Measuring the COVID-19 Mortality Burden in the United States: A Microsimulation Study[*]

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ABSTRACT

Background: A full assessment of the COVID-19 pandemic's mortality burden requires measuring years of life lost (YLLs) and accounting for quality-of-life differences.

Objective: To measure YLLs and quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic, by age, sex, race/ethnicity, and comorbidity.

Design: State-transition microsimulation model.

Data Sources: Health and Retirement Study, Panel Study of Income Dynamics, excess death data from Centers for Disease Control and Prevention, and nursing home death counts from Centers for Medicare & Medicaid Services.

Target Population: US population ages 25 and over.

Time Horizon: Lifetime

Perspective: Individual

Intervention: COVID-19 pandemic through March 13, 2021

Outcome Measures: YLLs and QALYs lost per 10,000 population. Our estimates account for the age, sex, and race/ethnicity of decedents, along with: obesity, smoking behavior, lung disease, heart disease, diabetes, cancer, stroke, hypertension, dementia, and nursing home residence.

Results of Base-Case Analysis: The COVID-19 pandemic resulted in 6.62 million QALYs lost (9.08 million YLLs) through March 13, 2021, with 3.6 million (54%) lost by those ages 25-64. The toll on Black and Hispanic communities was the greatest, especially among men 65+ who lost 1,138 and 1,371 QALYs per 10,000. Absent the pandemic, 38% of decedents would have experienced at or above average life expectancies for their age-sex-race/ethnicity subgroup.

Results of Sensitivity Analysis: Accounting for uncertainty in COVID-19 mortality risk factors yielded similar results.

Limitation: Estimates may vary depending on assumptions about mortality and quality-of-life projections.

Conclusions and Relevance: Beyond simply excess deaths alone, the COVID-19 pandemic imposed greater life expectancy burden on those 25-64, including those with or at above-average life expectancies, and disproportionate burden on Black and Hispanic communities.

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INTRODUCTION

The COVID-19 pandemic has imposed considerable excess mortality burdens worldwide. In the United States, the Centers for Disease Control and Prevention (CDC) estimates that the pandemic caused 740,247 excess deaths between March 22, 2020 and March 13, 2021. Measuring this mortality burden is critical for identifying vulnerable populations and evaluating pandemic mitigation measures.

However, excess deaths do not readily translate into years of life lost (YLLs), another standard measure of mortality burden (1-3). Because COVID-19 deaths are concentrated among older adults, who have lower life expectancy than young and middle-aged adults, existing excess pandemic-related death estimates may understate YLLs among younger adults. Moreover, the few extant studies estimating YLLs from the COVID-19 pandemic adjust for age differences, but not for common COVID-19 mortality risk factors such as obesity or diabetes, or for quality-of-life (4-7). These prior YLL estimates may overstate mortality burden if frail individuals with shorter life expectancies are more likely to die from COVID-19.

We used an established, validated microsimulation model to estimate YLLs and quality-adjusted life-years (QALYs) lost due to excess pandemic mortality during the period from March 22, 2020 until March 13, 2021 for the US population ages 25+. At the end of our observation window, COVID-19 full vaccination rates ranged from 8.1% for ages 25-39 to 40.5% for ages 75+, and the two predominant COVID-19 variants were Alpha B.1.1.7 (59.5%) and Iota B.1.526 (15.6%) (as of April 10, 2021) (8, 9).

METHODS

We used microsimulation to project what life expectancy would have been for a nationally representative cohort of Americans ages 25+ if the COVID-19 pandemic had never happened. To compute YLLs and QALYs lost from the pandemic, we identified cohort members who most resembled pandemic-related decedents and summed the total and quality-adjusted life-years they were projected to have lived absent the pandemic. As illustrated in Figure 1, we pursued three different analytic approaches to identify cohort members most likely to have died from the COVID-19 pandemic. The first ("Average Risk") analysis assigned equal excess mortality risk to all individuals within an age, sex, and race/ethnicity subgroup, similar to subgroup life table analyses (4-7). The second ("Individualized Risk") analysis, our preferred approach, allowed mortality risk within an age-sex-race/ethnicity subgroup to vary with individual characteristics, health status, and COVID-19 risk factors. The third ("Frailty-Based Risk") analysis presumed the pandemic selectively targeted individuals with the highest projected mortality risk in each subgroup and serves as a lower bound for our YLLs estimates.

Microsimulation Modeling Steps

Projecting Life Expectancy

We used the Future Elderly Model (FEM) and the Future Adult Model (FAM) microsimulation models to project life expectancy under the assumption of zero excess deaths from the COVID-19 pandemic. These microsimulation models have been used in prior research to forecast pre-pandemic disease incidence, functional status, quality-of-life, smoking behavior, and mortality (10-20). FEM and FAM use data collected from two longitudinal surveys, the Health and Retirement Study (HRS) and the Panel Study of Income Dynamics (PSID), respectively, to forecast disease incidence, smoking behavior, quality-of-life, and mortality for adults ages 25+ (Figure 1; Supplement 2; Supplement 4) (21, 22). The HRS surveys a nationally representative sample of individuals over age 50, and the PSID surveys a nationally representative sample of all ages. Mortality is measured in these surveys using proxy reports. Quality-of-life is measured using the EuroQol five dimensions questionnaire (EQ-5D) and imputed in the HRS and PSID using variables in common with the Medical Expenditure Panel Survey (Section 3.1 of Supplement 1). Smoking behavior and disease incidence are measured using survey responses.

FAM simulations started with PSID respondents ages 25-44 in 2009, whose outcomes were simulated through 2021; in each year of the simulation, the sample was replenished with a new cohort of 25-year-olds. This produced a nationally representative sample ages 25-54 in 2020. FEM simulations began with HRS respondents ages 51+ in 2016, whose outcomes were simulated through 2021 (without replenishment), to produce a nationally representative sample ages 55+ in 2020. Together, the FEM and FAM output included 28,175 simulants, which when weighted provided a nationally representative sample of the 223 million US adults ages 25+ and alive as of July 1, 2020. Mortality, quality-of-life, smoking behavior, and disease incidence for these simulants were then projected into years beyond 2020 based on statistical models estimated from HRS and PSID data on disease incidence, disability, and mortality (Supplements 3 and 5). Projecting lifetime outcomes under the assumption of zero excess pandemic deaths generated non-pandemic individual, subpopulation and population life expectancy projections employed in this study.

Mortality in the FEM and FAM microsimulations depended on both fixed and time-varying components (Supplement 3 and 5). The fixed components include sex, race/ethnicity, and education. The time-varying components, updated as the simulation progresses, include age, chronic health conditions, functional limitations, and smoking behavior. To account for expected future declines in mortality rates, we applied an adjustment factor from Social Security Administration actuarial forecasts (Section 6 Supplement 2; Section 3.3 Supplement 4) (23).

Estimating YLLs and QALYs Lost from the COVID-19 Pandemic

To estimate YLLs and QALYs lost during the pandemic by 5-year age group, sex, and race/ethnicity (White/Black/Hispanic), we started with weekly data collected from the CDC (Section 1 of Supplement 1). The CDC estimated total excess deaths by comparing deaths in 2020 and 2021 to deaths in prior years and estimated COVID-19-related deaths based on cause of death listed on death certificates. We aggregated these data to estimate total excess deaths and COVID-19-related deaths by 5-year age group, sex, and race/ethnicity over the period March 22, 2020 through March 13, 2021. We defined non-COVID-19 excess deaths as the difference between total excess deaths and COVID-19-related deaths.

Next, we identified the simulants in our microsimulation model that "experienced" these excess deaths using three different approaches, described below. In each approach, we computed YLLs and QALYs lost for each simulant experiencing excess death by computing their projected life expectancy absent the pandemic. Summing across all simulants yields our estimate of total YLLs and QALYs lost from excess pandemic deaths. QALYs lost were calculated similarly, by incorporating the quality-of-life index, which ranges from 0 to 1, and estimating projected QALYs for each dying simulant. Both YLLs and QALYs lost are undiscounted, which facilitates their comparison and corresponds to traditional YLL calculations (24). Since quality-of-life adjustments can be imperfect (25), we report both YLLs and QALYs lost in our main tables.

The first approach to identifying simulants experiencing excess deaths is labeled the "Average Risk" analysis. It presumed that excess mortality risk is uniform within each age-sex-race/ethnicity subgroup. The "Individualized Risk" analysis, our second and preferred approach, presumed that COVID-19 mortality risk within each subgroup varies with underlying COVID-19 risk factors identified in UK data on COVID-19 deaths. Non-COVID-19 excess mortality risk depended on pre-pandemic all-cause mortality risk, as estimated by our FEM and FAM microsimulations. The third approach ("Frailty-Based Risk" analysis) presumed that individuals with the highest pre-pandemic all-cause mortality risk in each subgroup are also at the highest risk of dying during the pandemic. All three approaches allocated identical numbers of excess pandemic deaths overall and by age-sex-race/ethnicity subgroup, matching CDC estimates.

To account for individual COVID-19 mortality risk factors in the "Individualized Risk" analysis, we used mortality odds ratios (OR) for 11 different comorbidity risk factors from a recent associational study of over 17 million adults in England (Section 2 of Supplement 1) (26, 27). These estimates were derived from longitudinal electronic medical records (EMR) from 40% of the population of England, spread geographically across the whole country. Our analysis includes the following risk factors: body mass index (BMI) 30-35, BMI 35-40, BMI 40+, former smoker, hypertension, lung disease, heart disease, diabetes mellitus, cancer, stroke, and dementia (Table 1 of Supplement 1). We excluded risk factors that lacked statistically significant ($P < 0.05$) OR estimates, such as current smoker. The use of EMR data, rather than insurance claims, permits more reliable analysis of smoking status and of BMI category (28).

In our simulated cohort, the most influential risk factor, dementia ($OR = 3.62$), presents in only 2.5 percent of the population and skews towards the oldest age groups (Figure 1 of Supplement 1). By contrast, moderate risk factors such as former smoker ($OR = 1.26$), diabetes mellitus ($OR = 1.41$), and obesity ($OR = 1.07$, BMI 30-35; $OR = 1.44$, BMI 35-40; $OR = 2.11$, BMI 40+) are significantly more prevalent overall and among younger adults. Most of the 2020 US population (72.7%) and adult population ages 25-64 (67.9%) had one or more risk factors positively associated with COVID-19 mortality (Figure 1 of Supplement 1).

The counts of COVID-19-related deaths among residents in certified Medicare skilled nursing facilities and Medicaid nursing facilities up through March 13, 2021 were collected from the

Centers for Medicare & Medicaid Services (CMS) (29). These data were used to calculate a twelfth COVID-19 mortality odds ratio, which was applied to nursing home residents in the microsimulation (Section 2 of Supplement 1).

Microsimulation Model Validation

The mortality and quality-of-life projections produced by the FEM and FAM microsimulation models have been validated in prior research (19, 30). Mortality forecasts line up closely with published death counts and perform at least as well as alternative forecasts used by the Social Security Administration (19). In addition, we performed a data-splitting exercise to validate population, smoking behavior, cancer, diabetes, heart disease, hypertension, lung disease, and stroke forecasts using pre-COVID-19 era data (Section 7 of Supplement 2; Section 10 of Supplement 4).

We provide additional validation specific to the COVID-19 context by comparing YLL estimates from the model-based Average Risk analysis—which does not adjust for comorbidity risk factors—to analogous YLL estimates calculated using a 2018 CDC period life table that reports life expectancy by age, sex, and race/ethnicity (31).

Sensitivity Analyses

We assessed uncertainty around microsimulation parameter estimates via a non-parametric bootstrap that resampled the data underlying the FEM and FAM models (32). We assessed uncertainty in the estimated COVID-19 mortality odds ratios by drawing from a multivariate normal distribution (26, 27). The distribution was based on the variance-covariance matrix resulting from estimation of the odds ratios (Section 3.2 of Supplement 1). We express the propagated uncertainty in our results with 95% uncertainty intervals (UI).

Role of the Funding Source

The funding source had no role in the design of the study; the collection, analysis, and interpretation of the data; or the decision to approve publication of the finished manuscript.

RESULTS

Table 1 presents the CDC's excess death data for adults ages 25-64 and 65+, by sex and race/ethnicity. A total of 740,247 excess deaths occurred between March 22, 2020 and March 13, 2021, of which 545,324 were classified as COVID-19 and 194,923 as non-COVID-19. Estimates of YLLs and QALYs lost, computed for each analytic approach, appear under "Longitudinal outcomes". To assess uncertainty in the microsimulation estimates, we report 95% UIs in Supplement 1 Tables 2-3.

Mortality Burden Adjusted for Age, Sex, and Race/Ethnicity Alone

Table 1 presents YLLs based on life expectancies obtained from a 2018 CDC period life table that accounts only for age, sex, and race/ethnicity (31). YLLs in each subgroup equal the number of excess deaths in that subgroup multiplied by the CDC life expectancy estimate. They are analogous to previously published estimates of YLLs due to COVID-19 (4-7). This life table approach estimates 10.68 million total YLLs from the COVID-19 pandemic.

Table 1 also reports estimates from the Average Risk analysis, which assumes that the COVID-19 pandemic caused deaths at random within age-sex-race/ethnicity subgroups. This approach estimated 10.56 (95% UI, 10.43 to 10.69) million total YLLs, within 1.1% of the life table estimate of 10.68 million YLLs. This concordance provides additional validation of the microsimulation's mortality forecasts over the relevant age-sex-race/ethnicity subgroups. The 10.56 million YLLs estimated by this approach correspond to 7.96 million QALYs lost, after accounting for decedents' projected quality-of-life.

Mortality Burden Adjusted for Underlying Risk Factors

Table 1 reports results from the Individualized Risk analysis, which allowed COVID-19 mortality within each age-sex-race/ethnicity subgroup to vary with individual risk factors. This approach, which provides our preferred estimates, implies that the COVID-19 pandemic resulted in 6.62 million (95% UI, 6.51 to 6.73) QALYs lost and 9.08 million YLLs, 14% lower than the 10.56 million YLLs reported for the Average Risk analysis, indicating that individuals with COVID-19 risk factors have below-average life expectancy for their subgroup. Adults ages 25-64 lost 213 (95% UI, 208 to 218) QALYS per 10,000, compared to 552 (95% UI, 544 to 560)

QALYs per 10,000 for adults ages 65+. While adults 65+ faced excess mortality risk per capita 9.9 times higher than their under-65 counterparts, their individualized QALYs lost per capita was only 2.6 times as high. Adults ages 85+ faced 70 times more excess mortality risk than 25-34 year-olds, but only 3.9 times more individualized loss of QALYs per capita (Table 2). This discrepancy remains when limiting the analysis to COVID-19-related excess deaths (Tables 6-8 of Supplement 1).

Finally, Table 1 reports YLLs if COVID-19 systematically targeted those with the shortest life expectancies in their subgroups, thereby minimizing YLLs and QALYs lost. This Frailty-Based Risk computation provides a polar contrast to the Average Risk computation, which assumed excess deaths occurred at random within each subgroup and produced per capita YLLs and QALYs lost equal to mean life expectancies for each subgroup. Because YLLs estimated in our preferred Individualized Risk computation lie much closer to the Average Risk estimates than the Frailty-Based Risk estimates, these comparisons suggest that the pandemic tends to target individuals with close to average life expectancy for their subgroup.

Figure 2 explores how decedents' life expectancy in the Individualized Risk analysis compares to mean life expectancy for their age-sex-race/ethnicity subgroups. The figure plots the probability distribution of the difference between projected life expectancy (assuming zero excess pandemic mortality) and the CDC-estimated average life expectancy for the relevant age-sex-race/ethnicity subgroup. Positive differences occur for healthier individuals predicted to die from the pandemic despite longer than average life expectancy for their subgroup. Most decedents under our analysis had below-average life expectancy for their subgroup (median difference $= -1.63$ years), but 37.6% (95% UI, 36.6 to 38.6) had projected life expectancy equal to or exceeding the average life expectancy for their subgroup. In separate age, sex, and race/ethnicity subgroup analyses, the fraction of decedents with at or above-average life expectancy ranged from 27.7% (95% UI, 25.9 to 29.5) (non-White females ages 65+) to 46.3% (95% UI, 44.4 to 48.2) (White males ages 25-64) (Figure 5 of Supplement 1).

Disparities in Quality-Adjusted Life-Years Lost

Figure 3 reports QALYs lost per 10,000 for groups with different comorbidities. These estimates do not control for other risk factors and represent the unconditional average risk faced by individuals with the relevant comorbidity. Nursing home residence and dementia are the two biggest risk factors, with mortality burdens ranging from 897 to 1,371 QALYs lost per 10,000. For adults 65+, the next two largest risk factors are history of stroke with 752 (95% UI, 720 to 783) QALYs lost per 10,000 and BMI over 40 with 733 (95% UI, 674 to 792) QALYs lost per 10,000. For adults 25 to 64, the next two largest risk factors are history of stroke with 378 (95% UI, 341 to 415) QALYs lost per 10,000 and diabetes with 361 (95% UI, 346 to 376 QALYs lost per 10,000 (Average Risk and Frailty-Based Risk analyses in Figures 6-7 of Supplement 1).

