Excess and laboratory-confirmed COVID-19-related mortality in Switzerland, a nationwide study

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# Introduction

The impact of the COVID-19 pandemic on mortality at the population level is of great concern to public health but difficult to quantify. There are two main approaches. The first relies on reporting laboratory-confirmed deaths, i.e., deaths of people with a recent positive SARS-CoV-2 RT-PCR or rapid antigen test. It is available in real-time but depends on the quality and comprehensiveness of the country’s registration system and testing availability. Therefore, the approach based on testing is rarely exhaustive, as some deaths will remain unidentified, for example, due to testing policies, shortages or overwhelmed health systems [1]. Further, laboratory-confirmed deaths exclude deaths that have been caused or averted indirectly due to control measures. The second approach relies on excess mortality and all-cause mortality data and counterfactual reasoning [2]. The observed number of deaths is compared to what would have been expected had the pandemic not occurred, based on mortality data from the previous years, demographic changes and covariates associated with mortality patterns. Excess mortality has the advantage of covering both the pandemic's negative and positive effects on mortality and the disadvantage of not being able to disentangle the different effects [3]. Also, estimations of excess mortality depend on model assumptions and methodological choices, such as age-specific population trends [4].

There have been many attempts to estimate excess mortality associated with COVID-19 in various settings [5][6][3]. Still, new approaches are needed to distinguish the proportion of excess mortality directly attributable to SARS-CoV-2 infections from indirect effects [3]. While data on laboratory-confirmed COVID-19-related deaths are incomplete, this may be overcome by analyzing trends in these deaths jointly with excess mortality across time, space and population groups. Excess deaths observed during peak epidemic activity, when laboratory-confirmed deaths are high, may inform the estimation of the total number of deaths attributable to SARS-CoV-2 infections, together with the proportion confirmed in laboratories (the ascertainment proportion). On the other hand, mortality deficits or excesses observed between epidemic waves may provide estimates of the indirect effect of the COVID-19 pandemic on mortality. Deficits in deaths observed following large epidemic waves may reflect mortality displacement, i.e., deaths occurring earlier than expected due to the “harvesting” effect. Changes in mortality that are evident over the entire pandemic period may be attributed to changes in behaviours. Examples include reductions in social contact that prevent the spread of other pathogens such as influenza, working from home, reducing traffic and road accidents, increases in anxiety or substance abuse that may increase suicide risk, or changes in health care seeking behaviours [7].

We studied laboratory-confirmed COVID-19-related deaths and excess mortality by time, space, and age group in Switzerland between February 2020 and April 2022. We computed the expected number of all-cause deaths in 2020 and 2021 by week, age group and location, accounting for the effect of temperature, national holidays, and population changes. We then developed a method to decompose all-cause mortality into deaths directly attributable to SARS-CoV-2 infection and deaths indirectly attributable to the pandemic. This approach allowed us to examine the completeness of ascertainment of deaths and the indirect effects of COVID-19 on all-cause mortality during different periods of the pandemic.

# Methods

## Data sources

We retrieved population data for the pre-pandemic years 2010 to 2019 from the *Federal Statistical Office* (FSO) [8]. We aggregate data by age (in five groups; 0-39, 40-59, 60-69, 70-79 and 80 years and older), sex (two groups) and administrative region (26 cantons). Data on all-cause deaths were also obtained from the FSO [9]. These consisted of counts of deaths from any cause by age, sex and canton for each week from 2010 to 2019 and afterwards for each week up to April 3, 2022. Coding of the cause of death listed in the death certificate takes up to one year, and information on causes of death were therefore not available for this analysis. We used data on ambient temperature from the European Centre for Medium-Range Weather Forecasts Reanalysis version 5 (ERA5) reanalysis data set and on national holidays from *nager.date* [11]. Daily mean ambient temperature between 2010 and 2022 at 0.25ox0.25o resolution was aggregated by taking means per week and canton. Holidays were considered as dummy variables and defined on a weekly basis for each canton (1 if there was at least one cantonal holiday, 0 otherwise). All data are available on github at https://github.com/jriou/covid19\_ascertain\_deaths.

The reporting of laboratory-confirmed SARS-CoV-2-related deaths has been mandatory in Switzerland since February 2020. The records are kept at the *Federal Office of Public Health* (FOPH) and are available on request [12]. They include age, sex, canton of residence, and the date and type of the positive SARS-CoV-2 test. Dates were grouped into seven epidemic phases by the FOPH: February 24 2020 to June 07 2020 (phase 1), June 08 2020 to September 27 2020 (phase 2), September 28 2020 to February 14 2021 (phase 3), February 15 2021 to June 20 2021 (phase 4), June 21 2021 to October 10 2021 (phase 5), October 11 2021 to December 19 2021 (phase 6) and December 20 2021 to April 24 2022 (phase 7).

