Covid-19 Mortality Rates Adjusted by Differences in Age Structure of Populations

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Covid-19 Mortality Rates Adjusted by Differences in Age Structure of Populations

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Abstract

One of the tools to monitor the dynamics of the Covid-19 pandemic has been, from its earliest days, the international comparison of mortality rates. The indisputable evidence that lethality is exponentially related to the age of the affected people implies that, for many purposes, a more appropriate indicator should compensate for differences in the age profile between populations. This article sets out a method for calculating such standardized mortality rates, which take into account both the discrepancies in the age pyramids and the mortality rates by age groups. Advancing relatively to the few other similar initiatives found in the literature, the method is applied to a group of 28 countries that on 1/28/2021 accounted for 82% of deaths caused by the pandemic. The age-adjusted mortality rates describe a picture quite different from that portrayed by the crude rates, with three different patterns of mortality. Six Latin American countries and South Africa assume leading positions in the ranking calculated based on these rates. Moreover, a partial but sufficiently accurate update of the calculation based on the number of deaths until 3/26/2021 indicates that in this ranking Brazil only stands behind Mexico and Peru.

Keywords: Covid-19; pandemic demography; standardized mortality rates; age-adjusted mortality rates.

1. Introduction

Unfortunately far from its ending, the pandemic has lasted already long enough to allow at least preliminary assessments of the measures to combat the disease and the health systems performance. This issue, of course, can be addressed on multiple geographical scales through comparative indicators of efforts and results. One of the possibilities is to compare the global mortality rates from the disease, a procedure that, in the case of an illness whose morbidity is so strongly correlated with the age of the victims, should not dispense with adjustment to the different age structures of the populations.

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Since the pandemic first days, international cooperative efforts have been made to gather indicators to monitor its spread[1]. The numbers of cases, deaths, and people recovered are tracked, both on the most recent day and the accumulated tolls to that day. The problems with the accuracy of the information and, further more, its internationally discrepant levels make the number of cases an unsuitable variable for comparison between countries. Even if the suffering caused by Covid-19 cannot in any way be narrowed to the situations that culminate in death, the differences in the availability of tests – especially, but not only, in the early stages of the pandemic – imply that case-based indicators are, strictly speaking, incomparable. Although death records are not problem-free, they provide a safer basis for comparative analyses.

Comparisons between countries with different demographic sizes require considering rates related to their populations. In the case of Covid-19, demographers [GOLDSTEIN & LEE, 2020; HEUVELINE & TZEN, 2021; QUEIROZ et al. 2020] insist, however, that the calculation of per capita rates is absolutely insufficient for several purposes, such as comparing the performance of the countries in coping with the disease. The enormous disparity in Covid-19 case-fatality rates according to age was recently summed up in a study based on data from 45 countries, which estimated that they range from 0.001% in the age group of 5 to 9 years to 8.29% for those aged 80 years or older [O'DRISCOLL et al., 2021: 142]. On the other hand, there are also huge differences between the age pyramids of the countries. The comparison between the populations of Pakistan and Portugal provides an extreme but enlightening example of the magnitude of these discrepancies. Although the Pakistani population is 22 times larger than the Portuguese population, there are more inhabitants in Portugal aged 90 years or older than in Pakistan.

It is not because we fail to recognize that other variables, such as gender and prevalence of comorbidities, also affect crude mortality rates, that this article prioritizes the age profile of populations and Covid-19 deaths. As will be seen later, data that discriminate deaths according to those other criteria are even more difficult to obtain. Moreover, none of them has as crucial and decisive an impact as age on the risk of death.

Therefore, the primary objective of this article is to calculate Covid-19 mortality rates adjusted by differences in age pyramids based on data on mortality by age group. Both the difficulty of obtaining this information and its relevance to other studies suggest that gathering data on mortality from the disease by age groups into a single source for the countries most affected by the pandemic is in itself a relevant secondary objective.

Following the introduction, the article unfolds successively in a very brief review of the pertinent literature, a section that details the methodological procedures, a topic that presents the results and, finally, the conclusion.

