National age and coresidence patterns shape COVID-19 vulnerability

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Edited by Douglas S. Massey, Princeton University, Princeton, NJ, and approved June 8, 2020 (received for review May 8, 2020)

Based on harmonized census data from 81 countries, we estimate how age and coresidence patterns shape the vulnerability of countries' populations to outbreaks of coronavirus disease 2019 (COVID-19). We estimate variation in deaths arising due to a simulated random infection of 10% of the population living in private households and subsequent within-household transmission of the virus. The age structures of European and North American countries increase their vulnerability to COVID-related deaths in general. The coresidence patterns of elderly persons in Africa and parts of Asia increase these countries' vulnerability to deaths induced by within-household transmission of COVID-19. Southern European countries, which have aged populations and relatively high levels of intergenerational coresidence, are, all else equal, the most vulnerable to outbreaks of COVID-19. In a second step, we estimate to what extent avoiding primary infections for specific age groups would prevent subsequent deaths due to within-household transmission of the virus. Preventing primary infections among the elderly is the most effective in countries with small households and little intergenerational coresidence, such as France, whereas confining younger age groups can have a greater impact in countries with large and intergenerational households, such as Bangladesh.

demography | households | COVID-19 | aging | global

The coronavirus disease 2019 (COVID-19) pandemic currently confronts nearly all of the world's countries. A growing number of governments are enforcing or recommending home quarantines to contain the spread of the virus. As the virus can be transmitted outside and within households, the effects of such measures will depend on the number of transmissions that take place outside and within the household. Evidence shows that the risk of severe disease and mortality increases sharply with age (1, 2). Therefore, the age structure of the population—what proportion are young or old—and the structure of coresidency—how big are households and how old are their members—are two key factors that determine the vulnerability of countries to outbreaks of COVID-19, and how effective general and age-specific household confinement policies can be in reducing mortality after an outbreak (3).

Results

Fig. 1 provides estimates of the number of deaths from COVID-19 per 100,000 individuals if countries were to experience an outbreak of COVID-19 of equal size, more specifically, a random infection of 10% of the population living in private households (i.e., excluding people living in old-age homes). Results are shown for 81 countries, covering all regions of the world, and are solely based on census-based microdata on age and coresidence patterns combined with age-specific infection fatality ratios (2). These ratios were not available to us for males and females separately, but uniform adjustments of age-specific death rates by sex lead to very similar results. The left-hand segment of each bar provides an estimate of direct mortality of individuals who catch the disease in a 10% random infection of the population (primary infections). The right-hand segment of the bars shows the additional deaths that would occur if all other members of the household become infected too (secondary infections). Lower rates of household transmission would reduce this number of indirect deaths proportionally. The direct effect depends on the age structure of the population; the indirect effect hinges on the size and age structure of households. Combined, they show how, all else equal, national age and coresidence patterns alter the vulnerability of a country to COVID-19 outbreaks.

The expected direct death rates per 100,000 individuals range from 19 in South Sudan to 120 in Italy. Together with Italy, three southern European countries—Greece, Portugal, and Spain—rank among the top six, followed by the rest of Europe and North America. Latin American countries form a homogenous cluster lower than the European and North American cluster. Asian countries spread all over the range, with estimates as high as 81 in South Korea and as low as 23 in Jordan. African countries tend to experience the lowest direct death rates. Where the elderly comprise a large portion of the population, the direct effect is high, whereas direct deaths are much lower where the elderly are vastly outnumbered by younger people.

Mortality due to intrahousehold contagion (right-hand segment of a bar in Fig. 1) does not follow the same order, because coresidence patterns differ widely across countries, even among those countries with similar age structures (4–7). The ratio between indirect and direct effects is a simple indicator of the importance of coresidence patterns, in particular, of the elderly, the most vulnerable group. For European and North American countries, direct and indirect deaths are roughly equal. In Latin America, indirect deaths could approximately double the number of direct deaths. The ratio between potential indirect and direct deaths in Asia ranges from 1.3 (South Korea) to 3.7 (Laos). In Africa, indirect deaths would be 3 to 4 times the number of direct deaths. Such variation is closely associated with cross-national variation in coresidence patterns and, more specifically, with the number and age of the persons with whom elderly people reside.

