Excess mortality of acute myocardial infarction and cardiac arrest in the US during COVID-19 pandemic from March 2020 to March 2022

Supplementary Information

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S1 Technical details for data and methods

S1.1 Data

The Wide-ranging Online Data for Epidemiologic Research database (WONDER) of the Centre for Disease Control and Prevention reported provisional data collected from jurisdictions according to death certificates. We obtained the weekly death counts for all 50 US states and the District of Columbia between January 2018 and March 2022 from WONDER [1]. The data that supported the findings of this study were publicly available. Death counts for jurisdictions less than 10 were suppressed to null value according to the confidentiality standards. We identified the deaths with the underlying causes of acute myocardial infarction (AMI) and cardiac arrest (CA) according to the International Statistical Classification of Diseases and Related Health Problems, Tenth Revision (ICD-10) code (I21 for AMI, and I46 for CA). Deaths with a contributing cause of COVID-19 that was diagnosed or mentioned on the death certificate were excluded.

Although the death data downloaded were up to May 7, 2022, death counts in recent period might suffer a relatively high missing or under-ascertainment rate due to reporting lags, which could vary from 1 to 8 weeks or more. Previous studies estimated that most jurisdictions achieved about 75% of data complete within 8 weeks [2]. Concerning large residual incompleteness, we excluded data from the most recent period from April to May 2022 before analysis.

To calculate mortality rates, we retrieved the annual population size for different sex, age, and ethnic groups in each jurisdiction during 2015-2020 from the US Census Bureau (accessed via https://data.census.gov/cedsci/). We used population counts in 2020 to represent the counts in 2021 and 2022.

S1.2 Stratification into subgroups

Besides performing analysis for each jurisdiction of the US, we also consider the subgroups according to the following stratification. The analysis for excess death were conducted for each sex (female, and male), age (20 - 64, 65 - 84, and ≥ 85 years), and ethnic (non-Hispanic white, non-Hispanic black, and Hispanic) group and cause-specific death (AMI, and CA).

For the time period, we considered two calendar periods that were March 2020 - February 2021, and March 2021 - March 2022. For different periods of COVID-19 pandemic, we also estimated the excess death statistics for five pandemic waves according to patterns of COVID-19 deaths reported in the US. The start day of each pandemic wave depended on the time when death counts were at the trough, and the wave ended on the day before the next wave. According to the daily surveillance of COVID-19 deaths (shown at https://covid.cdc.gov/covid-data-tracker/#trends_dailydeaths), the COVID-19 pandemic in the US was divided into five waves. Thus,

- Wave I was from Week 10, 2020 (March 1, 2020) to Week 23, 2020 (June 6, 2020),
- Wave II was from Week 24, 2020 (June 7, 2020) to Week 40, 2020 (October 3, 2020),
- Wave III was from Week 41, 2020 (October 4, 2020) to Week 25, 2021 (June 26, 2021),

- Wave IV was from Week 26, 2021 (June 27, 2021) to Week 47, 2021(November 27, 2021), and
- Wave V was from Week 48, 2021 (November 28, 2021) to Week 15, 2022 (March 26, 2022).

Figure S1.1 showed the time series of death of acute myocardial infarction and cardiac arrest across the five pandemic waves (waves I - V). In addition, the five pandemic waves also (roughly) matched the timing of emerging time of SARS-CoV-2 variants that circulated and became dominant in the US, see Fig S1.2. The dominant SARS-CoV-2 variants were believed to be the major contributor of different pandemic waves.

Figure S1.1. Weekly number of observed deaths versus expected deaths of acute myocardial infarction and cardiac arrest, and estimated excess deaths of AMI and CA in the US. The periods of five pandemic waves were marked in each panel.

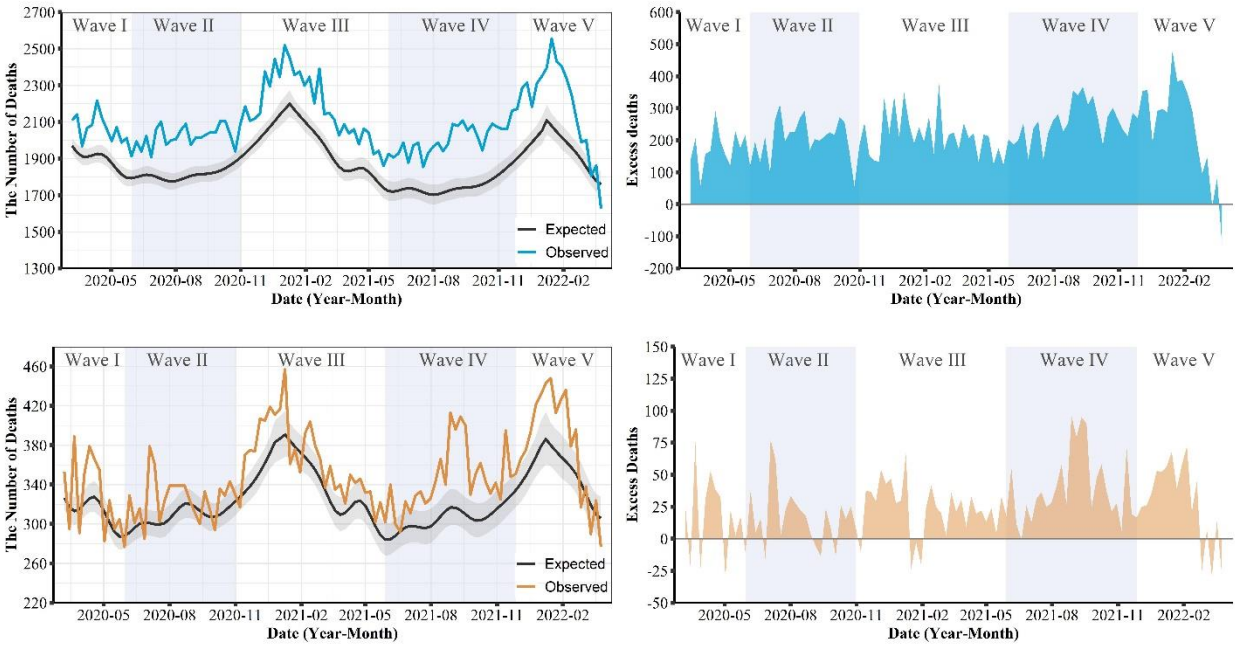
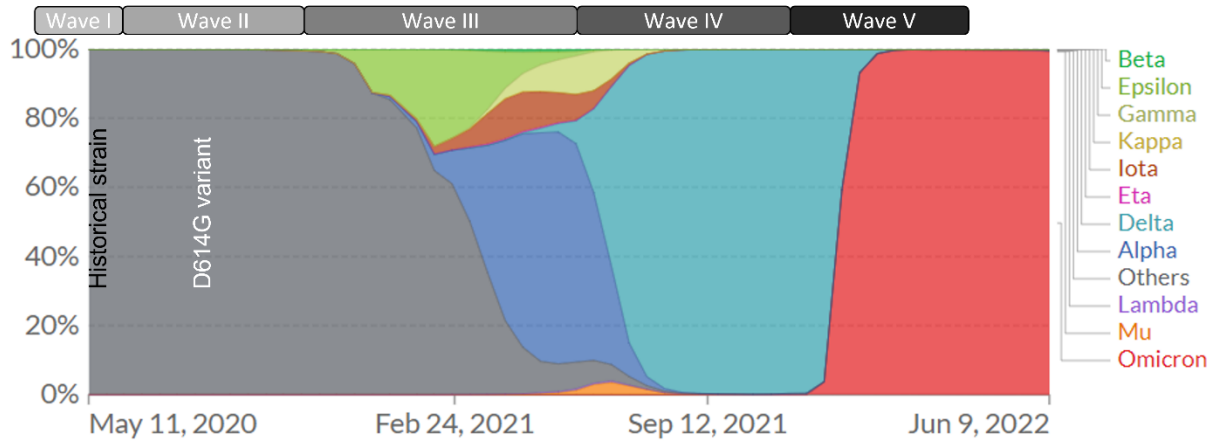