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[1] The two best-known sites that systematize the main data are probably Johns Hopkins University (https://coronavirus.jhu.edu/) and Worldometer (https://www.worldometers.info/coronavirus/).

2. Literature review

More than a year after its inception, the Covid-19 statistical monitoring remains a challenge. Although the tests that prove contagion are much more widely available today than in the early stages of the pandemic, not only is there still a disparity in the access to them among localities and social groups [O'DRISCOLL et al., 2021: 140], but also the effects of the previous bottleneck persist on any cumulative indicator of cases. The use of other variables in principle relevant to epidemiological follow-up, such as the numbers of hospitalizations, ICU admissions and intubations, is restricted by the different criteria used to define these events and, mainly, by the fact that they are not reported by most official systems that disclose information on the subject. For all these reasons, it is widely recognized that the number of deaths is a more reliable indicator of the size of the epidemic [O'DRISCOLL et al., 2021: 140] and for the understanding of its dynamics [HALLAL, 2020: 2403]. HEUVELINE and TZEN (2021: 6) also maintain that data on deaths are more comparable – and more reliable, although not totally immune to underestimates [ORELLANA et al., 2020] -, which makes them particularly relevant to evaluate public policy measures to address the pandemic. None of this, of course, implies ignoring the enormous human cost of cases of the disease that do not culminate in death.

When comparisons between locations are an important instrument of analysis, as in this article, the discrepancy of scales impels researchers to use indicators related to the population. The indicators of deaths per capita – most frequently calculated in relation to groups of 100 thousand or 1 million inhabitants – will, however, present important biases if the populations of the different localities are subject to distinct risks of developing severe forms of Covid-19 due to pre-pandemic conditions. The diffusion of comorbidities and the composition of the population by sex and age are the most important of such conditions.

The association between various chronic diseases and the risk for severe forms of Covid-19 is well established in the medical literature [ZHOU et al., 2020 and CHOW et al., 2020 apud BORGES & CRESPO, 2020]. Cardiovascular diseases, diabetes, respiratory diseases, obesity, and immunodepression are the most notorious. It has also been shown that the risk of death from Covid-19 is substantially higher among male individuals. A meta-analysis based on information from 46 countries and 44 US states concluded that this risk is 39% higher among men [PECKHAM et al., 2020: 2], a result that is in line with studies conducted in the first months of the pandemic [GOUJON et al., 2020: 5; GUILMOTO, 2020: 8]. Although the relative importance of each of them is not uncontroversial, the factors that explain this disparity are fixed in the literature. PECKHAM et al. (2020) do not rule out the relevance of sociocultural factors and differences in the prevalence of comorbidities, but, based on a detailed review of the biological differences between the two sexes, especially regarding the immune system response to infection, they decisively stress the latter factors.

Anyway, there is no doubt that the aggressiveness and lethality of the disease increase with the age of the person affected [GOLDSTEIN & LEE, 2020: 4; VILLANI et al., 2020: 4; O'DRISCOLL et al., 2021: 140]. More than that, age is the variable most directly related to the probability of death from Covid-19, which "increases exponentially with age (…) in all countries where this has been examined" [CRIMMINS, 2020: 142]. The reduction of immunity and the higher prevalence of comorbidities are the primary explanations for this situation [VERITY et al., 2020 apud GOUJON et al., 2020]. The degradation of the immune system with aging, expressed in the lower availability of specific categories of naïve T cells, would be particularly severe in the case of a completely new virus. Besides, other aspects of immune function also worsen in the elderly. As deregulation levels in five cytokines double between the ages of 50 and 80, the risk of uncontrolled immune reactions, hyperinflammatory processes associated with 'cytokine storms' that can overload vital systems and lead to death, is higher [CRIMMINS, 2020: 142]. On the other hand, the presence of comorbidities increases continuously with age [BORGES & CRESPO, 2020: 6].