Table 1 reports QALYs lost per 10,000 people for adults ages 65+ and adults ages 25-64, by sex and race/ethnicity. Compared to similarly aged White populations, the Black and Hispanic populations ages 65+ lost about twice as many QALYs per person, and those ages 25-64 lost about three times as many as their White counterparts (Figure 8 of Supplement 1). Hispanic males ages 65+ lost 1,371 (95% UI, 1,295 to 1,447) QALYs per 10,000, and Black males ages 65+ lost 1,138 (95% UI, 1,088 to 1,189) QALYs per 10,000. Individuals in nursing homes or with dementia suffered the largest absolute disparities in QALYs lost per person for the Hispanic and Black populations, compared to the White population (Figure 4). We report corresponding estimates for the Average Risk and Frailty-Based Risk analyses in our Supplementary Materials (Figures 9-10 of Supplement 1).

DISCUSSION

Our model estimated that the US COVID-19 pandemic resulted in 9.08 million YLLs through March 13, 2021. By comparison, Americans lost an estimated 15.4 million YLLs from cancer and an estimated 14.7 million from cardiovascular diseases in 2019 (33). In approximately one year, the COVID-19 pandemic resulted in one-half the premature mortality caused by all cancers combined or all cardiovascular diseases combined. Earlier research on the COVID-19 mortality burden has emphasized the much higher death rate among older populations (34, 35). While excess deaths provide an important measure of mortality burden, calculating YLLs and QALYs lost reveals the pandemic has also imposed a considerable mortality burden on younger populations. Over our observation window, the pandemic resulted in 4.7 million YLLs for adults ages 25-64, who by way of comparison lost 6.8 million YLLs, 5.3 million YLLs, 1.9 million YLLs, and 0.61 million YLLs from all cancers, cardiovascular diseases, self-harm/interpersonal violence, and unintentional injuries in 2019, respectively (33). While the excess mortality rate for the population ages 65+ exceeds that of adults ages 25-64 by nearly a factor of 10, this factor falls below 3 when examining YLLs and QALYs lost.

The number of excess deaths among the 25-64 understates their mortality burden relative to the 65+ because many of those deaths occurred among individuals with otherwise near-normal lifespans. Although COVID-19 disproportionately targets individuals with comorbidities, adults ages 25-64 with these comorbidities still have high life expectancy relative to 65+ adults. The case of obesity, which affects 39.1% of the population ages 25-64, is instructive (Figure 1 in Supplement 1). Overall, 40-year-olds expect to live 39 more years on average, and 65-year-olds expect 18 more years. Prior studies suggest that obesity reduces life expectancy at age 40 by 6-7 years for non-smokers (36). Thus, the unexpected death of a 40-year-old obese non-smoker takes away 32-33 life-years, about 14-15 more than an unexpected death for a typical 65-year-old. COVID-19 increases the otherwise moderate hazard of body weight-related risk factors on lifespan.

Blacks and Hispanics bear a disproportionate share of the mortality burden, despite the former having lower age-adjusted life expectancy than Whites. In terms of QALYs lost per capita, Hispanic men ages 65+ lost 2.5 times more QALYs per capita than similarly aged White men, and Hispanic men ages 25-64 lost 3 times more than similarly aged White men. For both Black and Hispanic men, the number of QALYs lost per capita exceeded those associated with all comorbidities except dementia and living in a nursing home.

This study has several limitations. Our results exclude deaths that occurred after March 13, 2021 and thus underestimate the total COVID-19 pandemic mortality burden. We do not account for the effects of possible morbidity caused by COVID-19 in survivors, or other morbidity effects that may have resulted from the COVID-19 pandemic response. Our analysis relies on recent estimates of the mortality odds ratios for COVID-19 risk factors from a study of the UK population. While validation analyses suggest these estimates pertain well to the US population, knowledge about their accuracy and generalizability continues to develop (37). Although our sensitivity analysis suggests the estimated uncertainty around these parameters would not change our qualitative conclusions, major changes to these parameters could significantly alter our estimates. Our microsimulation's projections of mortality and other health outcomes are based on data from the HRS and PSID. While our data-splitting exercises show that the model's projections perform well prior to 2020, it is impossible to know the predictive accuracy of the microsimulation projections for future years. Our estimates are specific to the US and may not generalize to other countries. However, our methods may be useful to researchers tackling this problem for other countries, provided that data on excess deaths by demographic group and on health characteristics are available. Similarly, our estimates depend on the set of variants circulating over our analysis window and may not generalize to more recent variants of concern, e.g., Delta B.1.617.2. Finally, while our analysis documents a disproportionately higher mortality burden for Black and Hispanic men, it cannot determine what underlying societal factors cause these differences.

Measuring the mortality burden of the COVID-19 pandemic in terms of YLLs and QALYs lost provides important insights. The adult population ages 25-64 bears a larger share of the total COVID-19 excess mortality burden than the population ages 65+, despite the latter incurring a significantly larger total number of deaths. Excess mortality rates among adults ages 25-64 were 9.9 times smaller than for adults 65+ when measured using deaths per capita, but only 2.6 times smaller when measured using QALYs lost per capita. Although individuals with comorbidities face higher mortality risks, our analysis nevertheless estimates that more than one-third of decedents would have enjoyed normal or better life expectancy than their peers of the same age, sex, and race/ethnicity. Efforts to mitigate pandemic harms should include both the young and old, and particularly target Black and Hispanic populations.

ARTICLE INFORMATION

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Reproducible Research Statement

Study protocol: Details are available in Supplements 2 and 4.

Statistical code: Code is available by request.

Data set: Data sets are available online, as described in Supplement 1.

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EXHIBIT LEGEND

Table 1. Years of life lost and quality-adjusted life-years lost due to the US COVID-19 pandemic, by age group, sex, and race/ethnicity

Table 2. Years of life lost and quality-adjusted life-years lost due to the US COVID-19 pandemic, by 10-year age group

Figure 1. Structure of the microsimulation model

Figure 2. Predicted years of life lost due to the US COVID-19 pandemic, relative to average life expectancy in the decedent's age-sex-race/ethnicity subgroup

Figure 3. Number of quality-adjusted life-years lost per 10,000, by age group and comorbidity

Figure 4. Number of quality-adjusted life-years lost per 10,000, by race/ethnicity and comorbidity

Table 1. Years of life lost and quality-adjusted life-years lost due to the US COVID-19 pandemic, by age group, sex, and race/ethnicity

	Totals			Ages 25-64						Ages 65+					
				Female			Male			Female			Male		
Outcome	Ages 25-64	Ages 65+	Ages 25+	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White
Population, thousands	167,910	55,182	223,092	11,219	13,991	58,603	10,283	15,786	58,029	2,946	2,601	25,042	2,030	2,032	20,531
CDC excess deaths															
Deaths	173,995	566,252	740,247	15,224	14,736	25,865	29,308	38,110	50,752	45,068	38,867	180,944	44,844	48,052	208,477
COVID-19	105,726	439,598	545,324	9,600	10,838	16,992	13,456	25,764	29,076	28,777	27,478	152,850	28,833	36,999	164,661
Non-COVID-19	68,269	126,654	194,923	5,624	3,898	8,873	15,852	12,346	21,676	16,291	11,389	28,094	16,011	11,053	43,816
Deaths per 10k	10.4	102.6	33.2	13.6	10.5	4.4	28.5	24.1	8.7	153.0	149.4	72.3	220.9	236.5	101.5
COVID-19	6.3	79.7	24.4	8.6	7.7	2.9	13.1	16.3	5.0	97.7	105.6	61.0	142.1	182.1	80.2
Non-COVID-19	4.1	23.0	8.7	5.0	2.8	1.5	15.4	7.8	3.7	55.3	43.8	11.2	78.9	54.4	21.3
Longitudinal outcomes															
YLLs, thousands															
Period life table	5,163	5,514	10,678	455	492	790	793	1,188	1,446	485	452	1,634	456	557	1,930
Average Risk	5,133	5,429	10,562	437	465	800	797	1,157	1,478	435	390	1,739	415	484	1,967
Individualized Risk	4,668	4,412	9,080	389	431	710	720	1,079	1,339	342	318	1,384	338	406	1,625
Frailty-Based Risk	2,472	1,145	3,616	195	262	252	427	721	615	101	100	324	94	145	380
QALYs lost, thousands															
Average Risk	4,025	3,934	7,959	328	357	631	620	916	1,174	300	268	1,266	298	348	1,454
Individualized Risk	3,574	3,046	6,620	282	324	542	546	841	1,039	221	207	957	231	279	1,151
Frailty-Based Risk	1,688	590	2,278	120	174	155	291	530	417	49	51	161	50	82	198
YLLs per 10k															
Period life table	308	999	479	405	352	135	771	753	249	1,645	1,737	652	2,247	2,744	940
Average Risk	306	984	473	389	332	137	775	733	255	1,476	1,499	694	2,043	2,381	958
Individualized Risk	278	800	407	347	308	121	700	684	231	1,159	1,223	553	1,663	1,998	792
Frailty-Based Risk	147	207	162	173	187	43	415	457	106	342	386	129	465	714	185
QALYs lost per 10k															
Average Risk	240	713	357	292	255	108	603	580	202	1,019	1,030	506	1,467	1,710	708
Individualized Risk	213	552	297	251	231	93	531	533	179	751	794	382	1,138	1,371	561
Frailty-Based Risk	101	107	102	107	124	27	283	336	72	165	195	64	246	403	96

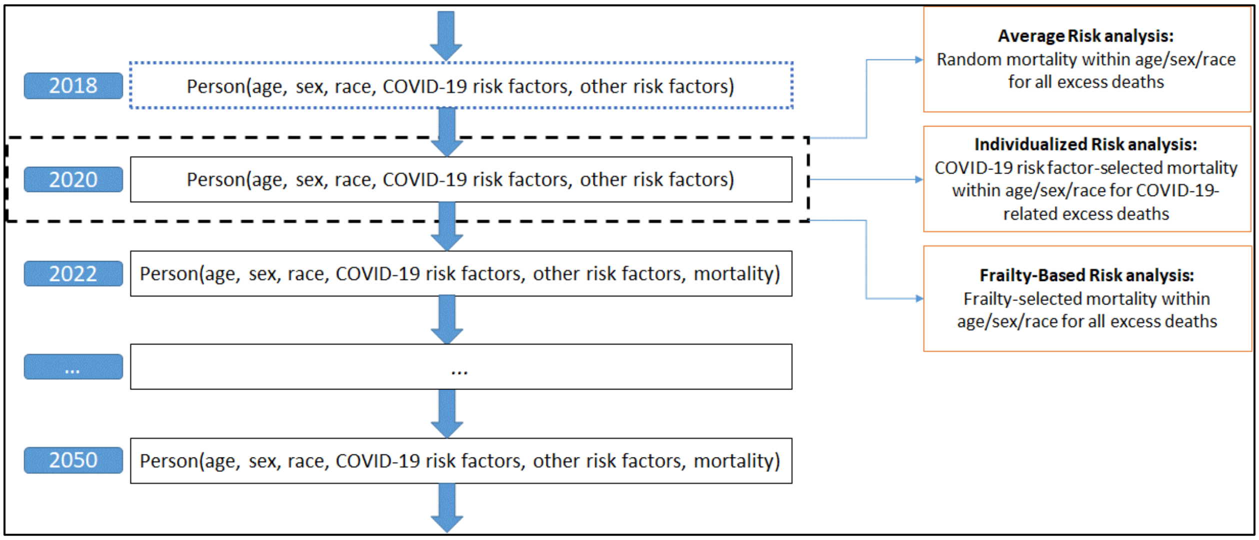
This table reports the years of life lost (YLLs) and quality-adjusted life-years (QALYs) lost over the time period March 22, 2020 through March 13, 2021 as a result of the US COVID-19 pandemic. We report 95% uncertainty intervals in Tables 2-3 of Supplement 1. Population data were obtained from the Health and Retirement Study and the Panel Study of Income Dynamics. The longitudinal outcomes estimates presented in this table are based on the number of excess deaths reported by the Centers for Disease Control and Prevention (CDC). Period life table estimates of YLLs are equal to the number of excess deaths multiplied by life expectancy obtained from a 2018 CDC period life table that varies by age, sex, and race/ethnicity. The YLLs and QALYs lost estimates for the Average Risk, Individualized Risk, and Frailty-Based Risk analyses are derived from the Future Elderly Model and the Future Adult Model, which use microsimulation to produce individual-level forecasts of mortality and quality-of-life for the US population ages 25+ (Figure 1). The Average Risk analysis assumes that each excess death occurred randomly within the 5-year age, sex, and race/ethnicity category that corresponds to that death. The Individualized Risk analysis assigns all COVID-19-related excess deaths within the age-sex-race/ethnicity subgroup in proportion to estimates of COVID-19 comorbidity mortality odds ratios, and assigns non-COVID-19-related deaths in proportion to the 2020 (pre-COVID-19) annual mortality hazard projected by the microsimulation. The Frailty-Based Risk analysis assigns all excess deaths within the subgroup to the individuals with the highest annual mortality hazard projected by the microsimulation.

Table 2. Years of life lost and quality-adjusted life-years lost due to the US COVID-19 pandemic, by 10-year age group

	Age							
Outcome	**25+**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85+**
Population, thousands	223,092	44,195	40,899	40,589	42,228	32,432	16,228	6,522
CDC excess deaths								
Deaths	740,247	18,136	29,977	34,455	91,427	180,021	197,977	188,254
COVID-19	545,324	3,669	9,362	26,150	66,545	120,318	151,569	167,711
Non-COVID-19	194,923	14,467	20,615	8,305	24,882	59,703	46,408	20,543
Deaths per 10k	33.2	4.1	7.3	8.5	21.7	55.5	122.0	288.6
COVID-19	24.4	.8	2.3	6.4	15.8	37.1	93.4	257.1
Non-COVID-19	8.7	3.3	5.0	2.0	5.9	18.4	28.6	31.5
Longitudinal outcomes								
YLLs, thousands								
Period life table	10,678	870	1,190	1,062	2,042	2,747	1,863	905
Average Risk	10,562	886	1,194	1,069	1,984	2,679	1,831	918
Individualized Risk	9,080	846	1,091	1,004	1,727	2,257	1,518	637
Frailty-Based Risk	3,616	693	731	589	459	615	388	141
QALYs lost, thousands								
Average Risk	7,959	719	957	847	1,501	1,998	1,320	617
Individualized Risk	6,620	676	851	782	1,266	1,620	1,041	385
Frailty-Based Risk	2,278	524	513	401	250	328	196	67
YLLs per 10k								
Period life table	479	197	291	262	484	847	1,148	1,387
Average Risk	473	200	292	263	470	826	1,129	1,408
Individualized Risk	407	191	267	247	409	696	935	977
Frailty-Based Risk	162	157	179	145	109	190	239	216
QALYs lost per 10k								
Average Risk	357	163	234	209	355	616	813	946
Individualized Risk	297	153	208	193	300	499	642	591
Frailty-Based Risk	102	119	125	99	59	101	121	102

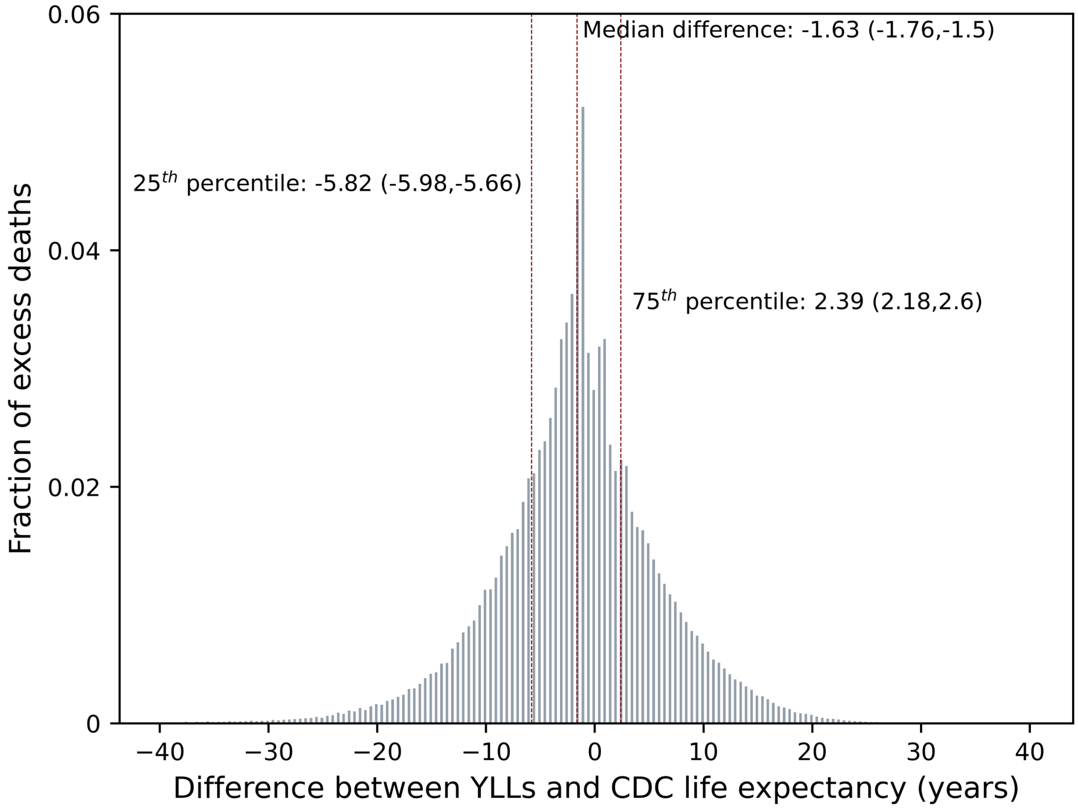
This table reports the years of life lost (YLLs) and quality-adjusted life-years (QALYs) lost over the time period March 22, 2020 through March 13, 2021 as a result of the US COVID-19 pandemic. We report 95% uncertainty intervals in Tables 4-5 of Supplement 1. Population data were obtained from the Health and Retirement Study and the Panel Study of Income Dynamics. The longitudinal outcomes estimates presented in this table are based on the number of excess deaths reported by the Centers for Disease Control and Prevention (CDC), which are reproduced in the second row. Period life table estimates of YLLs are equal to the number of excess deaths multiplied by life expectancy obtained from a 2018 CDC period life table that varies by age, sex, and race/ethnicity. The YLLs and QALYs lost estimates for the Average Risk, Individualized Risk, and Frailty-Based Risk analyses are derived from the Future Elderly Model and the Future Adult Model, which use microsimulation to produce individual-level forecasts of mortality and quality-of-life for the US population ages 25+ (Figure 1 of the main text). The Average Risk analysis assumes that each excess death occurred randomly within the 5-year age, sex, and race/ethnicity category that corresponds to that death. The Individualized Risk analysis assigns all COVID-19-related excess deaths within the age-sex-race/ethnicity subgroup in proportion to estimates of COVID-19 comorbidity mortality odds ratios, and assigns non-COVID-19-related deaths in proportion to the 2020 (pre-COVID-19) annual mortality hazard projected by the microsimulation. The Frailty-Based Risk analysis assigns all excess deaths within the subgroup to the individuals with the highest annual mortality hazard projected by the microsimulation.

