Beyond Deaths per Capita: Three CoViD-19 Mortality Indicators for Temporal and International Comparisons

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Updated Version, 5/28/2020

Original Manuscript Submitted 4/29/2020, Published 5/5/2020 at:
https://www.medrxiv.org/content/10.1101/2020.04.29.20085506v1

Abstract
CoViD-19 deaths to population size ratios fail to account for well-documented age and sex differences in CoViD-19 mortality. To assess trends across populations for which CoViD-19 deaths might not be available by age and sex, an indirect age-and-sex adjustment can still be performed. The corresponding Comparative CoViD-19 Mortality Ratio (CCMR) only requires *population* age and sex compositions.
To compare CoViD-19 and overall mortality levels, the Crude Death Rate (CDR) and life expectancy at birth for recent calendar years are the most widely available overall mortality indicators. Readily comparable to an annual CDR, a Crude CoViD-19 Death Rate (CCDR) can be calculated for periods of any duration. CoViD-19-induced declines in projected life expectancy at birth for 2020 can also be calculated from existing life tables.
We calculate the CCMR and CCDR for the period from their first CoViD-19 death to the present using US age and sex data and current estimates of CoViD-19 deaths in 166 Countries whose population composition is available from the UN, 28 Provinces in China, the 50 United States and DC. Across these 245 populations, 14 States and 11 Countries have CCMR values above 1—the US value by construction. Most affected to date, the period CCDR in New York exceeds its CDR for the most recent year available (7.83 per thousand in 2017).
We also calculate CCMR and CCDR values corresponding to projections for the 50 States and DC, and for 49 countries, for which we can additionally calculate reductions in 2020 life expectancy at birth using UN life tables. This suggests life-expectancy reductions between .5 and 1 year for 7 European Countries, 3 South-American Countries and the US. The .55 reduction in the U.S. amounts to nearly twice the largest single-year decline induced by HIV/AIDS (-.3 between 1992 and 1993) or the total decline induced by opioid overdoses (also -.3 between 2014 and 2017), and would bring US life expectancy at birth down to its lowest level since 2008. As current CoViD-19 death counts likely underestimate the total increase in deaths and current projections do not account for possible new infection waves later this year, the impact on 2020 life expectancies at birth should be expected to exceed these figures.

Acknowledgment
The authors benefited from facilities and resources provided by the California Center for Population Research at UCLA (CCPR), which receives core support (P2C-HD041022) from the Eunice Kennedy Shriver National Institute of Child Health and Human Development (NICHD).

Beyond Deaths per Capita

Background

As of this writing, 5.75 million cases of the novel coronavirus disease 2019 (CoViD-19) have been reported and more than 350,000 deaths attributed to the disease worldwide according to Johns Hopkins University's Center for Systems Science and Engineering (CSSE).[1] The most frequently cited of several online tools that have been developed to track the fast expanding pandemic, the CSSE interactive dashboard maps the location and number of confirmed CoViD-19 cases, deaths, and recoveries for all affected countries.

The CCSE numbers illustrate a public health emergency that developed at a very fast pace. In response, national and local institutions have issued public-health orders to slow the spread of the disease and "flatten the curve" so that the number of infected individuals in need of intensive care peaks at a level lower than local hospital capacity. Comparing CoViD-19 trends over time and place may thus provide important public health insights about the strategies that have succeeded in reducing the need for emergency hospitalizations and, eventually, the CoViD-19 death toll. The number of reported cases seems to represent only a small, varying fraction of the actual number of cases,[2] depending in particular on variable testing capacities. Deaths attributed to CoViD-19 provide a more reliable basis for comparative assessments. As the HIV pandemic made clear,[3] a pandemic is more reliably tracked with mortality data. While the current CoViD-19 death toll is also undercounted due to cause-of-death mis-diagnostics and delays in reporting deaths at home and nursing homes, this death undercount is of a much smaller magnitude than the case undercount and can be expected to decline further over time.

The United States currently has the highest estimated number of CoViD-19 deaths, having surpassed Italy, which earlier surpassed China. Obviously, comparing the number of deaths in countries home to 60 million (Italy), 330 million (U.S.A.) or 1.4 billion (China) people makes little sense. Dividing the number of CoVid-19 deaths by the population size, a comparative table on the CSSE website displays vastly different ratios: from .33 deaths per 100,000 people in China, to 16.43 in the United States and to 43.66 in Italy (as of April 26, 2020.)[1] Considering the countries with at least 1,000 deaths, the largest ratio at the time appeared to be in Belgium, with 6,917 deaths but a ratio of 60.56 deaths per 100,000 people.

