**Title: Estimating the burden of COVID-19 pandemic on mortality, life expectancy and lifespan inequality in England and Wales: A population-level analysis**

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**Keywords:** excessdeaths, health inequality, infectious diseases, COVID-19 pandemic

**Abstract**

**Background:** COVID-19 related deaths may be misclassified as other causes of death thereby underestimating the full impact of the pandemic on mortality. The aim of this study is to determine the impact of the COVID-19 pandemic on mortality, life expectancy and lifespan inequality from week 10, when the first COVID-19 death was registered, to week 33 starting August 10 of 2020 in England and Wales.

**Methods:** We estimated age and sex-specific excess mortality risk and deaths above a baseline adjusted for seasonality with a systematic comparison of four different models using data from the Office for National Statistics. We additionally provide estimates of life expectancy at birth and lifespan inequality defined as the standard deviation in age at death using life tables.

**Results:** We estimate that there have been 51,334 (95% Prediction Interval: 48,641, 54,056) excess deaths in the first 33 weeks of 2020, 54% of which occurred in men. Excess deaths increased sharply with age and men experienced elevated risks of death in all age groups. Life expectancy at birth dropped 1.1 and 1.4 years for females and males relative to the 2019 levels, respectively. Lifespan inequality also fell over the same period by six months for both sexes.

**Conclusion:** Quantifying excess deaths and their impact on life expectancy at birth provides a more comprehensive picture of the full COVID-19 burden on mortality. Whether mortality will return to -or even fall below- the baseline level remains to be seen as the pandemic continues to unfold and diverse interventions are put in place.

**Main text word count:** 2,998 (excluding references)

**Summary boxes:**

**What is already known on this topic:** COVID-19 related deaths may be misclassified as other causes of death thereby underestimating the full impact of the pandemic on mortality. Excess mortality, the difference between observed deaths and what would have been expected in the absence of the pandemic, is a useful metric to quantify the overall impact of the pandemic on mortality and population health. Life expectancy at birth and lifespan inequality assess the cumulative impact of the pandemic on population health.

**What this study adds:** We examine death registration data from the Office for National Statistics from 2015 to week 33 (beginning on August 10) in 2020 to quantify the impact of the COVID-19 pandemic on mortality in England and Wales thus far. We estimate excess mortality risk by age and sex, and quantify the impact of excess mortality risk on excess deaths, life expectancy and lifespan inequality. During weeks 10 through 33 of 2020, elevated mortality rates resulted in 51,334 additional deaths compared with baseline mortality. Life expectancy at birth for males and females in the 33 weeks of 2020 was 78.5 and 82.4 years, which represent a decline of 1.1 and 1.4 years of life lost relative to the year 2019. Lifespan inequality, a measure of the spread or variation in ages at death, declined due to the increase of mortality at older ages.

**Introduction**

Estimating the number of deaths caused by the coronavirus disease 2019 (COVID-19) is an important challenge [1]. Insufficient testing capacity for SARS-CoV-2 during the pandemic and misclassification of causes of death make the true toll of COVID-19 hard to estimate [2]. Moreover, the events and interventions that took place during the pandemic may have indirectly affected other causes of death [3]. Both fear of COVID-19 and the overstretching of the healthcare system may have deterred care-seeking for both chronic and acute conditions, potentially increasing mortality from other, non-COVID, causes[4]. Similarly, lockdown policies might have decreased deaths from external causes such as road traffic accidents, or increased deaths from causes such as suicide or related to domestic violence.