Figure S1.2. The timing and distribution of major SARS-CoV-2 variants that circulated in the US. The periods of five pandemic waves were marked on the top of this figure. Wave I matched the circulation of historical strains (Wuhan strain), wave II matched the emerging of D614G variants, wave III matched the emerging of Alpha and Epsilon variants (in light green and blue, respectively), wave IV matched the emerging of Delta variants (in cyan), and wave V matched the emerging of Omicron variants (in red). This figure was revised from the open-access figure downloaded via https://ourworldindata.org/grapher/covid-variants-area?country=~USA, which was plotted based on the open-source sequencing data in GISAID and accessed on June 12, 2022.



S1.3 Statistical analysis

To train the model that will then be used for estimating the expected death counts, we used mixed-effect Poisson log-linear regression models to fit the weekly death data, where the weekly death rates were regressed by using jurisdiction-specific populations as offset. For the temporal patterns of death time series varying from 2015 to 2022, the time-varying patterns of deaths were decomposed into a long-term trend and a seasonality explicitly, and the jurisdiction-specific differences were also modelled by allowing these time-varying patterns to vary across jurisdictions. The long-term trends in death counts were accounted for by using a linear term for the calendar year (from 2015 to 2022). The within-year periodicity (i.e., seasonality) was parameterized as a natural spline function for epidemiological weeks (from week 1 to week 52 with each calendar year) with a degree of freedom to be further estimated. Besides the long-term trend and seasonality, the effect of the COVID-19 pandemic was modelled as a dummy variable to compare the average level of death before (dummy = 0) versus during (dummy = 1) the pandemic, which is 0 for the calendar date before March 2020 and 1 otherwise.

All aforementioned model parameters (intercepts and slopes) were fitted hierarchically, with fixed effects and random effects that allowed each parameter to vary by jurisdiction. Using the maximum likelihood approach, we fitted 21 candidate models that adjusted the seasonality using spline function with a degree of freedom from 4 to 24. The Akaike information criterion (AIC) of each candidate model was calculated and treated as an estimator of the trade-off between goodness-of-fit and model complexity. The degree of freedom of model with the lowest AIC value was then considered best-fit degree of freedom for seasonality, and was then used for reconstructing the models in the main analyses.

The expected death counts (baseline) are estimated as counterfactual death counts (by assuming without effects of the COVID-19 pandemic) from March 1, 2020 to March 26, 2022 for each cause of mortality. The counterfactual death counts from 2020 to 2022 were estimated for each sex, age, and ethnic group and cause-specific death. Excess deaths were measured as net difference between the observed and expected death counts. As such, we calculated the following four statistics for different subgroups.

- excess deaths (observed death counts – expected death counts),
- weekly average excess deaths (excess deaths / number of weeks during period),
- excess mortality (excess deaths / population size), and
- change percentage (relative ratio – 1 = observed death counts / expected death counts – 1 = excess deaths / expected deaths × 100%)

The statistical uncertainty was assessed by using the 95% confidence interval (CI). The 95% CI was constructed by mean ± 1.96 standard error (SE), where the SE was calculated by using the delta method with first-order Taylor approximation. All analyses were carried out using R statistical software (version 3.6.2).

S1.4 Ethics statement

This study followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) reporting guidelines. All data used in this analysis are fully anonymized and aggregated without any identifiable information. As the study used publicly available data, which were aggregated and de-identifiable, the institutional review board approval and informed consent were not needed.

S2 Supplementary figures

Figure S2.1. Weekly excess death estimates of acute myocardial infarction (panels A), and cardiac arrest (panels B) by age (left panels), sex (middle panels) and ethnic (right panels) groups from March 2020 to March 2022 in the US.

