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Original Article

Effect of COVID-19 Epidemic on Life Expectancy and Years of Life Lost in Iran: A Secondary Data Analysis

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Abstract

Background: The COVID-19 pandemic has caused a significant number of deaths in many countries around the world. This study provides an estimate of the effect of the COVID-19 epidemic on life expectancy and years of life lost (YLL) in Iran.

Methods: This study is a secondary data analysis carried out in 2020. Mortality data from COVID-19 were obtained from the Ministry of Health and Medical Education. Since the calculation of mortality rates requires the number of people at risk of death, this data was obtained from the Statistics Center of Iran and was used after a detailed evaluation. The effect of COVID-19 on mortality is evaluated using the techniques of a multi-decrement life table and the corresponding single-reduction life table. The YLL is calculated using the standard method provided by the World Health Organization.

Results: Analysis of mortality data showed that deaths due to COVID-19 could reduce life expectancy at birth by 1.4 years in 2020. Therefore, life expectancy at birth declined from 75.1 years to 73.7 years. Furthermore, the deaths due to COVID-19 from the outbreak to early February 2021 have caused about 800,000 years of YLL, which is almost as much as the YLL caused by cancers and tumors.

Conclusion: A decrease in life expectancy at birth by more than one year in countries with a life expectancy of over 70 years, such as Iran, can delay the increase in life expectancy for several years.

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Keywords ● COVID-19 ● Mortality ● Pandemic ● Life expectancy ● Causes of death

What's Known

- COVID-19 has caused a large number of deaths in Iran: over 58000 from the outbreak until early February 2021, according to the Ministry of Health and Medical Education.
- Estimation of life expectancy index and years of life lost using secondary data analysis quantifies these effects in an interpretable way.

What's New

- We project that COVID-19 will reduce Iran's life expectancy at birth in 2020 by 1.4 years. Therefore, life expectancy at birth declined from 75.1 years to 73.7 years
- The deaths from COVID-19 from the outbreak to early February 2021 have caused about 800,000 years of life lost, which is almost as much as cancers and tumors.

Introduction

While human concerns about epidemics and globalization had almost been allayed, the emergence and widespread outbreak of the COVID-19 epidemic posed great challenges to communities. In December 2019, an outbreak of a respiratory disease associated with a new Coronavirus was reported in Wuhan, China. The virus spread all around the world, and the World Health Organization declared the Coronavirus (COVID-19) to be a worldwide disease.[1] Although infectious and parasitic diseases such as AIDS, malaria, tuberculosis, and influenza are still present in the world today,[2] the rate of spread, transmission, and the death toll has not been such as to have such massive

economic, social, cultural, and health effects.[3]

The three basic and interrelated theories used to analyze and explain changes in the level and pattern of mortality include the demographic transition, the epidemiological transition, and the health transition. Based on these theories, the impact of epidemic and pandemic diseases on mortality has been drastically reduced, and this group of diseases have been declining.[4] Today, destructive, man-made diseases are the leading causes of death and have become important.[5-7] The COVID-19 virus pandemic has caused significant deaths in many countries around the world. Given the prevalence of COVID-19, the abovementioned theories are criticized. These theories ignore or at least underestimate the importance of pandemics,[7] especially in the post-mortality transition period. The prevalence of coronavirus and its effect on mortality patterns and life expectancy at birth, a main indicator used in the healthy population, shows that infectious and parasitic infectious diseases can still play an important role in having low mortality fluctuations, which deserves careful consideration.

Some recent studies have examined the effect of COVID-19 on life expectancy. Trias-Llimós and Bilal examined the role of the COVID-19 crisis on the life expectancy of the city of Madrid, which was the city most impacted by the disease in Spain. The results of their study, based on mortality data from March 9th to May 10th, showed that the reduction in life expectancy due to COVID-19 was 1.9 years for men and 1.6 years for women. These figures show that life expectancy at birth for the city of Madrid has returned to where it was in 2009.[8] Estimates also show that the impact of COVID-19 on US life expectancy by 2020 is about 1.2 years and has reduced the life expectancy at the age of 65 years by 0.87 years. It is estimated that the population of Africans and Latinos will experience a decrease of 1.2 and three years in life expectancy, which is several times higher than the figure for Caucasians (0.68 years). These findings suggest that COVID-19 has offset the increase in life expectancy at birth since 2006.[9]

Previous studies in Iran have examined the level of life expectancy and years of life lost due to various diseases.[10-12] Awareness about demographic and health consequences of different kinds of diseases can provide useful information to health policymakers in order to develop new priorities in health policies and programs, in addition to helping with the optimal allocation of resources for future research activities and public health programs. However, since the outbreak of COVID-19, no study has been conducted that uses specialized demographic techniques to examine the impact of COVID-19 on life expectancy and years of life lost in Iran. Therefore, the purpose of this study is to make the first estimations with regard to the potential impact of the COVID-19 pandemic on period life expectancy and life years of Iranians in 2020.