Despite differences in ratios, the combined death rate (direct plus indirect) reproduces a broad regional pattern similar to the one observed in direct mortality, but with variation in the specific position of countries. For instance, countries with similar direct death rates, such as France and Spain, show remarkably different indirect rates, due to higher levels of intergenerational coresidence in Spain. Countries with similar indirect death rates, such as Italy and China, have quite distinct direct death rates, due to differences in their age structure.

Preventing Primary Infection of Specific Age Groups. Debates exist about the role that specific age groups, and particularly children, play in the transmission of the virus (8). In addition, countries

Author contributions: A.E. and J.W.V. designed research; A.E., I.P., and D.B. performed research; D.B. analyzed data; and A.E., I.P., D.B., and J.W.V. wrote the paper.

The authors declare no competing interest.

Data deposition: Information about data, methods, and code are available at https://www.medrxiv.org/content/10.1101/2020.05.13.20100289v1.

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First published June 23, 2020.

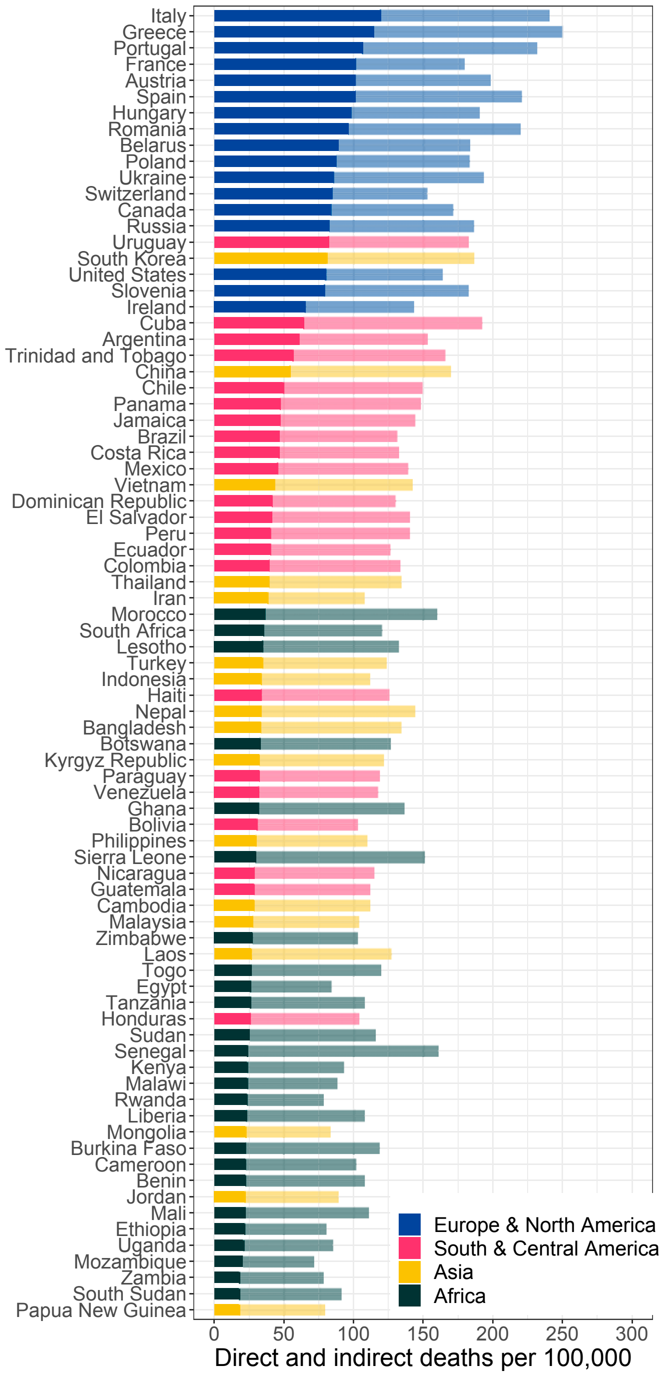

Fig. 1. COVID-19 vulnerability to national age and coresidence patterns. Estimated number of direct (dark) and indirect (light) deaths per 100,000 individuals if 10% of the population living in private households were to be infected by COVID-19 at random. Analyses based on most recent available data from either 2000 or 2010 census rounds.