## Statistical methods

### *Population model*

We used the population size on December 31 for the years 2010 to 2019 by age group, sex and canton to predict population sizes in each stratum and week of the entire study period (January 01, 2010, to April 03 2022) in a two-step procedure. First, we fitted Bayesian hierarchical Poisson regression models to population data from 2010 to 2019. This model included a linear yearly trend, a fixed effect by sex, and independent random effects by week (seasonality), age group, sex and canton. We compared different models using higher interactions and yearly linear trends that vary by space, age and sex. We compared the different models using a cross-validation scheme that excluded the last three years of available data (2017-2019) and determined that the best model included all possible two-way interactions between sex, age, canton, and week and an overdispersion parameter. We obtained posterior distributions of the population in each stratum for December 31 2020, 2021 and 2022, under the counterfactual scenario that the pandemic did not occur. In a second step, we used linear interpolation to obtain weekly population size estimates, with uncertainty. Online Supplement Section 1.1 provides further details.

### *Expected deaths model*

We estimated the expected number of all-cause deaths for each week between February 24 2020, the day of the first confirmed SARS-CoV-2 case in Switzerland, and April 03 2022, by age, sex and canton of residence using the historical data (2010 to 2019), expanding a previously proposed model [13]. We used Bayesian spatio-temporal models accounting for population trends and including covariates related to temperature and national holidays. To account for uncertainty in population estimates, we applied the model multiple times over the samples of the posterior distributions of the population predictions. Since the effect of temperature on all-cause mortality is expected to be U-shaped, we used a random walk of order 2 to allow for a flexible fit. We accounted for seasonality using a random walk of order 1 at the weekly level and for exceptional events using week-level independent random effects. We accounted for long-term trends with a linear slope at the yearly level and for spatial autocorrelation using conditional autoregressive priors. We modeled spatial autocorrelation using an extension of the BYM model, allowing for a mixing parameter measuring the proportion of the marginal variance explained by the spatial autocorrelation term [15]. The model has been internally validated and found to be unbiased, having a high predictive accuracy in the older groups [13]. We used the model to obtain posterior distributions of the expected number of all-cause deaths by age group, sex and canton each week between February 24, 2020, and April 03 2022. Online Supplement Section 1.2 provides further details.

### *Decomposition model*

We developed a method to decompose the observed all-cause deaths into 1) the number expected given historical trends and 2) the number attributed to the COVID-19 pandemic. We used a Poisson regression model with an identity link and no intercept term of the form:

where is the observed number of all-cause deaths on week , is the number of laboratory-confirmed SARS-CoV-2-related deaths, is the expected number of all-cause deaths given historical trends, and is a normally-distributed overdispersion term centered at zero.

Within this formulation, is the number of all-cause deaths for each unit increase in laboratory-confirmed deaths after adjusting for the expected number of all-cause deaths, given historical trends. That means that under perfect case ascertainment . If , then we observe a greater number of deaths attributed to SARS-CoV-2 infections compared with the number of laboratory-confirmed deaths. The ascertainment proportion of COVID-19-related deaths is obtained by . This relies on the assumption that when there is at least one laboratory-confirmed death in a given week, then the excess in observed all-cause deaths can be directly attributed to COVID-19. In a similar way, is the number of all-cause deaths for each unit increase in the expected number of all-cause deaths, after adjusting for the direct effect of COVID-19. We expect when the net effect of the pandemic-related behavioral, societal and health system changes on all-cause deaths is zero. The estimate of can thus be interpreted as a measure of the indirect effect of the pandemic on mortality. If , then there were fewer all-cause deaths than expected after removing the direct effect of COVID-19, which implies an indirect protective effect of all changes and control measures associated with the pandemic. Estimates of and thus provide a way to understand the interplay between laboratory-confirmed COVID-19-related deaths and excess all-cause deaths and allow to differentiate between direct and indirect consequences of the COVID-19 pandemic on mortality.

