**Excess all-cause mortality and COVID-19 related mortality: a temporal analysis in 22 countries, from January until August 2020**

**Running title:** Excess all-cause mortality during the COVID-19 pandemic

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**Abstract**

**Background**

This study aimed to investigate overall and sex-specific excess all-cause mortality since the inception of the COVID-19 pandemic until August 2020, among 22 countries.

**Methods**

Countries reported weekly or monthly all-cause mortality from January 2015 until end of June or August 2020. Weekly or monthly COVID-19 deaths were reported for 2020. Excess mortality for 2020 was calculated by comparing weekly or monthly 2020 mortality (observed deaths) against a baseline mortality obtained from 2015-2019 data for the same week or month using two methods: a) difference in observed mortality rates between 2020 and the 2015-2019 average, and b) difference between observed and expected 2020 deaths.

**Results**

Brazil, France, Italy, Spain, Sweden, UK (England, Wales, Northern Ireland, Scotland), and the USA demonstrated excess all-cause mortality, while Australia, Denmark, and Georgia experienced a decrease in all-cause mortality. Israel, Ukraine and Ireland demonstrated sex-specific changes in all-cause mortality.

**Conclusion**

All-cause mortality up to August 2020 was higher than previous years in some, but not all, participating countries. Geographical location and seasonality of each country, as well as the prompt application of high stringency control measures, may explain the observed variability in mortality changes.

**Keywords:** COVID-19; SARS-CoV-2; pandemic; mortality; infection control

**Key Messages:**

* Some countries showed excess all-cause mortality between January and August 2020, whereas others displayed either negligible excess mortality or even a decrease in all-cause mortality
* Excess mortality may be partly attributed to delayed application of strict control measures
* Lack of excess mortality may be due to seasonality and/or strict control measures in the participating countries
* Sex-specific mortality was different from total mortality in some countries
* The synergistic effect of several predictors of mortality warrants investigation

**Introduction**

A new coronavirus, Severe Acute Respiratory Syndrome CoronaVirus 2 (SARS-CoV-2), emerged in late 2019 as a cause of pneumonia in humans. SARS-CoV 2 rapidly spread worldwide from the initial outbreak site in the city of Wuhan, China, leading the World Health Organization (WHO) to declare a global pandemic on March 11, 2020. One year after its identification, the novel coronavirus infected more than 80 million individuals and was responsible for more than 2.04 million deaths, with confirmed cases in 214 countries1.

To assess the health burden of the coronavirus disease 2019 (COVID-19) pandemic, the excess mortality (defined as the difference between expected and observed mortality in a given time period) has been investigated and described in several countries2–11. However, the impact of the COVID-19 pandemic on mortality is not completely captured by the analysis of the reported COVID-19 deaths and cases due to limited testing capacity, disruption of health services, and possible reduction of other causes of death as a consequence of restrictive control measures. Indeed, many studies have highlighted that COVID-19 deaths represent only a small proportion of the excess mortality observed since the start of the pandemic in several countries5,6,12,13, indicating that indirect excess deaths may also contribute to the overall mortality burden. This is particularly true in countries heavily affected by the pandemic such as Italy5,6, France6, Brazil14,15, the United Kingdom (UK)6 and the United States of America (USA)12,13. Thus, analysis of overall excess mortality represents an important complementary tool to investigate the influence of SARS-CoV-2 pandemic on mortality. Importantly, in the case of COVID-19, during the initial weeks of the pandemic most countries lacked adequate testing and healthcare systems were overwhelmed with patients displaying symptoms of COVID-19; therefore, many cases and deaths that should have been attributed to COVID-19 were not tested and identified16–18. For this reason, all-cause excess deaths (i.e., observed deaths during the pandemic over those expected in the same period of previous years) is recommended by WHO and the European Centre for Disease Prevention and Control as a more reliable metric for comparing countries/regions19.