Thus far, COVID-19 mortality in England and Wales has often been tallied via confirmed or presumed deaths due to COVID-19, usually due to a positive SARS-CoV-2 test. An alternative approach to estimate the mortality burden of COVID-19 is to quantify the number of deaths during the pandemic compared to a baseline level of what would have been expected if the pandemic had not occurred. This approach for estimating excess all-cause mortality has been widely used to quantify the mortality toll of previous epidemics such as influenza[5]. Excess mortality may be quantified in different ways and the “excess numbers of deaths'' approach has been commonly used so far in England and Wales by the Office of National Statistics (ONS)[6]. While this metric provides an important measure of the burden of the pandemic on a society, simply counting total excess deaths does not provide an understanding of the substantial variation by age and sex over time in elevated mortality risks[7,8], nor does it allow for a comparison of current mortality conditions with past conditions due to changes in population age structure over the period. Furthermore, excess deaths do not provide an understanding of the cumulative impact of the pandemic on summary indicators of population health such as life expectancy.

Life expectancy at birth is a commonly used age-standardised summary indicator of population health that expresses the average number of years a newborn would be expected to live given the death rates in a particular period. While no individual would actually be expected to experience a set of death rates observed in a given period throughout their life, life expectancy provides a snapshot of the mortality profile in a given period. Additionally, life expectancy does not require the arbitrary choice of a standard population as done with reported standardised death rates. Furthermore, life can shed additional light on the cumulative burden of a crisis such as COVID-19 on population health and enable comparisons with previous population health conditions. Lifespan inequality is another complementary indicator of population health which has implications for public health planning. While life expectancy is a measure of average mortality, lifespan inequality is another age-standardized summary indicator of the variation in length of life (or conversely, ages at death). It is akin to the Gini Coefficient used by policymakers in understanding patterns of income or wealth inequality. Lifespan inequality has important implications at both the individual and the societal level[9,10]. Greater lifespan inequality means that individuals face greater uncertainty about when they will die, potentially affecting decisions such as health behaviours [11]. Lifespan inequality also has important implications for health and social care planning and budgets, with higher levels implying greater dispersion in the ages at death [9]. Lifespan inequality is one of the most fundamental measures of inequality that reflects how unevenly population health improvements are shared within a population and has begun to be reported in health and demographic research[10].

We estimate all-cause excess deaths from week 10 (March 2-8), the week in which the first death attributable to COVID-19 was registered in England and Wales, to latest available data from week 33 of 2020 (August 10). Our work builds on existing estimates and approaches in three ways. First, we provide estimates disaggregated by age and sex, to highlight variations in excess deaths during the pandemic in England and Wales. Second, we develop refined model-based counterfactual estimates of excess deaths that better account for exposures and seasonal mortality patterns. We also systematically assess the sensitivity of excess deaths to different model-based estimates. Third, we provide estimates of life expectancy and lifespan inequality during the first 33 weeks of 2020 and compare them with previous mortality trends. By considering all three measures together: excess deaths, life expectancy and lifespan inequality, this study presents a comprehensive assessment of the mortality impacts of the COVID-19 pandemic thus far.

**Methods**

***Data***

We extracted all-cause death counts stratified by week of death registration and sex from 2010 to the week for which latest data were available (week 33 of 2020) from the ONS for England and Wales. While weekly mortality data is available by 5-year age groups for 2020, this level of disaggregation is not available for previous years. Therefore, we use 6 age-groups (0-14, 15-44, 45-64, 65-74, 75-84 and 85-older years of age) for modelling weekly deaths to harmonise weekly death data across 2010 to 2020, and used the 5-year age intervals for calculating life expectancy and lifespan inequality estimates for 2020. We also obtained population estimates from ONS from 2010 to 2019[12], and population projections for 2020[13]. As these projections represent the population at the mid-year point, we used standard interpolation techniques[14] to estimate weekly mean population by sex and age groups over the study period to use them as offset in the modelling. Yearly death counts by 5-year age groups were used to calculate annual indicators[15] such as life expectancy and lifespan inequality.

The population coverage of vital registration in England and Wales is complete. Between March and May 2020, 81.1% of all deaths and 86.5% of deaths involving COVID-19 were registered within 1 week of occurrence[16]. Death registration in this period witnessed increased efficiency compared to trends noted in previous years due to changes implemented in the Coronavirus Act 2020 [17,18]. Based on trends from past years, 92% of deaths are registered within 1 month of occurrence. As the extent of bias caused by registration delays is not properly understood, we do not attempt to implement any correction factors to minimize risks of over-correction and inflating our findings.

