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# BMJ Open Assessing relative COVID-19 mortality: a Swiss population-based study

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## ABSTRACT

**Objective** Severity of the COVID-19 has been previously reported in terms of absolute mortality in SARS-CoV-2 positive cohorts. An assessment of mortality relative to mortality in the general population is presented.

**Design** Retrospective population-based study.

**Setting** Individual information on symptomatic confirmed SARS-CoV-2 patients and subsequent deaths from any cause were compared with the all-cause mortality in the Swiss population of 2018. Starting 23 February 2020, mortality in COVID-19 patients was monitored for 80 days and compared with the population mortality observed in the same time of year starting 23 February 2018.

**Participants** 5 102 300 inhabitants of Switzerland aged 35–95 without COVID-19 (general population in spring 2018) and 20 769 persons tested positively for COVID-19 during the first wave in spring 2020.

**Measurements** Sex-specific and age-specific mortality rates were estimated using Cox proportional hazards models. Absolute probabilities of death were predicted and risk was assessed in terms of relative mortality by taking the ratio between the sex-specific and age-specific absolute mortality in COVID-19 patients and the corresponding mortality in the 2018 general population.

**Results** Absolute mortalities increased with age and were higher for males compared with females, both in the general population and in positively tested persons. A confirmed SARS-CoV-2 infection substantially increased the probability of death across all patient groups at least eightfold. The highest relative mortality risks were observed among males and younger patients. Male COVID-19 patients exceeded the population hazard for males (HR 1.21, 95% CI 1.02 to 1.44). An additional year of age increased the population hazard in COVID-19 patients only marginally (HR 1.00, 95% CI 1.00 to 1.01).

**Conclusions** Healthcare professionals, decision-makers and societies are provided with an additional population-adjusted assessment of COVID-19 mortality risk. In combination with absolute measures of risk, the relative risks presented here help to develop a more comprehensive understanding of the actual impact of COVID-19.

## INTRODUCTION

Early reports from China and Italy<sup>1–7</sup> on disease severity of COVID-19 caused unprecedented public health interventions around the world, ranging from social distancing measures or school and university closings to

## Strengths and limitations of this study

- An assessment of COVID-19 risk in terms of relative mortality rates comparing a cohort of symptomatic and confirmed COVID-19 patients to the general population is provided.
- Relative mortality for quantifying sex-specific and age-specific COVID-19 risk is unaffected by seasonal effects, cause of death (COVID-19 related or not), impact of public health interventions or testing coverage.
- The study excluded patients younger than 35 years and older than 95 years, as well as patients tested posthumously or after having been admitted to a hospital for reasons other than COVID-19.
- Information about the distribution of relevant comorbidities was not available on population level and the associated risk was not quantified.
- Differential COVID-19 risk for relevant patient subpopulations, such as pregnant women, low-income residents, ethnic or cultural minorities, was not assessed.

complete lockdowns of societies. The absolute mortality in patients diagnosed with COVID-19, that is, the case fatality rate, has been the main entity used for communicating risks associated with the disease.<sup>2–6</sup> Risk factors for mortality risk, most prominently higher age, being male and pre-existing medical conditions, have become publicly known.<sup>1 3 4</sup>

On the current occasion of liberalisation of the most stringent public health interventions in many countries, an assessment of the actual impact of the COVID-19 pandemic is called-for. Healthcare professionals, politicians and societies at large currently engage in a discussion about the appropriateness of the mitigation measures taken, and the first scientific contribution on the matter has arisen.<sup>8</sup>

The probability of death estimated from hundreds of thousands of COVID-19 patients is constantly reported from many countries.<sup>2–4 9</sup> These numbers can, however, be hard to compare, due to differences in testing regimens, varying ascertainment of mortality,

different age structures of societies or different health-care and public health systems.<sup>10</sup> As an alternative risk difference of disease impact, excess numbers of deaths has been reported for some populations, that is, the number of observed all-cause deaths during the time of the COVID-19 pandemic (end of February to mid-May 2020 in most European countries) minus the expected number of deaths in the given population. Reports on the number of excess deaths observed since the onset of the pandemic are available from Portugal,<sup>11</sup> Spain,<sup>12</sup> northern Italy,<sup>13 14</sup> various other European countries<sup>15</sup> and the USA.<sup>16</sup> However, cross-country comparisons are again difficult, because the success or failure of public health interventions and possible overruns of hospital capacities will be reflected in the presence and magnitude of excess mortality.<sup>14</sup>