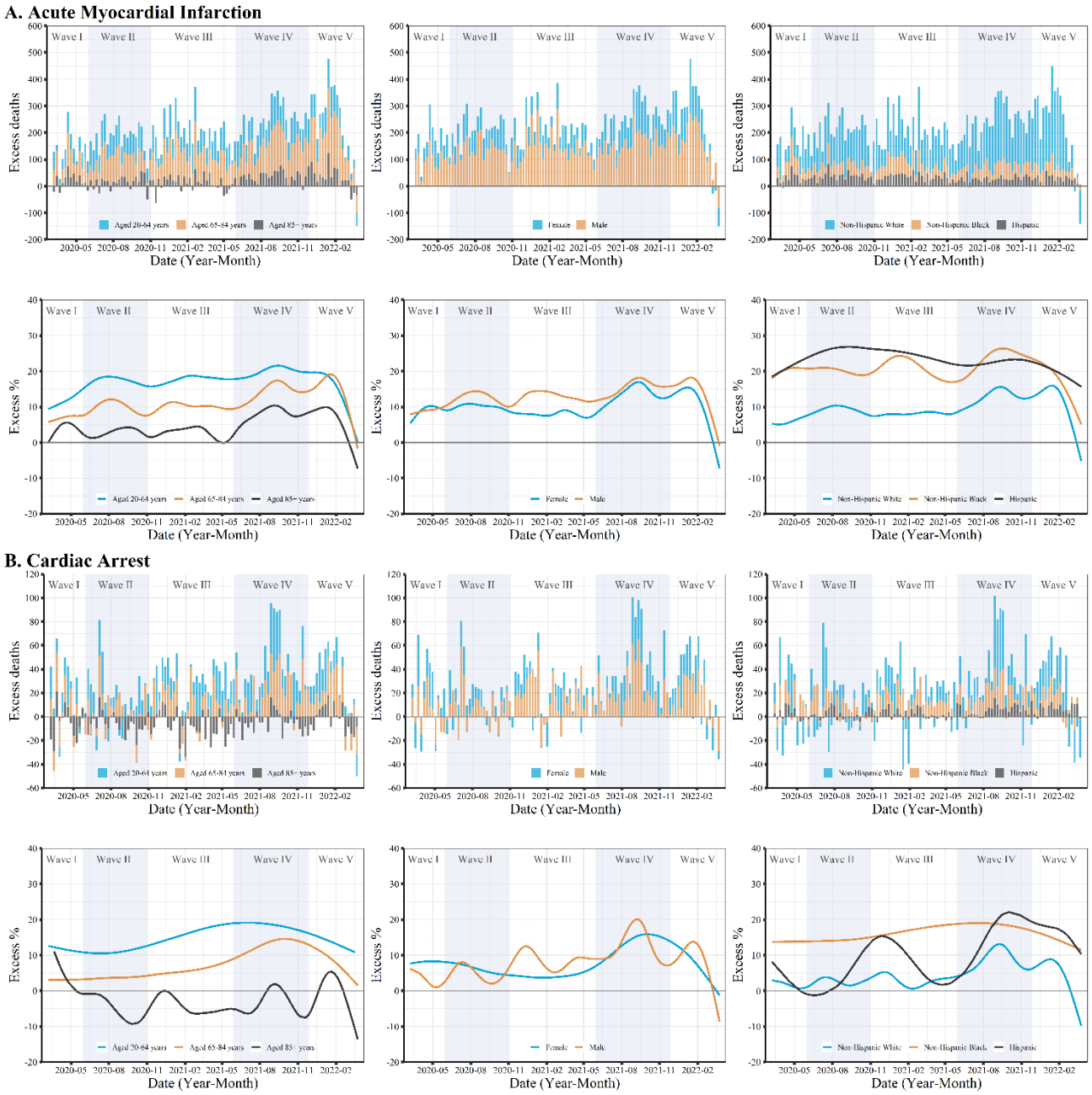
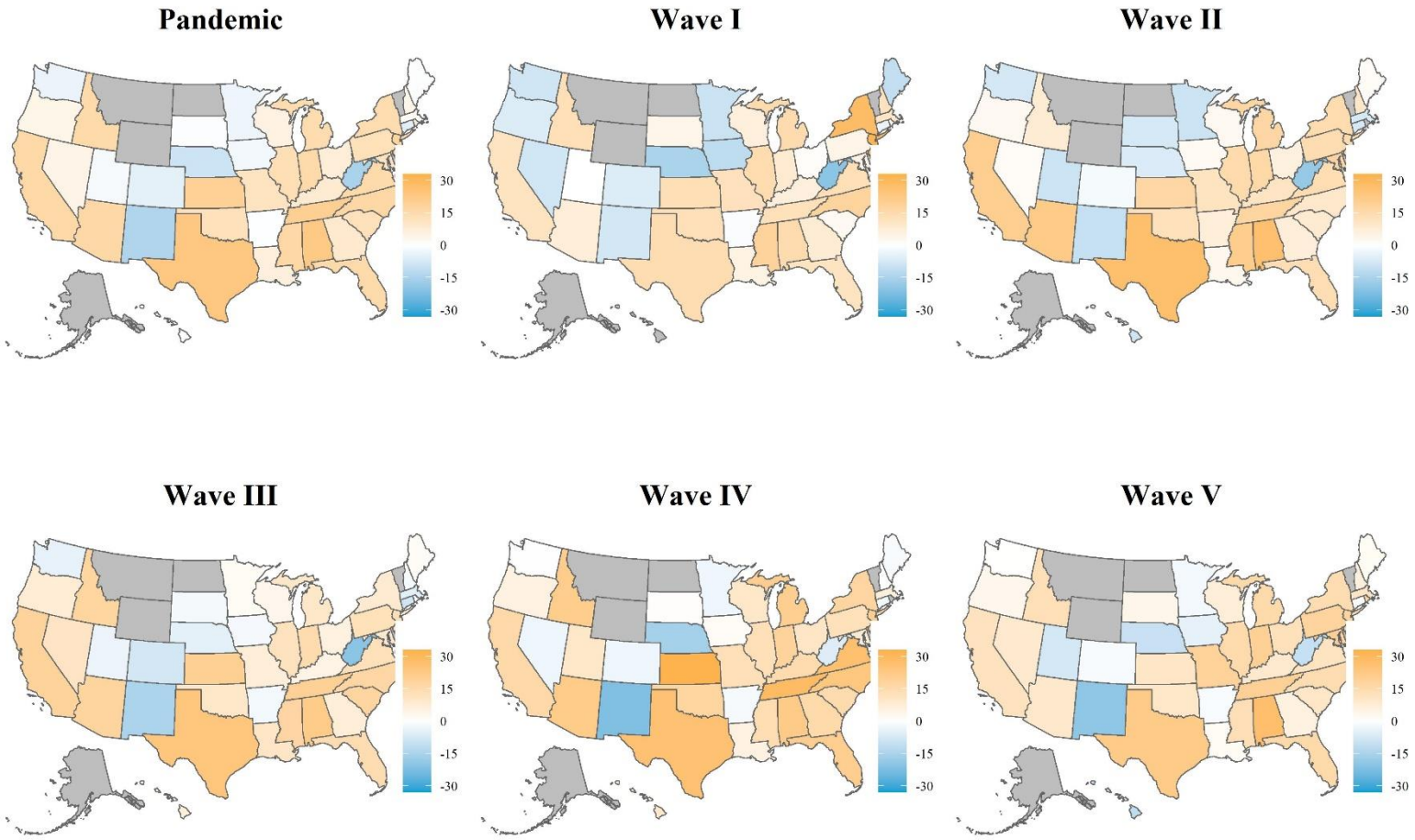


Figure S2.2. Maps of excess death rates (per million population) of acute myocardial infarction from March 2020 to March 2022 and stratified by five pandemic waves in each US jurisdiction.

Figure S2.3. Maps of change in percentage of mortality of acute myocardial infarction from March 2020 to March 2022 and stratified by five pandemic waves in each US jurisdiction.



S3 Supplementary tables

Table S3.1. The excess mortality estimates of acute myocardial infarction from March 2020 to March 2022 in each US jurisdiction.