We extended the model presented above to examine these associations by phase (from 1 to 6 as defined by the Federal Office of Public Health), by age group (0-39, 40-59, 60-69, 70-79 and 80+ years), and by area (26 cantons). To this end, we introduced multiple and for each phase, age group or area separately, with the additional constraint of a multilevel structure allowing a smoothing towards the global mean of the estimator [16]. To propagate the uncertainty of the expected number of deaths, we fitted the above models using 200 samples of the posterior distribution of the expected number of deaths. We then combined the resulting samples of the betas.

# Results

A total of 156,193 deaths from all causes were recorded in Switzerland from February 24 2020, to April 03 2022, compared to an expected 142,408 (138,044 to 149,125) had the pandemic not occurred. This translates into 13,786 (7,068 to 18,149) excess all-cause deaths over the pandemic period, a relative increase of 9.7% (95%CrI: 4.7 to 13.1). There were periods of substantial relative excess mortality; 7.3% (95%CrI: 3.8 to 10.8) during phase 1, 33.9% (95%CrI: 26.4 to 41.4) during phase 3 and 15.9% (95%CrI: 8.3 to 22.8) during phase 6. There was some evidence for a harvesting effect during phase 4 with relative excess mortality of -4.3% (95%CrI: -9.9 to 0.2). The age groups affected most by the pandemic were those over 70 years of age (Figure 1A), whereas the cantons affected the most overall were Schwyz, Jura and St. Gallen. During the first phase of the pandemic the areas hit the most were the ones near the borders with France and Italy (cantons of Ticino, Geneva, Vaud and Valais), whereas excess mortality was more homogeneous during phase 3 and more focused on the northern and eastern regions during phase 6 (Figure 1B).

During the period, 13,130 laboratory-confirmed COVID-19-related deaths were reported. Weekly counts of laboratory-confirmed deaths generally aligned with estimates of excess all-cause mortality in Switzerland, with a correlation coefficient of 0.89 (95%CrI: 0.85 to 0.92) on aggregate at the country level (Figure 2) and of 0.72 (95%CrI: 0.65 to 0.76) when stratifying by canton and age group. The number of excess all-cause deaths was greater than the counts of laboratory-confirmed deaths during epidemic waves (phases 1, 3 and 6). The overall estimate of was 1.38 (95%CrI: 1.22 to 1.54), suggesting that there were, on average, 38% (95%CrI: 22% to 54%) more deaths directly attributable to COVID-19 than laboratory-confirmed deaths during the period, or that the ascertainment proportion was 72% (95%CrI: 65% to 82%) (Table 1). Given the 13,130 laboratory-confirmed deaths over the period, this implies that the total number of deaths directly attributable to COVID-19 in Switzerland until April 03 2022, can be estimated at 18,140 deaths (15,962 to 20,174).

After accounting for COVID-19-related deaths, the observed number of all-cause deaths was slightly lower than expected based on historical trends. This is quantified by , estimated at 0.97 (95%CrI: 0.93 to 1.01), indicating 3% (95%CrI: -1% to 7%) fewer all-cause deaths than expected during the COVID-19 pandemic after adjusting for the direct effects of SARS-CoV-2 infection on mortality. Still, the data are compatible with no indirect beneficial effect or a slightly harmful indirect effect.

Looking at the variation of these indicators across phases shows that the relative number of deaths directly attributable to COVID-19 for each laboratory-confirmed death () was around 1.5 during phases 1 and 3 and around 2 during phase 6, suggesting an ascertainment proportion of COVID-19 deaths during periods of high incidence ranging between 50% and 66% (Figure 3A). This estimate is less precise during periods where counts of laboratory-confirmed cases were low (phases 2, 4, 5 and 7), and remain compatible with 1 (perfect ascertainment). Variation of by age group suggests that more deaths were not ascertained in age groups 70-79 and 80 years old or older, while the data were compatible with 100% ascertainment () in populations below 70 years old. Estimates of by canton show generally homogeneous results, indicating similar degrees of ascertainment across cantons. There were a few exceptions with higher estimates of , potentially signaling an issue in the local reporting system in cantons Jura and Zug. The relative deficit in all-cause deaths that can be indirectly attributed to the COVID-19 pandemic () showed less variation by phase, age group or canton (Figure 3B). Still, the indirect beneficial effect was more pronounced during phases 1, 3 and 4 (corresponding to the periods with the most stringent control measures) and in people aged between 40 and 69 years.