A complete treatment of the issue addressed in this article should preferably deal with all three factors, adjusting mortality rates to the previous prevalence of comorbidities and differences in demographic structures regarding sex and age. The data available at the time this article is being written make this impossible. Albeit from the earliest moments of the pandemic, researchers have called governments to systematize and disseminate data on cases and deaths disaggregated by age and sex [DOWD et al., 2020: 9,696], the crossing of this information in most cases remains unavailable. The record of comorbidities among those killed by Covid-19 is even more flawed and less available [HEUVELINE & TZEN, 2020: 8]. Considering that not only age is the factor that most markedly conditions the risk of severe Covid-19 and death, but also that heterogeneity between populations is much higher in age composition than in gender distribution [GUILMOTO, 2020: 9], it is justifiable in an initial research effort to focus on the age-related adjustment.

The literature review allowed us to identify two studies whose central objectives were to promote adjustments in Covid-19 mortality rates that are close to those proposed in this article. VILLANI et al. (2020) calculated analogous age-standardized mortality rates, but for only five European countries and based on data available up to 8/30/2020. More recently, HEUVELINE and TZEN (2021) have undertaken a much more geographically comprehensive effort, covering 186 countries and some subnational units particularly affected by the pandemic. In contrast to the wider geographical scope, this study allowed for a less complete procedure of mortality rates adjustment. Indeed, the "indirect" standardization they calculated neutralizes the effects of different age pyramids on rates but assumes for all countries and localities the same pattern of mortality by age group – in this case, that observed in the USA. Even defending the procedure adopted when the availability of data hinders the "direct" standardization, the authors do not fail to recognize problems arising from it, especially in the case of differences in mortality rates between countries in the older age groups. It is precisely the most complete adjustment procedure for a wide range of countries that this article proposes to do.

3. Methods

Adjusting Covid-19 mortality rates to compensate for differences in the age structure of populations requires data on the population of countries (*P*) and the cumulative number of deaths (*M*) broken down by age group. Those data allow us to calculate both the crude mortality rate (*m*) and an adjusted mortality rate (*a*) based on a uniform pattern of age structure.

Given:

P_{ij}, the population of country i in the age group j;

M_{ij}, the cumulative number of Covid-19 deaths in country i in the age group j; and

$m_{ij} = \frac{M_{ij}}{P_{ij}}$, the cumulative Covid-19 mortality rate in country i in the age group j.

Then a_i, the Covid-19 mortality rate in country i adjusted by differences in the age composition of the countries, should be defined as follows:

$$a_i = \frac{\sum_{j=1}^{k} A_{ij}}{P_i}$$

In which:

$A_{ij} = m_{ij} \cdot e_j \cdot P_i$ corresponds to the cumulative number of deaths that country i would have in each age group j with the mortality rate observed in the country in this age group and the population it would have in this age group if the age composition of the population were the same in all countries – in this article, we assumed the distribution by age groups given by the world population age pyramid;

$e_j = \frac{\sum_{i=1}^{n} P_{ij}}{\sum_{j=1}^{k}\sum_{i=1}^{n} P_{ij}}$ is the portion of each age group j in the total population of the set of countries; and

$P_i = \sum_{j=1}^{k} P_{ij}$ is, of course, the population of each country i.

Replacing the previous definitions, a_i can be rewritten more analytically as:

$$a_i = \frac{\sum_{j=1}^{k} m_{ij} \cdot e_j \cdot P_i}{\sum_{j=1}^{k} P_{ij}}$$

Calculating adjusted mortality rates[2], therefore, requires basic data on the population and deaths broken down by age group and by countries. In the case of demographic information, data

[2] An alternative exercise would be to calculate the number of deaths that each country would have if the mortality rate by age group were given by an international standard and not by the rate actually observed in the country. This exercise, which corresponds to the so-called indirect standardization and is beyond the scope of this article, would allow estimating the number of surplus deaths (or lives saved, if the signal were reversed) in the country in

availability is broad, and access is trivial. The Population Division of the Department of Economic and Social Affairs of the United Nations displays estimates for the population of all countries in the world disaggregated by age measured as whole numbers up to 99 years of age and with an additional range for people aged 100 years or older. In this article, we employ estimates for 2020 published by the UN in August 2019 [UNITED NATIONS, 2019]. The only exception concerns population data from England and Wales. As information on deaths appropriately disaggregated by age is available only for these two units together and not for the entire United Kingdom[3], which is the unit represented in the UN statistics, it was necessary to collect population data for England and Wales. In this case, the source is the UK Office for National Statistics.