Jurisdictions	Observed death counts	Expected death counts	Excess death			
			Total counts	Counts per week	Mortality (per million)	Change %
Alabama	3462	2825 (2488, 3213)	637 (249, 974)	6 (2, 9)	130.2 (50.9, 199.1)	22.5 (8.8, 34.5)
Arkansas	6028	6051 (5431, 6736)	-23 (-708, 597)	0 (-7, 6)	-7.6 (-235.1, 198.2)	-0.4 (-11.7, 9.9)
Arizona	4038	3468 (3079, 3911)	570 (127, 959)	5 (1, 9)	79.5 (17.7, 133.7)	16.4 (3.7, 27.7)
California	21261	18300 (17218, 19445)	2961 (1816, 4043)	27 (17, 37)	75.3 (46.2, 102.8)	16.2 (9.9, 22.1)
Colorado	2105	2211 (1914, 2562)	-106 (-457, 191)	-1 (-4, 2)	-18.6 (-80.4, 33.6)	-4.8 (-20.7, 8.6)
Connecticut	1427	1502 (1290, 1758)	-75 (-331, 137)	-1 (-3, 1)	-21.0 (-92.7, 38.4)	-5.0 (-22, 9.1)
Delaware	62	-	-	-	-	-
Florida	15749	13661 (12788, 14590)	2088 (1159, 2961)	19 (11, 27)	98.4 (54.6, 139.6)	15.3 (8.5, 21.7)
Georgia	6158	5672 (5113, 6312)	486 (-154, 1045)	4 (-1, 10)	46.2 (-14.6, 99.4)	8.6 (-2.7, 18.4)
Hawaii	159	159 (107, 233)	0 (-74, 52)	0 (-5, 4)	0.0 (-52.1, 36.6)	0.0 (-46.5, 32.7)
Iowa	1998	2048 (1752, 2390)	-50 (-392, 246)	0 (-4, 2)	-15.9 (-124.4, 78.1)	-2.4 (-19.1, 12)
Idaho	1608	1390 (1163, 1648)	218 (-40, 445)	2 (0, 4)	124.3 (-22.8, 253.7)	15.7 (-2.9, 32)
Illinois	9700	8544 (7903, 9239)	1156 (461, 1797)	11 (4, 17)	90.9 (36.3, 141.3)	13.5 (5.4, 21)
Indiana	5851	5062 (4552, 5626)	789 (225, 1299)	7 (2, 12)	117.8 (33.6, 194)	15.6 (4.4, 25.7)
Kansas	1831	1533 (1293, 1813)	298 (18, 538)	3 (0, 5)	102.3 (6.2, 184.7)	19.4 (1.2, 35.1)
Kentucky	6312	5819 (5279, 6417)	493 (-105, 1033)	5 (-1, 10)	110.5 (-23.5, 231.5)	8.5 (-1.8, 17.8)
Louisiana	3378	3183 (2777, 3664)	195 (-286, 601)	2 (-3, 6)	41.8 (-61.3, 128.8)	6.1 (-9.0, 18.9)
Massachusetts	3194	3147 (2749, 3603)	47 (-409, 445)	0 (-4, 4)	6.8 (-59.5, 64.7)	1.5 (-13, 14.1)
Maryland	3458	3112 (2707, 3576)	346 (-118, 751)	3 (-1, 7)	57.3 (-19.5, 124.4)	11.1 (-3.8, 24.1)
Maine	767	771 (635, 945)	-4 (-178, 132)	0 (-3, 2)	-3.0 (-132.8, 98.4)	-0.5 (-23.1, 17.1)
Michigan	6762	5905 (5410, 6438)	857 (324, 1352)	8 (3, 13)	85.9 (32.5, 135.6)	14.5 (5.5, 22.9)
Minnesota	2087	2151 (1830, 2541)	-64 (-454, 257)	-1 (-4, 2)	-11.4 (-81.1, 45.9)	-3.0 (-21.1, 11.9)
Missouri	7173	6435 (5864, 7060)	738 (113, 1309)	7 (1, 12)	120.5 (18.5, 213.7)	11.5 (1.8, 20.3)
Mississippi	5471	4691 (4215, 5216)	780 (255, 1256)	7 (2, 12)	261.6 (85.5, 421.2)	16.6 (5.4, 26.8)
Montana	42	-	-	-	-	-
North Carolina	6694	5739 (5185, 6349)	955 (345, 1509)	9 (3, 14)	91.9 (33.2, 145.3)	16.6 (6.0, 26.3)
North Dakota	47	-	-	-	-	-
Nebraska	792	872 (735, 1034)	-80 (-242, 57)	-1 (-4, 1)	-41.6 (-125.8, 29.6)	-9.2 (-27.8, 6.5)
New Hampshire	223	215 (163, 281)	8 (-58, 60)	0 (-3, 3)	5.9 (-42.8, 44.3)	3.7 (-27, 27.9)
New Jersey	5407	4596 (4135, 5116)	811 (291, 1272)	8 (3, 12)	91.3 (32.8, 143.2)	17.6 (6.3, 27.7)
New Mexico	830	969 (811, 1167)	-139 (-337, 19)	-2 (-5, 0)	-66.3 (-160.7, 9.1)	-14.3 (-34.8, 2)
Nevada	979	938 (801, 1110)	41 (-131, 178)	1 (-2, 2)	13.5 (-43.2, 58.7)	4.4 (-14, 19.0)
New York	11448	9995 (9144, 10929)	1453 (519, 2304)	13 (5, 21)	74.5 (26.6, 118.1)	14.5 (5.2, 23.1)
Ohio	9753	9099 (8371, 9903)	654 (-150, 1382)	6 (-1, 13)	56 (-12.8, 118.4)	7.2 (-1.6, 15.2)
Oklahoma	1896	1689 (1438, 1983)	207 (-87, 458)	2 (-1, 4)	52.4 (-22.0, 116)	12.3 (-5.2, 27.1)
Oregon	2253	2168 (1849, 2549)	85 (-296, 404)	1 (-3, 4)	20.4 (-70.9, 96.7)	3.9 (-13.7, 18.6)
Pennsylvania	10537	9348 (8658, 10084)	1189 (453, 1879)	11 (4, 17)	92.9 (35.4, 146.9)	12.7 (4.8, 20.1)
Rhode Island	95	88 (64, 119)	7 (-24, 31)	1 (-3, 3)	6.6 (-22.7, 29.3)	8.0 (-27.3, 35.2)
South Carolina	4178	3714 (3305, 4183)	464 (-5, 873)	4 (0, 8)	91.1 (-1, 171.5)	12.5 (-0.1, 23.5)
South Dakota	1015	1022 (866, 1204)	-7 (-189, 149)	0 (-3, 2)	-8.0 (-214.9, 169.4)	-0.7 (-18.5, 14.6)
Tennessee	7780	6482 (5896, 7130)	1298 (650, 1884)	12 (6, 17)	191.7 (96, 278.2)	20.0 (10.0, 29.1)
Texas	19205	15574 (14592, 16627)	3631 (2578, 4613)	34 (24, 43)	126.8 (90, 161.1)	23.3 (16.6, 29.6)
Utah	734	747 (611, 924)	-13 (-190, 123)	0 (-3, 2)	-4.1 (-60.3, 39)	-1.7 (-25.4, 16.5)
Virginia	5544	4809 (4296, 5387)	735 (157, 1248)	7 (1, 12)	86.4 (18.5, 146.7)	15.3 (3.3, 26.0)
Washington	4191	4356 (3854, 4917)	-165 (-726, 337)	-2 (-7, 3)	-22.0 (-96.6, 44.9)	-3.8 (-16.7, 7.7)
West Virginia	1623	1909 (1619, 2254)	-286 (-631, 4)	-3 (-6, 0)	-158.2 (-349.1, 2.2)	-15.0 (-33.1, 0.2)
Wisconsin	4477	4246 (3826, 4720)	231 (-243, 651)	2 (-2, 6)	39.8 (-41.8, 112.1)	5.4 (-5.7, 15.3)

Note: The "-" in this table were generated because the death counts are relatively rare such that the regression model cannot be trained.