Excess mortality in countries less affected by COVID-19 and the extent to which any excess can be attributed to COVID-19 are less well researched. In addition, most studies investigating excess mortality to date have focused on single countries or world regions and have mostly relied on publicly available data2–11. Furthermore, existing studies have not interpreted the differences across jurisdictions or over time in the context of COVID-19 control measures and/or death reporting criteria2–11. This leaves a gap as to the excess mortality picture in countries without publicly available data, and in the interpretation of differences based on factors beyond excess deaths alone.

To this end, an international consortium consisting of over 50 institutions across 52 countries and six continents was formed to investigate excess mortality during the COVID-19 pandemic. The consortium attempts to include countries worldwide without restriction and constitutes an ongoing effort to monitor overall and cause-specific mortality resulting from the COVID-19 pandemic. The present study investigates overall and sex-specific excess all-cause mortality, since the inception of the COVID-19 pandemic until August 2020, in 22 countries.

**Methods**

*Data acquisition*

In this study, we examined the mortality data from 22 countries participating in the international consortium (Supplementary Figure 1 and Supplementary Table 1) that have collected and provided data until the end of either June (n=5) or August 2020 (n=17), depending on data availability. Information was collected for total and sex-specific all-cause mortality (for 2015-2020), as well as total and sex-specific COVID-19 deaths (for 2020). Anonymous data was collected from national vital statistics databases, either publicly available or with restricted access, from each participating country to the latest available data point of 2020 (Supplementary Table 1).

Countries reported all-cause mortality and COVID-19 deaths by week (either International Organization for Standardization - ISO - week, starting on Monday; or epidemiological - Epi - week, starting on Sunday; or other national counting week system, depending on the country). COVID-19 death reporting also differed between countries, as shown in Supplementary Table 1. Some countries (n=11) reported as COVID-19 deaths, deaths among positive cases irrespective of where COVID-19 was listed on the death certificate. Thus COVID-19 was either listed among the chain of causes leading to death or as a contributing condition on the death certificate (*cause of death, COD, or contributing condition*)20. Other countries (n=11) reported as COVID-19 deaths only the deaths where COVID-19 was listed among the chain of causes leading to death (*COD*)20; of these latter, France reported only hospital and nursing homes COVID-19 deaths. The national primary data sources used in this study and endorsed by the national partners might differ from publicly available repositories/databases, primarily due to retrospective addition of cases and deaths declared with some delay. Data was collected during October and November 2020, several weeks after the end of the study period, to account for reporting delays (ranging from a few days to a few weeks)6,21,22. The national data source, the period of available mortality data, time unit, and COVID-19 deaths definition used per country are summarized in Supplementary Table 1.

*Statistical analysis*

Excess mortality for 2020 was calculated by comparing weekly or monthly 2020 mortality (observed deaths) against a baseline mortality obtained from 2015-2019 data for the same week or month using two different methods. The choice of five years for the baseline mortality estimation was based on widely adopted practices from well-established surveillance consortia3,23,24 as well as on other published studies2. In the first method the baseline was computed as the average mortality rate of the previous five years8. In the second method, the baseline was estimated based on historical data accounting for seasonality, and long- and short-term trends; representing the expected number of deaths in 202024–26.