Figure 1. Structure of the microsimulation model



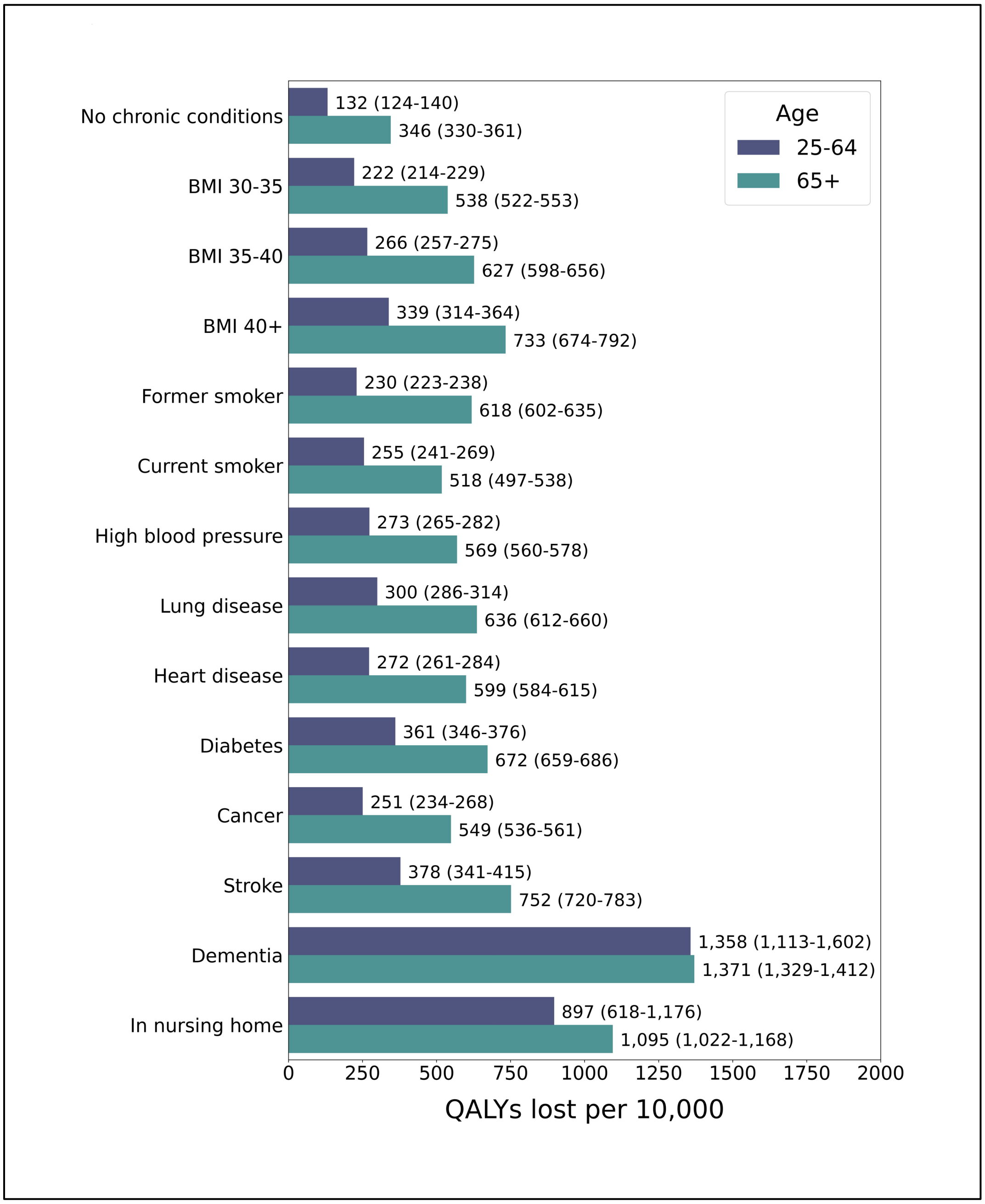
This figure shows how this study uses a microsimulation model of individuals to estimate years of life lost (YLLs) for COVID-19 excess deaths for the US population. The microsimulation is based on the Future Adult Model (FAM) and the Future Elderly Model (FEM), which are used to forecast health outcomes for adults ages 25-54 and adults ages 55+ as of 2020, respectively. First, these models forecast mortality, quality-of-life, smoking behavior, and disease incidence at the individual level for a nationally representative population for the 2009-2117 (FAM) and 2016-2086 (FEM) time periods, under the assumption of zero excess deaths from the COVID-19 pandemic. Second, a fixed number of individuals in the model die during the 2020-2021 time period as a result of the COVID-19 pandemic. For each 5-year age, sex, and race/ethnicity subgroup, this fixed number of decedents is set equal to the number of excess deaths reported by the CDC. The Average Risk analysis assumes that these deaths occurred randomly within the age-sex-race/ethnicity subgroup. The Individualized Risk analysis assumes that the COVID-19-related excess deaths occurred within the age-sex-race/ethnicity subgroup in proportion to COVID-19 mortality odds ratios for 12 different comorbidity risk factors, and that non-COVID-19-related excess deaths occurred based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. The Frailty-Based Risk analysis assumes that, within each subgroup, all excess deaths occurred among the individuals with the highest projected mortality risk, as estimated by the FEM and FAM.

Figure 2. Predicted years of life lost due to the US COVID-19 pandemic, relative to average life expectancy in the decedent's age-sex-race/ethnicity subgroup



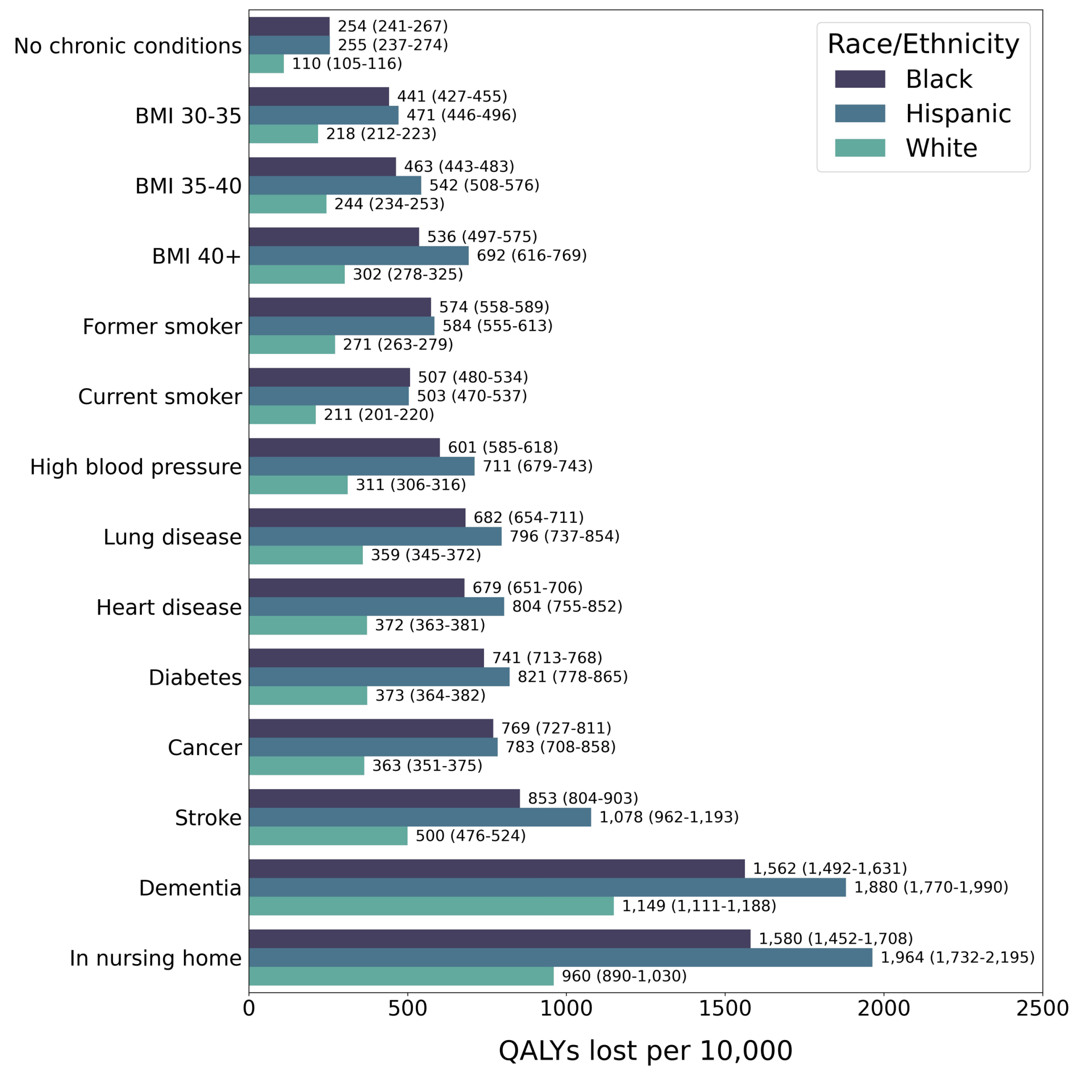
This figure reports the distribution of the difference between the life expectancy of individuals dying in the Individualized Risk analysis (in the absence of any excess pandemic mortality) and the simulated decedent's age-, sex-, and race/ethnicity-adjusted life expectancy as reported in the 2018 period life table from the Centers for Disease Control and Prevention (CDC). An x-axis value of 0 indicates that the decedent's predicted YLLs, which are estimated by microsimulation under the Individualized Risk analysis, equals the average CDC life expectancy in her age-sex-race/ethnicity subgroup. Values greater than zero correspond to decedents with YLLs above the average CDC life expectancy for their subgroup, while values less than zero correspond to individuals with YLLs below the average CDC life expectancy. The dashed, red vertical lines report the median, 25th percentile, and 75th percentile of the distribution. 95% uncertainty intervals for those three estimates are given in parentheses in the figure labels. The fraction of decedents with YLLs equal to or exceeding the CDC life expectancy for their subgroup, i.e., with an x-axis value equal to or exceeding 0, is 0.376 (95% uncertainty interval, 0.366 to 0.386). Across all decedents, the mean difference between their estimated YLLs and their subgroup's CDC life expectancy is -1.81 (95% uncertainty interval, -2.00 to -1.62) years (see text for median).

Figure 3. Number of quality-adjusted life-years lost per 10,000, by age group and comorbidity



This figure reports the number of quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic among US adults ages 25-64 and ages 65+, by comorbidity, over the time period March 22, 2020 through March 13, 2021. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Individualized Risk analysis, which assumes all COVID-19 excess deaths reported by the CDC are distributed within 5-year age, sex, and race/ethnicity group in proportion to estimated COVID-19 mortality odds ratios for different comorbidities. Estimates for dementia and living in a nursing home pertain only to ages 55+. Non-COVID-19-related excess deaths are assumed to occur based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. BMI: Body Mass Index.

Figure 4. Number of quality-adjusted life-years lost per 10,000, by race/ethnicity and comorbidity



This figure reports the number of quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic among US adults ages 25+, by comorbidity and race/ethnicity, over the time period March 22, 2020 through March 13, 2021. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Individualized Risk analysis, which assumes all COVID-19 excess deaths reported by the CDC are distributed within 5-year age, sex, and race/ethnicity group in proportion to estimated COVID-19 mortality odds ratios for different comorbidities. Estimates for dementia and living in a nursing home pertain only to ages 55+. Non-COVID-19-related excess deaths are assumed to occur based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. BMI: Body Mass Index.

Measuring the COVID-19 Mortality Burden in the United States: A Microsimulation Study

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August 2021

This appendix provides additional information and analyses not reported in the main text.

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List of Supplementary Tables and Figures

Section 1. Excess Mortality Data

Our data on excess deaths come from two separate datasets provided by the Centers for Disease Control and Prevention (CDC). We use the first dataset to determine our sample period, which we define as the largest set of weeks with uninterrupted excess mortality. The second dataset provides weekly counts of total excess deaths and COVID-19-related deaths.

We obtained the first dataset from the CDC's estimates of "excess deaths associated with COVID-19" for the US and Puerto Rico on June 26, 2021. This first dataset is available at:

https://data.cdc.gov/NCHS/Excess-Deaths-Associated-with-COVID-19/xkkf-xrst/

We relied on the CDC's implementation of the Farrington Surveillance algorithm to compare deaths in 2020 and 2021 to deaths from prior years, as described here:

https://www.cdc.gov/nchs/nvss/vsrr/covid19/excess_deaths.htm

According to the CDC's algorithm, statistically significant excess mortality commenced in week 13 of 2020 (the week beginning on March 22, 2020) and persisted until week 10 of 2021 (the week ending on March 13, 2021). Week 11 was the first week since the onset of the COVID-19 pandemic in which there was not a statistically significant excess death toll (based on the data we downloaded on June 26, 2021). We therefore defined our sample period as March 22, 2020 through March 13, 2021.

Next, we extracted the weekly number of COVID-19 deaths (defined as deaths where ICD-10 code U07.1 was listed as a contributing cause of death) and the weekly number of deaths above the average (as compared to 2015-2019) for each age-sex-race/ethnicity category for the time period March 22, 2020 through March 13, 2021. This second dataset is available at:

https://data.cdc.gov/NCHS/AH-Excess-Deaths-by-Sex-Age-and-Race/m74n-4hbs

To align the CDC's race/ethnicity categories with the other data sources described below, we recoded them as follows. The CDC categories non-Hispanic White, non-Hispanic Asian, non-Hispanic American Indian or Alaska Native, non-Hispanic Native Hawaiian or Other Pacific Islander, or Other were coded as White; the category non-Hispanic Black was coded as Black; and the category Hispanic was coded as Hispanic.

The number of deaths estimated by the CDC for the most recent weeks of the dataset was adjusted to account for reporting lags. Because this adjustment is imperfect, it can result in negative values for non-COVID-19 weekly excess deaths. We therefore set negative values for non-COVID-19 weekly excess deaths reported by the CDC during the time period April 14, 2021 through March 13, 2021 to zero.

Finally, we calculated the total number of excess deaths and the total number of COVID-19 deaths by summing across all weeks, for each age-sex-race/ethnicity subgroup. The number of non-COVID-19 excess deaths for each age-sex-race/ethnicity subgroup was determined by subtracting total COVID-19 deaths from the total number of excess deaths. In a small number of age-sex-race/ethnicity subgroups, the total number of non-COVID-19 excess deaths was slightly negative; per CDC methodology, these negative values were set equal to zero.