Table S3.2. The excess mortality estimates of cardiac arrest from March 2020 to March 2022 in each US jurisdiction.

Jurisdictions	Observed death counts	Expected death counts	Excess death			
			Total counts	Counts per week	Mortality (per million)	Change %
Alabama	4966	4257 (3748, 4843)	709 (123, 1218)	7 (1, 11)	144.9 (25.1, 248.9)	16.7 (2.9, 28.6)
Arizona	44	-	-	-	-	-
Connecticut	118	114 (94, 136)	4 (-18, 24)	0 (-2, 2)	1.1 (-5.0, 6.7)	3.5 (-15.8, 21.1)
Florida	1120	1173 (995, 1387)	-53 (-267, 125)	-1 (-3, 2)	-2.5 (-12.6, 5.9)	-4.5 (-22.8, 10.7)
Georgia	1217	1114 (949, 1323)	103 (-106, 268)	1 (-1, 3)	9.8 (-10.1, 25.5)	9.2 (-9.5, 24.1)
Illinois	1193	1137 (962, 1343)	56 (-150, 231)	1 (-2, 3)	4.4 (-11.8, 18.2)	4.9 (-13.2, 20.3)
Indiana	262	248 (207, 295)	14 (-33, 55)	1 (-1, 2)	2.1 (-4.9, 8.2)	5.6 (-13.3, 22.2)
Kentucky	1036	980 (820, 1177)	56 (-141, 216)	1 (-2, 3)	12.6 (-31.6, 48.4)	5.7 (-14.4, 22)
Louisiana	1177	1204 (1022, 1421)	-27 (-244, 155)	0 (-3, 2)	-5.8 (-52.3, 33.2)	-2.2 (-20.3, 12.9)
Massachusetts	347	331 (270, 403)	16 (-56, 77)	1 (-2, 3)	2.3 (-8.1, 11.2)	4.8 (-16.9, 23.3)
Missouri	864	740 (603, 896)	124 (-32, 261)	2 (-1, 4)	20.2 (-5.2, 42.6)	16.8 (-4.3, 35.3)
North Carolina	324	276 (202, 377)	48 (-53, 122)	2 (-2, 5)	4.6 (-5.1, 11.7)	17.4 (-19.2, 44.2)
New Jersey	3048	2619 (2211, 3117)	429 (-69, 837)	4 (-1, 8)	48.3 (-7.8, 94.2)	16.4 (-2.6, 32.0)
Nevada	1989	1947 (1620, 2345)	42 (-356, 369)	0 (-3, 3)	13.9 (-117.5, 121.8)	2.2 (-18.3, 19.0)
New York	631	651 (548, 780)	-20 (-149, 83)	0 (-3, 2)	-1.0 (-7.6, 4.3)	-3.1 (-22.9, 12.7)
Ohio	3423	3253 (2846, 3734)	170 (-311, 577)	2 (-3, 5)	14.6 (-26.6, 49.4)	5.2 (-9.6, 17.7)
Pennsylvania	2034	2242 (1932, 2600)	-208 (-566, 102)	-2 (-5, 1)	-16.3 (-44.2, 8.0)	-9.3 (-25.2, 4.5)
South Carolina	492	422 (342, 526)	70 (-34, 150)	2 (-1, 4)	13.7 (-6.7, 29.5)	16.6 (-8.1, 35.5)
Tennessee	992	1077 (828, 1411)	-85 (-419, 164)	-1 (-6, 2)	-12.6 (-61.9, 24.2)	-7.9 (-38.9, 15.2)
Texas	2628	2286 (1876, 2794)	342 (-166, 752)	3 (-2, 7)	11.9 (-5.8, 26.3)	15.0 (-7.3, 32.9)
Virginia	712	720 (595, 876)	-8 (-164, 117)	0 (-3, 2)	-0.9 (-19.3, 13.7)	-1.1 (-22.8, 16.2)

Note: The "-" in this table were generated because the death counts are relatively rare such that the regression model cannot be trained.

Table S3.3. The excess death estimates of acute myocardial infarction stratified by five COVID-19 pandemic waves in each US jurisdiction.