While comparing the number of deaths to the population size is a necessary first step in comparing CoVid-19 mortality across countries, this ratio does not possess several desirable properties. First, the ratio does not control for age and sex population compositions, whereas strong variations in CoViD-19 mortality by age and sex are have been well established in several countries. [4-5] Moreover, the ratio is not directly comparable to the most widely available measure of overall mortality, the Crude Death Rate (CDR): as it does not control for the time dimension, the ratio does not differentiate between numbers of deaths recorded in periods of different durations. The ratio may thus appear quite small in comparison to values of the CDR (say, 850 deaths per 100,000 person-year in the US), but most CoViD-19 deaths to date occurred in the last 2 months whereas the CDR typically includes deaths for entire calendar years. Finally, the value of ratio does not provide any intuition regarding the level of CoViD-19 mortality relative to overall mortality, for which the most easily interpretable indicator remains life expectancy at birth.

Methods and Data

To address these shortcomings, this article illustrates the properties of 3 comparative indicators of CoViD-19 mortality. First, the Crude CoViD-19 Death Rate (CCDR) is simply a period death *rate*, structured like the Crude Death Rate (CDR), that is, expressed in deaths per person-*year*:

$$CCDR[t_1, t] = \frac{D^C[t_1, t]}{N(t_m).(t_1 - t)}$$

This indicator only requires an estimate or a projection of the cumulative number of CoViD-19 deaths in a given population by time t, $D^C[t_1,t]$, the time of the first CoViD-19 death in the area, t_1, and the size of the population at some point t_m within that timeframe, $N(t_m)$.

Second, the Comparative CoViD-19 Mortality Ratio (CCMR) is an indirectly sex-and-age-standardized measure, structured like the Comparative Mortality Ratio (CMR):[6]

$$CCMR[t_1, t] = \frac{D^C[t_1, t]}{\sum_i {}^{US}M_i^C . N_i(t_m)}$$

where ${}^{US}M_i^C$ is the CoViD-19 death rate specific to age group i in the U.S.A. and $N_i(t_m)$ is the size of the age group in the population. This indicator was selected because a direct adjustment for age and sex would require numbers of CoViD-19 deaths by age and sex. Such breakdowns remain unavailable for many populations. Including the largest number of registered deaths to date, the weekly-updated Center for Disease Control (CDC) breakdown of CoViD-19 deaths by age for the U.S.A. was selected as the standard.

The third indicator translates the cumulative number of deaths due to CoViD-19 in the population during a reference period into an estimated decline in life expectancy at birth for the population for that reference period. This calculation requires previously projected life table functions for the period (i.e., not including CoViD-19 mortality). With life tables typically available for single or multiple calendar-year periods only, the difference can be calculated for a single calendar year, preferably for each sex separately, as:

$$\Delta e_0^o[Y] = e_0^o[Y] - {}^{-C}e_0^o[Y]$$

where ${}^{-C}e_0{}^0[Y]$ represents life expectancy at birth previously projected for the calendar year Y (i.e., not including CoViD-19 mortality) and $e_0{}^0[Y]$ represents its new projected value accounting for projected CoViD-19 mortality.

Details on the calculation of these three indicators are described in the online supplementary materials of this article. To illustrate the properties of these indicators, we calculate their values for a weekly updated set of cumulative CoViD-19 death counts, from Johns Hopkins University's CSSE,[1] and projections, from the Institute for Health Metrics and Evaluation (IHME).[7] Specifically, we calculate the CCDR and CCMR for the period starting on the date of the first CoViD-19 deaths reported in the population[8] and ending on the reference date of the estimates for 166 Countries whose population composition is available from the United Nations (UN), 28 Provinces in China, the 50 United States and DC. We do the same for the 49 countries, 50 States and DC for which IHME provides projections (currently until August 4th, 2020). Moreover, we use UN life tables to calculate reductions in life expectancy at birth for calendar year 2020 corresponding to these projections in the 49 Countries.