Materials and Methods

The data for the present study was extracted from a research project on "Demographic Dimensions and Consequences of coronavirus COVID-19 in Iran" with the research code No. 11.92707, which was conducted by the National Institute for Population Research (NIPR). This study was a secondary data analysis and did not pursue any intervention. However, the study was approved by the Ethics Committee of NIPR (code: 11/92707). The target population in this study was all Iranians in 2020, who were at risk of COVID-19. Calculating life expectancy at birth in Iran in 2020 requires data on mortality and age-exposed populations. Calculating the life table in Iran for the year 2020 requires the number of deaths by age. Given that this statistic has not been published to date, using the mortality data by age in Iran from the years 2016 to 2019 (obtained from the National Organization for Civil Registration),[13] and the Lee-Carter method,[14] the number of deaths for 2020 was estimated. The Lee-Carter method, as an extrapolation method, is a combination of a rich demographic model with minimum parameters and time series methods. In addition, population data for 2020 were estimated based on Iran's population in 2016, taken from the Population and Housing Census.[15] On the other hand, in order to investigate the effect of COVID-19 on life expectancy in Iran, information on mortality due to COVID-19 in Iran in 2020 were obtained from the registry of the Ministry of Health and Medical Education.[16]

To evaluate the impact of COVID-19 on mortality in Iran, the number of years that can be added to life expectancy at birth was calculated. In this method, it is calculated that assuming COVID-19 is removed from the causes of death in Iran in 2020, how many years will be added to life expectancy at birth. The effect of this cause of death was evaluated using the techniques of a multi-decrement life table and the corresponding single-reduction life table.[17]

In multi-decrement life table analysis, calculating life table columns, such as ${}_na_x$, ${}_nq_n$,

${}_nd_x$, ${}_nL_n$, etc., is based on a simple life table approach. For this purpose, mortality rates are converted to a probability of death based on the following formula:[18]

$$ {}_nq_x = \frac{{}_nm_x}{1 + (n - {}_n\alpha_x)\ {}_nm_x} $$

Where: x – exact age; n – number of years in the age interval; ${}_nq_x$ - the probability of an individual at age x dying before the end of the age interval (x, x+n); ${}_nm_x$ - central death rate for the age interval (x, x+n); ${}_n\alpha_x$ - the average number of years lived in the age interval (x, x+n) by those dying during that age interval.

$$ {}_nq_x^i = {}_nq_x\ \frac{{}_nD_x^i}{{}_nD_x} $$

Then, the probabilities of death (${}_nq^i_x$), disregarding COVID-19, were estimated by:

Where ${}_nD_x$ - number of deaths in the age interval x to x+n for all causes; ${}_nD^i_x$ number of deaths in the age interval x to x + n attributable to COVID-19.

In constructing the related single-decrement life table, it is necessary to remove every cause of death and the proportion of deaths due to all causes except the considered cause in all age groups, (R^{-i}), which is calculated using the following formula:[19]

$$ R^{-i} = \frac{{}_nD_x - {}_nD_x^i}{{}_nD_x} $$

Estimating the contribution of mortality from COVID-19 to overall mortality also permits us to estimate the effect of completely eliminating COVID-19 through "cause-deleted" life table analysis.[19] If COVID-19 was eliminated as a cause of death, survival at the age interval *x* to *x+n* would be represented as:

$$ {}_nP_x^{-i} = {}_nP_x^{R-i} $$

In addition, the number of years of life lost due to COVID-19 was calculated. The YLL index is a valuable analytical tool for prioritizing health problems by selecting a unit of time as a unit of measurement and comparing years of life lost due to death with a standard life expectancy curve.[15, 16] The method used in this study in accordance with the standard of the World Health Organization to calculate the years of life lost, by applying a discount rate of 0.03 for the future time and applying the age weight for different years of life, is as follows:[20]

