Correcting for deaths outside of hospital and ICU

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Objective

To estimate the age-stratified proportion of severe and critical cases among individuals infected with SARS-CoV-2 (ISR and ICR respectively), we identified countries with age-stratified seroprevalence studies that also report the age-stratified number of patients that were hospitalized (indicator of severe disease) or admitted to the ICU (indicator of critical disease). This allows us to estimate the ISR and ICR directly, by dividing the number of hospitalizations and ICU admissions by the estimated number of infected individuals.

However, one factor that may affect this procedure is that hospitalizations and ICU admissions may not fully reflect severe and critical cases. In particular, it is frequent for deaths in older patients to occur outside of the hospital or the ICU, thus constituting severe and critical cases that are not reported in the hospitalization numbers. To minimize the effect of this phenomenon in our estimations, we analyze to what extent COVID-19 deaths are not reported in hospitalization and ICU numbers across locations and ages, so as to correct for this phenomenon in our analysis.

Analysis of raw data

Data points with more deaths than ICU admissions

Our dataset of countries with serology studies and hospitalization or ICU data contains 10 locations: New_Zealand, South_Korea, Spain, Ireland, Sweden, Ile_de_France, England, Netherlands, Atlanta, NYC.

First we look for the most salient indicator of deaths outside of the hospital or the ICU: populations were the number of reported deaths is higher than the number of reported hospitalizations or ICU admissions. We find that 10 locations and ages that show this property (**Table 1**). Some of these points show a death count one order of magnitude larger than hospitalizations and ICU admissions (or two orders of magnitude in the case of England), underscoring the need to correct for deaths not included in hospital and ICU counts.

Table 1: Data points with more deaths than Hospitalizations or ICU

Age	Location	Hospitalized	ICU	Deaths
70-79	New_Zealand	18	4	7
80-89	New_Zealand	8	0	8
90+	New_Zealand	4	0	5
70+	Spain	52760	3009	23910
70+	Sweden	NA	465	4485
60-69	England	NA	3055	5016
70-79	England	NA	1852	12232
80+	England	NA	298	29948
80-89	Netherlands	2095	NA	2746
90+	Netherlands	308	NA	1194

Ratio of deaths to hospitalizations in public data and in hospital mortality studies

Next, we compared the ratio between deaths and hospitalization (or ICU) counts reported by the countries, to the reported in-hospital (or ICU) lethality in the literature. Since the ratio with public data takes into account all deaths, and the ratio of in-hospital studies take into account only hospital deaths, a deviation between the two may reflect the presence of deaths outside the hospital.

As can be seen in **Figure 1 (left)**, for most ages the ratio of deaths to hospitalizations is close to the in-hospital lethality fitted to several literature reports (black line and shaded region). Nonetheless, at the oldest ages, all the locations are above the fitted line, suggesting that for the oldest ages there are deaths outside of the hospital. For the ratio of deaths to ICU admissions (**Figure 1, right**), we see that almost all points across ages are above the ratio fitted to in-ICU mortality studies, indicating a widespread occurrence of deaths outside of the ICU.

In particular, we can look at the ratio between the ratios shown in the plot (the in-hospital mortality and the ratio in public data) to approximate what proportion of deaths occurs in the hospital (deaths in hospital rate, or DHR) or ICU (deaths in ICU rate, or DIR) for each age. The formula for DHR is shown below, and