The emergence of mature data on the course of the COVID-19 pandemic from many countries allows its actual impact on societies and healthcare systems to be discussed in light of the short-term relative mortality. This relative risk compares the absolute all-cause mortality observed in patients diagnosed with COVID-19 during the spring 2020 outbreak with the absolute all-cause mortality in the uninfected population of earlier years during the same calendar time of year. The population mortality varies between females and males, and over attained age, with males and older individuals experiencing a higher short-term risk of dying. How much of the increased mortality reported for male and older COVID-19 patients<sup>1 4 6 7</sup> can be attributed to the increase in population mortality risk in general is an important question awaiting an answer. Furthermore, sex-specific and age-specific relative COVID-19 mortality allows a stratified assessment of risk-increase caused by a SARS-CoV-2 infection.<sup>17</sup>

We report an assessment of age-adjusted relative COVID-19 mortalities for females and males based on an analysis of individual population level and COVID-19 death records from Switzerland covering the time between 24 February 2020 and 14 May 2020.

## METHODS

### Study design and data sources

For this population-based study, Swiss general population data from 2014 to 2018, including individual death records, were obtained from the Swiss Federal Statistical Office (Bundesamt für Statistik). In addition, COVID-19 surveillance reports from the Swiss Federal Office of Public Health (Bundesamt für Gesundheit) on all individuals tested positively for SARS-CoV-2 during the first wave between 24 February 2020 and 14 May 2020 were available, also including individual dates of tests and occurred deaths.

Official SARS-CoV-2 testing in Switzerland was performed by PCR only, based on lower and upper respiratory tract samples from symptomatic persons. Individuals experiencing the following symptoms were eligible for testing<sup>18</sup>: cough, sore throat, muscle pain, dyspnoea

**Table 1** 2018 study population

Criterion	Cohort	
	Swiss 2018	Swiss COVID-19
Total	8 484 130	334 271*
Alive 23 February	8 472 995	
SARS-CoV-2 positive after 23 February		30 460
Sex known		30 437
35–95 years old	5 102 300	23 288
Not in hospital		20 769
Study population	5 102 300	20 769
Deaths	14 054	894

Swiss 2018 population cohort (as of 1 January 2018) and Swiss COVID-19 cohort (SARS-CoV-2 positive cases in a total of 334 271 tests performed in Switzerland between 24 February 2020 and 14 May 2020). The table contains the number of persons meeting the inclusion criteria. study population refers to the number of observations in the two cohorts analysed.

\*The total number of tests includes multiple counts of persons tested more than once.

(with or without fever) and acute anosmia or ageusia. Testing of asymptomatic persons was only recommended to control local outbreaks in hospitals or nursing homes. A number of hospitals started to test all patients admitted to the hospital at different time points regardless of symptoms. Information of whether or not a person experienced symptoms during an infection was not available for this analysis. All positive and negative SARS-CoV-2 test results were directly reported to the Federal Office of Public Health, patients were followed up subsequently, and all positive cases were included in this analysis.

### Study population

The study population consists of two cohorts. The first cohort consists of persons with a SARS-CoV-2 positive PCR test between 35 and 95 years of age at time of testing. We excluded younger COVID-19 patients because no deaths were observed in this group. Individuals tested post-mortem or after hospitalisation for other reasons were not included as the aim was to study relative mortality in a cohort of newly infected people who did not have a short-term increased mortality risk. Very old persons (older than 95) years were also excluded for this reason. We refer to this cohort as the 'Swiss COVID-19' cohort in the sequel. The second cohort was defined as all inhabitants of Switzerland alive on 23 February 2018 aged 35–95 years.

Table 1 describes the selection process defining the study population. For an additional sensitivity analysis, the Swiss 2014–2017 study populations were defined analogously.

### Statistical analysis

Exploratory analyses were performed comparing the sex and age distributions between the Swiss population cohort

and the Swiss COVID-19 cohort. Absolute numbers and ratios were computed for females and males. In addition to mean ages, nonparametric density estimates of age stratified by sex were computed and compared between the two cohorts.