$$ YLL = \frac{KCe^{ra}}{(\beta + \mathrm{r})^2} $$

$$ \begin{bmatrix} e^{-(r+\beta)(L+a)}\,[-(r+\beta)(L+a) - 1] \\ -e^{-(r+\beta)a}[-(r+\beta)a - 1] \end{bmatrix} $$

$$ + \frac{1+K}{r}\,(1 - e^{-rL}) $$

Where α - age of death (years); r - discount rate (3%); β - age weighting constant (e.g. β=0.04); K - age-weighting modulation constant (e.g. K=1); C - adjustment constant for age-weights (e.g.C=0.1658); L - standard life expectancy at age of death (years).

Results

To date (February 26, 2021), based on Worldometer's elaboration of the latest United Nations data (https://www.worldometers.info/coronavirus/), in terms of the number of COVID-19 cases, Iran is ranked 16th, and in terms of the number of deaths, it is ranked ninth in the world. The difference between Iran's ranking in terms of cases and morbidity and the rankings of other

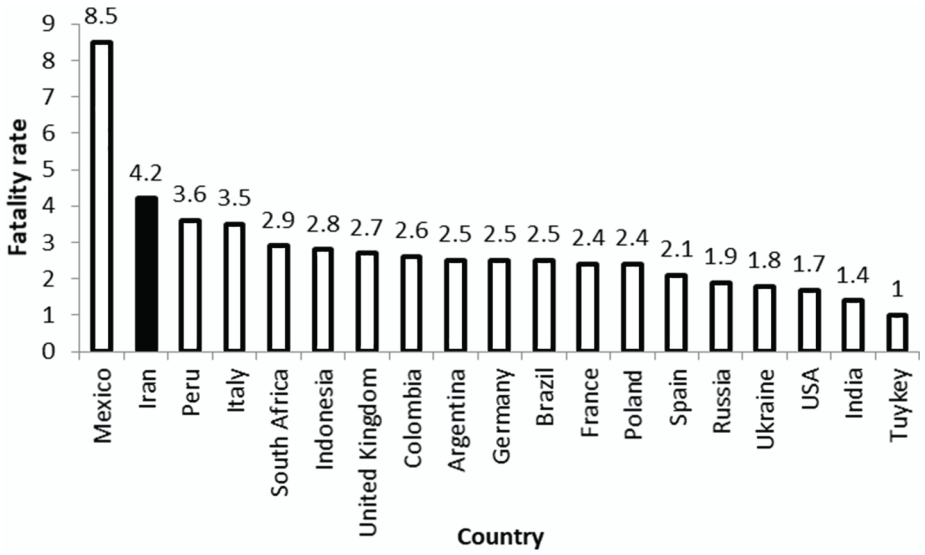

Figure 1: Fatality rate shows the COVID-19 death rate in Iran and countries with the highest number of patients.

countries in the world indicates the higher fatality rate (number of deaths/number of cases) of this disease in Iran. As figure 1 shows, the fatality rate of COVID-19 in Iran is 4.2% to date; this figure is higher in Iran than the 20 countries with the highest numbers of deaths and infections (except Mexico). Recently, with the increase of daily tests, the mortality rate in Iran has approached the global levels.

Figure 2 shows the age distribution of definitive cases and the death toll from COVID-19 up to September 19th, 2020. The age-related pattern of the death toll from COVID-19 is different from that of infected patients. Therefore, the highest relative share of deaths is in the elderly age groups (60 years and above), and the age group of 80 years and above has the highest relative share of deaths. Over 70% of the death toll from COVID-19 has occurred in people over the age of 60, and more than a quarter of them have been in the age group of 80 years and older alone. On the other hand, less than 4% of all deaths has occurred in people aged 40 and under.

Table 1 shows the estimated life expectancy at birth in Iran, assuming the absence of COVID-19. According to the table, the mortality rate of children under one year old is estimated at 19 per thousand children. In the absence of COVID-19, the combined life expectancy for men and women in 2020 was estimated to be 75.1 years in Iran. Moreover, assuming the absence of COVID-19, life expectancy at the age of 60 in Iran was 20.6 years for the total population.