Jurisdictions	Total counts of excess death					Excess mortality (per million)				
	Wave I	Wave II	Wave III	Wave IV	Wave V	Wave I	Wave II	Wave III	Wave IV	Wave V
Alabama	56 (11, 95)	119 (66, 167)	222 (86, 340)	119 (39, 189)	121 (47, 183)	11.4 (2.2, 19.4)	24.3 (13.5, 34.1)	45.4 (17.6, 69.5)	24.3 (8.0, 38.6)	24.7 (9.6, 37.4)
Arkansas	-7 (-81, 61)	63 (-25, 145)	-48 (-284, 173)	-20 (-169, 108)	-11 (-149, 110)	-2.3 (-26.9, 20.3)	20.9 (-8.3, 48.1)	-15.9 (-94.3, 57.4)	-6.6 (-56.1, 35.9)	-3.7 (-49.5, 36.5)
Arizona	31 (-17, 73)	115 (57, 166)	221 (66, 359)	149 (51, 231)	54 (-30, 130)	4.3 (-2.4, 10.2)	16.0 (7.9, 23.1)	30.8 (9.2, 50.0)	20.8 (7.1, 32.2)	7.5 (-4.2, 18.1)
California	270 (145, 392)	547 (399, 690)	1228 (817, 1614)	542 (311, 765)	374 (144, 582)	6.9 (3.7, 10.0)	13.9 (10.1, 17.5)	31.2 (20.8, 41.0)	13.8 (7.9, 19.4)	9.5 (3.7, 14.8)
Colorado	-18 (-54, 16)	-6 (-53, 32)	-65 (-191, 41)	-12 (-88, 54)	-5 (-71, 48)	-3.2 (-9.5, 2.8)	-1.1 (-9.3, 5.6)	-11.4 (-33.6, 7.2)	-2.1 (-15.5, 9.5)	-0.9 (-12.5, 8.4)
Connecticut	-6 (-32, 17)	-17 (-49, 13)	-45 (-137, 28)	-5 (-56, 39)	-2 (-57, 40)	-1.7 (-9, 4.8)	-4.8 (-13.7, 3.6)	-12.6 (-38.4, 7.8)	-1.4 (-15.7, 10.9)	-0.6 (-16, 11.2)
Delaware	-	-	-	-	-	-	-	-	-	-
Florida	195 (95, 291)	299 (172, 421)	691 (367, 994)	559 (361, 748)	344 (164, 507)	9.2 (4.5, 13.7)	14.1 (8.1, 19.8)	32.6 (17.3, 46.8)	26.3 (17, 35.3)	16.2 (7.7, 23.9)
Georgia	57 (-12, 121)	61 (-20, 141)	145 (-82, 338)	173 (31, 289)	50 (-71, 156)	5.4 (-1.1, 11.5)	5.8 (-1.9, 13.4)	13.8 (-7.8, 32.1)	16.5 (2.9, 27.5)	4.8 (-6.8, 14.8)
Hawaii	0 (0, 0)	-2 (-10, 5)	3 (-16, 17)	4 (-21, 19)	-5 (-27, 11)	-	-1.4 (-7.0, 3.5)	2.1 (-11.3, 12.0)	2.8 (-14.8, 13.4)	-3.5 (-19.0, 7.7)
Iowa	-32 (-69, 3)	6 (-36, 46)	-14 (-140, 91)	6 (-63, 67)	-16 (-84, 39)	-10.2 (-21.9, 1.0)	1.9 (-11.4, 14.6)	-4.4 (-44.4, 28.9)	1.9 (-20.0, 21.3)	-5.1 (-26.7, 12.4)
Idaho	21 (-4, 44)	15 (-16, 43)	89 (-2, 170)	62 (5, 115)	31 (-23, 73)	12.0 (-2.3, 25.1)	8.6 (-9.1, 24.5)	50.7 (-1.1, 96.9)	35.3 (2.9, 65.6)	17.7 (-13.1, 41.6)
Illinois	157 (83, 227)	194 (101, 279)	378 (131, 605)	210 (65, 344)	217 (81, 342)	12.3 (6.5, 17.9)	15.3 (7.9, 21.9)	29.7 (10.3, 47.6)	16.5 (5.1, 27.1)	17.1 (6.4, 26.9)
Indiana	56 (-9, 113)	125 (49, 194)	270 (71, 450)	179 (62, 286)	159 (52, 256)	8.4 (-1.3, 16.9)	18.7 (7.3, 29)	40.3 (10.6, 67.2)	26.7 (9.3, 42.7)	23.7 (7.8, 38.2)
Kansas	28 (-2, 56)	38 (1, 68)	113 (10, 205)	94 (35, 140)	25 (-26, 69)	9.6 (-0.7, 19.2)	13.0 (0.3, 23.3)	38.8 (3.4, 70.4)	32.3 (12, 48.1)	8.6 (-8.9, 23.7)
Kentucky	44 (-16, 100)	97 (19, 170)	93 (-117, 283)	173 (42, 291)	86 (-33, 189)	9.9 (-3.6, 22.4)	21.7 (4.3, 38.1)	20.8 (-26.2, 63.4)	38.8 (9.4, 65.2)	19.3 (-7.4, 42.4)
Louisiana	20 (-32, 63)	13 (-46, 69)	118 (-51, 258)	34 (-69, 121)	10 (-88, 90)	4.3 (-6.9, 13.5)	2.8 (-9.9, 14.8)	25.3 (-10.9, 55.3)	7.3 (-14.8, 25.9)	2.1 (-18.9, 19.3)
Massachusetts	44 (-7, 88)	-34 (-92, 16)	-55 (-215, 88)	37 (-60, 119)	55 (-35, 134)	6.4 (-1, 12.8)	-4.9 (-13.4, 2.3)	-8.0 (-31.3, 12.8)	5.4 (-8.7, 17.3)	8.0 (-5.1, 19.5)
Maryland	18 (-31, 65)	78 (17, 128)	102 (-61, 248)	46 (-52, 130)	102 (9, 180)	3.0 (-5.1, 10.8)	12.9 (2.8, 21.2)	16.9 (-10.1, 41.1)	7.6 (-8.6, 21.5)	16.9 (1.5, 29.8)
Maine	-11 (-30, 4)	2 (-22, 21)	4 (-50, 44)	-2 (-37, 28)	3 (-39, 35)	-8.2 (-22.4, 3.0)	1.5 (-16.4, 15.7)	3.0 (-37.3, 32.8)	-1.5 (-27.6, 20.9)	2.2 (-29.1, 26.1)
Michigan	118 (58, 175)	152 (83, 220)	215 (22, 391)	229 (119, 332)	143 (42, 234)	11.8 (5.8, 17.5)	15.2 (8.3, 22.1)	21.6 (2.2, 39.2)	23.0 (11.9, 33.3)	14.3 (4.2, 23.5)
Minnesota	-26 (-68, 9)	-31 (-81, 14)	13 (-120, 119)	-12 (-99, 59)	-8 (-86, 56)	-4.6 (-12.1, 1.6)	-5.5 (-14.5, 2.5)	2.3 (-21.4, 21.2)	-2.1 (-17.7, 10.5)	-1.4 (-15.4, 10.0)
Missouri	104 (33, 168)	111 (30, 187)	169 (-54, 373)	155 (26, 272)	199 (78, 309)	17 (5.4, 27.4)	18.1 (4.9, 30.5)	27.6 (-8.8, 60.9)	25.3 (4.2, 44.4)	32.5 (12.7, 50.5)
Mississippi	107 (53, 158)	151 (83, 213)	287 (104, 453)	130 (14, 231)	105 (1, 201)	35.9 (17.8, 53)	50.6 (27.8, 71.4)	96.2 (34.9, 151.9)	43.6 (4.7, 77.5)	35.2 (0.3, 67.4)
Montana	-	-	-	-	-	-	-	-	-	-
North Carolina	137 (67, 201)	86 (0, 161)	348 (131, 545)	257 (130, 372)	127 (17, 230)	13.2 (6.5, 19.4)	8.3 (0.0, 15.5)	33.5 (12.6, 52.5)	24.7 (12.5, 35.8)	12.2 (1.6, 22.1)
North Dakota	-	-	-	-	-	-	-	-	-	-
Nebraska	-10 (-20, -1)	-8 (-27, 10)	-17 (-80, 35)	-33 (-75, 3)	-12 (-40, 10)	-5.2 (-10.4, -0.5)	-4.2 (-14.0, 5.2)	-8.8 (-41.6, 18.2)	-17.2 (-39.0, 1.6)	-6.2 (-20.8, 5.2)
New Hampshire	4 (-4, 10)	2 (-4, 6)	-1 (-24, 19)	0 (-9, 8)	3 (-17, 17)	3.0 (-3.0, 7.4)	1.5 (-3.0, 4.4)	-0.7 (-17.7, 14)	0.0 (-6.6, 5.9)	2.2 (-12.5, 12.5)
New Jersey	200 (140, 254)	100 (30, 160)	218 (28, 388)	164 (62, 252)	129 (31, 218)	22.5 (15.8, 28.6)	11.3 (3.4, 18.0)	24.5 (3.2, 43.7)	18.5 (7.0, 28.4)	14.5 (3.5, 24.5)
New Mexico	-16 (-50, 12)	-17 (-49, 6)	-52 (-122, 5)	-30 (-62, -5)	-24 (-54, 1)	-7.6 (-23.8, 5.7)	-8.1 (-23.4, 2.9)	-24.8 (-58.2, 2.4)	-14.3 (-29.6, -2.4)	-11.4 (-25.8, 0.5)
Nevada	-8 (-24, 3)	2 (-19, 18)	34 (-22, 80)	-5 (-41, 25)	18 (-25, 52)	-2.6 (-7.9, 1.0)	0.7 (-6.3, 5.9)	11.2 (-7.3, 26.4)	-1.7 (-13.5, 8.3)	5.9 (-8.3, 17.2)
New York	392 (284, 493)	218 (95, 334)	302 (-36, 604)	318 (131, 494)	223 (45, 379)	20.1 (14.6, 25.3)	11.2 (4.9, 17.1)	15.5 (-1.8, 31)	16.3 (6.7, 25.3)	11.4 (2.3, 19.4)
Ohio	10 (-76, 90)	78 (-23, 172)	186 (-102, 443)	188 (17, 341)	192 (34, 336)	0.9 (-6.5, 7.7)	6.7 (-2, 14.7)	15.9 (-8.7, 37.9)	16.1 (1.5, 29.2)	16.4 (2.9, 28.8)
Oklahoma	29 (-4, 56)	30 (-4, 62)	61 (-47, 149)	59 (-3, 114)	28 (-29, 77)	7.3 (-1.0, 14.2)	7.6 (-1, 15.7)	15.4 (-11.9, 37.7)	14.9 (-0.8, 28.9)	7.1 (-7.3, 19.5)
Oregon	-17 (-58, 16)	8 (-39, 51)	60 (-73, 173)	23 (-60, 93)	11 (-66, 71)	-4.1 (-13.9, 3.8)	1.9 (-9.3, 12.2)	14.4 (-17.5, 41.4)	5.5 (-14.4, 22.3)	2.6 (-15.8, 17)
Pennsylvania	53 (-27, 130)	195 (102, 288)	439 (174, 686)	217 (66, 357)	285 (138, 418)	4.1 (-2.1, 10.2)	15.2 (8.0, 22.5)	34.3 (13.6, 53.6)	17.0 (5.2, 27.9)	22.3 (10.8, 32.7)
Rhode Island	1 (-5, 5)	-	0 (-8, 8)	-	6 (-11, 18)	0.9 (-4.7, 4.7)	-	0.0 (-7.6, 7.6)	-	5.7 (-10.4, 17.0)
South Carolina	12 (-35, 56)	46 (-18, 100)	232 (65, 372)	111 (10, 201)	63 (-27, 144)	2.4 (-6.9, 11.0)	9.0 (-3.5, 19.6)	45.6 (12.8, 73.1)	21.8 (2, 39.5)	12.4 (-5.3, 28.3)
South Dakota	5 (-17, 25)	-12 (-38, 9)	-7 (-62, 41)	2 (-48, 45)	5 (-24, 29)	5.7 (-19.3, 28.4)	-13.6 (-43.2, 10.2)	-8 (-70.5, 46.6)	2.3 (-54.6, 51.2)	5.7 (-27.3, 33)
Tennessee	108 (36, 174)	171 (87, 252)	456 (226, 662)	360 (222, 484)	203 (79, 312)	15.9 (5.3, 25.7)	25.3 (12.8, 37.2)	67.3 (33.4, 97.8)	53.2 (32.8, 71.5)	30.0 (11.7, 46.1)
Texas	298 (177, 413)	673 (529, 810)	1357 (981, 1704)	767 (552, 971)	536 (339, 715)	10.4 (6.2, 14.4)	23.5 (18.5, 28.3)	47.4 (34.3, 59.5)	26.8 (19.3, 33.9)	18.7 (11.8, 25.0)
Utah	0 (-9, 9)	-8 (-24, 6)	-10 (-81, 42)	16 (-26, 48)	-11 (-50, 18)	0.0 (-2.9, 2.9)	-2.5 (-7.6, 1.9)	-3.2 (-25.7, 13.3)	5.1 (-8.3, 15.2)	-3.5 (-15.9, 5.7)