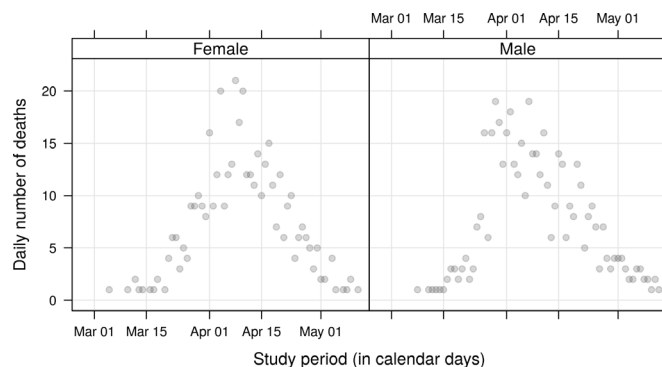
Mortality data were analysed using survival analysis. For the Swiss population cohort, follow-up started on 23 February 2018, and ended at date of death or on date of administrative censoring (14 May 2018). The underlying time scale for all analyses was time since 23 February, measured in days. The Swiss COVID-19 cohort was handled in two different ways. Throughout, the follow-up started on the day of the positive test and ended at time of death or on date of administrative censoring (14 May 2020). When estimating relative rates (contrasting to the general population), the underlying time scale was time since 23 February (measured in days), using a delayed entry approach. For predicting the probability of death, number of days since positive test was used as the underlying time scale.

Sex-specific and age-specific HRs with 95% CIs were estimated using a stratified Cox proportional hazards model, allowing for separate baseline rates in the Swiss COVID-19 and Swiss 2018 population cohorts, with 65-year-old females as reference. Sex and age were modelled with main effects only for the Swiss 2018 cohort, whereas for the Swiss COVID-19 cohort, interaction effects between SARS-CoV-2 status and sex and age were included to capture the additional mortality effects among the patients. P values and 95% CIs for HRs were adjusted for multiplicity (see online supplemental material S1).

To quantify the impact on mortality associated with a SARS-CoV-2 diagnosis, the 60-day probability of death was predicted from the fitted model estimates, which captures deaths occurring within 60 days of 23 February or positive test, for the Swiss 2018 population cohort and Swiss COVID-19 cohort, respectively. Using these probabilities, the sex-specific relative mortality (and associated 95% confidence bands) was calculated by taking the ratio between the two, along an age gradient between 35 and 95 years. The relative mortality incorporated uncertainty in the Swiss COVID-19 cohort only.<sup>19</sup>

The assumption of proportional hazards was assessed by fitting models allowing for time-varying effects. Potential deviations from the linear age effect were assessed in a Cox model allowing nonlinear effects of age. The main effects only model was compared with a model including sex×age interactions. As a sensitivity analysis, all models were refitted using the Swiss 2014–2017 general populations as reference. Further details on the statistical analyses performed can be found in online supplemental material S1.

All analyses were performed in the R system for statistical computing<sup>20</sup> (V.4.0.2) with the survival<sup>21</sup> and mlt<sup>22 23</sup> add-on packages and independently replicated in Stata<sup>24</sup> (V.16), using the stpm2<sup>25 26</sup> and merlin<sup>27</sup> commands, see online supplemental material S2.



**Figure 1** Swiss COVID-19 cohort. Number of deaths from all causes reported between February 2020 and 14 May 2020 in COVID-19 patients (35 and 95 years old, not admitted to a hospital prior to testing, excluding postmortem tests).

### Patient and public involvement

No patient involved.

### RESULTS

The daily number of deaths observed during the 80-day study period (24 February 2020–14 May 2020) in the Swiss COVID-19 cohort increased rapidly from mid-March and peaked during the first days of April, in both males and females (figure 1). The numbers reduced to less than ten reported deaths per day during the last week of the study period.

Characteristics of the Swiss COVID-19 cohort, the Swiss 2018 population cohort, and the earlier Swiss population cohorts (2014–2017) are presented in table 2. The ratio of females to males indicate that patients in the Swiss COVID-19 cohort were more likely female. The mean age was similar between the two cohorts, with SARS-CoV-2 positive patients being between one (females) and up to 3 years (males) older than individuals in the Swiss population cohort. The similarity was further observed when comparing the whole age distribution among females and males, between cohorts (figure 2). However, there was a slight over-representation of older people, between 85 and 95 years of age, in SARS-CoV-2 positive individuals.