Data on Covid-19 deaths broken down by age group are not easy to find. Hence, we believe that the presentation in a single publication of mortality rates by age is, in itself, an important result of this article. The next paragraphs describe the effort of collecting and systematizing these data. The sources are detailed in Chart 1.

Recognizing beforehand the impossibility of obtaining this information from a single source and, therefore, the size of the data collection work, our initial goal was to cover countries that, together, accounted for 90% of Covid-19 deaths. Of the 34 countries required to achieve this goal, minimally updated age-disaggregated data for six countries could not be found: Russia, Iran, Belgium, Romania, Iraq, and Bolivia. The other 28 countries for which the searches were successful accounted for 82% of deaths by 1/28/2021.

For 20 of those countries, we obtained the number of deaths for nine homogeneous age ranges (0-9, 10-19, 20-29, 30-39, 40-49, 50-59, 60-69, 70-79 and 80 years or more) directly, through aggregating more disaggregated ranges or through small adjustments[4]. Data for 11 of these countries – Germany, Canada, Spain, France, England (including Wales), Italy, the Netherlands, Portugal, Sweden, Switzerland (including Liechtenstein), and Ukraine – were obtained from just one source: the website of the French National Institute of Demographic

relation to an international pattern of pandemic mortality by age group and would provide another indicator of the quality of the response of the health system and measures to combat the epidemic adopted by each country. It would filter the effects of differences in age structures of populations, but not in mortality rates by age group.

[3] Covid-19 deaths data from Scotland and Northern Ireland are presented in a different and much less open disaggregation (0, 1-14, 15-44, 45-64, 65-74, 75-84 and 85 years or more).

[4] Minor adjustments were necessary in the cases of Brazil and Mexico. In Brazil, the data published do not accumulate information from the two calendar years of the pandemic and discriminate the initial age groups into less than 1 year, 1 to 5 years, and 6 to 19 years (SVS/MS, 2020; SVS/MS, 2021). Besides aggregating data from 2020 and 2021, in order to allocate deaths in similar ranges to those adopted in most countries, it was necessary to resort to individualized records in the Epidemiological Influenza Information System (SIVEP Influenza) on people affected by Covid-19 who received hospital treatment for Severe Acute Respiratory Syndrome (https://opendatasus.saude.gov.br/dataset/bd-srag-2020). For Mexico, it was not possible to read the values of the graph that presents the information of the age groups from 5 to 9 years, 10 to 14 years, and over 100 years. This implies identifying as unknown the age of 175 of the 165,731 deaths in Mexico until 2/8/2021, and underestimating mortality rates in this country in the age groups from 0 to 9 years and 10 to 19 years.

Studies (INED). Information from the nine other countries in this group – South Africa, Argentina, Brazil, Colombia, the Philippines, Hungary, Mexico, Peru, and Poland – comes from the health authorities' websites in each of these countries. Finding them often required the use of search expressions in the native languages of each country and the translation into English of the headings of tables and graphs. As in other studies that adopted similar procedures in the collection of information [PECKHAM et al. 2020: 5], Google Translator was used for this purpose.