To calculate excess death rates per 10,000 people in each age-sex-race/ethnicity subgroup, we divided the number of excess deaths by the subgroup's population, as estimated by the Health and Retirement Study (HRS) for those over age 55 and the Panel Study of Income Dynamics (PSID) for younger age groups. The HRS and the PSID serve as the host databases for the microsimulation model of years of life lost, as described in Section 3 below.

Section 2. COVID-19 Mortality Odds Ratios

We obtained COVID-19 mortality odds ratios (OR) for different risk factors from the most recent update of an associational study of over 17 million adults using the openSAFELY platform in England (1, 2). These estimates apply to the entire population that was registered with a general practice using the openSAFELY platform. Thus, these estimates are not limited to hospitalized or symptomatic people. COVID-19 deaths are identified as those where the underlying cause is coded as U07.1 ("COVID-19, virus identified") or U07.2 ("COVID-19, virus not identified") between February 1, 2020 and November 9, 2020. By contrast, the National Center for Health Statistics did not implement U07.2 for US mortality statistics; instead, all confirmed and suspected COVID-19 deaths are coded as U07.1. The openSAFELY analytic platform includes general practitioner practices that use electronic health record software SystmOne (1).

Our study employs the reported COVID-19 mortality ORs from Table A2 (fully adjusted COVID-19 deaths 2020) of Bhaskaran et al. (2021) to calculate a COVID-19 risk score that estimates each individual's likelihood of dying from COVID-19, based on comorbidities associated with increased risk of COVID-19 mortality (2). We only incorporated risk factors that had ORs reported as statistically significant ($P < 0.05$). In cases where there were multiple OR estimates that informed a single risk factor modeled by the microsimulation, such as cancer or diabetes, we used all the OR estimates provided that at least one was statistically significant. The estimates that we use in our study are listed in the third column of Supplement Table 1.

An individual's risk score was defined as 1 multiplied by the product of the odds ratios corresponding to their comorbidities. An individual with no comorbidities thus has a risk score of 1, while an individual with a body mass index (BMI) of 35 and high blood pressure has a risk score of 1.30 ($= 1.44 \times 0.90$) (Supplement Table 1). We used the exact OR estimates for the following comorbidities, which were defined analogously in both the openSAFELY study and our microsimulation: former smoker, high blood pressure, lung disease, heart disease, stroke, dementia, and BMI categories 30-35, 35-40 and 40+. The OR estimates for diabetes and cancer were reweighted to match the definitions in the microsimulation. The microsimulation includes a binary measure of cancer, but the openSAFELY study reports odds ratios for six different cancer groups: two types of cancer (haematological & non-haematological) crossed with three possible diagnosis windows (diagnosed < 1 year ago, diagnosed 1-4.9 years ago, and diagnosed 5 or more years ago). We employed the average of the log odds ratios of those six estimates, weighted by the populations reported in the openSAFELY study. We employed a similar weighted average for diabetes, which has three reported OR estimates in the openSAFELY study but is measured with a binary variable in our microsimulation.

The excess death data obtained from the CDC are available only in 5-year age groups. To increase precision, we used the estimates from Bhaskaran et al. to interpolate the distribution of excess deaths over single years of age within each 5-year age group. We accomplished this interpolation by first estimating a loglinear model of ORs provided for age categories in Bhaskaran et al. Age bins were converted to an average age (29 years for 18-39, 44.5 for 40-49, 54.5 for 50-59, 64.5 for 60-69, and 74.5 for 70-79; 80+ group is omitted), and the model was fitted with age as independent variable and the log COVID-19 mortality OR as dependent variable:

$$\log OR = \alpha + \beta AGE + e$$

This regression yielded the estimates $\hat{\alpha} = -5.845$ (95% $CI,$ -6.148 to -5.542) and $\hat{\beta} = 0.105$ (95% $CI,$ 0.101 to 0.110). We then applied the predicted value to each individual's COVID-19 mortality risk score.

Finally, our COVID-19 risk score also accounts for whether the individual resides in a nursing home, since nursing home deaths represent a large share of total deaths. To calculate the odds ratio for this comorbidity, we first obtained data on the number of COVID-19 deaths among residents in certified Medicare skilled nursing facilities/Medicaid nursing facilities. Data from the Centers for Medicare & Medicaid Services (CMS) were retrieved from:

https://data.cms.gov/Special-Programs-Initiatives-COVID-19-Nursing-Home/COVID-19-Nursing-Home-Dataset/s2uc-8wxp.

This dataset reported that there were 130,296 COVID-19 deaths among residents of nursing homes between January 1, 2020 and March 13, 2021. These data allow us to compute the share of total COVID-19 deaths that occurred in nursing homes. We then solved for the odds ratio that, when applied to our COVID-19 risk score, yielded a distribution of decedents consistent with this share.

Section 3. Methods

We rely on an established microsimulation framework to calculate years of life lost (YLLs). The Future Elderly Model (FEM) and Future Adult Model (FAM) are dynamic microsimulation models based on biennial, longitudinal, nationally representative survey data for the United States. The FEM and FAM have been validated extensively with regards to trends in chronic disease prevalence, disease risk factors like BMI and smoking, functional limitations, quality-of-life, and mortality. The FEM relies primarily on the Health and Retirement Study (HRS), a nationally representative household survey of Americans over the age of fifty. The FAM is based on the Panel Study of Income Dynamics (PSID), a nationally representative survey of Americans of all ages. Both simulations model individuals' health risk factors, chronic illness incidence, limitations in function, mortality, and more over the life course. Full details, including model validation, are available in Supplement 2 and Supplement 4. The data and code used to produce the estimates for our study are publicly available from our Subversion repository:

https://schweb.lahrc.lahealthresearchcloud.org/svn/AIM_covid/

Some datasets, such as the survey input data for the simulation (e.g. PSID, HRS), must be retrieved from the original sources because our Data Use Agreements do not allow us to redistribute them.

Our analysis measures YLLs and quality-adjusted life years (QALYs) lost relative to baseline. The projected life expectancy for each excess death is the number of life-years lived in the microsimulation under the assumption of zero excess deaths. Summing projected life expectancy across all excess deaths then yields the total YLLs. QALYs lost are calculated by summing the quality-of-life index. Both YLLs and QALYs lost are undiscounted. We use the FAM to estimate YLLs and QALYs lost for people ages 25 to 54 in 2020, and the FEM for people ages 55+ in 2020.

FAM simulations begin in 2009 and are replenished with cohorts of 25-year-olds through 2021. Incoming 25-year-old simulants are based on PSID respondents but have their sample weights adjusted to match demographic characteristics from US Census Projections (3). FAM simulations end in 2117. FEM simulations are started in 2016 with individuals ages 51+ as of that year, without replenishing cohorts. FEM simulations end in 2086. Together, the FEM and FAM include 28,175 simulants, which differ along numerous socioeconomic and health dimensions and are weighted to be nationally representative of the 223 million US adults ages 25+ and alive as of July 1, 2020.

To increase precision, the simulations are repeated using 150 Monte Carlo replications and then averaged when estimating the distributions of future outcomes. To quantify YLLs and QALYs lost from COVID-19 and non-COVID-19 excess deaths, we assign those deaths to individuals in the microsimulation's output for the 2020 calendar year, based on their demographics and health characteristics. The assignment of excess deaths based on age-sex-race/ethnicity and health is accomplished by appropriately adjusting the simulants' weights, and varied across our three analyses as described below.

The first analysis assumes that all COVID-19 and non-COVID-19 excess deaths occur randomly within each age-sex-race/ethnicity subgroup. No distinction was made between COVID-19 excess deaths and non-COVID-19 excess deaths. This "Average Risk" analysis is analogous to calculating YLLs using a life table that adjusts for the age, sex, and race/ethnicity of the decedent.

The second analysis, which serves as our preferred (baseline) approach, matches the distribution of COVID-19 excess deaths within each subgroup to the mortality odds ratios estimated for each of 12 different COVID-19 risk factors. Specifically, we assume that COVID-19 excess deaths are distributed in the subgroup in proportion to individuals' COVID-19 risk score, which was constructed using COVID-19 mortality odds ratios as described above. We assume that non-COVID-19 deaths are distributed according to the baseline mortality risk framework employed in the FEM and FAM. Thus, this approach distinguishes between risk factors associated with COVID-19 and those associated with non-COVID-19 excess deaths.

In the third analysis, we assume that all excess deaths (both COVID-19 and non-COVID-19) occur among the simulants with the highest mortality rate within each subgroup, as estimated by the microsimulation model. This "Frailty-Based Risk" analysis assumes that only the frailest individuals died. To accomplish this, we first ranked individuals by mortality risk, as estimated by the FEM and FAM, within their age-sex-race/ethnicity subgroup. In each age-sex-race/ethnicity subgroup, we then systematically selected the highest mortality risk individuals until all excess deaths were accounted for. No distinction was made between COVID-19 excess deaths and non-COVID-19 excess deaths.

Comparing our preferred Individualized Risk analysis to the alternative Frailty-Based Risk and Average Risk analyses clarifies the extent to which COVID-19 mortality afflicts those with below-average versus average longevity for their demographic subgroup.

3.1 Measuring outcomes

Years of Life Lost (YLLs)

For the Average Risk, Individualized Risk, and Frailty-Based Risk analyses, YLLs for each excess death are equal to the number of life-years lived in the microsimulation under the counterfactual assumption of zero excess deaths. Deaths are determined at 2-year intervals in the microsimulation. For the Average Risk and Individualized Risk analyses, counterfactual deaths were assumed to occur at the midpoint of the relevant 2-year interval. For the Frailty-Based Risk analysis, we conservatively assumed that counterfactual deaths occurred at the beginning of the 2-year interval, which minimizes the potential number of YLLs.

In the period life table analysis reported in Table 1 of the main text, we project life expectancy using 2018 CDC period life tables that adjust for single year of age, sex, and race/ethnicity. These tables are publicly available online:

https://ftp.cdc.gov/pub/Health_Statistics/NCHS/Publications/NVSR/69-12 (tables 5,6, 8, 9, 11 and 12)

Our YLL estimates are based on $e(x)$, the average number of years of life remaining at exact age x.

Quality-Adjusted Life Years (QALYs) lost

Quality-of-life is measured using the EuroQol five dimensions questionnaire (EQ-5D). These five dimensions are based on five survey questions that elicit the extent of a respondent's problems with mobility, self-care, daily activities, pain, and anxiety/depression. These questions are then weighted using stated preference data to compute the relative importance of each one and combined to create a single quality-of-life measure that is anchored at 0 (equivalent to death) and 1 (perfect health) (4). This index is first measured using the Medical Expenditure Panel Survey (MEPS), and then mapped to the HRS and PSID using variables common to both databases (Section 9.2 of Supplement 2).

QALYs lost for each excess death is calculated by summing the EQ-5D index over the years for which the individual is alive in the counterfactual model.

3.2 Assessing uncertainty

We employ two approaches to quantify uncertainty in our analyses. The first stems from uncertainty in the transition models used for the microsimulation models and the second stems from uncertainty in COVID-19 mortality odds ratio estimates. We employ a nonparametric bootstrap approach to create 50 separate sets of transition model estimates for use in the microsimulation, each of which is simulated 150 times in a Monte Carlo fashion (5). Uncertainty in the COVID-19 mortality ORs is incorporated by drawing from a multivariate normal distribution of the underlying parameters from the logistic model. Distributions of risk factors that consist of multiple subcategories in Bhaskaran et al. (cancer and diabetes) were created by weighted draws of the underlying distributions (2). The underlying distribution was based on the variance-covariance matrix from Bhaskaran et al. (2021), as provided by the authors. These draws are randomly paired with the nonparametric bootstrap transition estimates. Results from each bootstrapped simulation are then used to calculate 95% uncertainty intervals around the mean outcomes.

Section 4. Additional Results

Supplement Table 2 and Supplement Table 3 report the lower and upper bounds of the 95% percent uncertainty interval corresponding to the estimates presented in Table 1 of the main text, respectively.

Supplement Table 4 and Supplement Table 5 report the lower and upper bounds of the 95% percent uncertainty interval corresponding to the estimates presented in Table 2 of the main text, respectively.

Supplement Table 6 reports YLLs and QALYs lost by COVID-19 vs. non-COVID-19 excess deaths and 10-year age group. Supplement Table 7 and Supplement Table 8 report the lower and upper bounds of the 95% uncertainty interval corresponding to the estimates presented in Supplement Table 6.

Supplement Figure 1 illustrates the prevalence of COVID-19 related comorbidities in the US population for different age groups, as estimated by the FEM and FAM. Supplement Figure 2, Supplement Figure 3, and Supplement Figure 4 present corresponding prevalence estimates separately for Blacks, Hispanics, and Whites.

Supplement Figure 5 shows how the estimated distribution from Figure 2 of the main text varies by sex and race/ethnicity, for ages 26-64 and ages 65+.

Supplement Figure 6 and Supplement Figure 7 report the corresponding versions of Figure 3 of the main text, for the Average Risk and Frailty-Based Risk analyses.

Supplement Figure 8 reports the number of quality-adjusted life-years lost per 10,000, by age group, sex, and race/ethnicity, for the Individualized Risk analysis.

Supplement Figure 9 and Supplement Figure 10 report the corresponding versions of Figure 4 of the main text, for the Average Risk and Frailty-Based Risk analyses.

Supplement Table 1. COVID-19 mortality odds ratios for different comorbidities

Comorbidity	FEM/FAM definition	Odds ratio (95% CI)	Source	Notes
$30 \leq BMI < 35$	Derived from "How tall are you?" and "How much do you weigh?" (FAM) or "About how tall are you?" and "About how much do you weigh?" (FEM)	1.07 (1.03-1.12)	Bhaskaran et al. (2021)	
$35 \leq BMI < 40$		1.44 (1.36-1.54)	Bhaskaran et al. (2021)	
$40 \leq BMI$		2.11 (1.93-2.29)	Bhaskaran et al. (2021)	
Former smoker (excl. current smokers)	Derived from "Did you ever smoke cigarettes?" & "Do you smoke cigarettes?"	1.26 (1.22-1.30)	Bhaskaran et al. (2021)	
High blood pressure	"Has a doctor ever told you that you have high blood pressure or hypertension?"	0.90 (0.87-0.94)	Bhaskaran et al. (2021)	Source definition: systolic≥ 140 mm Hg or diastolic≥ 90 mm Hg
Lung disease	"Not including asthma, has a doctor ever told you that you have chronic lung disease such as chronic bronchitis or emphysema?"	1.66 (1.59-1.73)	Bhaskaran et al. (2021)	Excluding asthma
Heart disease	"Has a doctor ever told you that you have had a heart attack, coronary heart disease, angina, congestive heart failure, or other heart problems?"	1.23 (1.19-1.27)	Bhaskaran et al. (2021)	
Diabetes	"Has a doctor ever told you that you have diabetes or high blood sugar?"	1.41 (1.36-1.46)	Bhaskaran et al. (2021)	Weighted average of HbA1c<58 mmol/mol, HbA1c>=58 mmol/mol, and no recent HbA1c measure
Cancer	"Has a doctor ever told you that you have cancer or a malignant tumor?" (FAM) "Has a doctor ever told you that you have cancer or a malignant tumor, excluding minor skin cancer?" (FEM)	1.12 (1.08-1.16)	Bhaskaran et al. (2021)	Weighted average of all haematological and non-haematological cancers, with diagnosis at any time in the past
Stroke	"Has a doctor ever told you that you have had a stroke?"	1.53 (1.46-1.59)	Bhaskaran et al. (2021)	
Dementia	Based on Telephone Interview for Cognitive Status (TICS) or proxy respondents(6)	3.62 (3.41-3.84)	Bhaskaran et al. (2021)	
Nursing home	"Are you living in a nursing home or other health care facility? Def: A nursing home or other health facility provides all of the following services for its residents: dispensing of medication, 24-hour nursing assistance and supervision, personal assistance, and room & meals."	2.45 (2.20-2.69)	CMS (2021) https://data.cms.gov/Special-Programs-Initiatives-COVID-19-Nursing-Home/COVID-19-Nursing-Home-Dataset/s2uc-8wxp	Sum of all deaths reported in "residents_weekly_covid_19" for all locations

The first column lists the 12 COVID-19-related comorbidities accounted for in the Individualized Risk analysis. The second column describes how the comorbidity is measured in the surveys underlying the Future Elderly Model and Future Adult Model microsimulations. The third column reports the mortality odds ratio used to construct the COVID-19 risk score. The odds ratio is obtained either from Bhaskaran et al. (2021) or from a calibration exercise using nursing home deaths obtained from CMS (2021) (2, 7). BMI: body mass index.