*Method 1: Observed 2020 versus 2015-2019 average mortality rate*

For each country (n = 22) and year, the weekly or monthly observed number of deaths was divided by the country’s population at the beginning of the particular year to obtain weekly and monthly mortality rates. Therefore, country-specific populations were assumed to be constant throughout the year and mortality rates were expressed as deaths per 100,000 population. Mortality rates instead of number of deaths were used to account for population differences. Total and sex-specific population estimates for the participating countries were obtained from the World bank27, except for the UK nations for which data from the Office for National Statistics28 was used, and for Cyprus for which Eurostat data29 was used to include only the population in the Republic of Cyprus government-controlled area. Population estimates for 2019 were also applied to 2020 data.For each country, the average weekly or monthly total and sex-specific year-to-date (YTD) mortality rate for 2015-2019 was calculated and plotted against weekly or monthly 2020 mortality rates up to the latest available data point of 2020, to provide a visual representation of excess mortality by time-point. For data visualisation, we downloaded and used a stringency index (SI); a composite measure based on nine response indicators including school closures, workplace closures, and travel bans, rescaled to a value from 0 to 100 (100=strictest), from the *Oxford COVID-19 Government Response Tracker*30. Although the index should not be interpreted as a score for the appropriateness or effectiveness of a country’s response, it provides indication on the number and strictness of government policies. For each country and time unit of 2020, the SI was categorised as: low (<25%), moderate (between 25-74%), and high (≥75%). The SI categories were then plotted together with the country profiles of excess mortality.

Then, the average YTD mortality rate between 2015-2019 was considered as the ‘baseline’, while excess mortality for 2020 was estimated for each country by subtracting the baseline from the 2020 YTD mortality rate. For Sweden and Cape Verde, only monthly data was available for this analysis. For Colombia trimester data were used for the YTD comparison (trimester data could not be graphically compared). For all other countries weekly data was used for the graphical and YTD comparisons.

*Method 2: Observed versus expected 2020 deaths*

Expected number of deaths for 2020 was modelled using Poisson regression, assuming a quasi-Poisson distribution to account for over-dispersion in the weekly mortality counts. We used a Generalized Linear Model with a linear time trend (weekly mortality as the time unit) to adjust for secular trends, and two sine and cosine terms for yearly and half-yearly seasonal cycles. The terms for sine-type cyclical seasonality were chosen based on the weekly distribution of the data and periodograms. Other periodicities (i.e., 4 and 9 months) were also tested but were omitted because the effect was negligible and did not improve the model fit. The same model was applied to all countries with weekly data, separately. The regression models were built on complete weeks and any truncated weeks were excluded. Truncated weeks were observed during the last week of the year in Australia, England and Wales, Scotland, and during the last two weeks in Northern Ireland. Different death counts around Christmas and New Year were observed and accounted for2. The residual variation was corrected for skewness by applying a 2/3 power transformation25. The 95% Confidence Intervals and standard deviation for expected deaths were also estimated. The weekly results of the observed *versus* expected deaths are displayed graphically for each country using z-scores [(number of observed deaths – expected mortality) / standard deviation of the residuals]. Z-scores range between -2 and +2 is considered ‘normal’ and a value of >4 z-scores is considered a substantial increase3,31.

Then, the sum of expected 2020 deaths was subtracted from the sum of the observed 2020 deaths to obtain an estimate of excess deaths. The statistical significance of excess deaths was determined using the 95% Confidence Intervals estimated by the model.

It is important to note that only countries providing weekly data (n = 19) were included in the second methodological approach. In addition, 2019 weekly mortality was not available for Scotland and, therefore, the estimation of ‘baseline’ was based on 2015-2018 data in both methods. For Northern Ireland and Spain, sex-specific all-cause mortality was not available at the time of data analysis, thus sex-specific all-cause mortality was calculated for 17 countries. England & Wales were considered as one country for the purposes of analysis and reporting of results, as combined data are routinely provided this way. For each country the reported type of COVID-19 death was used in both methods and no between-country comparisons were attempted. A sensitivity analysis involving the truncation of the observation period to week 26 (June 2020) for all countries was conducted to investigate any further reporting delay.

All analyses were performed in R Statistical Software, version 3.6.1 (The R Foundation for Statistical Computing, Vienna, Austria).