Chart 1

Sources and Reference Dates of Data Collection on Covid-19 Deaths by Age

Country	Office/ Report	Internet address	Login Date	Reference date
South Africa	National Institute for Communicable Diseases, Daily Hospital Surveillance Report	www.nicd.ac.za/diseases-a-z-index/covid-19/surveillance-reports/daily-hospital-surveillance-datcov-report/	2/2/2021	2/2/2021
Argentina	Grupo de Investigación en Bases de Datos / Universidad Tecnológica Nacional	gibd.github.io/covid/Argentina.html	2/1/2021	2/1/2021
Brazil	Secretaria de Vigilância em Saúde / Ministério da Saúde, Boletim Epidemiológico Especial # 44 e # 46	www.gov.br/saude/pt-br/media/pdf/2021/janeiro/22/boletim_epidemiologico_covid_46-final.pdf	2/1/2021	1/2/2021
		www.gov.br/saude/pt-br/media/pdf/2021/janeiro/07/boletim_epidemiologico_covid_44.pdf	2/1/2021	
Chile	Departamento de Estadísticas e Información de Salud / Ministerio de Salud, Informe Semanal de Defunciones por Covid-19 # 34	www.minsal.cl/wp-content/uploads/2021/02/Informe-Semanal-N%C2%BA34-Estadi%CC%81sticas-de-Defuncio%CC%81n-Covid19.pdf	2/10/2021	2/4/2021
	Ministerio de Ciencia, Tecnología, Conocimiento e Innovación	github.com/MinCiencia/Datos-COVID19/blob/master/output/producto10/FallecidosEtario_T.csv	2/10/2021	
Colombia	Instituto Nacional de Salud	www.ins.gov.co/Noticias/Paginas/coronavirus-casos.aspx	2/2/2021	2/1/2021
Ecuador	Ministerio de Salud Pública	www.salud.gob.ec/wp-content/uploads/2020/09/Boletin-196_Nacional_MSP.pdf	2/2/2021	9/11/2020
Philippines	Department of Health	ncovtracker.doh.gov.ph/	2/2/2021	2/2/2021
Hungary	National Center for Public Health	koronavirus.gov.hu/elhunytak	2/10/2021	2/9/2021
India	Hindustan Times, "88% of Covid-19 fatalities, 40% of cases in 45+ age group: Govt data," published 19/12/2020	www.hindustantimes.com/india-news/88-of-covid-fatalities-40-of-cases-in-45-age-group-govt-data/story-0RvZ2kT1CXMRonZjl6pGlL.html	2/1/2021	12/18/2020
Indonesia	Komite Penanganan Covid-19 Dan Pemulihan Ekonomi Nasional	data.covid19.go.id/public/index.html	2/12/2021	2/10/2021
Mexico	Conacyt/Dirección General de Epidemiología	datos.covid-19.conacyt.mx/	2/9/2021	2/8/2021
Pakistan	Pakistan Institute of Development Economics, PIDE Covid-19 Dashboard	pide.org.pk/index.php?option=com_content&view=article&id=695	2/3/2021	12/16/2020
Peru	Centro Nacional de Epidemiología / Instituto Nacional de Salud, Prevención y Controle de Enfermedads - MINSA	covid19.minsa.gob.pe/sala_situacional.asp	2/10/2021	2/9/2021
Poland	Ministerstwa Zdrowia, Raport zakażeń koronawirusem (SARS-CoV-2)	www.gov.pl/web/koronawirus/wykaz-zarazen-koronawirusem-sars-cov-2	2/11/2021	11/6/2020
	Wyborcza.pl	biqdata.wyborcza.pl/biqdata/7,159116,26497931,smiertelnosc-i-zachorowania-wg-wieku-mamy-dane-z-krajowego.html?disableRedirects=true	2/11/2021	
Czech Republic	Ministerstvo Zdravotnictví	https://onemocneni-aktualne.mzcr.cz/covid-19/prehledy-khs	2/11/2021	2/10/2021
Turkey	T.C. Saglik Bakanligi, COVID-19 Haftalık Durum Raporu, 19/10/2020 - 25/10/2020, p. 6	https://covid19.saglik.gov.tr/Eklenti/39229/0/covid-19-haftalik-durum-raporu---43pdf.pdf?_tag1=70F7CD89B8F7191D8FAD3ACF29EF550190C31B61	2/11/2021	10/25/2020
Other countries	Institut National d 'Études Démographiques, The demography of Covid-19 deaths.	dc-covid.site.ined.fr/en/data/	1/27/2021	12/23/2020 to 1/21/2021

Information from the other eight countries – Chile, Ecuador, the USA, India, Indonesia, Pakistan, the Czech Republic, and Turkey – of the 28 countries is more heterogeneous, especially concerning the age groups of the deceased. Each adopts a different criterion to define age groups. Although this jeopardizes a little the comparability of results, it does not prevent the calculation of the adjusted mortality rate, since population data are available with a disaggregation compatible with any age brackets that can be defined. Also, except for the USA, whose data were compiled by the INED, the information was obtained by the same case-by-case procedure reported in the previous paragraph. Again, sources were almost always the websites of the national health authorities. India and Pakistan are exceptions. For Pakistan, the source is the website of the Pakistan Institute of Development Economics (PIDE). For India, one of the main Indian newspapers, Hindustan Times, cites the Ministry of Health and the Family Welfare[5].