***Excess mortality***

We estimated the baseline number of deaths in the absence of COVID-19 by fitting four different models. First, we fitted Generalized Additive Models assuming Negative Binomial and Poisson distributions of deaths during the period of study[19]. These models include a log-linear mortality trend by sex and age, smooth effects for age and seasonality, and an interaction between age and seasonality (see Supplement section 1). The smoothed effects are stratified by sex. Second, we fitted a Generalized Poisson Linear Model adjusted for year-to-year seasonality[20], also known as extended Serfling model[21]. These previous models included indicator variables for systematic ruptures in death registration observed in weeks coinciding with holidays (weeks 1, 52 and 22). Finally we created an empirical baseline by averaging the death rates observed in each week of the years 2015-2019 (see Supplement Figures 1 and 2).

We fitted the models to the weekly death counts from January 4, 2010 to the week starting on March 2, 2020. This baseline was then projected forward until August 16, 2020 (week 33). Excess mortality is then defined as the observed weekly death count minus the baseline, summed across the pandemic period from March 2 (week 10) to August 16 (week 33), 2020. From this baseline, 95% predictive intervals were constructed by sampling death counts from Negative Binomial and Poisson distributions depending on the model’s underlying distribution.

We report excess death estimates from the negative binomial model in the main text but estimates comparing the different approaches are provided in the supplementary materials. This choice is based on out-of-sample predictive performance on past non-COVID weekly death counts.

***Demographic Methods***

Life expectancy and lifespan inequality by sex were estimated using the yearly death counts and population estimates for the years preceding 2020 using standard demographic techniques[9], from which 95% predictive intervals were generated[22]. For the first 33 weeks of 2020, death counts over the first 33 weeks were aggregated over age groups and death rates were calculated using proportionally the mid-year population estimate.

***Code and Data availability***

All analyses were carried out using R software[23]. All analysis scripts and data are available in a public repository.

**Results**

***Estimates of excess deaths***

The first death attributable to COVID-19 in England and Wales was registered in the week starting in March 2, 2020 (week 10). From that week until the end of week 33 on August 16, 2020, there were 292,073 registered deaths, from which an estimated 51,334 (51,334, 54,056) are excess mortality above the expected baseline (see Figure 1). This estimate represents a 21.3% (19.9, 22.7) increase in deaths compared to the expected level.

Death rates during the pandemic were consistently higher among males in all groups compared to females (see Supplement Figure 3). Male excess deaths accounted for 54% (27,649 deaths) of this total, compared to 46% (23,685 deaths) among females over the same period. Between March 2 and August 16, 2000, male deaths exceeded the expectation by 22.9% (21.2 24.6) and female death counts by 19.7% (17.8, 21.7).

*[Figure 1 about here]*

The 15 to 44 year old age group accounted for 331 (124, 533) excess deaths (6.1% (3.2, 9) above the expected level). For older age groups excess deaths rose sharply (see Figure 2). The toll of the pandemic resulted in 6,030 (5,396, 6,698) and 7,976 (7,151, 8,789) excess deaths among people between 45-64 and 64-74 years of age, respectively. These numbers are 21.2% (18.6,24.1) and 20.3% (17.8, 22.9) above the baseline. The largest numbers of lives lost were estimated among the groups 75-85 and 85 and older, with 23.4% (20.7, 26.0) and 21.7% (19.3,24.3) more deaths than expected. Among the former, 16,105 (14,593, 17,539), excess deaths were estimated, while among the oldest age group there were 20,944 (18,977, 22,923) deaths above the baseline. No significant excess deaths have been found among those younger than 15 years. Note the larger number of female excess deaths in the 85+ group is due to there being 1.6 times more females in this age group compared to males.