Virginia	80 (20, 136)	101 (26, 171)	216 (15, 397)	248 (123, 355)	90 (-27, 189)	9.4 (2.4, 16.0)	11.9 (3.1, 20.1)	25.4 (1.8, 46.7)	29.1 (14.5, 41.7)	10.6 (-3.2, 22.2)
Washington	-46 (-107, 3)	-50 (-121, 16)	-68 (-263, 109)	-2 (-127, 108)	1 (-108, 101)	-6.1 (-14.2, 0.4)	-6.7 (-16.1, 2.1)	-9.1 (-35.0, 14.5)	-0.3 (-16.9, 14.4)	0.1 (-14.4, 13.4)
West Virginia	-47 (-81, -15)	-50 (-91, -13)	-128 (-243, -34)	-25 (-106, 41)	-36 (-110, 25)	-26.0 (-44.8, -8.3)	-27.7 (-50.3, -7.2)	-70.8 (-134.4, -18.8)	-13.8 (-58.6, 22.7)	-19.9 (-60.9, 13.8)
Wisconsin	33 (-19, 80)	16 (-44, 70)	49 (-119, 199)	82 (-20, 169)	51 (-41, 133)	5.7 (-3.3, 13.8)	2.8 (-7.6, 12.1)	8.4 (-20.5, 34.3)	14.1 (-3.4, 29.1)	8.8 (-7.1, 22.9)

Note: The "-" in this table were generated because the death counts are relatively rare such that the regression model cannot be trained. The periods of the five COVID-19 pandemic waves were defined as Wave I (Week 10 March 1 2020 to Week 23 June 6 2020), Wave II (Week 24 June 7 2020 to Week 40 October 3 2020), Wave III (Week 41 October 4 2020 to Week 25 June 26 2021), Wave IV (Week 26 June 27 2021 to Week 47 November 27 2021), and Wave V (Week 48 November 28 2021 to Week 12 March 26 2022).

Table 3.4. The excess death estimates of cardiac arrest stratified by five COVID-19 pandemic waves in each US jurisdiction. Here, 30 US jurisdiction were not included in the table due to unavailability of state-specific data.