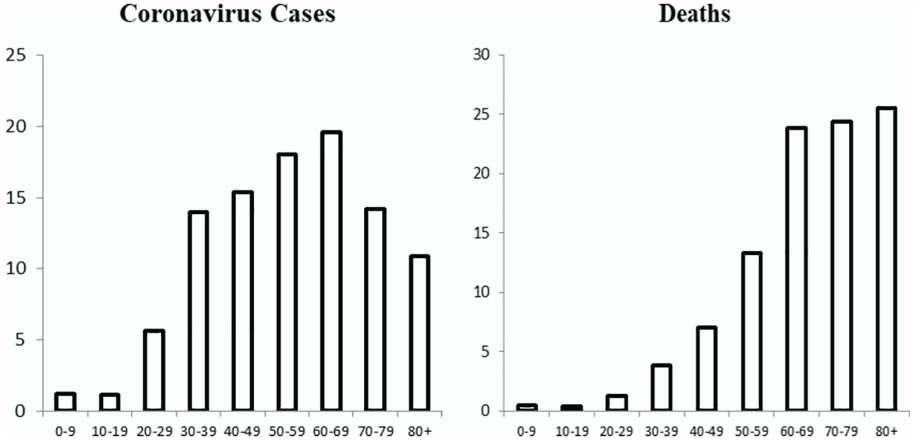

Figure 2: Diagram shows the age distribution of definitive cases and the death toll from COVID-19 up to September 19th, 2020.

Table 1: Summary life table assuming the absence of COVID-19 in Iran in 2020

Age	q (x,n)	l (x)	d (x,n)	L (x,n)	T (x)	e (x)
0	0.0185	100000	1847	98348	7510114	75.1
1	0.0023	98153	222	392056	7411766	75.51
5	0.0023	97931	224	489093	7019711	71.68
10	0.0025	97706	243	487924	6530617	66.84
15	0.0061	97463	591	485959	6042693	62
20	0.0067	96872	648	482726	5556733	57.36
25	0.0054	96225	524	479787	5074007	52.73
30	0.0054	95700	512	477246	4594220	48.01
35	0.007	95188	666	474357	4116974	43.25
40	0.0098	94522	925	470415	3642617	38.54
45	0.013	93597	1221	465128	3172202	33.89
50	0.0216	92376	1994	457245	2707074	29.31
55	0.0315	90381	2851	445255	2249830	24.89
60	0.0505	87531	4421	427475	1804575	20.62
65	0.088	83110	7313	398768	1377100	16.57
70	0.1545	75797	11707	351491	978332	12.91
75	0.2349	64090	15057	284190	626841	9.78
80	0.3625	49033	17774	202063	342651	6.99
85+	...	31259	31259	140588	140588	4.5

q (x,n): Probability that the persons in the cohort are alive at the beginning of the age interval x and would die during the next age interval; l (x): Total number of the person that survives at the exact age of x; d (x,n): Number of deaths between the exact ages of x and x+1; L (x,n): Number of person-years lived between the ages of x and x+1; T (x): Total number of person-years that would be lived by the cohort lx after attaining the age of x; e (x): Average number of complete years of life lived after attaining the age of x

Table 2 shows the life table in 2020, assuming that the coverage of deaths due to COVID-19 is complete. Therefore, in calculating the life table, the number of deaths due to COVID-19 is about 59,500, as recorded by the registration system of the Ministry of Health and Medical Education. Life expectancy at birth in Iran in 2020, with the fulfillment of the assumption above, is estimated as 73.7 years. This means that the COVID-19 disease reduces life expectancy at birth in Iran by about 1.4 years. Life expectancy at 60 also decreased from 20.6 years to 19.5 years. This means that the COVID-19 disease is expected to reduce the life expectancy of 60-year-old Iranians by 1.1 years in 2020.

Table 3 shows the number of Years of life lost (YLL) due to COVID-19 and their rates per thousand persons. Assuming that the coverage