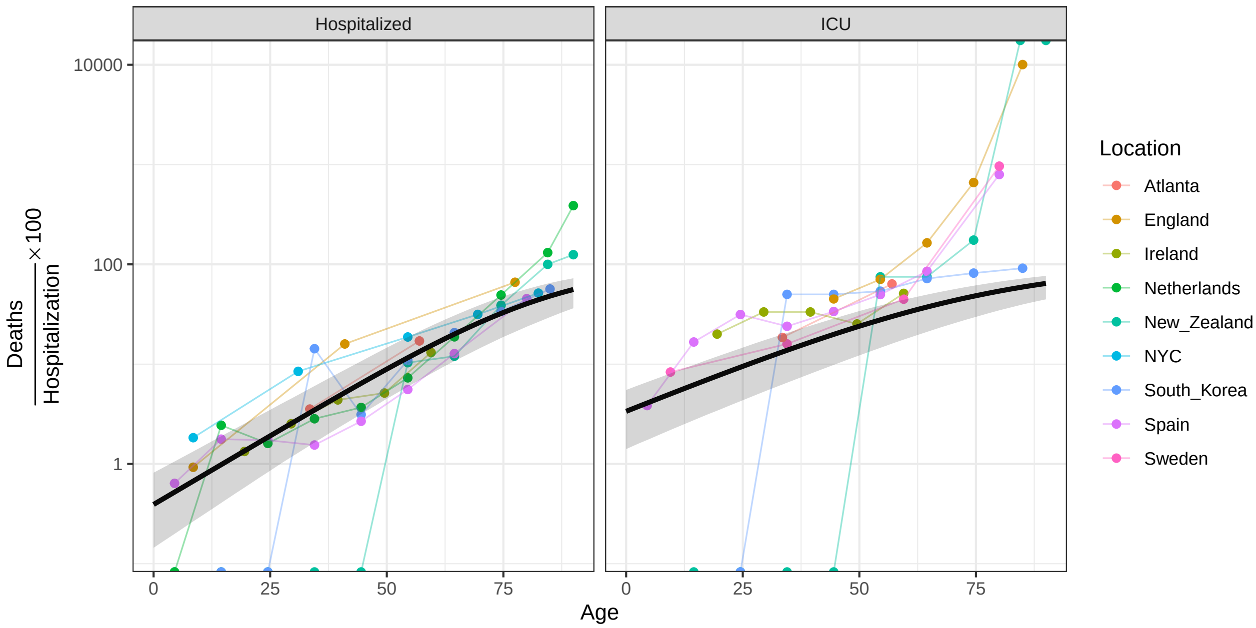

Figure 1: Ratio of deaths to hospitalizations (left) and ICU admissions (right). Dots show the ratio for public data for different locations. The black line and shaded region show the fitted ratio for in-hospital and in-ICU lethality

the formula for DIR is analogous:

$$DHR = \frac{Mortality_{Hospital}}{\left(\frac{Deaths_{Total}}{Hospitalizations}\right)} = \frac{\left(\frac{Deaths_{Hospital}}{Hospitalizations}\right)}{\left(\frac{Deaths_{Total}}{Hospitalizations}\right)} = \frac{Deaths_{Hospital}}{Deaths_{Total}} \tag{1}$$

Locations with disaggregated death data

Some locations have disaggregated data of total deaths and deaths in the hospital or ICU. We can compare these data to the ratios obtained in the previous section.

We observe in Figure 3 the ratios of in-hospital (and in-ICU) deaths to total deaths for different countries and ages. We see that the different countries show a general agreement in the magnitude of the ratio between hospital and ICU deaths to total deaths. Furthermore, these numbers seem in general agreement with what is expected from comparing the observed deaths to hospitalization ratio in the previous section to the reported in-hospital (or in-ICU) mortality. For example, we reported that for the 50-59 year range the ratio of ratios is 0.56, while the ratio between ICU deaths and total deaths for the 50-59 age range for England is 0.45. The ratio of ratios for hospitalization deaths for 80+ was 0.85, and the ratio of hospital deaths to total deaths at 80+ is 0.51 for England, and at 80-89 is 0.34 for Netherlands.