Jurisdictions	Total counts of excess death					Excess death rate (per million)				
	Wave I	Wave II	Wave III	Wave IV	Wave V	Wave I	Wave II	Wave III	Wave IV	Wave V
Alabama	18 (-44, 72)	71 (-7, 141)	326 (124, 505)	214 (87, 324)	80 (-37, 176)	3.7 (-9.0, 14.7)	14.5 (-1.4, 28.8)	66.6 (25.3, 103.2)	43.7 (17.8, 66.2)	16.3 (-7.6, 36.0)
Arizona	-	-	-	-	-	-	-	-	-	-
Connecticut	2 (-8, 11)	0 (-2, 2)	1 (-3, 5)	0 (0, 0)	1 (-5, 6)	0.6 (-2.2, 3.1)	0.0 (-0.6, 0.6)	0.3 (-0.8, 1.4)	-	0.3 (-1.4, 1.7)
Florida	-10 (-28, 5)	-21 (-50, 4)	-24 (-101, 35)	3 (-47, 46)	-1 (-41, 35)	-0.5 (-1.3, 0.2)	-1 (-2.4, 0.2)	-1.1 (-4.8, 1.6)	0.1 (-2.2, 2.2)	0.0 (-1.9, 1.6)
Georgia	-7 (-25, 6)	28 (-1, 50)	15 (-60, 78)	27 (-19, 64)	40 (-1, 70)	-0.7 (-2.4, 0.6)	2.7 (-0.1, 4.8)	1.4 (-5.7, 7.4)	2.6 (-1.8, 6.1)	3.8 (-0.1, 6.7)
Iowa	-	-	-	-	-	-	-	-	-	-
Illinois	27 (5, 47)	1 (-24, 25)	-17 (-88, 45)	20 (-21, 52)	25 (-22, 62)	2.1 (0.4, 3.7)	0.1 (-1.9, 2.0)	-1.3 (-6.9, 3.5)	1.6 (-1.7, 4.1)	2 (-1.7, 4.9)
Indiana	2 (-5, 9)	2 (-4, 8)	7 (-10, 19)	3 (-1, 6)	0 (-13, 13)	0.3 (-0.7, 1.3)	0.3 (-0.6, 1.2)	1.0 (-1.5, 2.8)	0.4 (-0.1, 0.9)	0.0 (-1.9, 1.9)
Kentucky	7 (-11, 21)	7 (-16, 25)	22 (-52, 85)	10 (-31, 43)	10 (-31, 42)	1.6 (-2.5, 4.7)	1.6 (-3.6, 5.6)	4.9 (-11.7, 19)	2.2 (-6.9, 9.6)	2.2 (-6.9, 9.4)
Louisiana	0 (-15, 12)	-8 (-39, 16)	-20 (-99, 51)	11 (-40, 50)	-10 (-51, 26)	0.0 (-3.2, 2.6)	-1.7 (-8.4, 3.4)	-4.3 (-21.2, 10.9)	2.4 (-8.6, 10.7)	-2.1 (-10.9, 5.6)
Massachusetts	3 (-5, 10)	-1 (-3, 1)	4 (-20, 28)	3 (-13, 15)	7 (-15, 23)	0.4 (-0.7, 1.5)	-0.1 (-0.4, 0.1)	0.6 (-2.9, 4.1)	0.4 (-1.9, 2.2)	1.0 (-2.2, 3.3)
Missouri	8 (-1, 16)	4 (-16, 23)	62 (-9, 119)	57 (15, 98)	-7 (-21, 5)	1.3 (-0.2, 2.6)	0.7 (-2.6, 3.8)	10.1 (-1.5, 19.4)	9.3 (2.4, 16.0)	-1.1 (-3.4, 0.8)
Mississippi	-	-	-	-	-	-	-	-	-	-
North Carolina	2 (-3, 7)	10 (-6, 22)	19 (-24, 50)	10 (-11, 24)	7 (-9, 19)	0.2 (-0.3, 0.7)	1 (-0.6, 2.1)	1.8 (-2.3, 4.8)	1 (-1.1, 2.3)	0.7 (-0.9, 1.8)
New Jersey	159 (109, 203)	33 (-30, 80)	113 (-60, 261)	48 (-56, 132)	76 (-32, 161)	17.9 (12.3, 22.8)	3.7 (-3.4, 9.0)	12.7 (-6.8, 29.4)	5.4 (-6.3, 14.9)	8.6 (-3.6, 18.1)
Nevada	21 (-19, 57)	10 (-39, 52)	62 (-76, 177)	-13 (-100, 57)	-38 (-122, 26)	6.9 (-6.3, 18.8)	3.3 (-12.9, 17.2)	20.5 (-25.1, 58.4)	-4.3 (-33, 18.8)	-12.5 (-40.3, 8.6)
New York	-8 (-20, 3)	-11 (-30, 4)	-15 (-52, 13)	4 (-24, 28)	10 (-23, 35)	-0.4 (-1.0, 0.2)	-0.6 (-1.5, 0.2)	-0.8 (-2.7, 0.7)	0.2 (-1.2, 1.4)	0.5 (-1.2, 1.8)
Ohio	5 (-42, 48)	37 (-23, 91)	15 (-154, 158)	35 (-68, 123)	78 (-24, 157)	0.4 (-3.6, 4.1)	3.2 (-2, 7.8)	1.3 (-13.2, 13.5)	3.0 (-5.8, 10.5)	6.7 (-2.1, 13.4)
Pennsylvania	-3 (-42, 33)	-50 (-97, -9)	-84 (-211, 26)	-27 (-99, 34)	-44 (-117, 18)	-0.2 (-3.3, 2.6)	-3.9 (-7.6, -0.7)	-6.6 (-16.5, 2.0)	-2.1 (-7.7, 2.7)	-3.4 (-9.1, 1.4)
South Carolina	7 (-7, 19)	14 (-6, 26)	36 (-13, 77)	8 (-3, 16)	5 (-5, 12)	1.4 (-1.4, 3.7)	2.7 (-1.2, 5.1)	7.1 (-2.6, 15.1)	1.6 (-0.6, 3.1)	1.0 (-1, 2.4)
Tennessee	-10 (-30, 5)	-14 (-43, 8)	-26 (-160, 75)	-13 (-95, 49)	-22 (-91, 27)	-1.5 (-4.4, 0.7)	-2.1 (-6.3, 1.2)	-3.8 (-23.6, 11.1)	-1.9 (-14.0, 7.2)	-3.2 (-13.4, 4)
Texas	-10 (-63, 34)	11 (-59, 63)	30 (-146, 174)	182 (74, 272)	129 (28, 209)	-0.3 (-2.2, 1.2)	0.4 (-2.1, 2.2)	1.0 (-5.1, 6.1)	6.4 (2.6, 9.5)	4.5 (1, 7.3)
Virginia	2 (-15, 16)	0 (-17, 12)	-7 (-59, 37)	-6 (-34, 15)	3 (-39, 37)	0.2 (-1.8, 1.9)	0.0 (-2, 1.4)	-0.8 (-6.9, 4.3)	-0.7 (-4, 1.8)	0.4 (-4.6, 4.3)
Washington	-	-	-	-	-	-	-	-	-	-

Note: The "-" in this table were generated because the death counts are relatively rare such that the regression model cannot be trained. The periods of the five COVID-19 pandemic waves were defined as Wave I (Week 10 March 1 2020 to Week 23 June 6 2020), Wave II (Week 24 June 7 2020 to Week 40 October 3 2020), Wave III (Week 41 October 4 2020 to Week 25 June 26 2021), Wave IV (Week 26 June 27 2021 to Week 47 November 27 2021), and Wave V (Week 48 November 28 2021 to Week 12 March 26 2022).

Supplementary references

1. **Excess Deaths Associated with COVID-19** [https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm]
2. **Estimating excess mortality due to the COVID-19 pandemic: a systematic analysis of COVID-19-related mortality, 2020-21**. *Lancet* 2022.