Table 2: Life table in Iran, in the presence of COVID-19, in 2020

Age	q (x,n)+1	l (x)+1	d (x,n)+1	L (x,n)+1	T (x)+1	e (x)+1
0	0.0187	100000	1866	98332	7370535	73.71
1	0.0023	98134	227	391967	7272203	74.1
5	0.0024	97907	231	488956	6880236	70.27
10	0.0026	97676	252	487747	6391280	65.43
15	0.0062	97423	605	485729	5903533	60.6
20	0.007	96819	676	482390	5417804	55.96
25	0.0058	96142	553	479306	4935414	51.33
30	0.0058	95589	552	476600	4456109	46.62
35	0.0078	95037	745	473425	3979509	41.87
40	0.0114	94292	1071	468925	3506084	37.18
45	0.0151	93221	1408	462815	3037159	32.58
50	0.0254	91813	2336	453646	2574344	28.04
55	0.0372	89478	3332	439622	2120698	23.7
60	0.0607	86146	5231	418674	1681077	19.51
65	0.1043	80915	8441	385106	1262403	15.6
70	0.18	72474	13044	331498	877297.4	12.1
75	0.2676	59430	15903	258410	545799.8	9.18
80	0.3978	43527	17317	174963	287389.9	6.6
85+	...	26210	26210	112427	112427	4.29

q (x,n)+1: Probability that the persons in the cohort are alive at the beginning of the age interval x and would die during the next age interval due to COVID-19; l (x)+1: Total number of persons that survive at the exact age of x with COVID-19; d (x,n)+1: Number of deaths between the exact ages of x and x+1 with COVID-19; L (x,n)+1: Number of person-years lived between the ages of x and x+1 with COVID-19; T (x)+1: Total number of person-years that would be lived by the cohort lx after attaining the age of x with COVID-19; e (x)+1: Average number of complete years of life lived after attaining the age of x with COVID-19

Table 3: Number and rate of Years of life lost (YLL(due to COVID-19 in 2020

Age group	Number	Rate (1000 population)
Under one year	2743	4.95
1-4	2870	0.37
5-9	2976	0.42
10-14	3050	0.53
15-19	3862	0.82
20-24	8451	1.64
25-29	12831	1.63
30-34	22182	2.18
35-39	35379	4.16
40-44	44633	7.36
45-49	50587	9.051
50-54	67635	15.81
55-59	85615	21.37
60-64	113123	34.68
65-69	102639	49.41
70-74	84023	68.54
75-79	65908	76.17
80-84	50722	73.11
85+	30409	53.57
Total	789655	9.18