The all-cause mortality rate among 65 year old males from the Swiss 2018 population cohort was 1.49 times that among females of the same age. The mortality rate further increased by a factor of 1.13 for each additional year of age (table 3). In 2018, males experienced the same mortality as females aged 3.23 years older.

The additional increment in the mortality rate for individuals in the Swiss COVID-19 cohort were smaller than the sex and age effects observed in the Swiss 2018 population cohort (difference in log-HRs between population and patients 0.21, 95% CI 0.04 to 0.38, for the sex effect and 0.12, 95% CI 0.11 to 0.13, for the age effect). Being a male COVID-19 patient was associated with an HR of 1.21, relative to males in the general population (table 3). The HR comparing the hazard of males to females in the Swiss COVID-19 cohort was  $1.49 \times 1.21 = 1.80$  (HR, 95% CI



**Table 2** Study populations

Cohort	Sex			
	Female		Male	
	N	Age	N	Age
COVID-19	11 275 (54.29%)	58.70 (16.32)	9 494 (45.71%)	58.63 (14.59)
2018	2 622 758 (51.40%)	57.74 (14.83)	2 479 542 (48.60%)	56.04 (13.79)
2017	2 595 313 (51.42%)	57.66 (14.81)	2 451 485 (48.58%)	55.91 (13.72)
2016	2 566 742 (51.46%)	57.58 (14.81)	2 420 681 (48.54%)	55.78 (13.68)
2015	2 535 790 (51.52%)	57.49 (14.79)	2 385 821 (48.48%)	55.65 (13.63)
2014	2 504 819 (51.59%)	57.40 (14.80)	2 350 354 (48.41%)	55.51 (13.60)

Number of observations (N) and age (mean and SD) for females and males 35–95 years old and alive on 23 February of the respective year. The first row corresponds to the Swiss COVID-19 cohort of 2020.

1.58 to 2.06). On the log-HR scale, the sex effect for male COVID-19 patients is  $0.40 + 0.19 = 0.59$  and thus roughly two-thirds of the increased risk in a direct comparison of male to female COVID-19 patients can be attributed to the higher mortality of males in the general population. The CI for the COVID-19×male term (HR 1.21, 95% CI 1.02 to 1.44) reflects a substantial uncertainty regarding the prognostic relevance of being male with respect to COVID-19 mortality.

Each additional year of age increased the COVID-19 mortality rate by a factor of  $1.13 \times 1.00 = 1.14$  (HR, 95% CI 1.13 to 1.14). Formulated alternatively, the age-related hazard doubled every 5.63 life-years in the Swiss 2018 population cohort and every 5.42 life-years in the Swiss COVID-19 cohort. This additional effect of age in COVID-19 patients was rather small (HR, 95% CI 1.00 to 1.01) and not significant at the 5% level. Hazards of male patients were comparable to hazards of female patients 4.60 years older.

The 60-day sex-specific and age-specific probability of death (absolute mortality) was considerably larger in the COVID-19 cohort (figure 3, top panel and table 4). The absolute number of expected deaths per 100 000 persons within 60 days ranged from 2 and 4 (35-year-old females and males) to 3 946 and 5 814 (95-year-old females and males) in the 2018 population cohort. In COVID-19

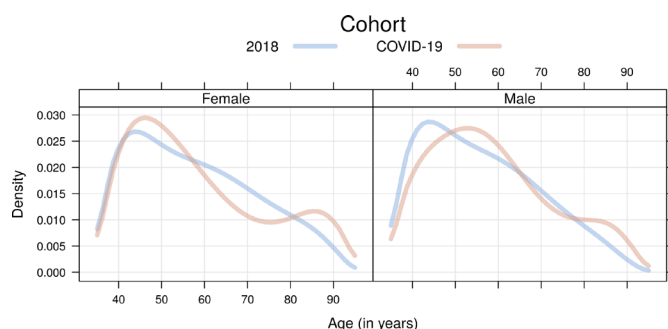
patients, these numbers increased to 43 and 82 expected deaths in 35-year-old females and males and to 38 289 and 60 349 expected deaths in 95-year-old females and males.