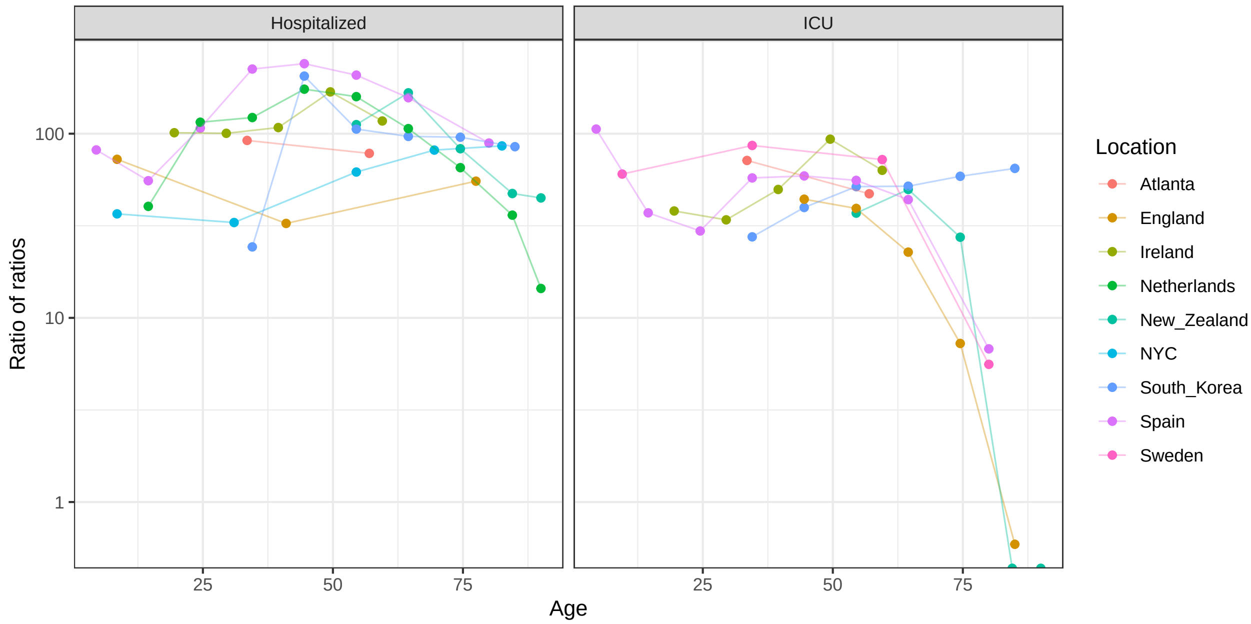

Figure 2: Ratio of death to hospitalization (left) and ICU (right) in public data over the ratio as obtained from in-hospital or in-ICU mortality.

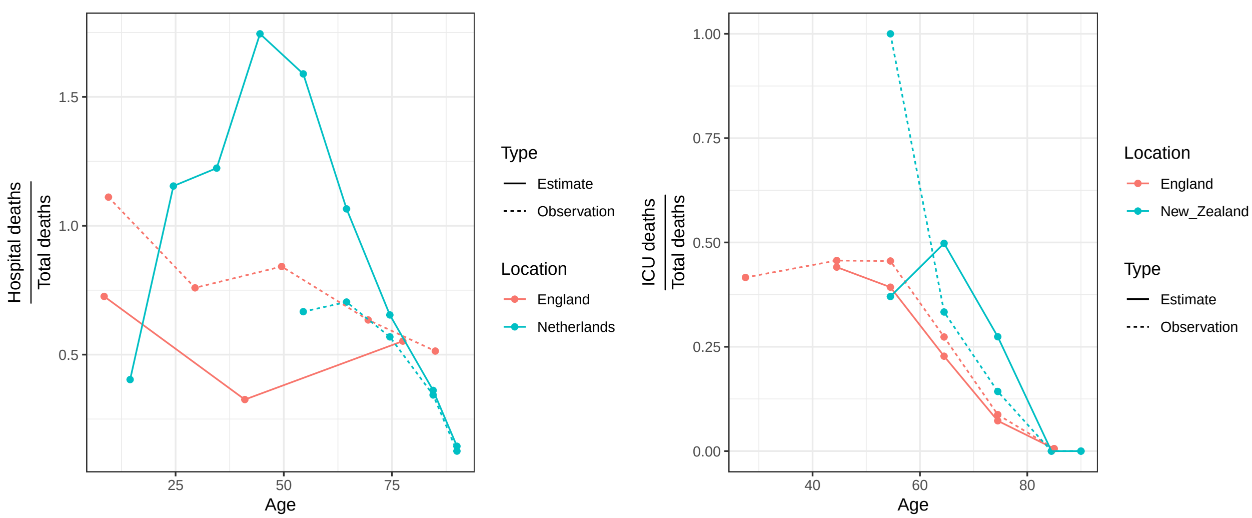

Figure 3: Ratio of hospital (left) and ICU (right) deaths to the total reported deaths for each age stratum.

Correction of data of critical and severe outcomes

In order to correct for deaths outside of the hospital and ICU, thus counting them as severe and critical cases, we estimated from the total number of deaths for a given location and age, how many occurred inside the hospital or the ICU, and how many occurred outside. Then, we added the number of deaths estimated to occur outside of the hospital or the ICU to the count of severe or critical cases, respectively. This procedure was not applied in countries where the data allowed to discriminate between deaths inside and outside of the hospital or ICU.