have adopted age-specific policies such as school closures and extended confinement of the elderly in their homes. This provokes the question to what extent preventing primary infection of certain age groups would reduce the number of deaths that can arise due to within-household transmission of the virus.

The bars in Fig. 2 provide information about the expected mortality from direct and indirect deaths if primary infections for specific age groups could be averted. Results are shown for 10 countries chosen to illustrate diverse interactions between age structures and coresidence patterns. The first column shows the total number of deaths per 100,000 population if no age group is excluded from primary infection. The other columns indicate the total number of direct and indirect deaths per 100,000 population if primary infections could be averted for a particular age group.

Deaths due to primary infection are reduced most in all countries if infections of individuals aged 65 y or more are prevented. There is much more variation in how much avoiding primary infections of specific age-groups affects the number of indirect deaths that arise due to secondary infection (within-household transmission). In France, indirect deaths are simulated to go down considerably if no person aged 65 y or older were to be infected directly. This indicates that elderly persons primarily live with other persons aged 65 y or older in France. These coresidence patterns also imply that avoiding primary infections for other age groups has relatively little effect on deaths that emerge due to within-household transmission of the virus in France. At the other extreme, there are countries, such as Bangladesh, where preventing direct infections of the elderly would barely reduce indirect deaths and where avoiding the primary infection of children or adults aged 19 y to 49 y has a larger impact on indirect deaths. This result is explained by the high levels of intergenerational coresidence of the elderly, together with the fact that children comprise a large share of the total population in these countries. Other countries fall between these two extremes, with the United States being similar to France, and Ghana and South Africa resembling Bangladesh. Some cases combine elements from both extremes, such as Italy, where confining both the elderly and individuals aged 19 y to 49 y reduces indirect deaths. However, in none of the scenarios do indirect deaths go down considerably. This illustrates the double challenge that countries such as Greece, Italy, Portugal, and Spain face: The combination of an aged population with intergenerational residence leads to high estimated death rates due to COVID-19 but also makes preventing deaths due to within-household transmission of the virus particularly challenging.

Discussion

In confronting COVID-19, epidemiologists should analyze and policy makers should consider how age structure and coresidence patterns in their countries can shape the number of infections and deaths. Differences in age structures put countries at different risk; a less considered factor, coresidence patterns, modulates this risk. In our simulations, which can be considered baseline scenarios before accounting for specific national policies, the proportion dying per 100,000 population is 240 in Italy and 71 in Mozambique (Fig. 1). In contrast, under the same assumptions, the proportion of the population that becomes infected is 28% in Italy and 44% in Mozambique. Because of different age and coresidence patterns, Italy is confronted with more deaths per capita than Mozambique but fewer infections. The effectiveness of policies in one country compared with another country should be evaluated in light of different baseline vulnerabilities. Our results are applicable to persons living in private households. Had we been able to systematically consider persons living in old-age homes, country differences in vulnerability could change based on the share and health status of the population living in institutions. In countries where the elderly form a large part of the population and primarily live with their generational peers, avoiding the primary infection of elderly people will considerably reduce direct deaths and will also prevent indirect deaths due to within-household transmission of the virus. In countries where the elderly form a small part of the population but live together with young people, indirect deaths through infection within households can outnumber direct deaths. Therefore, avoiding primary infections of the elderly will be less effective in reducing deaths, because the elderly might