Rate of YLL: Number of Years of life lost per 1000 population

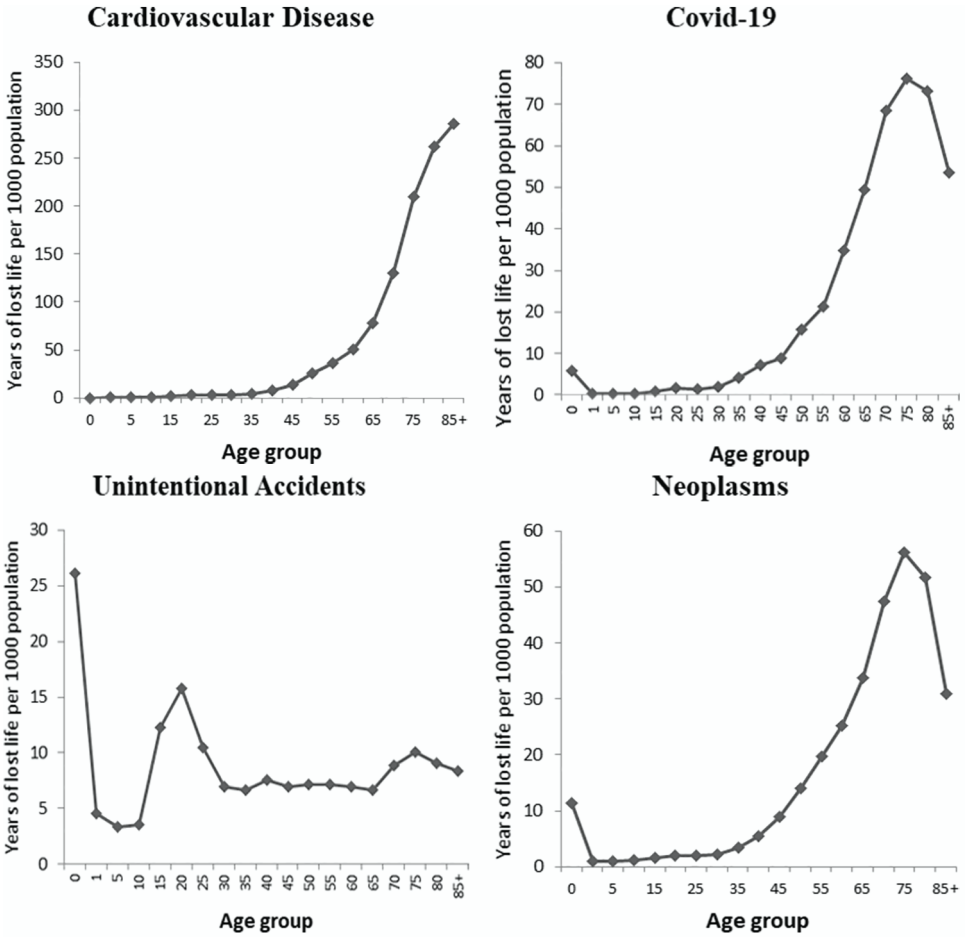

Figure 3: Diagram shows the age pattern of years of life lost rates of the main causes of death in 2019 and COVID-19 in Iran.

of the death toll from COVID-19 is complete, about 790,000 YLL due to COVID-19 have occurred in 2020. This data indicates that the rate of YLL is 9.18 per thousand persons. Therefore, with increasing age, the number of YLL also increases and reaches the highest number in the age group of 60-64 years. Then, assuming the full coverage of the registry, it reaches 113 thousand YLL, and then it decreases again and eventually reaches about 30 per thousand persons in the last age group (85 years and older).

Furthermore, in this study, the YLL caused by COVID-19 in 2020 was compared with the YLL caused by the main causes of death in 2019, as shown in figure 3. It should be noted that since the mortality information of other causes of death in 2020 has not been published, for this purpose, the mortality data of the main causes of death were related to 2019, and they were obtained from the Civil Registration Organization.

Cardiovascular disease was the leading cause of premature loss of life for both sexes in 2019, so the resulting YLL rate is about 18 years per thousand persons. Moreover, unintentional accidents are the second leading cause, and cancers and tumors are the third leading cause of YLL in Iran. Although unintentional accidents account for a smaller proportion of deaths than cancers, the younger structure of unintentional accident deaths makes them almost identical in YLL. Therefore, according to this statistic, it can be said that the years of premature YLL caused by COVID-19 in Iran in 2020 are somewhat higher than these rates for unintentional accidents and cancers in 2019. It should be noted that the death registration coverage is the same for the main causes of death in the country. The age pattern of YLL regarding the main causes of death in 2019 and COVID-19 is shown in figure 3. As can be seen, among infants under one-year-old, the YLL rate for cardiovascular disease is higher than other causes of death. YLL rates of cardiovascular disease, cancer, and COVID-19 are low at the age of 50 and below. But after that, and especially over 60 years, they increase. These rates for cardiovascular disease have been far higher than those of other major causes of death in Iran. The YLL rate of cardiovascular disease in people at the age of 85 years and older is over 300 years per thousand persons, while this figure for cancers and COVID-19 at

the highest level does not reach 80 years per thousand.

On the other hand, the age pattern of YLL caused by unintentional accidents is very different from that of other causes of death. At a young age, the rate for unintentional accidents is higher than that of other causes of death, and conversely, at an older age, these rates for unintentional accidents are significantly lower than those of other causes of death. In general, the age pattern of YLL due to COVID-19 in 2020 is mostly similar to YLL rates due to cancers and tumors.

Discussion

The estimation of life expectancy at birth in Iran showed that the death toll from COVID-19 could reduce life expectancy by 1.4 years in 2020. Other studies showed that the coronavirus epidemic has reduced life expectancy in the United States. According to researchers at the University of Southern California and Princeton University, deaths from COVID-19 have reduced life expectancy by 1.13 years; this is the largest decrease in life expectancy in the last 40 years, which reduces life expectancy in the United States down to 77.48 years.[9] Although the death rate due to COVID-19 is higher in the United States than it is in Iran (0.7 per thousand persons in Iran compared with 1.4 per thousand persons in the United States), the younger structure of deaths in Iran has a significant impact on life expectancy at birth than the United States and other countries that have an older age structure of death.