Supplement Table 2. Lower bound of 95% uncertainty interval: years of life lost and quality-adjusted life-years lost due the US COVID-19 pandemic, by age group, sex, and race/ethnicity

	Totals			Ages 25-64						Ages 65+					
				Female			Male			Female			Male		
Outcome	Ages 25-64	Ages 65+	Ages 25+	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White
Population, thousands	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
CDC excess deaths															
Deaths	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Deaths per 10k	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Longitudinal outcomes															
YLL, thousands															
Period life table	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Average Risk	5,043	5,354	10,432	428	442	788	768	1,100	1,452	417	375	1,703	391	462	1,921
Individualized Risk	4,560	4,339	8,939	378	407	694	690	1,018	1,313	327	301	1,354	317	387	1,579
Frailty-Based Risk	2,338	1,072	3,465	177	231	229	386	643	573	88	90	291	78	123	325
QALYs lost, thousands															
Average Risk	3,951	3,877	7,858	321	338	621	599	871	1,152	287	256	1,239	280	331	1,419
Individualized Risk	3,485	2,990	6,508	274	304	528	525	792	1,016	211	191	933	216	264	1,115
Frailty-Based Risk	1,592	543	2,170	110	152	140	262	471	388	41	44	142	39	67	161
YLL per 10k															
Period life table	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Average Risk	301	972	468	381	316	134	750	699	251	1,423	1,451	682	1,949	2,280	940
Individualized Risk	272	789	401	337	291	118	674	646	226	1,117	1,163	543	1,596	1,903	774
Frailty-Based Risk	139	195	155	158	166	39	376	408	99	300	346	116	392	606	159
QALYs lost per 10k															
Average Risk	235	704	352	286	242	106	585	553	199	980	987	497	1,394	1,634	693
Individualized Risk	208	544	292	244	218	90	513	503	175	719	737	374	1,088	1,295	546
Frailty-Based Risk	95	98	97	98	109	24	256	299	67	140	171	57	197	328	79

This table reports the lower bound of the 95% uncertainty interval for the estimates presented in Table 1 of the main text. Uncertainty intervals were obtained by performing a non-parametric bootstrap that resampled the data underlying the Future Elderly Model and Future Adult Model and drew COVID-19 mortality odds ratios from an independent multivariate normal distribution. YLL: years of life lost. QALYs: quality-adjusted life-years.

Supplement Table 3. Upper bound of 95% uncertainty interval: years of life lost and quality-adjusted life-years lost due the US COVID-19 pandemic, by age group, sex, and race/ethnicity

	Totals			Ages 25-64						Ages 65+					
				Female			Male			Female			Male		
Outcome	Ages 25-64	Ages 65+	Ages 25+	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White	Black	Hispanic	White
Population, thousands	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
CDC excess deaths															
Deaths	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Deaths per 10k	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Longitudinal outcomes															
YLL, thousands															
Period life table	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Average Risk	5,223	5,504	10,692	446	488	812	827	1,214	1,503	453	405	1,774	439	505	2,012
Individualized Risk	4,776	4,485	9,221	400	456	726	750	1,141	1,364	356	335	1,414	358	424	1,671
Frailty-Based Risk	2,605	1,218	3,768	212	292	276	468	799	656	113	111	356	111	167	436
QALYs lost, thousands															
Average Risk	4,098	3,991	8,060	335	375	641	641	962	1,195	314	280	1,293	315	364	1,490
Individualized Risk	3,663	3,102	6,732	290	343	556	568	891	1,061	232	222	982	246	294	1,187
Frailty-Based Risk	1,784	637	2,385	131	195	170	320	588	446	56	57	180	61	97	235
YLL per 10k															
Period life table	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.
Average Risk	311	996	479	398	348	139	801	767	259	1,529	1,547	706	2,137	2,481	976
Individualized Risk	284	810	413	356	325	124	727	721	235	1,201	1,282	563	1,730	2,093	809
Frailty-Based Risk	155	220	169	189	209	47	454	505	113	383	425	142	538	822	211
QALYs lost per 10k															
Average Risk	244	722	361	298	268	109	621	608	206	1,059	1,073	514	1,540	1,786	723
Individualized Risk	218	560	302	259	245	95	550	563	183	783	851	390	1,189	1,447	575
Frailty-Based Risk	106	115	107	117	139	29	311	372	77	190	218	72	296	478	114

This table reports the upper bound of the 95% uncertainty interval for the estimates presented in Table 1 of the main text. Uncertainty intervals were obtained by performing a non-parametric bootstrap that resampled the data underlying the Future Elderly Model and Future Adult Model and drew COVID-19 mortality odds ratios from an independent multivariate normal distribution. YLL: years of life lost. QALYs: quality-adjusted life-years.

Supplement Table 4. Lower bound of 95% uncertainty interval: years of life lost and quality-adjusted life-years lost due the US COVID-19 pandemic, by 10-year age group

	Age							
Outcome	**25+**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85+**
Population, thousands	.	.	.	.	.	.	.	.
CDC excess deaths								
Deaths	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Deaths per 10k	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Longitudinal outcomes								
YLL, thousands								
Period life table	.	.	.	.	.	.	.	.
Average Risk	10,432	867	1,166	1,031	1,954	2,636	1,799	899
Individualized Risk	8,939	824	1,058	965	1,686	2,214	1,481	623
Frailty-Based Risk	3,465	658	683	530	410	564	361	125
QALYs lost, thousands								
Average Risk	7,858	704	934	818	1,476	1,963	1,293	603
Individualized Risk	6,508	659	824	751	1,230	1,586	1,011	376
Frailty-Based Risk	2,170	498	478	359	217	294	179	58
YLL per 10k								
Period life table	.	.	.	.	.	.	.	.
Average Risk	468	196	285	254	463	813	1,105	1,371
Individualized Risk	401	187	259	238	400	683	911	949
Frailty-Based Risk	155	149	167	131	97	174	223	192
QALYs lost per 10k								
Average Risk	352	159	229	201	350	606	794	919
Individualized Risk	292	149	201	185	292	490	622	573
Frailty-Based Risk	97	113	117	89	52	91	110	90

This table reports the lower bound of the 95% uncertainty interval for the estimates presented in Table 2 of the main text. Uncertainty intervals were obtained by performing a non-parametric bootstrap that resampled the data underlying the Future Elderly Model and Future Adult Model and drew COVID-19 mortality odds ratios from an independent multivariate normal distribution. YLL: years of life lost. QALYs: quality-adjusted life-years.

Supplement Table 5. Upper bound of 95% uncertainty interval: years of life lost and quality-adjusted life-years lost due the US COVID-19 pandemic, by 10-year age group

	Age							
Outcome	**25+**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85+**
Population, thousands	.	.	.	.	.	.	.	.
CDC excess deaths								
Deaths	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Deaths per 10k	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Longitudinal outcomes								
YLL, thousands								
Period life table	.	.	.	.	.	.	.	.
Average Risk	10,692	905	1,222	1,106	2,015	2,722	1,864	938
Individualized Risk	9,221	867	1,124	1,043	1,768	2,299	1,555	652
Frailty-Based Risk	3,768	727	778	648	508	666	415	158
QALYs lost, thousands								
Average Risk	8,060	735	981	877	1,526	2,032	1,346	631
Individualized Risk	6,732	693	878	812	1,301	1,653	1,071	395
Frailty-Based Risk	2,385	551	547	442	283	362	213	75
YLL per 10k								
Period life table	.	.	.	.	.	.	.	.
Average Risk	479	205	299	273	477	839	1,152	1,445
Individualized Risk	413	196	275	257	418	708	959	1,005
Frailty-Based Risk	169	165	190	160	120	206	256	241
QALYs lost per 10k								
Average Risk	361	166	240	216	361	626	832	972
Individualized Risk	302	157	215	200	308	509	661	609
Frailty-Based Risk	107	125	134	109	67	111	131	114

This table reports the upper bound of the 95% uncertainty interval for the estimates presented in Table 2 of the main text. Uncertainty intervals were obtained by performing a non-parametric bootstrap that resampled the data underlying the Future Elderly Model and Future Adult Model and drew COVID-19 mortality odds ratios from an independent multivariate normal distribution. YLL: years of life lost. QALYs: quality-adjusted life-years.

Supplement Table 6. Individualized Risk analysis: years of life lost and quality-adjusted life-years lost due to the US COVID-19 pandemic, by COVID-19 vs. non-COVID-19 excess deaths and 10-year age group

	Age							
Outcome	**25+**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85+**
Population, thousands	223,092	44,195	40,899	40,589	42,228	32,432	16,228	6,522
CDC excess deaths								
Deaths	740,247	18,136	29,977	34,455	91,427	180,021	197,977	188,254
COVID-19	545,324	3,669	9,362	26,150	66,545	120,318	151,569	167,711
Non-COVID-19	194,923	14,467	20,615	8,305	24,882	59,703	46,408	20,543
Deaths per 10k	33.2	4.1	7.3	8.5	21.7	55.5	122.0	288.6
COVID-19	24.4	.8	2.3	6.4	15.8	37.1	93.4	257.1
Non-COVID-19	8.7	3.3	5.0	2.0	5.9	18.4	28.6	31.5
Longitudinal outcomes								
YLL, thousands								
COVID-19 deaths	5,973	180	363	775	1,330	1,592	1,170	562
Non-COVID-19 deaths	3,108	665	728	229	397	665	348	76
QALYs lost, thousands								
COVID-19 deaths	4,313	146	288	606	981	1,150	803	340
Non-COVID-19 deaths	2,307	531	563	176	285	470	238	46
YLL per 10k								
COVID-19 deaths	268	41	89	191	315	491	721	861
Non-COVID-19 deaths	139	151	178	57	94	205	214	116
QALYs lost per 10k								
COVID-19 deaths	193	33	70	149	232	354	495	521
Non-COVID-19 deaths	103	120	138	43	67	145	147	70

This table reports the years of life lost (YLLs) and quality-adjusted life-years (QALYs) lost over the time period March 22, 2020 through March 13, 2021 as a result of the US COVID-19 pandemic. We report 95% uncertainty intervals in Tables 7-8 of Supplement 1. Population data were obtained from the Health and Retirement Study and the Panel Study of Income Dynamics. The longitudinal outcomes estimates presented in this table are based on the number of COVID and non-COVID excess deaths reported by the Centers for Disease Control and Prevention (CDC), which are reproduced in the second row. The YLLs and QALYs lost estimates for the Individualized Risk analysis are derived from the Future Elderly Model and the Future Adult Model, which use microsimulation to produce individual-level forecasts of mortality and quality-of-life for the US population ages 25+ (Figure 1 of the main text). The Individualized Risk analysis assigns all COVID-19-related excess deaths within the age-sex-race/ethnicity subgroup in proportion to estimates of COVID-19 comorbidity mortality odds ratios, and assigns non-COVID-19-related deaths in proportion to the 2020 (pre-COVID-19) annual mortality hazard projected by the microsimulation.

Supplement Table 7. Lower bound of 95% uncertainty interval: Individualized Risk analysis: years of life lost and quality-adjusted life-years lost due the US COVID-19 pandemic, by COVID-19 vs. non-COVID-19 excess deaths and 10-year age group

	Age							
Outcome	**25+**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85+**
Population, thousands	.	.	.	.	.	.	.	.
CDC excess deaths								
Deaths	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Deaths per 10k	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Longitudinal outcomes								
YLL, thousands								
COVID-19 deaths	5,879	176	351	746	1,300	1,560	1,142	548
Non-COVID-19 deaths	3,050	648	706	219	385	652	338	73
QALYs lost, thousands								
COVID-19 deaths	4,239	142	277	583	955	1,124	780	331
Non-COVID-19 deaths	2,262	517	545	168	274	460	230	44
YLL per 10k								
COVID-19 deaths	264	40	86	184	308	482	703	836
Non-COVID-19 deaths	137	147	173	54	91	201	208	112
QALYs lost per 10k								
COVID-19 deaths	190	32	68	144	226	347	480	504
Non-COVID-19 deaths	101	117	133	41	65	142	141	68

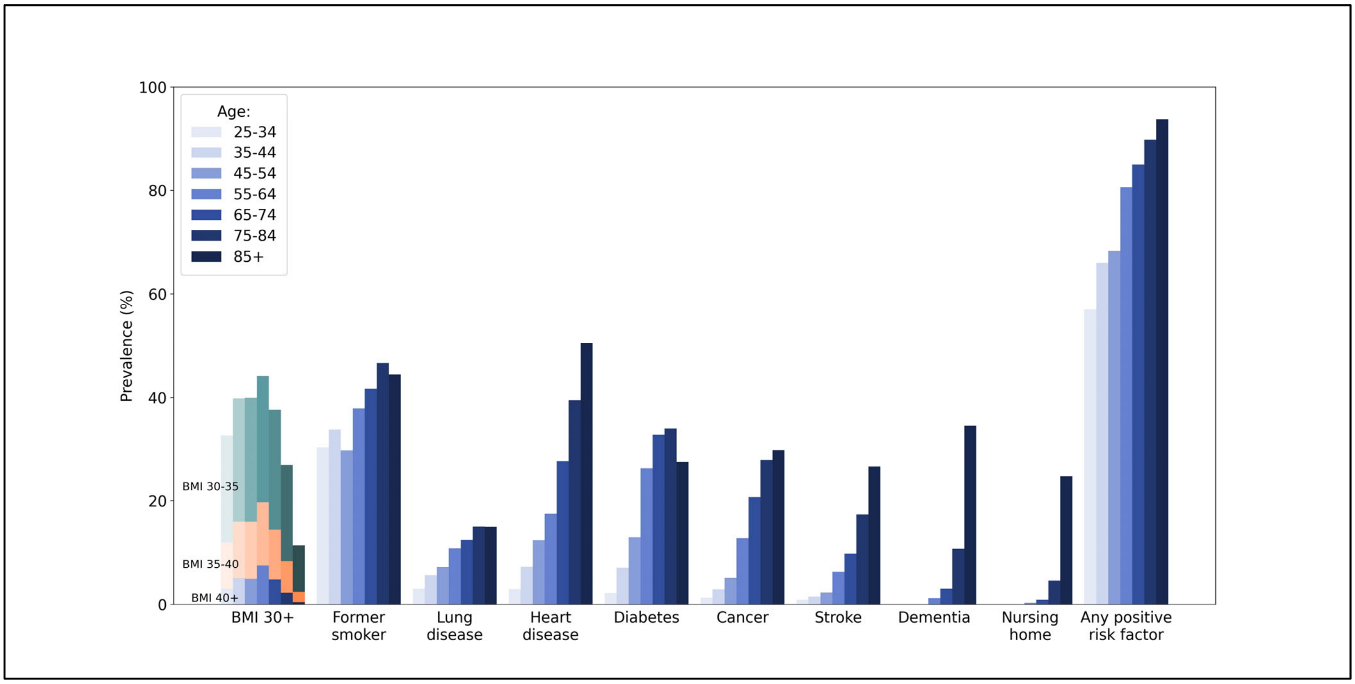
This table reports the lower bound of the 95% uncertainty interval for the estimates presented in Table 6 of Supplement 1. Uncertainty intervals were obtained by performing a non-parametric bootstrap that resampled the data underlying the Future Elderly Model and Future Adult Model and drew COVID-19 mortality odds ratios from an independent multivariate normal distribution. YLL: years of life lost. QALYs: quality-adjusted life-years.

Supplement Table 8. Upper bound of 95% uncertainty interval: Individualized Risk analysis: years of life lost and quality-adjusted life-years lost due the US COVID-19 pandemic, by COVID-19 vs. non-COVID-19 excess deaths and 10-year age group

	Age							
Outcome	**25+**	**25-34**	**35-44**	**45-54**	**55-64**	**65-74**	**75-84**	**85+**
Population, thousands	.	.	.	.	.	.	.	.
CDC excess deaths								
Deaths	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Deaths per 10k	.	.	.	.	.	.	.	.
COVID-19	.	.	.	.	.	.	.	.
Non-COVID-19	.	.	.	.	.	.	.	.
Longitudinal outcomes								
YLL, thousands								
COVID-19 deaths	6,066	185	376	804	1,360	1,624	1,199	576
Non-COVID-19 deaths	3,165	683	749	240	410	678	357	78
QALYs lost, thousands								
COVID-19 deaths	4,387	150	298	629	1,007	1,176	826	348
Non-COVID-19 deaths	2,353	544	581	184	295	480	246	48
YLL per 10k								
COVID-19 deaths	272	42	92	198	322	500	740	887
Non-COVID-19 deaths	142	154	183	59	97	209	221	120
QALYs lost per 10k								
COVID-19 deaths	197	34	73	155	238	362	510	538
Non-COVID-19 deaths	105	123	142	45	70	148	152	73

This table reports the upper bound of the 95% uncertainty interval for the estimates presented in Table 6 of Supplement 1. Uncertainty intervals were obtained by performing a non-parametric bootstrap that resampled the data underlying the Future Elderly Model and Future Adult Model and drew COVID-19 mortality odds ratios from an independent multivariate normal distribution. YLL: years of life lost. QALYs: quality-adjusted life-years.