# Discussion

In this study, we examined all-cause mortality patterns during the COVID-19 pandemic in Switzerland, from the diagnosis of the first case end of February 2020 to spring 2022. Detailed data on the population structure, mortality, weather and national holidays from the ten years before the COVID-19 pandemic allowed us to assess what mortality would have been in 2020-2022 had the pandemic not occurred. This allowed a detailed estimation of excess all-cause mortality during the pandemic period by time, space and age, appropriately propagating uncertainty from all sources. Our results confirm the massive impact on mortality of the epidemic wave of autumn/winter 2020-2021 on the Swiss population, a situation never observed since the 1918 influenza pandemic [6]. We also found evidence that the epidemic wave of autumn 2021 again led to many avoidable deaths.

We compared excess all-cause mortality over time with the number of laboratory-confirmed COVID-19 deaths. As expected, we found that these time-series were aligned, although imperfectly. Using a statistical model, we characterize the similarities and discrepancies between laboratory-confirmed COVID-19-related deaths and excess mortality by time, space, and age group. We decomposed all-cause deaths into mortality excesses directly attributable to COVID-19 and mortality excesses or deficits indirectly attributable to the pandemic. We found that during periods of high incidence the estimated number of deaths directly caused by COVID-19 was higher than the number of laboratory-confirmed deaths. Overall, COVID-19 was responsible for an estimated 18,000 deaths during the study period during which only around 13,000 laboratory-confirmed COVID-19-related deaths were reported in Switzerland. Ascertainment was markedly lower during periods of high incidence, suggesting shortcomings concerning testing or reporting in overwhelmed healthcare institutions. The even lower ascertainment towards the end of the study period could be partially explained by reduced testing due to the availability of vaccines. Under-ascertainment was also concentrated in older age groups, pointing towards retirement and nursing homes as the places where incomplete ascertainment occurs, in line with other reports [1].

Besides directly causing many deaths, we also found some evidence that the COVID-19 pandemic had an indirect, beneficial effect on all-cause mortality. This reduction of all-cause mortality was estimated at 3%, but the wide credibility intervals are compatible with no indirect effect or a very small harmful indirect effect. A first explanation could be mortality displacement or a “harvesting effect”, whereby COVID-19 precipitated deaths that would have occurred shortly anyway. Mortality displacement was likely following the largest wave of mortality in autumn and winter 2020/21, but it cannot explain the slightly lower mortality found during other periods. Of note, the deficit of deaths not directly related to COVID-19 was mostly evident in age groups 40 to 69, and not in in the elderly where mortality displacement is to be expected. Second, the deficit could be attributed to the indirect effect of the pandemic, including non-pharmaceutical interventions and its consequences such as reductions in mobility and traffic, social contacts and activities, or air pollution levels. This explanation is supported by the observation that the indirect beneficial effect was more pronounced during phases 1, 3 and 4, corresponding to the periods with the most stringent control measures [17]. The fact that it mostly occurred in age groups 40 to 69 favors explanations relating to reductions in mobility, traffic and outdoor activities, as opposed to a reduced circulation of other pathogens such as influenza, which would have led to mortality deficits in the elderly. In any case, we find no argument in favor of a detrimental effect of non-pharmaceutical interventions on mortality, which does not presume of any other harmful effects on mental and social health.

This study has several strengths and limitations. We used a statistically rigorous approach to estimate the expected number of deaths in 2020-2022 had the pandemic not occurred by age group and over space and time. Our approach has been thoroughly validated, and accounts for the most important determinants of deaths count data, including projected population sizes and observed temperature. We also properly handle the uncertainty coming from different sources of data and propagated it into the final estimates. Our estimates of excess mortality are in accordance with other works [REFS]. We then developed a statistical method to differentiate all-cause deaths into death excesses directly attributable to SARS-CoV-2 infections and deaths excesses or deficits indirectly attributable to the pandemic. This approach was tailored to the research question and allowed us to bring further insights about the mortality patterns during the COVID-19 pandemic. This work also has a few limitations. Most importantly, we could not access information about the cause of death, that could help solving some remaining questions about the mechanisms of the indirect beneficial effect of the COVID-19 pandemic on mortality. Our study also remain subject to ecological bias. Our study focuses on the short-term effect of the COVID-19 pandemic and does not provide any insights about the long-term effect of the pandemic, such as reduced cancer screening, which might impact mortality in the long run. We did not stratify by sex, but previous analysis suggested small, if any, discrepancies in the observed and excess number of deaths across the different sexes.

Comparisons:

* Compare numbers to ref. 3 and <https://elifesciences.org/articles/69336> (see <https://github.com/dkobak/excess-mortality>). Karlinsky et al. report an excess mortality of 12,000 (18% of baseline annual deaths) and 90% ascertainment.

