ctk} \tag{3}$$

where y_{ctk} was mortality per 100,000 population in week t of year k in location c, W_{ct} was a week-location fixed effect, k indicated year, and ϵ_{ctk} was residual error. Country-specific linear trend parameters β_c^F were estimated as fixed effects while β_c^R were estimated as random effects. We considered both models fit on all data and models fit separately on the set of weeks in each period (delta: 26-51 and omicron: 52-53, 1-12).

We first used 2018 and 2019 as test data. We fit models (1)-(3) on data from 2015-2017, predicting out-of-sample mortality for each country-week in 2018, and 2015-2018, predicting out-of-sample mortality in 2019. We estimated root mean-squared error for each period of weeks (delta: 26-51 and omicron: 52-53, 1-12) ($\mathcal{P}$) and test year (K) at the week-level $\left(RMSE_{\mathcal{P},K} = \sqrt{\frac{1}{N_c}\sum_{c\in\mathcal{C}}\sum_{t\in\mathcal{P}}\left(y_{ctK} - \hat{y}_{ctK}\right)^2}\right)$ and at the period-level $\left(RMSE^{CP}_{\mathcal{P},K} = \sqrt{\frac{1}{N_c}\sum_{c\in\mathcal{C}}\left(\sum_{t\in\mathcal{P}}\left(y_{ctK} - \hat{y}_{ctK}\right)\right)^2}\right)$. We also ranked models by RMSE within each country and evaluated mean model ranks. We found that model (3) (random effects), estimated with all weeks of data (rather than separately for each period), either strictly or weakly dominated all other models over these metrics during these test years and periods.

Second, we fit models for data from 2015-2017, and predicted 2019 to approximate 2021 with only 2019 pre-intervention data. (We did not want to fit trend models on only 2 years of pre-pandemic data and therefore did not use 2018 as a test year.) Model (3) continued to outperform other models overall; for $RMSE^{CP}$ during omicron weeks, model (2) estimated on all pre-intervention data slightly outperformed model (3), but the magnitude of the difference was negligible. We therefore used model (3) estimated over all weeks combined as our main specification. See GitHub for further notes, summaries of model evaluation statistics, and sensitivity analyses.

Statistical Analyses

Table 1

To compare COVID-19 death rates across locations, we let d_{ct} be the number of COVID-19 deaths in location c during period t and p_{ct} be its population at time t. We assumed that $d_{ct} \sim Pois(\lambda_{ct})$ and

$$\mathbb{E}\left[log(\lambda_{ct})\right] = \beta_0 + \sum_{j\in\mathcal{C}, j\neq US} \beta_j \mathbb{I}\left(c = j\right) + log(p_{ct}),$$

where β_j compared the death rate in country j to the United States. We employed a similar model to make comparisons with the 10 most-vaccinated states and 10 least-vaccinated states. We used standard Wald tests to evaluate statistical significance.

Table 2

Per the model-fitting process described above, we modeled excess all-cause mortality:

$$y_{ctk} = \sum_{j\in\mathcal{C}}\sum_{w\in\mathcal{W}}\sum_{\ell\geq 2020} \beta_{jw\ell}\mathbb{I}\{c = j \cap t = w \cap k = \ell\} + W_{ct} + \beta^R_c k + \epsilon_{ctk},$$

where y_{ctk} was mortality per 100,000 population in week t of year k in location c, W_{ct} was a location-week fixed effect, and k indicated year. We estimated β^R_c as a random effect. Week-level treatment effects were saturated to avoid estimating pre-pandemic trends with pandemic data. In this framework, the linear combination of $\sum_{j=Comparator}\sum_{w,\ell\in\mathcal{P}}\beta_{jw\ell} - \sum_{j=US}\sum_{w,\ell\in\mathcal{P}}\beta_{jw\ell}$ compared excess mortality between each comparator location and the US over the set of week-years in period $\mathcal{P}$. We used standard Wald tests to evaluate statistical significance. We made similar comparisons between the 10 most-vaccinated states and 10 least-vaccinated states, and also compared state subgroups to other countries. To estimate the difference between COVID-19 and all-cause mortality, we used as an outcome $y_{ctk} - d_{ctk}$, where d_{ctk} was COVID-19 mortality per 100,000 for location c in week t and year k.