The short-term death probability for 42-year-old females diagnosed with COVID-19 was about 0.1%, comparable with 65-year-old females in the 2018 population cohort. Similarly, 55-year-old infected males were associated with a probability of death around 1%, equivalent to the probability of 81-year-old not infected males in the general population. The probability of death in infected individuals was above 10% for females older than 82 and males older than 76 years.

The probabilities of death implied a nearly log-linear function of age, for both females and males, and in both cohorts of the study population. Hence, it follows that the relative risk comparing the mortality in young patients to the mortality in patients aged 20 years older, for example, would be constant regardless of the age of younger group of patients. The slope of the probabilities of death as a function of age was about the same in the Swiss COVID-19 cohort due to the models' negligible age effect attributable to the infection (table 3, COVID-19×age 65).

The sex-specific and age-specific relative mortality (figure 3 bottom panel and table 4) was largest in young male patients and declined with increasing age for both females and males. A relative mortality of 16 (in 50-year-old females) is interpreted as 50-year-old infected females being 16 times more likely to die within 60 days after the positive test than 50-year-old uninfected females were likely to die within 60 days following 23 February 2018. However, the 95% confidence bands demonstrated substantial uncertainty in the estimates of this relative risk; the lower confidence band was as large as 8 for 95-year-old females and 9 for 95-year-old males. The data were consistent with an at least 11-fold risk increase in younger females (35–80 years old) and with an at least 15-fold risk increase in younger males (35–75 years old).

Model diagnostics did not reveal relevant deviations from proportional hazards nor the main effects model, but indications of a nonlinear age effect in the Swiss COVID-19 cohort were found (online supplemental



**Figure 2** Swiss 2018 population and COVID-19 cohorts. Comparison of age densities between the Swiss 2018 population and COVID-19 cohorts, separately for females and males.

**Table 3** Swiss 2018 population and COVID-19 cohorts

Effect	log-HR	SE ×10	P value	HR	95% CI
Female	0			1	
Male	0.40	0.17	<0.001	1.49	1.43 to 1.55
Age 65	0			1	
Age 65	0.12	0.01	<0.001	1.13	1.13 to 1.13
COVID-19×female	0			1	
COVID-19×male	0.19	0.70	0.03	1.21	1.02 to 1.44
COVID-19×age 65	0			1	
COVID-19×age 65	0.00	0.03	0.45	1.00	1.00 to 1.01

Log-HR and HRs expressing the risk of being male ('male') and each year of age ('age 65') compared with the baseline hazard in 65-year-old females. Main effects were fitted to both cohorts, interaction effects to the Swiss COVID-19 cohort only. The interaction effects describe the additional risk on the log-HR or HR scale attributable to the infection. Estimates are given with SEs for log-HRs and 95% CIs for HRs, the latter and p values were adjusted for multiplicity.

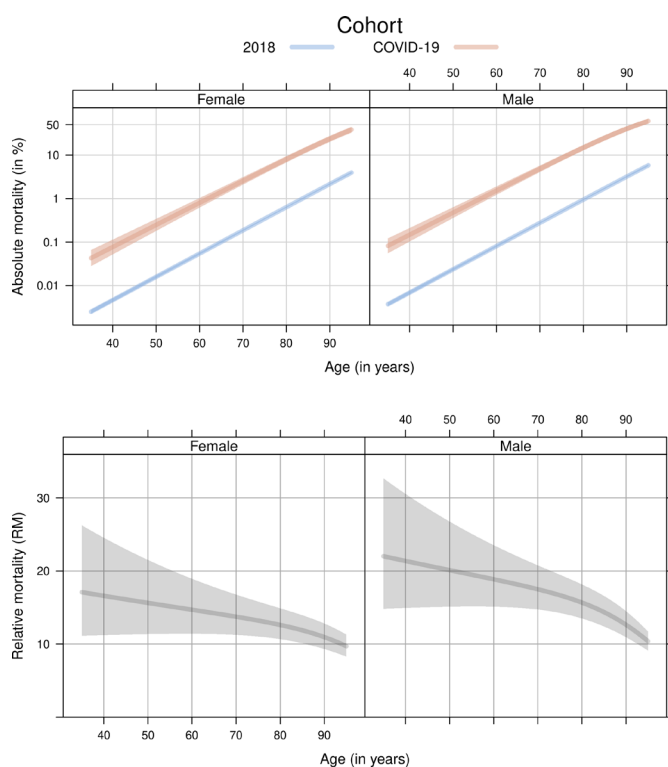
table S1, online supplemental figures S1 and S2). The non-linear model suggested a continuously and monotonically increasing hazard of age lacking any clear cut-off points for binary risk stratification. Sensitivity analyses (see online supplemental table S2, online supplemental figures S3–S10) demonstrated that results reported for

the 2018 study population were very close to the results for the 2014–2017 study populations.