We are running web-scraping tool to weekly update the CDC CoViD-19 deaths by age and sex, and both the CCSE and IHME total numbers of CoViD-19 deaths. Available on a Github repository,[9] the corresponding values of the 3 indicators are thus updated weekly as well.

Results

We briefly describe the properties of the 3 indicators using calculations from the most recent weekly data update (May 23, Table 1). Beginning with values of the indirectly age-standardized CCMR across the 245 populations considered here, the highest values are found in 4 US States (New York, New Jersey, Connecticut and Massachusetts), followed by DC and Belgium. Nine other States and 10 additional Countries have CCMR values above 1—the US value by construction.

Comparing the CCMR and CCDR illustrates the effect of indirect age-and-sex standardization. While the CCMR for Belgium is 3.4, the ratio of its CCDR to the US CCDR is 4.4. Differences in age-and-sex composition thus partly contributes to differences in CoViD-19 mortality between the two countries. More importantly, while the CCDR in Ecuador is lower than in the U.S. (.89 per thousand to 1.29 per thousand), its CCMR is higher. This shows that accounting for differences in age-and-sex compositions, CoViD-19 mortality is actually higher in Ecuador than in the U.S. and illustrates the importance of performing this type of adjustment.

Not recommended to compare trends across populations, the CCDR provides a useful metric to compare CoViD-19 to overall mortality. In the most affected population to date, the period CCDR in the State of New York (7.89 per thousand) for the period from its first reported CoViD-19 death to the date of the most recent estimate exceeds its CDR for the most recent year available (7.83 per thousand in 2017).[10] As the period CCDR controls for the duration of the period to which the cumulative count of deaths pertains, it is also useful to compare cumulative mortality numbers over time. Whereas the ratio of cumulative deaths per capita can only increase over time, the CCDR values for the period beginning with the first death will decline as soon as the number of additional deaths drops below its average for the period. This is illustrated here by the fact that CCDR values are higher for estimated than for projected mortality in the Countries and States first affected by CoViD-19. However, the IHME projections yields higher CCDR values for the period ending on August 4, 2020 than the current CSSE estimates in some Countries (e.g., .95 v. .49 per 1,000 in Brazil) and States (e.g., .60 v. 2.00 per thousand in Arizona).

According to IHME projections, declines in life expectancy at birth for 2020 of .5 to a year are projected in 7 European Countries (Belgium, France, Ireland, Italy, Spain, Sweden, and the United Kingdom), 3 South-American Countries (Brazil, Ecuador and Peru) and the U.S.A.

Discussion

The results above are used to illustrate the properties of the 3 proposed indicators and the limitations of considering CoViD-19 mortality differences across Countries only. To summarize, in order of increasing data requirements, the period CCDR incorporates the temporal dimension of CoViD-19 mortality. The CCMR (indirectly) standardizes for differences in population age distribution. Relative to the U.S.A., age standardization lowers the CoViD-19 mortality assessment in European Countries and raises it in South-American and most Asian countries. An age-standardized indicator as well, the decline in life expectancy at birth translates CoViD-19 mortality projections into an easily interpretable metric. A decline of .55 of a year in life expectancy at birth, currently projected in the U.S.A. and 10 other countries, would be comparable to twice the decline in life expectancy at birth during each of the last two public health crises in the U.S.A.: a decline from 75.8 in 1992 to 75.5 years in 1993 (AIDS mortality) and from 78.9 years in 2014 and 78.6 years in 2017 (opioid-overdose mortality).[11] However, the decline would be induced by mortality changes over a more condensed time scale in the case of the CoViD outbreak.

More importantly, data about the pandemic are changing too rapidly to draw any conclusion from the current values of the indicators. Based on a single set of estimates and projections, this set of results fails to express the uncertainty surrounding future projections and even current estimates. To take a single example, on April 29, 2020, the Global Epidemic and Mobility Model (GLEAM) used by researchers at Northeastern University projected between 60,000 and 121,000 CoViD-19 deaths in the U.S.A. by May 12, 2020 under the "mitigated" scenario with stay-at-home policy.[12] Other models suggested even higher numbers for the same period, whereas the IHME projected 68,000 deaths by August 4, 2020.[13] Moreover, at the moment none of these models can predict the likelihood of a second wave of infections later in the year.