*[Figure 2 about here]*

***Estimates of life expectancy and lifespan inequality***

Life expectancy at birth increased from 81.4 (81.3-81.4) years in 2005 to 83.5 (83.5,83.6) years in 2019 for females in England and Wales. Similarly, male life expectancy increased from 77.1 (77.1,77.2) to 79.9 (79.8,79.9) years in the same period. Using data from the first 33 weeks of 2020 yields an estimated life expectancy at birth of 82.4 (82.3,82.49) and 78.5 (78.5,78.6) for females and males, respectively. A reduction of 1.1 years for females and 1.4 years for males.

*[Figure 3 about here]*

From 2005 to 2019, lifespan inequality declined slowly from 13.8 (13.7, 13.9) to 13.5 (13.4,13.6) years for females and from 15.0 (15.0, 15.1) to 14.7 (14.6, 14.7) years for males. In the first half of 2020, we estimate that lifespan inequality fell sharply to 13 (12.9,13.1) and 14.2 (14.0, 14.2) years for females and males, respectively, corresponding to a reduction of over six months for both sexes.

**Sensitivity analysis**

We performed several sensitivity analyses. We refitted the seasonal baseline without including the first 9 weeks of 2020. This adjustment did not have major effects on our estimates and by taking the first 9 weeks into account we aligned our predictions with the observed trend at the beginning of the year. Our four models produce central estimates of the number of excess deaths between 45,640 and 51,334 depending on the choice of the model and its assumptions, they do not substantively affect the pattern of our results. For full details see Supplement Tables 1 and 2. In addition, we also estimated life expectancy using a piecewise constant hazard model and the results did not change.

**Discussion**

Excess deaths during the first half of the year 2020 shed light on the cumulative burden of the COVID-19 pandemic in England and Wales. While several European countries have experienced substantially increased mortality over the course of the pandemic, data at hand suggests that England and Wales are amongst the worst performers in terms of excess deaths, especially in the working-age group 15 to 64[24]. We estimated that 51,334 (48,641, 54,056) deaths would not have occurred in the absence of the pandemic. Our estimate is based on a systematic comparison of different approaches to estimating a mortality baseline from which excess is derived, and unlike existing approaches used for England and Wales[7], relies on a refined model that accounts for population exposures and seasonality. The toll of the pandemic had unequal impacts by age and sex in Europe and other regions[7,25,26]. Similarly for England and Wales, we found that excess mortality varied between sexes, with males accounting for 54%. Excess deaths increased sharply over age and male deaths were estimated to exceed females in all age groups, with the exception of those above age 85. This is explained by the population composition of England and Wales where more females survive to higher ages. Excess risk of mortality was consistently higher among men in all ages groups (see Supplement Figure 3).

Life expectancy in England and Wales steadily improved for 50 years before stagnating in the past decade [27,28]. We provide estimates of life expectancy for 2019 and the first 33 weeks of 2020 which show that life expectancy dropped a staggering 1.1 and 1.4 years for females and males respectively between these years. Moreover, our 2020 estimates for life expectancy fall 1.1 and 1.5 years below the official projected life expectancy in 2020 for females and males[29], respectively. It is likely that our estimates of excess deaths and life expectancy losses until this period are underestimated, as these estimates are based on deaths registered so far, a small fraction of which may have experienced registration delays[16]. Recent evidence suggests that reversals and stagnation in life expectancy amongst developed countries are usually a result of mid-life mortality crises [28]. In contrast, life expectancy losses during the pandemic have come about from sharp increases in older age mortality in both sexes. Trends across the second half of the year are unclear. Provided there is not a substantial ‘second wave’ of COVID-19 and that the pandemic affected the most fragile individuals[30] (e.g. in the most deprived areas[31] and with pre-existing conditions[16]), the remaining population may see lower than usual death rates in the rest of 2020, thereby making the overall life expectancy losses less severe. However, even if death rates fall 10% below the baseline level, life expectancy for 2020 would still be five months lower than expected for females and males. Alternatively, there could be long-term health effects among the millions of COVID-19 survivors that continue to impact future mortality risk[32]. For instance, if mortality declines but is still 10% higher than the baseline death rates for the rest of the year, life expectancy losses would be around 1.1 and 1.4 years for females and males, respectively.