According to Aburto, from 2019 to 2020, in 24 of the 26 countries where high-quality vital statistics are now available, including most European countries, Chile, and the United States, life expectancy at birth has decreased. Men in the United States and Bulgaria experienced the greatest loss of life expectancy at birth in 2020 (2.1 and 1.6 years, respectively).[21] Moreover, the decline in life expectancy caused by COVID-19 in the city of Madrid in 2020 was estimated at about 1.7 years.[8] The decline in life expectancy at birth due to COVID-19 in Brazil in 2020 was estimated at 1.94 years.[22] Given that the age structure of the population of Iran is middle-aged, the results are not comparable with studies in regions or countries that have the age structure of an elderly population. The impact of the COVID-19 epidemic on the life expectancy of a population, however, is not so clear-cut. On the one hand, since the virus kills a disproportionate number among older populations, the number of years lost with respect to the existing average life expectancy might be smaller than expected. On the other hand, its rapid spread might cause a high level of excess mortality, as observed in many countries, that is consistently large enough to affect the life table of a country or a region.[23]

While COVID-19 is a highly infectious disease, it has a low mortality rate when viewed in a historical context. The impact of the COVID-19 epidemic was significantly less than that of the 1918 influenza epidemic, which killed about 50 million people with an average mortality rate of about 2.5 percent. The flu in 1918 and the outbreak of the Ebola virus in 2014 reduced life expectancy at birth in the United States and Liberia by 11.8 years and 1.6-5.6 years, respectively.[24, 25] Like the influenza pandemic of 1918, COVID-19 serves as a short break in the long-term improvement of life expectancy in history, and it is unlikely that the process of improvement in life expectancy would not resume in the coming years.

From a demographic perspective, the main feature of COVID-19 is that the vast majority of severe cases of the disease involve the older population, especially those aged 70 and older. The results of this study also showed that the elderly were the most obvious victims of the COVID-19 crisis. This finding is consistent with the results of other studies.[26-28] Therefore, supporting the health of the elderly and short-term and long-term care measures during the outbreak of COVID-19 is one of the most important policy measures, which can play an important role in promoting community health and the well-being of the population.

The findings of this study showed that about 800,000 years of premature loss of life due to COVID-19 was expected in Iran in 2020. The relative impact of COVID-19 on the number of deaths was greater than that on the number of YLL, because COVID-19 affected older people disproportionately. Few studies have been conducted in this field in other countries;[29, 30] the study duration in these studies was less than one year, and hence, their results could not be compared with the results of this study. However, due to the younger age structure of deaths due to COVID-19, the YLL rate in Iran is expected to be at least higher than that of developed countries with older age structures.

We have shown that the COVID-19 epidemic can seriously affect Iran's annual life expectancy. Continued monitoring of life expectancy in Iran and other countries in West Asia and the Middle East provides valuable evidence of the impact of the overall epidemic on mortality in this region of the world. This study is one of the first studies on the demographic implications of COVID-19, at least in Iran and other developing countries. However, to calculate the effect of deaths due

to COVID-19 on mortality in the country, one of the most important limitations of this study is the unavailability of data on the number of deaths in 2020 and the main causes of death. To calculate the country's life expectancy in 2020, it was inevitably assumed that the number of deaths in this year has been a continuation of the increasing trend of mortality in recent years. However, the results of some studies showed that COVID-19 could affect the levels and patterns of other causes of death.[31, 32] For example, traffic fatalities can be expected to somewhat decrease. It can also affect the registration of deaths from heart disease, cancer, and respiratory diseases, which in turn can alter the overall predicted mortality rate.

Conclusion

It should be noted that infectious and parasitic infectious diseases can still play an important role in mortality fluctuations, a fact that deserves careful consideration. This can be an important lesson for the post-mortem and population transition period, especially for middle-income countries, whose age structure is rapidly aging. The elderly population in these countries, as well as in Iran, is growing rapidly, and they are currently the most vulnerable group against epidemics and infectious and parasitic pandemics such as COVID-19. Considering the forthcoming changes in Iran's demographic pattern toward aging and the high rate of population aging in the coming years, it seems necessary to take a special look at the issue of aging health and the adoption of appropriate policies to strengthen the immune system of the current and future elderly populations.

In order for demography to be an effective step in understanding and resolving the health crisis, we need to invest in data collection and analysis. The social response to complex health needs in the future should be designed based on scientific research with regard to evolving epidemiological and demographic realities, as well as the relative effectiveness of interventions.

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Authors' Contribution

H.B.R.N, M.S: Study concept and design, Acquisition, and interpretation of data, Drafting and critical revision of the manuscript; All authors have read and approved the final manuscript and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Conflict of Interest: None declared.

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