The eventual decline in life expectancy will also depend on the "downstream" effects of the pandemic and mitigating policies, which may affect mortality from other causes. While mortality rates from some causes may well decline (e.g., motor-vehicle injuries), mortality rates from other causes are likely to increase, especially in places where hospitals' intensive-care capacities became saturated by the surge in CoViD-19 emergency hospitalizations. Current CDC estimates on excess deaths[14] seem to indicate that either CoViD-19 deaths are under-reported or that CoViD-19 induced increases in mortality from other causes. A combination of these two factors is likely and neither factor is accounted for the projections and their translation into life-expectancy reduction latter.

The rapidly evolving understanding of CoViD-19 mortality continues to require frequent updates and flexibility. Calculating CCMR and CCDR for populations at more local level (within Countries or States) may also be desirable. For customized calculations derived for different periods and populations or from different data sources, our web-scraping script and calculation R-routine are also available on the Github repository.

Table 1: Comparative CoViD-19 Mortality Indicators for Selected Populations (ranked by CCMR estimate)

		Estimates		Projections		
Country, Province or State	**Region or Country**	**CCDR**	**CCMR**	**CCDR**	**CCMR**	$\Delta e_0^o(2020)$
New York	United States of America	7.89	5.80	3.65	2.68	--
New Jersey	United States of America	6.62	4.89	3.55	2.62	--
Connecticut	United States of America	5.76	3.97	3.13	2.16	--
Massachusetts	United States of America	5.19	3.81	3.01	2.21	--
District of Columbia	United States of America	3.81	3.76	1.98	1.96	--
Belgium	Western Europe	4.36	2.76	2.07	1.31	-0.967
Louisiana	United States of America	3.04	2.55	1.51	1.27	--
Rhode Island	United States of America	3.50	2.41	1.79	1.24	--
Michigan	United States of America	2.93	2.14	1.38	1.01	--
United Kingdom	Northern Europe	2.55	1.70	1.37	0.92	-0.714
Maryland	United States of America	2.08	1.68	1.68	1.35	--
Spain	Southern Europe	2.82	1.61	1.34	0.77	-0.705
Illinois	United States of America	1.97	1.53	1.57	1.22	--
Sweden	Northern Europe	2.06	1.30	1.29	0.81	-0.648
Italy	Southern Europe	2.21	1.14	1.16	0.60	-0.568
Netherlands	Western Europe	1.63	1.07	0.87	0.57	-0.464
United States of America	Northern America	1.29	1.00	0.91	0.70	-0.547
France	Western Europe	1.65	0.98	0.91	0.54	-0.551
Switzerland	Western Europe	1.05	0.67	0.48	0.30	-0.282
Brazil	Southern America	0.49	0.65	0.96	1.27	-0.777
Iran (Islamic Republic of)	Southern Asia	0.34	0.63	--	--	--
Canada	Northern America	0.82	0.58	0.58	0.41	-0.353
Arizona	United States of America	0.60	0.45	2.01	1.49	--
Turkey	Western Asia	0.29	0.42	0.14	0.21	-0.120
California	United States of America	0.44	0.37	0.38	0.32	--
Germany	Western Europe	0.49	0.27	0.26	0.14	-0.113
Hubei	China	0.21	0.24	--	--	--

Notes: Crude CoViD-19 Death Rates (CCDR, in deaths per thousand person-year) refer to the period between the first death from CoViD-19 in the population and the reference date of either the estimated or projected cumulative number of CoViD-19 deaths. The Comparative CoViD-19 Mortality Ratio (CCMR) uses age-and-sex CoViD-19 death rates for the U.S. and thus equals 1 for the U.S. by construction. Differences in projected life expectancy at birth for year 2020 ($\Delta e_0^o(2020)$) are expressed in years (see text and technical appendix for details).

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[8] Dates for most Countries and States were retrieved from the Institute for Health Metrics and Evaluation at https://covid19.healthdata.org. For other Countries, dates were obtained from the World Health Organization's daily situation reports at https://www.who.int/emergencies/diseases/novel-coronavirus-2019/situation-reports/

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[13] For different forecasts of the cumulative number of deaths in the U.S.A., for instance, see the CDC page at: https://www.cdc.gov/coronavirus/2019-ncov/covid-data/forecasting-us.html

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