# Conclusions

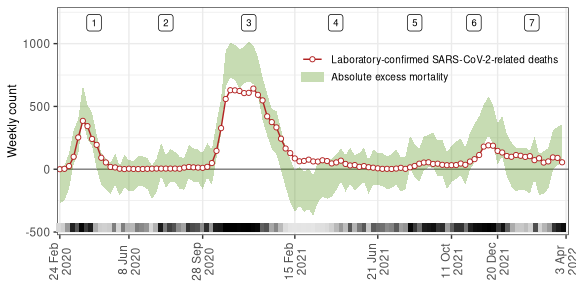
# Table and figures

**Table 1.** Number of expected and observed deaths from all causes, estimated excess mortality and laboratory confirmed COVID-19 deaths by seven epidemic phases February 2020 to April 2022.

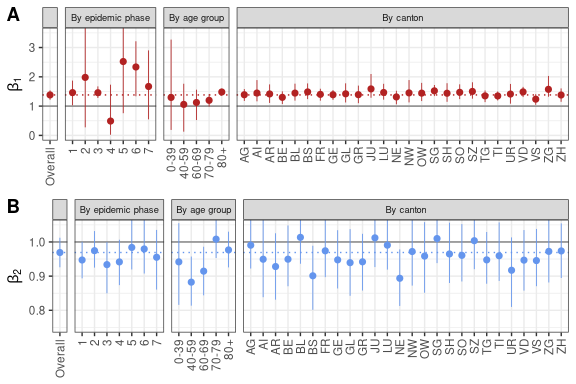
| Epidemic phase | Dates | Expected  deaths | Observed deaths | Excess  deaths | Relative excess mortality  (95% CrI) | Laboratory-confirmed COVID-19 deaths |
| --- | --- | --- | --- | --- | --- | --- |
| 1 | 24 Feb 2020 -  June 07 2020 | 19,376  (18,767 to 20,033) | 20,791 | 1,415  (758 to 2,024) | 7.3%  (3.8 to 10.8) | 1,725 |
| 2 | 08 Jun 2022 -  27 Sep 2020 | 19,180  (18,440 to 20,042) | 19,103 | -76  (-939 to 663) | -0.4%  (-4.7 to 3.6) | 104 |
| 3 | 28 Sep 2020 - 14 Feb 2021 | 27,004  (25,569 to 28,604) | 36,157 | 9,154  (7,553 to 10,588) | 33.9%  (26.4 to 41.4) | 7,652 |
| 4 | 15 Feb 2020 -  June 20 2021 | 23,386  (22,320 to 24,834) | 22,369 | -1,017  (-2,465 to 49) | -4.3%  (-9.9 to 0.2) | 895 |
| 5 | 21 Jun 2021 -  10 Oct 2021 | 19,174  (18,284 to 20,223) | 20,007 | 832  (-216 to 1,723) | 4.3%  (-1.1 to 9.4) | 380 |
| 6 | 11 Oct 2021 -  19 Dec 2021 | 13,036  (12,298 to 13,944) | 15,105 | 2,070  (1,161 to 2,807) | 15.9%  (8.3 to 22.8) | 956 |
| 7 | 20 Dec 2021 - 03 Apr 2022 | 21,370  (20,067 to 22,894) | 22,661 | 1,291  (-233 to 2,594) | 6.0%  (-1.0 to 12.9) | 1,418 |



**Figure 1.** (A) Estimated relative excess mortality by seven epidemic phases from February 2020 to April 2022 and five age groups. Medians with 95% credible intervals are shown. (B) Map of relative excess mortality in Switzerland by canton and epidemic phase.



**Figure 2.** Weekly counts of excess all-cause deaths (95% uncertainty intervals) and of laboratory-confirmed SARS-CoV-2-related deaths between February 24 2020 and April 03 2022 in Switzerland. The bar at the bottom shows the probability that excess all-cause deaths is greater than laboratory-confirmed SARS-CoV-2-related deaths (light gray is 0, black is 1). Numbers at the top indicate epidemic phases 1 to 7.



**Figure 3.** (A) Posterior estimates of , the additional number of deaths to be observed for each unit increase in laboratory-confirmed deaths, after adjusting for the expected number of all-causes deaths given historical trends. (B) Posterior estimates of , the additional number of deaths to be observed for each unit increase in the expected number of all-cause deaths, after adjusting for the direct effect of SARS-CoV-2 infections. Estimates of and are shown for the whole period, by phase, by age group and by canton.

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