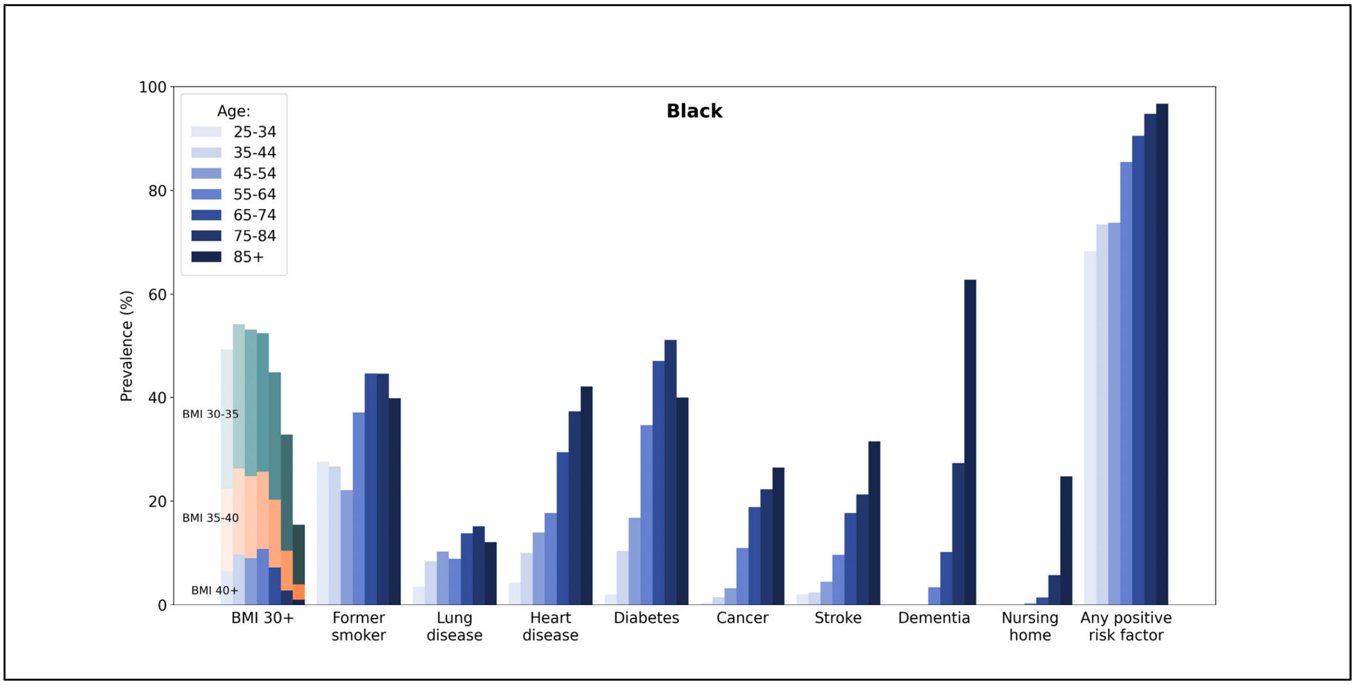
Supplement Figure 1. Prevalence of risk factors in 2020 that are positively associated with COVID-19 mortality



Age (years)	Prevalence in 2020, % (95% CI) BMI 30-35	BMI 35-40	BMI 40+	Former smoker	Lung disease	Heart disease	Diabetes	Cancer	Stroke	Dementia	In nursing home	Any positive risk factor
25-34	20.7	8.9	3.0	30.4	3.0	3.0	2.2	1.3	0.9	.	.	57.0
	(20.4 - 21.0)	(8.6 - 9.2)	(2.8 - 3.2)	(29.4 - 31.4)	(2.7 - 3.3)	(2.7 - 3.3)	(1.9 - 2.5)	(1.0 - 1.6)	(0.8 - 1.0)	.	.	(56.2 - 57.8)
35-44	23.8	10.9	5.1	33.8	5.6	7.3	7.1	2.9	1.5	.	.	66.0
	(23.4 - 24.2)	(10.6 - 11.2)	(4.7 - 5.5)	(32.9 - 34.7)	(5.1 - 6.1)	(6.8 - 7.8)	(6.4 - 7.8)	(2.5 - 3.3)	(1.3 - 1.7)	.	.	(65.4 - 66.6)
45-54	24.0	11.0	4.9	29.8	7.2	12.4	12.9	5.1	2.3	.	.	68.3
	(23.5 - 24.5)	(10.7 - 11.3)	(4.5 - 5.3)	(29.1 - 30.5)	(6.5 - 7.9)	(11.6 - 13.2)	(12.0 - 13.8)	(4.5 - 5.7)	(2.0 - 2.6)	.	.	(67.6 - 69.0)
55-64	24.5	12.2	7.5	37.9	10.8	17.5	26.3	12.8	6.3	1.2	0.3	80.6
	(23.9 - 25.1)	(11.6 - 12.8)	(6.8 - 8.2)	(35.9 - 39.9)	(9.6 - 12.0)	(16.5 - 18.5)	(24.8 - 27.8)	(11.4 - 14.2)	(5.4 - 7.2)	(0.8 - 1.6)	(0.2 - 0.4)	(79.0 - 82.2)
65-74	23.2	9.6	4.8	41.7	12.4	27.7	32.8	20.7	9.8	3.0	0.9	84.9
	(22.1 - 24.3)	(9.0 - 10.2)	(4.2 - 5.4)	(39.4 - 44.0)	(11.3 - 13.5)	(25.9 - 29.5)	(31.2 - 34.4)	(19.5 - 21.9)	(8.9 - 10.7)	(2.8 - 3.2)	(0.8 - 1.0)	(83.8 - 86.0)
75-84	18.6	6.1	2.3	46.7	15.0	39.5	34.0	27.9	17.4	10.7	4.6	89.8
	(17.9 - 19.3)	(5.6 - 6.6)	(1.8 - 2.8)	(44.1 - 49.3)	(14.1 - 15.9)	(37.5 - 41.5)	(32.3 - 35.7)	(26.3 - 29.5)	(15.6 - 19.2)	(10.1 - 11.3)	(4.1 - 5.1)	(88.8 - 90.8)
85+	9.0	2.0	0.4	44.5	15.0	50.5	27.5	29.9	26.7	34.6	24.8	93.8
	(8.2 - 9.8)	(1.6 - 2.4)	(0.3 - 0.5)	(40.8 - 48.2)	(13.4 - 16.6)	(47.8 - 53.2)	(25.1 - 29.9)	(27.6 - 32.2)	(24.9 - 28.5)	(33.0 - 36.2)	(22.9 - 26.7)	(92.6 - 95.0)

This figure reports the prevalence of different risk factors in the US adult population ages 25+ as of July 1, 2020. The estimates are produced by the Future Adult Model and the Future Elderly Model. The category "any positive risk factor" includes individuals who have at least one of the risk factors listed in the figure. 95% uncertainty intervals are given in parentheses. BMI: body mass index.

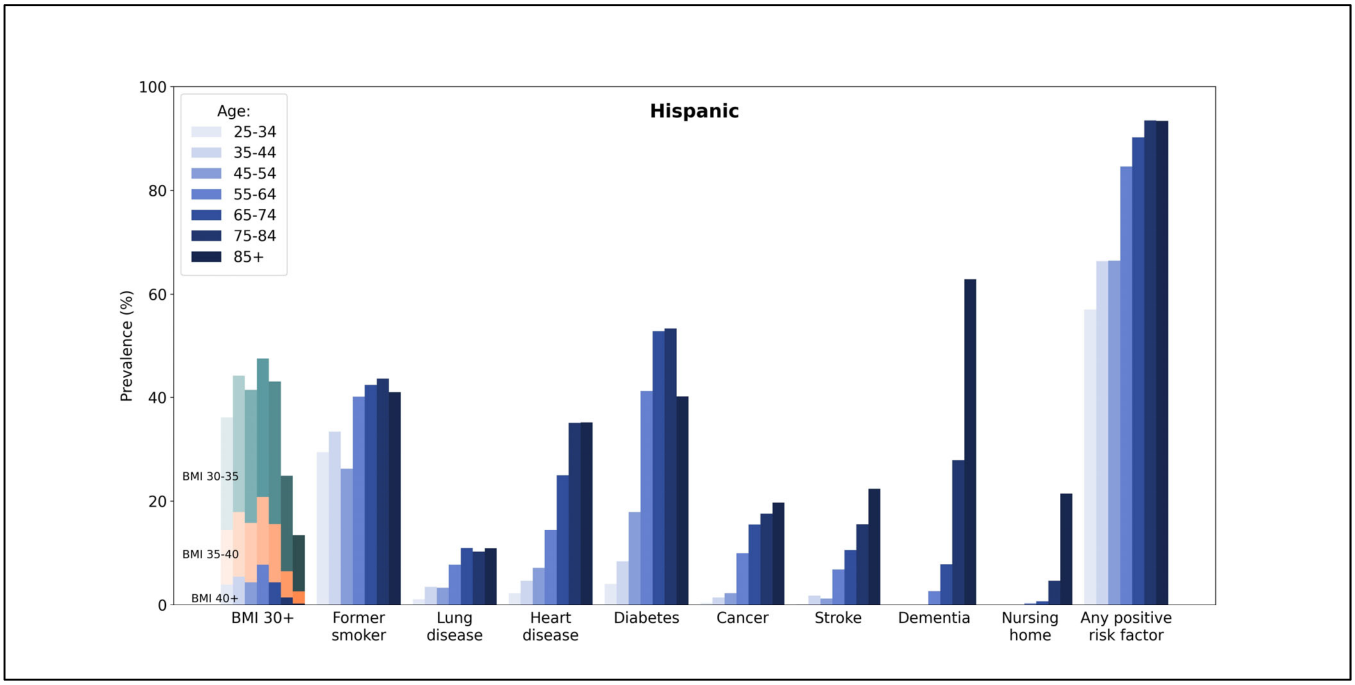
Supplement Figure 2. Black population: prevalence of risk factors in 2020 that are positively associated with COVID-19 mortality



Age (years)	Prevalence in 2020, % (95% CI)											
	BMI 30-35	**BMI 35-40**	**BMI 40+**	**Former smoker**	**Lung disease**	**Heart disease**	**Diabetes**	**Cancer**	**Stroke**	**Dementia**	**In nursing home**	**Any positive risk factor**
25-34	26.9	15.9	6.5	27.6	3.5	4.3	2.0	0.4	2.1	.	.	68.2
	(26.4 - 27.4)	(15.3 - 16.5)	(6.1 - 6.9)	(26.2 - 29.0)	(3.0 - 4.0)	(3.9 - 4.7)	(1.6 - 2.4)	(0.2 - 0.6)	(1.9 - 2.3)	.	.	(67.4 - 69.0)
35-44	27.9	16.6	9.7	26.7	8.4	10.0	10.4	1.5	2.4	.	.	73.5
	(27.2 - 28.6)	(16.0 - 17.2)	(9.2 - 10.2)	(25.6 - 27.8)	(7.6 - 9.2)	(9.3 - 10.7)	(9.6 - 11.2)	(1.1 - 1.9)	(1.9 - 2.9)	.	.	(72.7 - 74.3)
45-54	28.4	15.8	9.0	22.1	10.3	13.9	16.8	3.2	4.4	.	.	73.7
	(27.7 - 29.1)	(15.2 - 16.4)	(8.4 - 9.6)	(21.3 - 22.9)	(9.5 - 11.1)	(12.9 - 14.9)	(15.5 - 18.1)	(2.4 - 4.0)	(3.7 - 5.1)	.	.	(72.8 - 74.6)
55-64	26.8	14.9	10.8	37.1	8.9	17.7	34.6	10.9	9.7	3.4	0.3	85.5
	(25.6 - 28.0)	(14.0 - 15.8)	(9.3 - 12.3)	(34.0 - 40.2)	(7.4 - 10.4)	(15.6 - 19.8)	(31.4 - 37.8)	(8.9 - 12.9)	(7.6 - 11.8)	(2.2 - 4.6)	(0.2 - 0.4)	(84.1 - 86.9)
65-74	24.6	13.1	7.1	44.6	13.7	29.5	47.1	18.8	17.7	10.2	1.4	90.5
	(22.7 - 26.5)	(11.6 - 14.6)	(5.9 - 8.3)	(39.6 - 49.6)	(11.6 - 15.8)	(24.8 - 34.2)	(42.9 - 51.3)	(16.1 - 21.5)	(14.9 - 20.5)	(8.6 - 11.8)	(0.9 - 1.9)	(88.9 - 92.1)
75-84	22.4	7.6	2.8	44.6	15.2	37.3	51.2	22.3	21.3	27.3	5.7	94.7
	(20.2 - 24.6)	(5.8 - 9.4)	(1.6 - 4.0)	(40.6 - 48.6)	(10.5 - 19.9)	(31.5 - 43.1)	(44.9 - 57.5)	(18.8 - 25.8)	(18.3 - 24.3)	(23.7 - 30.9)	(3.8 - 7.6)	(92.6 - 96.8)
85+	11.5	3.0	1.0	39.8	12.1	42.1	40.0	26.5	31.5	62.7	24.8	96.7
	(8.6 - 14.4)	(1.8 - 4.2)	(0.4 - 1.6)	(30.3 - 49.3)	(8.4 - 15.8)	(36.1 - 48.1)	(33.2 - 46.8)	(21.7 - 31.3)	(25.5 - 37.5)	(57.9 - 67.5)	(21.0 - 28.6)	(95.4 - 98.0)

This figure reports the prevalence of different risk factors in the US adult Black population ages 25+ as of July 1, 2020. The estimates are produced by the Future Adult Model and the Future Elderly Model. The category "any positive risk factor" includes individuals who have at least one of the risk factors listed in the figure. 95% uncertainty intervals are given in parentheses. BMI: body mass index.

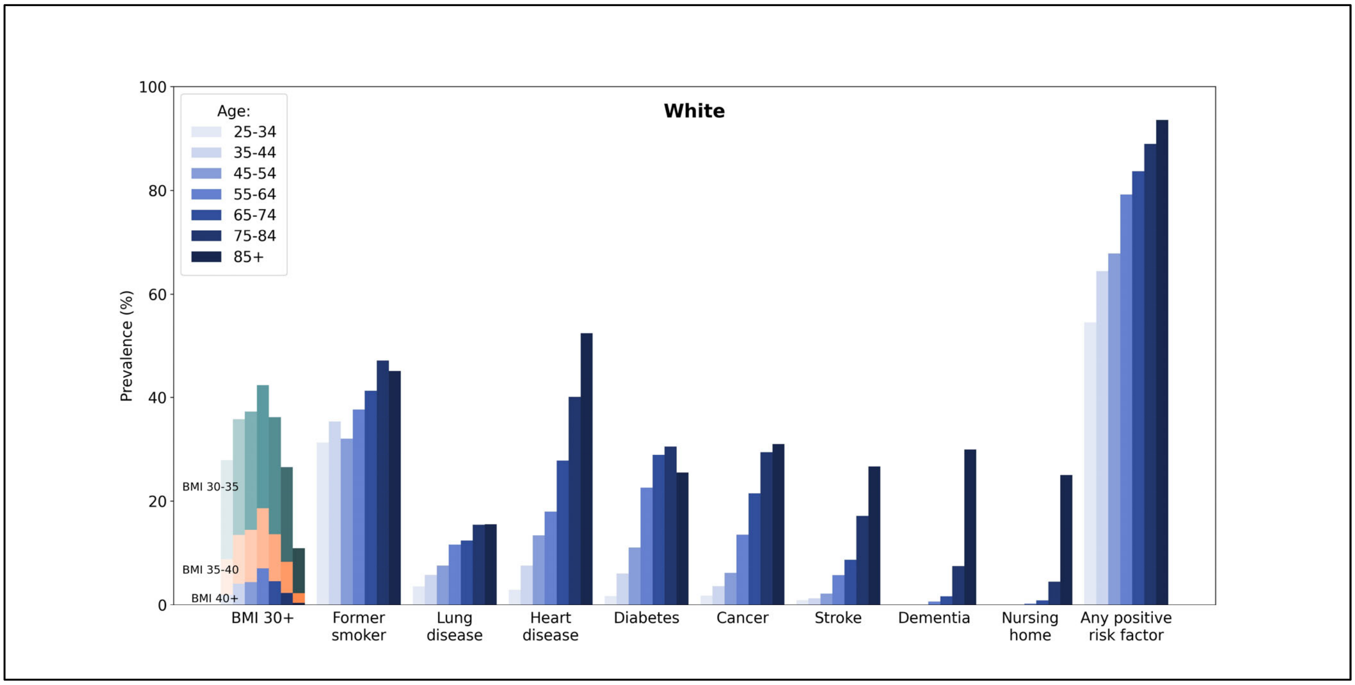
Supplement Figure 3. Hispanic population: prevalence of risk factors in 2020 that are positively associated with COVID-19 mortality