## DISCUSSION

The at least eightfold increase in probability of death found in female and male, young and old, symptomatic COVID-19 patients from Switzerland in comparison to the Swiss population of 2018 provides novel sex-specific and age-specific information on the severity of this pandemic. Short-term COVID-19 mortality has never previously been reported as a relative risk in direct relation to the short-term mortality in the general population. The comparison of absolute mortalities and case fatality rates between risk groups of COVID-19 patients without any population adjustment are likely to overestimate the increased mortality in males and older people. As presented here, two-thirds of the risk increase observed in male patients could be attributed to the generally increased population mortality.

The population-based setting with matched calendar time allows for estimation of COVID-19-related mortality in an unselected cohort of symptomatic and diagnosed patients, without the need to differentiate between deaths caused or not caused by COVID-19 in terms of death certificate information.<sup>28</sup> Seasonal effects were implicitly accounted for by comparing cohorts over the same time-of-year. Unlike other population studies estimating excess mortality, the probability of death in these cohorts could not be confounded by ongoing public health interventions or testing coverage.<sup>28</sup> Using data from Switzerland was especially useful for this type of analysis. The borders to northern Italy and Austria caused COVID-19 outbreaks early in the pandemic, broad and uniform symptom-based testing overseen by federal authorities was implemented quickly, and all test results were reported. A symptom-based testing regimen was carried out, with testing of asymptomatic persons only recommended to control local outbreaks in hospitals or nursing homes. In contrast



**Figure 3** Swiss 2018 population and COVID-19 cohorts. Comparison of absolute mortality (the probability of dying from any cause after 60 days, plotted on logarithmic scale) between the Swiss 2018 population and COVID-19 cohorts, separately for females and males of different ages (top). Comparison of relative mortality (RM, the ratio of absolute mortalities in the COVID-19 vs the 2018 cohort) between the two cohorts, for females and male of different ages (bottom). All estimates are plotted with 95% confidence bands.

**Table 4** Swiss 2018 population and COVID-19 cohorts

Sex	Age	Mortality		
		Absolute 2018	Absolute SARS-CoV-2	Relative (RM)
Female	35	2 (2–3)	43 (28–66)	17 (11–26)
	40	5 (4–5)	77 (52–114)	17 (11–25)
	45	9 (8–9)	138 (97–197)	16 (11–23)
	50	16 (15–17)	247 (180–341)	16 (11–22)
	55	29 (27–31)	444 (334–591)	15 (11–20)
	60	54 (51–57)	796 (618–1 026)	15 (11–19)
	65	100 (96–105)	1 426 (1 139–1 784)	14 (11–18)
	70	185 (178–193)	2 547 (2 086–3 108)	14 (11–17)
	75	343 (331–355)	4 529 (3 783–5 418)	13 (11–16)
	80	633 (613–655)	7 989 (6 757–9 434)	13 (11–15)
	85	1 169 (1 130–1 209)	13 893 (11 816–16 299)	12 (10–14)
	90	2 152 (2 073–2 234)	23 563 (20 057–27 569)	11 (9–13)
	95	3 946 (3 781–4 118)	38 289 (32 649–44 541)	10 (8–11)
Male	35	4 (3–4)	82 (55–121)	22 (15–33)
	40	7 (6–7)	147 (103–210)	21 (15–31)
	45	13 (12–14)	264 (191–364)	21 (15–29)
	50	24 (22–25)	474 (356–630)	20 (15–27)
	55	44 (41–46)	849 (660–1 093)	19 (15–25)
	60	81 (77–85)	1 520 (1 218–1 897)	19 (15–24)
	65	149 (143–156)	2 715 (2 235–3 295)	18 (15–22)
	70	276 (266–286)	4 824 (4 061–5 726)	17 (15–21)
	75	510 (493–527)	8 499 (7 266–9 930)	17 (14–19)
	80	941 (910–973)	14 748 (12 707–17 085)	16 (14–18)
	85	1 734 (1 673–1 797)	24 922 (21 519–28 758)	14 (12–17)
	90	3 185 (3 059–3 317)	40 246 (34 828–46 169)	13 (11–14)
	95	5 814 (5 549–6 091)	60 349 (52 823–67 987)	10 (9–12)