According to the ONS, between March 1st and June 30th, 2020 there were 50,335 deaths involving COVID-19, 46,736 (93%) of which assigned COVID-19 as the underlying cause of death based on information noted on the death certificate[33]. A sizable fraction of our estimate for excess deaths is thus likely to be directly linked to COVID-19. Based on preliminary cause of death analysis of other causes by the ONS, deaths occurring from Alzheimer disease and dementia, ischemic heart disease, cerebrovascular diseases, influenza and pneumonia and ‘symptoms signs and ill-defined conditions’ category were all higher between March and May 2020 [17]. Together Alzheimer and ‘symptom signs and ill-defined conditions’ experienced the largest increases in magnitudes compared to their size in previous years, and deaths occurring from asthma and diabetes at home also increased[17]. These preliminary cause-of-death patterns indicate that a significant fraction of the unexplained excess mortality may also be attributable to undiagnosed COVID-19. As more detailed cause-of-death data become available over the coming months, future research should seek to develop methods to disentangle excess deaths attributable to COVID-19 and other conditions.

Historically, lifespan inequality has tended to fall as life expectancy has increased [28], although more recently, studies have found a reversed relationship [9]. Our results show that life expectancy and lifespan inequality can indeed move in the same direction in periods of massive mortality stress such as during the pandemic. This effect has not been noted or documented elsewhere. While less inequality in lifespans is desirable in the context of life expectancy increases, here the high burden of mortality at working and older ages has contributed to lowering lifespan inequality at the expense of decreasing life expectancy, which is a failure. Whether lifespan inequality will increase or decrease over the next months, or years, will depend heavily on how mortality develops as the pandemic continues to unfold.

Our results have important implications for health and social care planning in England and Wales. To return life expectancy to an increasing trend will require major efforts from a healthcare system weakened by the unfolding pandemic as well as sustained investment in wider societal policies driving population health. These include the high levels of inequality with respect to health and length of life[34] which have worsened in the past decade[35]. It is also likely that uneven demand for healthcare services[36] for the next months due to the pandemic will put additional pressure on healthcare systems. In the midst of this uncertainty these systems must begin to address the huge impact on hospital waiting lists of months of deferred treatments for chronic health conditions, as well as the huge drop off in referrals for routine care[37] and the longer-term consequences of the suspension of programmes such as routine cancer screening during the pandemic[38]. In this context, the potential impact of low-cost, non-pharmaceutical interventions, such as facemasks use[39] and social contact restrictions[40] to help reduce the number of future COVID-19 cases and deaths is of the highest importance.

**Ethical approval:** This article used aggregated, fully anonymized, publicly available data. Therefore no ethics approval is needed

**Data sharing statement:** This analysis used publicly available data. All data and scripts are available at <https://doi.org/10.5281/zenodo.3946492>

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**List of Figures:**

*Figure 1. Cumulative excess deaths in England and Wales through the COVID-19 pandemic weeks 10-33 by sex. Shaded areas represent 95% prediction intervals. Excess deaths are defined as the total observed deaths subtracting the estimated baseline death count.*

*Figure 2. Cumulative excess deaths in England and Wales through the COVID-19 pandemic weeks 10-33 by sex and age groups. Shaded areas represent 95% prediction intervals. Excess deaths are defined as the total observed deaths subtracting the estimated baseline mortality.*

*Figure 3 Life expectancy and lifespan inequality (standard deviation of ages at death) estimates for the periods 2001-2019, and for 2020 considering the first 33 weeks of the year by sex. Shaded areas represent 95% prediction intervals.*