Age (years)	Prevalence in 2020, % (95% CI) BMI 30-35	BMI 35-40	BMI 40+	Former smoker	Lung disease	Heart disease	Diabetes	Cancer	Stroke	Dementia	In nursing home	Any positive risk factor
25-34	21.7	10.5	3.9	29.5	1.1	2.2	4.0	0.4	0.2	.	.	57.0
	(21.1 - 22.3)	(10.0 - 11.0)	(3.5 - 4.3)	(27.2 - 31.8)	(0.7 - 1.5)	(1.8 - 2.6)	(3.3 - 4.7)	(0.1 - 0.7)	(0.1 - 0.3)	.	.	(55.1 - 58.9)
35-44	26.3	12.5	5.4	33.4	3.5	4.6	8.4	1.4	1.8	.	.	66.4
	(25.3 - 27.3)	(11.6 - 13.4)	(4.7 - 6.1)	(31.4 - 35.4)	(2.6 - 4.4)	(3.6 - 5.6)	(6.2 - 10.6)	(0.7 - 2.1)	(1.5 - 2.1)	.	.	(64.5 - 68.3)
45-54	25.6	11.5	4.3	26.2	3.3	7.1	17.9	2.2	1.2	.	.	66.5
	(24.5 - 26.7)	(10.6 - 12.4)	(3.7 - 4.9)	(24.7 - 27.7)	(2.4 - 4.2)	(5.5 - 8.7)	(14.5 - 21.3)	(1.2 - 3.2)	(0.7 - 1.7)	.	.	(64.7 - 68.3)
55-64	26.8	13.0	7.7	40.1	7.7	14.4	41.2	10.0	6.8	2.7	0.3	84.6
	(25.4 - 28.2)	(11.6 - 14.4)	(5.4 - 10.0)	(36.7 - 43.5)	(5.8 - 9.6)	(11.8 - 17.0)	(35.9 - 46.5)	(7.1 - 12.9)	(4.9 - 8.7)	(1.7 - 3.7)	(0.1 - 0.5)	(81.8 - 87.4)
65-74	27.4	11.3	4.3	42.4	10.9	25.0	52.8	15.5	10.6	7.8	0.7	90.2
	(24.7 - 30.1)	(9.6 - 13.0)	(2.8 - 5.8)	(37.4 - 47.4)	(6.6 - 15.2)	(19.3 - 30.7)	(47.8 - 57.8)	(11.4 - 19.6)	(6.9 - 14.3)	(6.3 - 9.3)	(0.3 - 1.1)	(88.0 - 92.4)
75-84	18.4	5.0	1.4	43.7	10.3	35.1	53.4	17.6	15.5	27.9	4.6	93.5
	(13.5 - 23.3)	(2.7 - 7.3)	(0.4 - 2.4)	(34.7 - 52.7)	(6.8 - 13.8)	(28.8 - 41.4)	(42.9 - 63.9)	(12.1 - 23.1)	(10.8 - 20.2)	(24.5 - 31.3)	(2.7 - 6.5)	(91.1 - 95.9)
85+	10.8	2.4	0.3	41.0	10.9	35.2	40.2	19.7	22.4	62.9	21.4	93.4
	(6.8 - 14.8)	(1.1 - 3.7)	(0.1 - 0.5)	(32.8 - 49.2)	(7.3 - 14.5)	(27.5 - 42.9)	(29.4 - 51.0)	(13.5 - 25.9)	(15.6 - 29.2)	(56.8 - 69.0)	(17.0 - 25.8)	(89.7 - 97.1)

This figure reports the prevalence of different risk factors in the US adult Hispanic population ages 25+ as of July 1, 2020. The estimates are produced by the Future Adult Model and the Future Elderly Model. The category “any positive risk factor” includes individuals who have at least one of the risk factors listed in the figure. 95% uncertainty intervals are given in parentheses. BMI: body mass index.

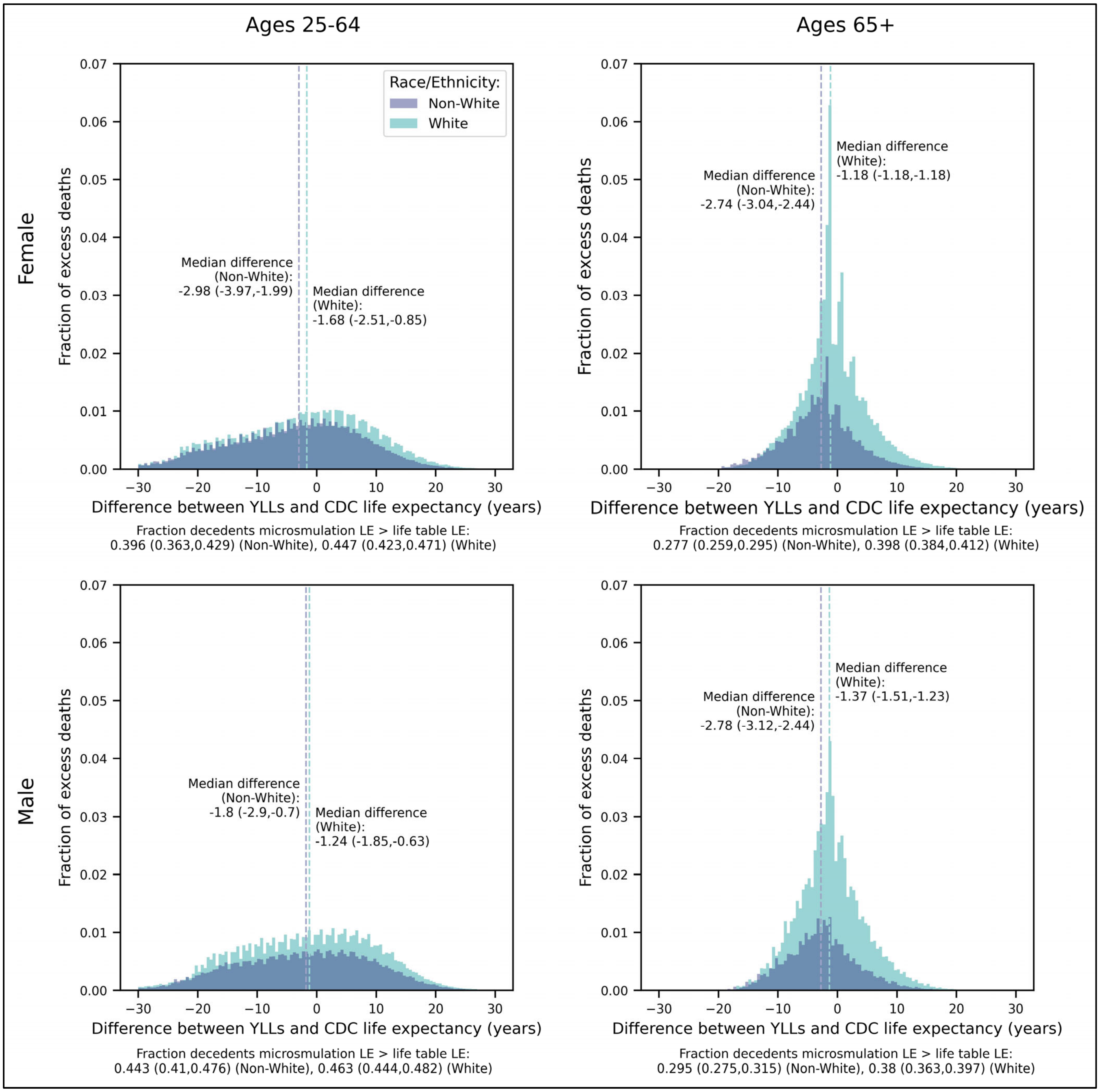
Supplement Figure 4. White population: prevalence of risk factors in 2020 that are positively associated with COVID-19 mortality



Age (years)	BMI 30-35	BMI 35-40	BMI 40+	Former smoker	Lung disease	Heart disease	Diabetes	Cancer	Stroke	Dementia	In nursing home	Any positive risk factor
	Prevalence in 2020, % (95% CI)											
25-34	19.1	6.9	1.9	31.3	3.6	2.9	1.7	1.8	0.9	.	.	54.5
	(18.8 - 19.4)	(6.7 - 7.1)	(1.7 - 2.1)	(30.2 - 32.4)	(3.3 - 3.9)	(2.6 - 3.2)	(1.5 - 1.9)	(1.5 - 2.1)	(0.8 - 1.0)	.	.	(53.8 - 55.2)
35-44	22.3	9.4	4.1	35.3	5.7	7.6	6.0	3.6	1.3	.	.	64.4
	(21.9 - 22.7)	(9.1 - 9.7)	(3.7 - 4.5)	(34.2 - 36.4)	(5.1 - 6.3)	(7.1 - 8.1)	(5.5 - 6.5)	(3.0 - 4.2)	(1.1 - 1.5)	.	.	(63.8 - 65.0)
45-54	22.8	10.1	4.4	32.0	7.6	13.4	11.0	6.1	2.2	.	.	67.8
	(22.3 - 23.3)	(9.8 - 10.4)	(4.0 - 4.8)	(31.2 - 32.8)	(6.8 - 8.4)	(12.5 - 14.3)	(10.3 - 11.7)	(5.3 - 6.9)	(1.9 - 2.5)	.	.	(67.1 - 68.5)
55-64	23.7	11.6	7.0	37.7	11.6	18.0	22.6	13.5	5.7	0.7	0.3	79.2
	(22.9 - 24.5)	(10.8 - 12.4)	(6.1 - 7.9)	(35.1 - 40.3)	(10.2 - 13.0)	(16.7 - 19.3)	(20.9 - 24.3)	(11.8 - 15.2)	(4.8 - 6.6)	(0.3 - 1.1)	(0.2 - 0.4)	(77.3 - 81.1)
65-74	22.6	9.0	4.6	41.3	12.4	27.8	28.9	21.5	8.7	1.6	0.9	83.7
	(21.5 - 23.7)	(8.3 - 9.7)	(3.8 - 5.4)	(38.8 - 43.8)	(11.2 - 13.6)	(26.0 - 29.6)	(27.0 - 30.8)	(20.2 - 22.8)	(7.8 - 9.6)	(1.4 - 1.8)	(0.7 - 1.1)	(82.4 - 85.0)
75-84	18.2	6.0	2.3	47.2	15.5	40.1	30.5	29.4	17.1	7.5	4.5	88.9
	(17.3 - 19.1)	(5.5 - 6.5)	(1.7 - 2.9)	(44.3 - 50.1)	(14.4 - 16.6)	(37.9 - 42.3)	(28.7 - 32.3)	(27.6 - 31.2)	(15.3 - 18.9)	(6.9 - 8.1)	(4.1 - 4.9)	(87.7 - 90.1)
85+	8.6	1.9	0.4	45.1	15.6	52.5	25.5	31.0	26.6	30.0	25.0	93.6
	(7.7 - 9.5)	(1.5 - 2.3)	(0.2 - 0.6)	(41.3 - 48.9)	(13.9 - 17.3)	(49.4 - 55.6)	(23.1 - 27.9)	(28.5 - 33.5)	(24.8 - 28.4)	(28.2 - 31.8)	(23.2 - 26.8)	(92.3 - 94.9)

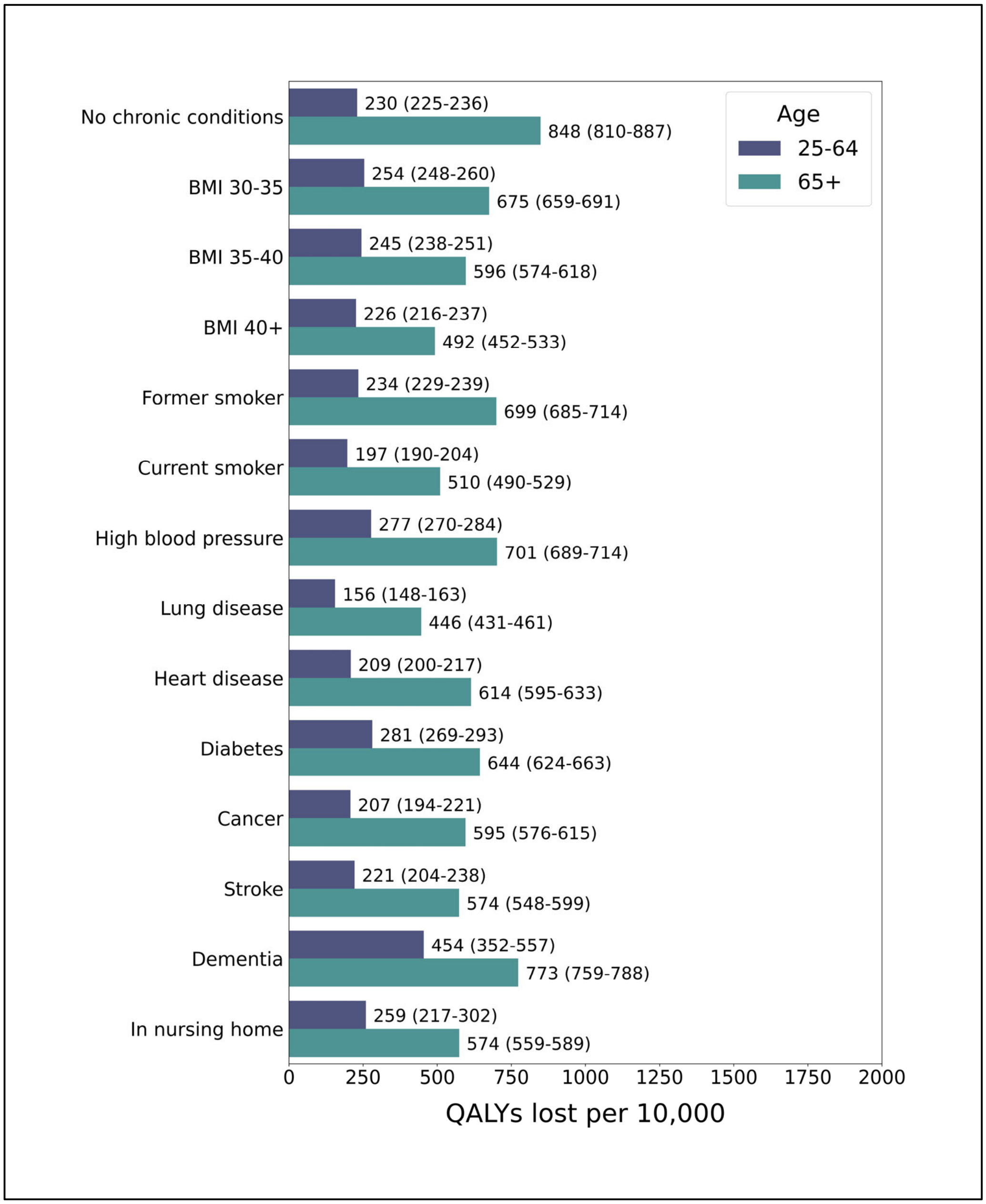
This figure reports the prevalence of different risk factors in the US adult White population ages 25+ as of July 1, 2020. The estimates are produced by the Future Adult Model and the Future Elderly Model. The category "any positive risk factor" includes individuals who have at least one of the risk factors listed in the figure. 95% uncertainty intervals are given in parentheses. BMI: body mass index.