**Results**

*Observed 2020 versus 2015-2019 average mortality rate*

Tables 1 and 2 compare the country-specific YTD mortality rates of the previous five years (2015-2019) to 2020 for the total population and by sex, respectively. The total all-cause mortality rate (total, males, and females) was higher during 2020 compared to the average of the previous five years in 11 out of the 22 participating countries: Brazil, Cyprus, England & Wales, France, Italy, North Ireland, Scotland, Spain, the USA, Slovenia, and Sweden. Among the total population, the highest increase, in descending order, was observed for England and Wales, Spain, the USA, Scotland, Brazil, and Northern Ireland (>50 deaths per 100,000 population). In France, Sweden, Slovenia, Italy, and Cyprus the increase was less pronounced (<35 deaths per 100,000 population; countries listed in descending order). Within the countries with higher 2020 mortality rate, COVID-19 was reported as a COD in five countries (Cyprus, England and Wales, France, Italy, the USA) and as a COD or contributing condition in the other six countries (Brazil, Northern Ireland, Scotland, Slovenia, Spain, Sweden).

By contrast, Cape Verde, Estonia, Georgia, and Norway had a reduced YTD mortality rate in 2020 compared to the previous five years (range between -12.5 and -64.1 deaths per 100,000 population).

In the rest of the participating countries (Australia, Austria, Colombia, Denmark, Ireland, Israel, Ukraine), we observed discordant results in the mortality rates change within the two sexes.

*Weekly/monthly 2020 mortality rate and COVID-19 control measures*

The 2020 all-cause mortality rate against the 2015-2019 average mortality rate per week is displayed graphically for each country using country-specific scales in Figure 1 for total population and Figure 2 by sex. Figure 3 displays countries reporting monthly data; trimester rates were not plotted. The same figures also display the progress of the control measures in each country using the weekly or monthly SI, and the onset of COVID-19 death reports.

As shown in Figures 1-3, excess mortality rate during 2020 was observed for Brazil, England and Wales, France, Ireland, Italy, Northern Ireland, Scotland, Spain, Sweden, and the USA. The maximum mortality rate was observed sometime between week 12/2020 (Italy; 36.2 deaths per 100,000 population) and weeks 19-20/2020 (Brazil; 17.0 deaths per 100,000 population); and in April 2020 in Sweden (100.8 deaths per 100,000 population). The mortality rate peaks for 2020 were observed in the same time for males and females in France, England and Wales, the USA, and Sweden. However, small peaks of excess mortality were observed in Australia (week 13/2020), Austria (weeks 12 and 15/2020), Cyprus (weeks 20-21/2020), Estonia (week 17/2020), Georgia (week 28/2020), Israel (weeks 14, 21, 34/2020), Slovenia (week 26/2020), and Ukraine (weeks 4, 17, 29/2020).

COVID-19 deaths were first reported in March 2020 for all the participating countries except in the case of Spain, Italy, and the USA for which COVID-19 deaths were first reported in February 2020 (Figures 1-3). In Australia, deaths due to COVID-19 started end of February – beginning of March; and in Georgia, late March – early April 2020. In Colombia, COVID-19 deaths were also first reported during the first trimester of 2020. At the same time, in all countries, the beginning of the implementation of moderate or high stringency control measures ranged from week 9 to week 13 (SI: 25-74 %), and from week 11 to week 18 (SI: ≥75 %).

*Observed versus expected 2020 deaths*

For most countries where all-cause deaths in 2020 (January-June/August) were higher than expected, mortality was raised for both males and females (Brazil, England and Wales, France, Scotland and the USA) (Tables 3 and 4). For Ukraine and Israel, only male deaths were elevated; for Ireland total and female deaths; and for Italy total and male deaths. For some countries (Northern Ireland, Spain) only total deaths were elevated.

On the contrary, all-cause 2020 deaths in Australia and Denmark (both sexes), and only total and male deaths in Georgia were lower than expected.

The weekly COVID-19 deaths in relation to excess deaths is displayed graphically in Supplementary Figure 2.