For this procedure, we first computed the DHR and DIR for each location and age with Equation 1, using the individual samples of the bayesian model fitted to hospital or ICU mortality. In this procedure, we set all samples with a DHR>1 to DHR=1. Then, we average the sampled DHRs and estimate the number of deaths outside the hospital (outside of hospital deaths, or OHD) for each age (A) and location (L) as:

$$OHD_A^L = DHR_A^L \times Deaths_A^L \tag{2}$$

We then add these estimated deaths to the severe cases. The same procedure is applied for out of ICU deaths and critical cases. Importantly, the number of severe or critical cases that this procedure adds to a given location and age is bounded by the number of deaths at that location and age. For young and middle-aged populations, the number of deaths is much smaller than the number of hospitalizations and ICU admissions, and thus this procedure does not change the number of severe and critical cases substantially.

In line with this, as can be seen in Figure 4, the proportion of severe and critical outcomes remain largely unchanged by the correction procedure for younger and middle age populations. Also, as could be expected from the analysis seen in Figures 1 and 2, the change is very small across all ages for severe disease. Thus, as could be expected from the analyses above, we see that the data points most affected by the procedure are those corresponding to critical disease outcome in older age individuals.

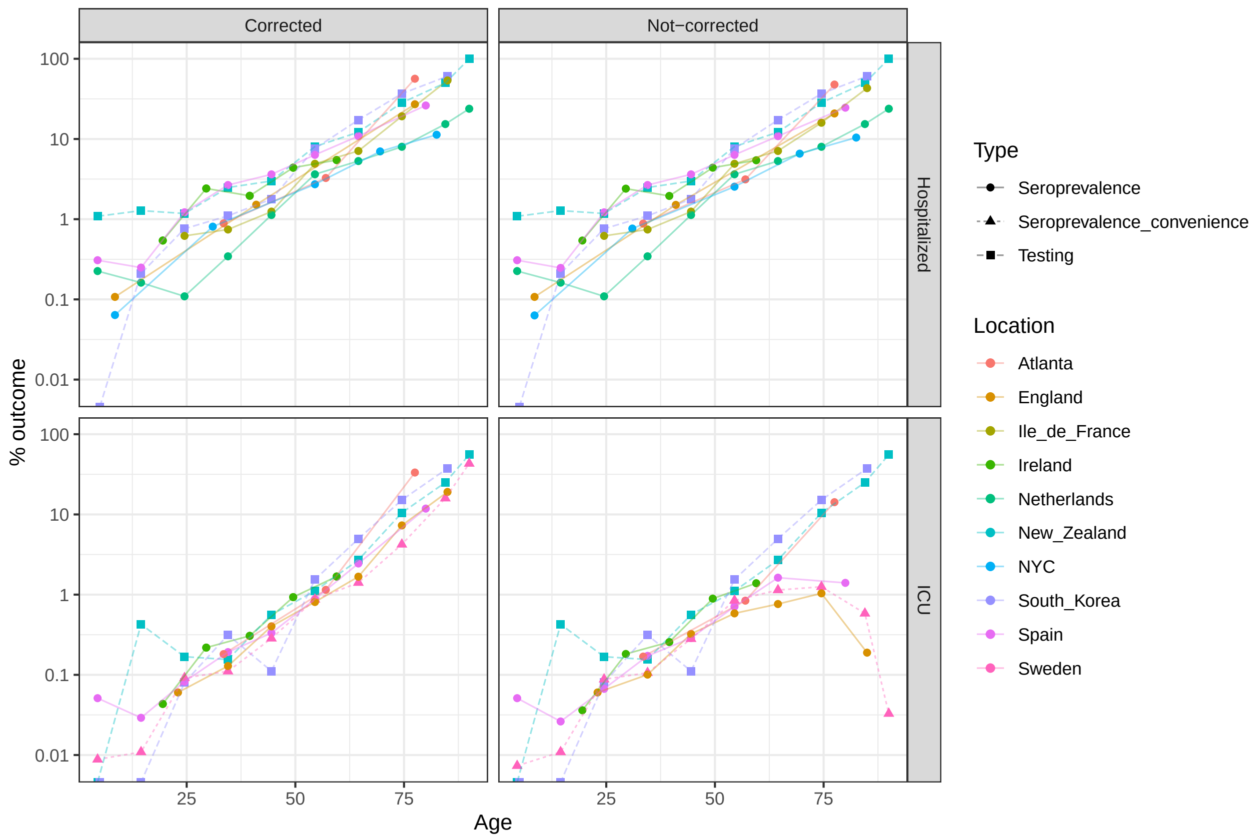

Figure 4: Percentage of infections that develop severe (top) and critical (bottom) disease, with the correction for out of hospital and out of ICU deaths applied (left) or without the correction (right)