Supplement Figure 5. Predicted years of life lost due to the US COVID-19 pandemic, relative to average life expectancy in the decedent's age-sex-race/ethnicity subgroup, by age group, sex, and race/ethnicity



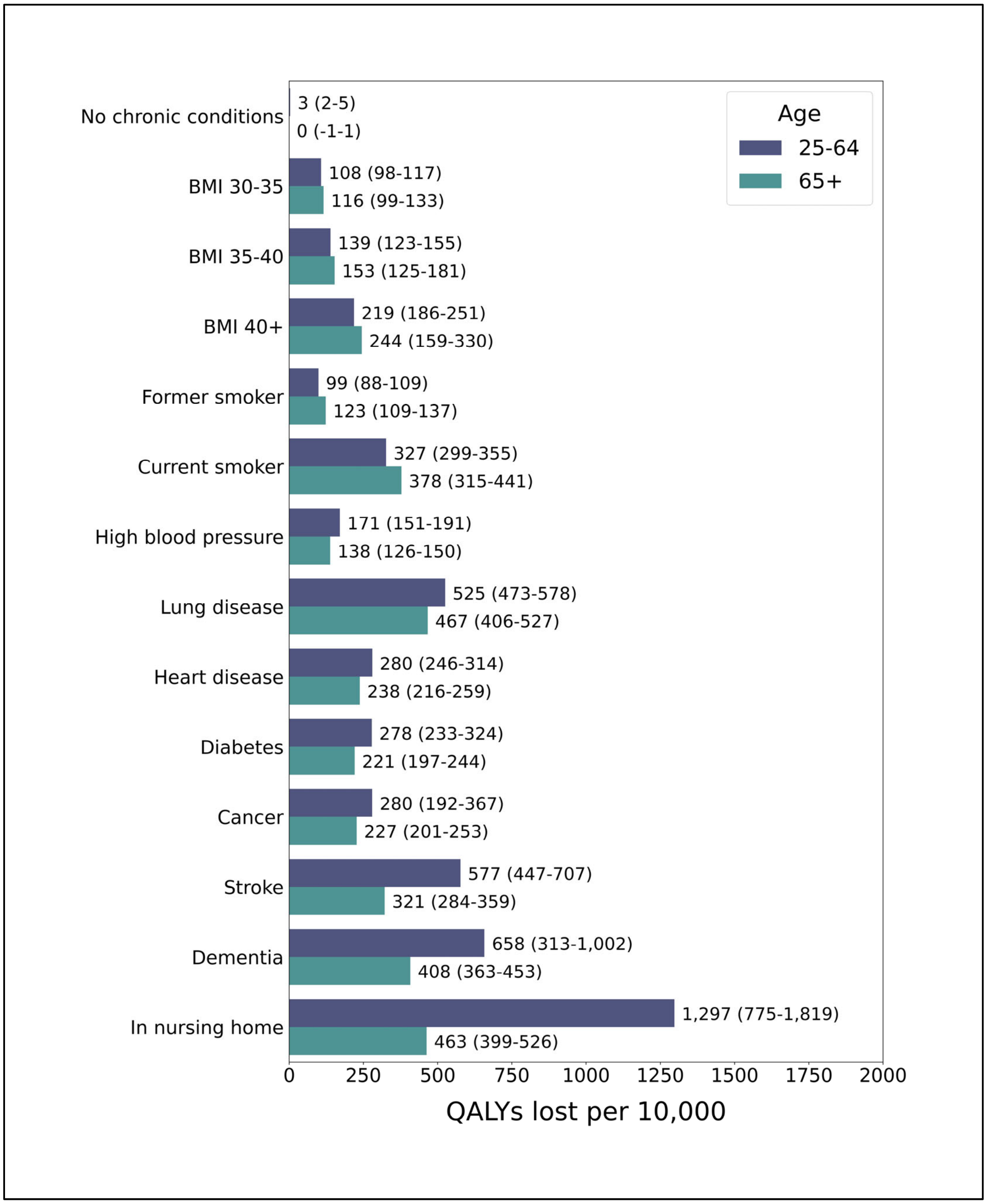
This figure reports the distribution of the number of years of life lost (YLLs) due the US COVID-19 pandemic, relative to the decedent's age-, sex-, and race/ethnicity-adjusted life expectancy as reported in the 2018 period life table from the Centers for Disease Control and Prevention (CDC). An x-axis value of 0 indicates that the decedent's YLLs, which are estimated by microsimulation under the Individualized Risk analysis assumptions, are equal to the average CDC life expectancy in their age-sex-race/ethnicity subgroup. Values greater than zero correspond to decedents with YLLs above the average CDC life expectancy for their subgroup, while values less than zero correspond to individuals with YLLs below the average CDC life expectancy. The dashed vertical lines report medians of the distributions. 95% uncertainty intervals are given in parentheses. LE: life expectancy.

Supplement Figure 6. Average Risk analysis: number of quality-adjusted life-years lost per 10,000, by age group and comorbidity



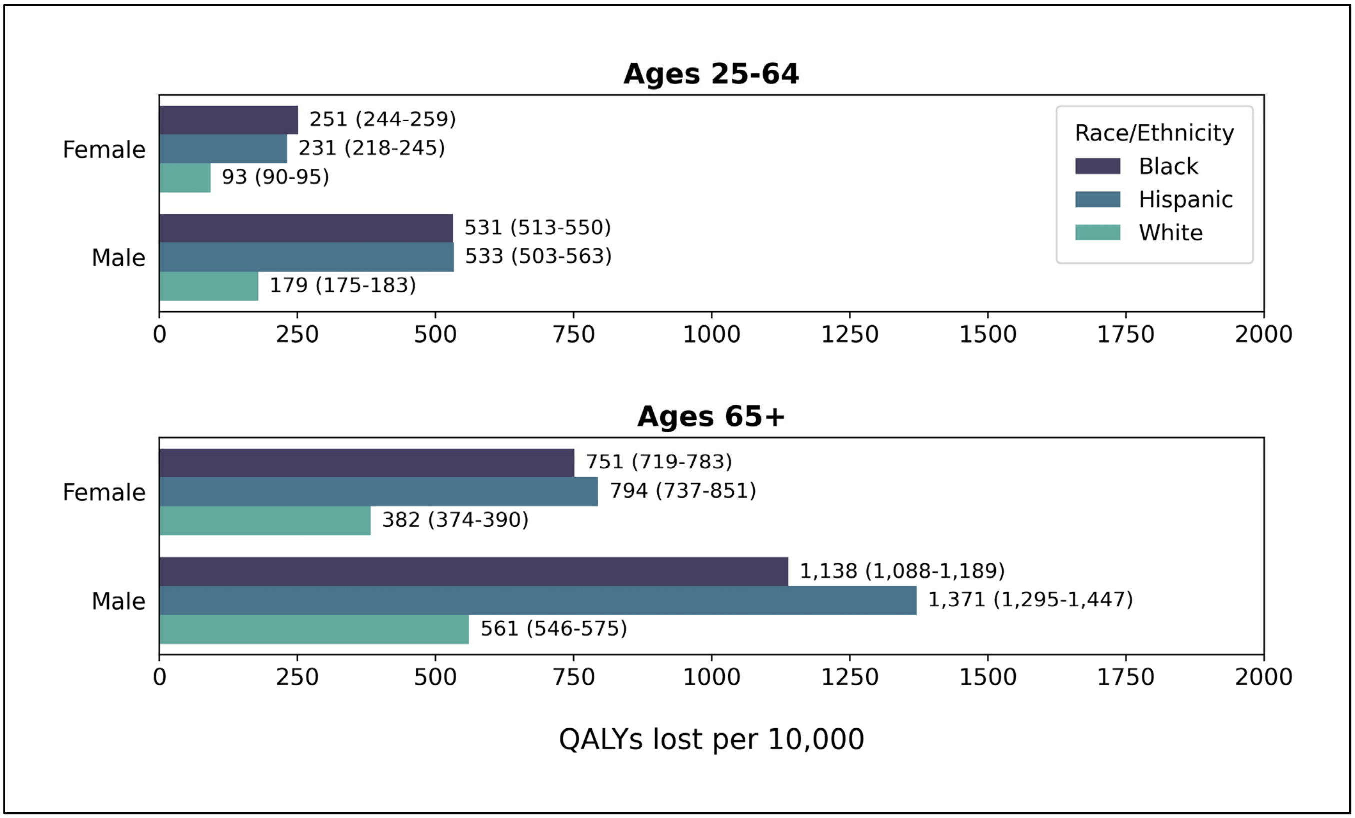
This figure reports the number of quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic among US adults ages 25-64 and ages 65+, by comorbidity, over the time period March 22, 2020 through March 13, 2021. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Average Risk analysis, which assumes that each excess death occurred randomly within the 5-year age, sex, and race/ethnicity category that corresponds to that death. Estimates for dementia and living in a nursing home pertain only to ages 55+. Non-COVID-19-related excess deaths are assumed to occur based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. BMI: Body Mass Index.

Supplement Figure 7. Frailty-Based Risk analysis: number of quality-adjusted life-years lost per 10,000, by age group and comorbidity



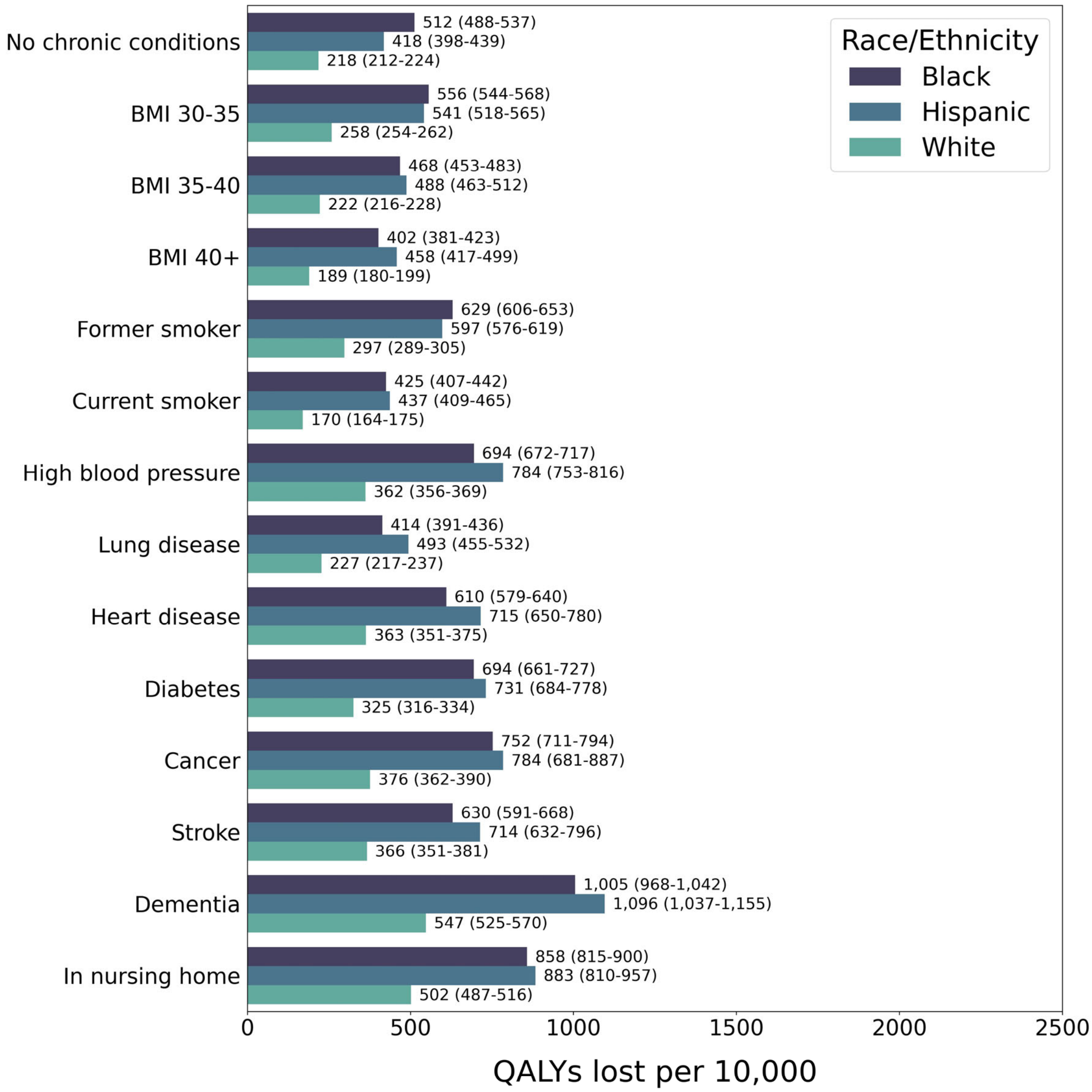
This figure reports the number of quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic among US adults ages 25-64 and ages 65+, by comorbidity, over the time period March 22, 2020 through March 13, 2021. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Frailty-Based Risk analysis, which assigns all excess deaths within the subgroup to the individuals with the highest annual mortality hazard projected by the microsimulation. Estimates for dementia and living in a nursing home pertain only to ages 55+. Non-COVID-19-related excess deaths are assumed to occur based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. BMI: Body Mass Index.

Supplement Figure 8. Number of quality-adjusted life-years lost per 10,000, by age group, sex, and race/ethnicity



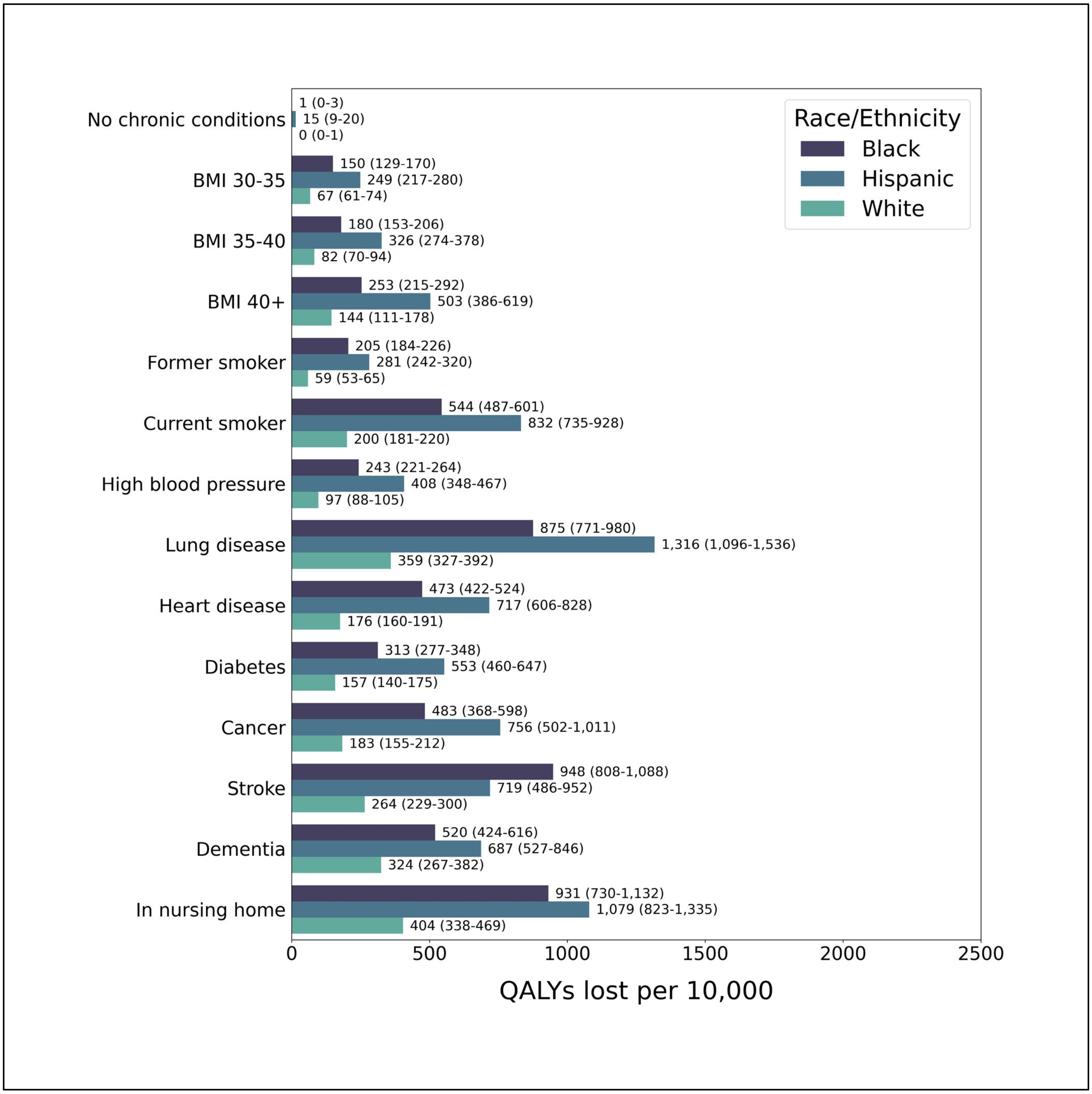
This figure reports the number of quality-adjusted life-years (QALYs) lost per 10,000 among US populations ages 25-64 and 65+, by race/ethnicity and sex, over the time period March 22, 2020 through March 13, 2021 as a result of the COVID-19 pandemic. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Individualized Risk analysis, which assigns all COVID-19-related excess deaths within the age-sex-race/ethnicity subgroup in proportion to estimates of COVID-19 comorbidity mortality odds ratios, and assigns non-COVID-19-related deaths in proportion to the 2020 (pre-COVID-19) annual mortality hazard projected by the microsimulation.

Supplement Figure 9. Average Risk analysis: number of quality-adjusted life-years lost per 10,000, by race/ethnicity and comorbidity



This figure reports the number of quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic among US adults ages 25-64 and ages 65+, by comorbidity and race/ethnicity, over the time period March 22, 2020 through March 13, 2021. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Average Risk analysis, which assumes that each excess death occurred randomly within the 5-year age, sex, and race/ethnicity category that corresponds to that death. Estimates for dementia and living in a nursing home pertain only to ages 55+. Non-COVID-19-related excess deaths are assumed to occur based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. BMI: Body Mass Index.

Supplement Figure 10. Frailty-Based Risk analysis: number of quality-adjusted life-years lost per 10,000, by race/ethnicity and comorbidity



This figure reports the number of quality-adjusted life-years (QALYs) lost from the COVID-19 pandemic among US adults ages 25-64 and ages 65+, by comorbidity and race/ethnicity, over the time period March 22, 2020 through March 13, 2021. 95% uncertainty intervals are given in parentheses. The estimates are produced by the microsimulation model's Frailty-Based Risk analysis, which assigns all excess deaths within the subgroup to the individuals with the highest annual mortality hazard projected by the microsimulation. Estimates for dementia and living in a nursing home pertain only to ages 55+. Non-COVID-19-related excess deaths are assumed to occur based on the (pre-COVID-19) mortality probabilities projected by the microsimulation. BMI: Body Mass Index.

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