*Weekly deaths z-score*

Figure 4 shows the weekly deaths z-score over time from week 1/2018 to week 26/2020 or week 35/2020, for the total population. The countries that showed a substantial increase (>4 z-scores) in the observed mortality during 2020 include Brazil, Cyprus, England and Wales, France, Ireland, Italy, Northern Ireland, Scotland, Spain and the USA. The first substantial weekly excess in all-cause deaths was observed in different weeks of 2020 depending on the country; from week 11 (Italy) to week 21 (Cyprus). This excess in mortality lasted from one (Cyprus) to seven (England and Wales, Scotland) weeks. In Brazil and the USA, a substantial excess mortality has been observed since week 17 and 14 of 2020, respectively.

Among the countries with a substantial excess of mortality for the total population, a similar excess was observed for both males and females in Brazil, France, Ireland, and the USA; with differences in the duration and timing of observed weekly excess mortality (Figure 5). However, a substantialexcess in mortality was observed only for total population in Cyprus, only for total and males in England and Wales, and only for total and females in Italy and Scotland.

The sensitivity analysis by truncating the observation period to week 26 for all countries did not show any difference for the participating countries experiencing the first wave of the pandemic in the first half of 2020 (data not shown).

**Discussion**

*Summary of findings*

In this investigation of 22 countries across five continents, we show that Brazil, France, Ireland, Italy, Spain, Sweden, UK (England & Wales, North Ireland, Scotland) and the USA demonstrated excess all-cause deaths between January and June or August, 2020, among males and females combined. In Italy the excess deaths were driven by excess deaths among males and in Ireland by excess deaths in females. On the other hand, we show that Australia, Denmark, and Georgia actually experienced a decrease in deaths in 2020 among males and females combined. Austria, Cyprus, Ireland, Israel, Norway, Slovenia, Ukraine, Cape Verde and Colombia experienced none or only very limited excess deaths among males and females combined.

Our findings on excess mortality in Brazil, France, Italy, Spain, Sweden, UK (England & Wales, North Ireland, Scotland) and the USA are in agreement with previous publications and reports2,3,5–8,10,11,13,32,33. Similarly, the lack of an increase in overall all-cause mortality in Australia, Austria, Denmark, Estonia, Israel and Norway was in agreement with previous reports2,3,32–34. Colombia was elsewhere demonstrated to have excess mortality during 202035, but the increase in mortality started towards the end of the observation period of Colombia for this study, explaining the lack of an increase in our results. To our knowledge, this is the first published analysis on excess mortality in Cyprus, Georgia, Ireland, Slovenia, Ukraine, and Cape Verde.

*Mortality burden across countries*

In several of the participating countries, moderate and high stringency control measures were first put in place on the same week or one week after the first reported COVID-19 deaths. Other countries implemented such measures ahead of the peak of the pandemic. Still, in some countries strict control measures were either applied with delay or not applied at all. As discussed below, the mortality burden observed in the participating countries of this study, seems to be, at least partly, related to the promptness in the application of control measures of high SI.

The magnitude of excess mortality observed in Brazil, France, Italy, Spain, Sweden, UK and the USA appears to correspond to lack of, or delay in, application of strict control measures by the respective governments after the first COVID-19 death in these countries. Italy, Spain, UK and Brazil enforced high stringency measures after three (Italy, UK), five (Spain), and seven (Brazil) weeks from the first COVID-19 death. Although for France it appears that strict measures were implemented soon after the first rise of COVID-19 deaths in hospitals and nursing homes (week 12) the first COVID-19 deaths occurred mid-February in the country36, suggesting a delay in enforcing strict control measures. Similarly, in the countries of the UK, the delay between the first death and the application of measures with a SI of ≥75% is likely to be longer due to limited testing taking place in the UK during the first weeks of the pandemic37. In Brazil, pre-existing inequalities in health care access, particularly to critically ill patients, also accounted for excess mortality38. On the other hand, Swedish and USA governments did not apply measures whose SI was above 75% for the duration of this study and this may have contributed to poorer control of the pandemic and higher excess mortality.