Estimated number of deaths per 100 000 hypothetical females or males with corresponding age. Population mortality in the Swiss 2018 cohort (absolute 2018), mortality in the Swiss COVID-19 cohort (absolute SARS-CoV-2), and the relative SARS-CoV-2 mortality (RM, the ratio of the second to the first column). CIs were obtained from 95% confidence bands given in figure 3.  
RM, relative mortality.

to reports from northern Italy,<sup>14</sup> the number of COVID-19 patients in need for hospitalisation never exceeded healthcare capacities, and every patient received the best possible treatment under the circumstances.

Absolute mortalities in the Swiss COVID-19 cohort were smaller than those reported for Italian and Chinese COVID-19 patients<sup>3–5</sup> between 40 and 80 years old. The numbers are expected to be higher than in Germany, where the overall case fatality rate was only 1.2% and more tests were performed in younger patients with mild symptoms.<sup>29</sup> Due to the differences in testing protocol, substantially higher or lower relative mortality may therefore be expected in other countries. The Swiss COVID-19 cohort excluded persons with known increased mortality risks (those tested posthumously or while being hospitalised), as well as very old and thus a priori frail persons. The figures presented here can nevertheless inform models developed for computing prognoses on the number of

expected deaths in real or hypothetical populations, because relative mortality is not affected by public health interventions which lead to a reduced or even non-existent excess mortality in many European countries. For the UK, prognoses assumed a 1-year relative mortality risk not larger than 2, uniformly for females and males of all ages.<sup>30</sup> A short-term 60-day relative mortality larger than eight, as found here, suggests that the actual risk might be larger than assumed based on prognostic models or reported elsewhere.<sup>31</sup> However, the more general question of the true COVID-19 relative mortality will be lower than that reported in this study, as the inclusion criteria for the COVID-19 cohort was defined on being symptomatic and testing positive for SARS-CoV-2. The true proportion of asymptomatic cases and the actual prevalence are ongoing questions.<sup>32</sup>

The sex and age effects on all-cause mortality attributable to COVID-19 are, however, still relevant and males

and older persons were associated with higher risk. Males had a 21% higher mortality rate than females, however, the uncertainty around this HR was large and the effect was absent in some populations of earlier years and in a model with sex×age interactions (see online supplemental table S1). The relative mortality (ratio of the probabilities of death) was approximately between ten and twenty across all age groups. This population-adjusted comparison of the risk between young and old patients suggest a less drastic relative impact of age on mortality than previously reported.<sup>8</sup> Stratification into low-risk and high-risk groups using a cut-off at 65 years of age, as seen in several published reports and recently advocated for,<sup>33</sup> seems hard to justify based on the continuously increasing age-specific absolute mortalities and almost constant relative mortalities reported here. Relative mortality can also help to explain an increased mortality in younger patients reported from countries with different age structure: In Chile, 8% of those who died after an SARS-CoV-2 infection were less than 50 years old,<sup>34</sup> a number much higher than observed in Europe. Potential deviations from these sex-specific and age-specific COVID-19 risks in relevant patient subgroups, such as patients with pre-existing conditions,<sup>1</sup> pregnant women,<sup>35</sup> and racial, ethnic or cultural minorities,<sup>36</sup> were not modelled because of lack of information on related variables.

In summary, the results suggest that COVID-19 risk assessment in terms of case fatality rates and excess mortalities should be complemented by population-adjusted relative mortalities such that a more complete picture can emerge, potentially leading to improvements for age-based risk stratification.

**Contributors** TH and MB defined the research question and were responsible for data acquisition. TH, MB, CEW and MC designed the study and planned the statistical analysis. TH preprocessed the data, which was analysed independently by TH (in R) and MC (in Stata). MB, HG, OK, MR and CEW interpreted models and discussed results. All authors contributed to drafting and revising of the manuscript, approved of the final version to be published and agree to be accountable for the accuracy and integrity of any part of the work.

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