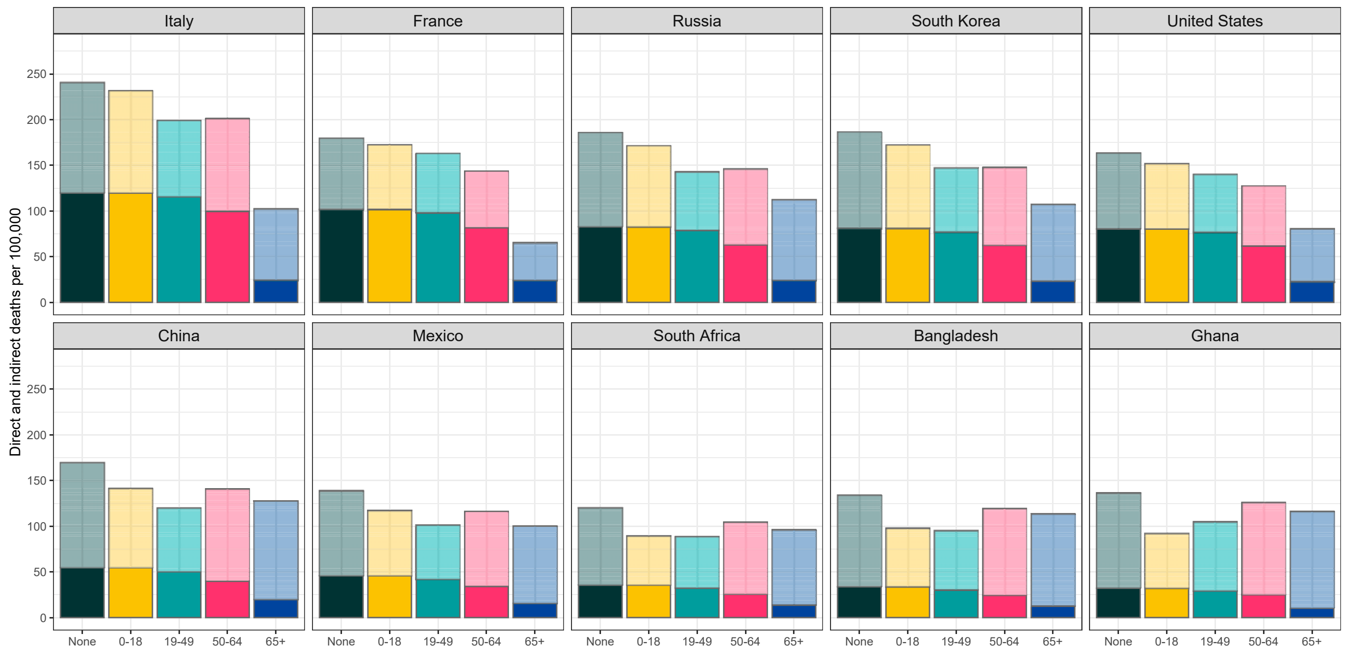

Fig. 2. Estimated number of direct (dark) and indirect (light) deaths per 100,000 individuals if primary infections of specific age groups are avoided. Data are from 2010 census round. Individuals from each age group who were selected in the 10% random draw are recoded as not infected before calculating direct deaths and simulating within household transmission.

still get infected by younger household members. In such cases, measures that reduce or avoid within-household transmission of the virus to the elderly become relatively more important to reduce mortality due to COVID-19.

Materials and Methods

Data on age structure and coresidence come from the most recent high-quality harmonized population microdata samples from Integrated Public Use Microdata Series (IPUMS) (9) on individuals living in private households (i.e., individuals living in collective dwellings such as old-age homes are excluded). For China, IPUMS data from 2000 were used but adjusted to the age structure of 2010 using data from the 2010 census available at the National Bureau of Statistics of China. For South Korea, data come from Statistics Korea. Mortality is determined by age-specific COVID-19 infection fatality ratios (2). For further information about data, methods, and code, see https://www.medrxiv.org/content/10.1101/2020.05.13.20100289v1.

ACKNOWLEDGMENTS. We thank A. Turu for help with the harmonization and graphic representation of the data. This analysis was supported by Grants ERC-2014-StG-637768, ERC-2019-COG-864616, and RTI2018-096730-B-I00.

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