Ireland enforced strict measures four weeks after the first COVID-19 death, which may have led to an initial surge in cases. However, mortality was decreased in the weeks subsequent to these strict measures, possibly leading to lower overall excess mortality. In Denmark, despite the lack of enforcement of measures with a SI ≥75%, the Danish government was among the first countries in Europe to act firmly against the virus by declaring a national lockdown and closing its borders which, along with other social factors, was sufficient to prevent excess mortality39.

On the contrary, the lack or only modest excess mortality in countries such as Austria, Estonia, Israel, Norway, Cyprus, Georgia, Slovenia and Ukraine, can be partly attributed to the implementation of measures of stringency ≥75% within 2 weeks of the first COVID-19 death in these countries. Previous studies gave evidence that a strict lockdown is associated with a rapid and large decrease in transmission as measured by the effective reproduction number40,41. Our study adds to this evidence by suggesting that the introduction of strict lockdown measures in the early pandemic phase may also be associated with lower mortality.

Furthermore, the decreased mortality seen in some countries located in the tropical region or in the southern hemisphere, such as Colombia, Cape Verde and Australia, are most likely attributed to the different timing of the COVID-19 pandemic in these countries. The different seasonality patterns and different meteorological factors, coupled with strict control measures informed from lessons learned based on countries affected earlier on, led to a mild impact of the pandemic in these countries before July, thereby explaining their lack of excess mortality within the date window of this study. More specifically, Colombia experienced a steady increase in cases since March but had its peak of the COVID-19 pandemic in July and August 2020; Australia had a minor peak in coronavirus cases in March, but the number of cases has substantially escalated in July 2020; and Cape Verde started seeing a surge in cases over the summer, but the peak of the pandemic was experienced in September-October 202030. Moreover, Australia was entering the influenza season as the restrictions were introduced and the government brought forward and expanded the flu vaccination campaign. As a consequence, flu deaths were delayed or avoided, contributing to reduced all-cause mortality.

*Sex differences*

In this study, some countries that did not display changes in mortality for the total population, demonstrated sex-specific increases or decreases. Males in Israel and Ukraine, and females in Ireland demonstrated increases in mortality. This highlights the importance of examining sex specific differences in all-cause mortality, as there is an evident sex difference excess mortality2.

*Challenges in COVID-19 and all-cause excess mortality investigations*

One challenge in excess mortality investigations, which complicates between-country statistical comparisons, is the issue of delays in death registrations within and between countries, which is complicated even further by whether the country reports deaths by the date of death, or by the date of registration. Delays in death reporting can range from a few days to a few weeks6,21,22. We attempted to account for such delays by allowing a minimum of four weeks between the end of the observation period and data acquisition and by carrying out a sensitivity analysis, which demonstrated that our results were not affected by reporting delays. However, death counts from each country may be differentially affected by delays in registrations, making comparisons up to one time-point inaccurate.

Another challenge which contributes to the variability of results between countries is differential practices in death reporting. Many studies have previously established significant inaccuracies in the cause of death as reported on death certificates and the WHO estimates that only 13% of the world’s population resides in countries with ideal death registration systems (reviewed in 42). These inaccuracies may have been exacerbated during the COVID-19 pandemic. More specifically, a report on the reporting COVID-19 deaths in five European countries has identified regulatory and legislative differences in the procedures followed regarding the completion of death certificates43. Differential practices between countries include, among others, the need for an external examiner, who is authorized to complete the death certificate, and the legislative requirement to notify authorities of suspected COVID-19 deaths. Additionally, regarding the cause of death, the report highlighted differences between countries in how this is documented on the death certificate, since in most countries the medical practitioner completing the form can exert considerable discretion on what is listed on the certificate. Information provided on the causes of death and reported on death certificates was found to vary considerably, based on different conventions and/or rules regarding whether COVID-19 was included as a direct or indirect cause of death.

Furthermore, the different COVID-19 death definitions adopted by each country, but also the testing practices followed during the pandemic by different countries (testing only hospitalized patients, not testing care-home residents, etc.) adds uncertainty to investigations of COVID-19 and all-cause mortality44,45.

Also, depending on their geographical location, different countries experienced the first wave of the pandemic and its peak during different weeks or months of the year. Early in the pandemic, northern hemisphere countries with cold climates appeared to be the most vulnerable to COVID-19 transmission, while southern hemisphere countries and tropical regions seemed to be the least affected46. As previously mentioned, these differences may be due to seasonality patterns and more specifically the role of meteorological factors affecting host susceptibility to infection, and modes of transmission46,47. The countries participating in this study have very diverse geographic locations, spanning both hemispheres. Even though we attempted to include in this publication data up until the end of August 2020, we were not able to fully capture the first wave of the pandemic; countries such as Cape Verde never experienced a peak in COVID-19 infections during this study’s observation period. Case numbers provide evidence that the COVID-19 pandemic only started to noticeably influence Cape Verde after June 202048. Therefore, the timing of such investigations needs to be considered when interpreting each country’s results.

Excess all-cause mortality investigations are made even more challenging by the evidenced differences in baseline mortality in different countries49. In this study, the crude YTD all-cause mortality rate for countries providing data until August ranged from 353.1 deaths per 100,000 population in Israel to 874.7 deaths per 100,000 population in Georgia. Differences in baseline mortality between countries can be attributed, among others, to the age-distribution of populations, the different burdens of disease and differential access to healthcare49. An appropriate measure to facilitate between-country comparisons is the P-Score, which takes the absolute difference in mortality as a percentage of the baseline mortality. However, even if excess mortality is presented in reference to baseline mortality, it is likely that baseline mortality and the reasons that contribute to a country’s baseline mortality can exaggerate or inflate excess mortality during the pandemic.

Finally, strictness and timeliness of government measures, and geographical location as discussed in this study, are not the only potential contributors to excess mortality due to COVID-19. Baseline health care availability, access and quality in each country, and particularly a country's critical care capacity, and its ability to surge this capacity quickly under rising cases were likely other contributors to excess mortality50. On the other hand, country prosperity was shown to be associated with a higher COVID-19 spread and mortality for several reasons outlined elsewhere51. Moreover, population density is associated both with COVID-19 infection and mortality52–54. Therefore, variation in population densities between countries may also contribute to a variation in COVID-19 mortality and excess mortality. Also, the demographic and immunological profile of populations, including their age structure, may also be impacting on their mortality experience during the COVID-19 pandemic55. Undeniably, the first wave of the pandemic unfolded diverse and complex responses of citizens, government and businesses. Civic behaviour in the respect of social distancing and use of masks, adequate contact tracing services coupled to sufficient testing capacity and smart use of mobile technologies, as well as community support and solidarity, along with good governance and tempered and evidenced-base government communication are good examples of the complexity of effective response and resiliency to COVID-1956. All the aforementioned complex factors probably synergistically or additively moderated mortality and contributed to the variability in mortality changes between countries. Albeit challenging and beyond the scope of the present study, a comprehensive analysis of the relative impact of these factors on COVID-19 and all-cause excess mortality is warranted.

*Strengths and Limitations*

Our study has some important strengths compared to other comparative mortality studies. First, it is one of the largest and most geographically diverse studies that relied on data from national and primary sources, rather than on publicly available data. Moreover, 19 out of the 22 countries (86.4%) included in the analysis were evaluated as having very high or high quality civil registration and vital statistics systems (only 2 and 1 countries were evaluated as low and medium quality, respectively) reinforcing the validity of our results57. In addition, it is one of the few studies investigating excess sex-specific mortality and also one of the few examining excess mortality in light of COVID-19 control measures. Lastly, our results were based on two independent methodologies, which demonstrated agreement in cases of increases or decreases in mortality. The use of two methodologies enabled us to investigate countries which lacked weekly mortality data, and it also allowed us to validate method 1, which can be considered a simpler approach and feasible even for countries with mortality data of limited granularity, against method 2, which is based on a more accurate statistical methodology.

At the same time, our study also has limitations. First, for all the reasons outlined in the discussion, our study did not attempt any between-country statistical comparisons or a pooled analysis but focused instead on the mortality picture of each of the participating countries independently. Secondly, due to the lack of age-group specific mortality data from many countries, investigation of excess mortality by age-group was not possible. Lastly, we cannot rule out that delays in death reporting may be affecting our results, even though we attempted to account for such delays by a) allowing at least four weeks between the end of the observation period and data acquisition, and b) performing a sensitivity analysis where the observation period was truncated at least three months before data acquisition.

**Conclusion**

In this excess mortality investigation including 22 countries across the globe, it became evident that up until the end of June or August 2020, several countries showed excess all-cause mortality compared to what was observed in or expected based on the previous five years.. Yet, other countries managed to avoid increases in all-cause mortality. The excess mortality picture in the 22 participating countries was shown to be heavily influenced by the geographical location and seasonality of each country, as well as the promptness of governments to apply control measures of high stringency. As the pandemic continues and even worsens in many Northern hemisphere countries and as it now heavily affects countries of the Southern hemisphere as well, the lessons learned from the first six or eight months of the pandemic can prove useful in order to minimize increases in all-cause mortality.

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**Table 1 – Excess mortality: Observed 2020 mortality rate *versus* 2015-2019 average mortality rate (deaths per 100,000 population) and COVID-19 mortality rate**

**Table 2 – Excess mortality by sex: Observed 2020 mortality rate *versus* 2015-2019 average mortality rate (deaths per 100,000 population) and COVID-19 mortality rate\*§**

**Table 3 - Excess deaths:** **Observed *versus*expected 2020 deaths**

**Table 4 - Excess deaths by sex: Observed *versus*expected 2020 deaths \*§**

**Colour Figure online, B&W Figure in print:**

**Figure 1 – Observed 2020 mortality rate *versus* 2015-2019 average mortality rate (per 100,000 population) and Stringency Index (SI,%) for countries providing weekly data (Solid vertical line indicates the start of the reported COVID-19 deaths)**

|  |  |  |
| --- | --- | --- |
| 2020 Mortality rate | 2015-2019 Mortality rate average | 2015-2019 Mortality rate range |
|  |  |  |

**Colour Figure online, B&W Figure in print:**

**Figure 2 – Observed 2020 mortality rate *versus* 2015-2019 average mortality rate (per 100,000 population) and Stringency Index (SI,%), by sex for countries providing weekly data (Solid vertical line indicates the start of the reported COVID-19 deaths)**

|  |  |  |
| --- | --- | --- |
| 2020 Mortality rate | 2015-2019 Mortality rate average | 2015-2019 Mortality rate range |
|  |  |  |

**Colour Figure online, B&W Figure in print:**

**Figure 3 – Observed 2020 mortality rate *versus* 2015-2019 average mortality rate (per 100,000 population) and Stringency Index (SI,%), for total population and by sex, for countries providing monthly data (Solid vertical line indicates the start of the reported COVID-19 deaths)**

|  |  |  |
| --- | --- | --- |
| 2020 Mortality rate | 2015-2019 Mortality rate average | 2015-2019 Mortality rate range |
|  |  |  |

**Colour Figure online, B&W Figure in print:**

**Figure 4 – Observed (z-score) *versus* Expected (baseline) deaths**

|  |  |  |  |
| --- | --- | --- | --- |
| Z-score | Baseline | -2 < Z-score < 2 | Z-score > 4 |
|  |  |  |  |

**Colour Figure online, B&W Figure in print:**

**Figure 5 – Observed (z-score) *versus* Expected (baseline) deaths by sex**

|  |  |  |  |
| --- | --- | --- | --- |
| Z-score | Baseline | -2 < Z-score < 2 | Z-score > 4 |
|  |  |  |  |