A last relevant general methodological information is that the numbers of deaths that served to calculate mortality rates by age group (m_{ij}) were not those directly obtained from the reported sources. When disaggregated by age groups, the reference dates for this information vary greatly and are not homogeneous even in the case of the most developed countries surveyed. As can be seen in Chart 1, despite the great effort made, in some countries, the most recent data obtained refers to dates as far as 9/11/2020 (Ecuador), 10/25/2020 (Turkey) or 11/6/2020 (Poland). Whatever the time lag, international benchmarking requires that the numbers of deaths by age group correspond to a single date. The procedure for this temporal standardization was very simple and involved solely the distribution of the accumulated contingent of deaths in each country until 1/28/2021, according to the pattern identified up to the most recent date the disaggregation by age group was available. In other words, this age pattern of mortality was extrapolated to that date[6].

4. Results

Tables 1 and 2 present Covid-19 mortality rates by age groups estimated based on the procedure described above. The first one reports the rates of those 20 countries for which it was possible to obtain information by homogeneous age groups, while the second does so for the other eight countries.

[5] Data for India are also the least accurate among those employed in this article. The original information refers to the percentage distribution of deaths by age group and does not have decimal places in the percentages. Similar percentages are the original data for Indonesia and Pakistan, but presented with an accuracy of two decimal places.

[6] Two other similar extrapolations in terms of procedure, but of distinct origin, were made in the case of South Africa and France. As the original information on the distribution by age of deaths is available only for deaths occurring in hospitals, for these two countries the age partition of these deaths was extrapolated to the set of deaths by Covid-19. It is worth noting that deaths in hospitals are widely prevalent in both South Africa (94%) and France (70%).

Table 1

Covid-19 deaths until 28/1/2021 per Million Inhabitants by Homogeneous Age Groups

Countries	0-9	10-19	20-29	30–39	40–49	50–59	60-69	70-79	80+	Total
Germany	1	0	5	9	31	107	395	1,449	6,626	667
Spain	6	4	16	29	75	279	974	3,080	12,788	1,236
France	1	1	8	29	86	297	1,005	2,844	11,649	1,143
Hungary	0	2	23	61	156	607	1,762	4,364	12,091	1,272
England and Wales	1	3	16	50	175	527	1,504	4,370	19,447	1,631
Italy	2	2	7	25	81	303	1,113	3,555	11,869	1,445
The Netherlands	1	1	3	11	33	112	445	2,150	10,959	813
Poland	4	4	9	57	165	455	1,318	3,669	8,935	963
Portugal	1	2	9	24	65	207	749	2,324	11,459	1,138
Sweden	5	3	12	22	58	186	604	2,427	15,180	1,141
Switzerland	3	0	3	7	20	116	563	2,439	14,661	1,075
Ukraine	2	6	20	56	179	576	1,306	2,247	2,449	537
South Africa	10	12	60	215	669	1,884	3,853	6,056	11,784	727
Argentina	6	11	44	110	343	1,079	2,977	5,890	13,149	1,053
Brazil	28	19	74	217	527	1,241	3,092	6,551	13,076	1,042
Canada	0	0	0	0	0	84	308	1,241	8,426	521
Colombia	9	9	60	168	450	1,188	3,204	7,181	16,011	1,040
Philippines	6	4	14	34	79	211	494	900	1,451	96
Mexico	11	7	79	315	1,014	2,547	5,261	8,472	9,239	1,203
Peru	27	25	78	222	739	2,109	4,789	7,850	12,585	1,221
Total	11	8	43	130	350	838	1,934	3,996	10,948	958
Simple average	6	6	27	83	247	706	1,786	3,953	11,192	998
of C.V.	1.26	1.13	0.99	1.08	1.12	1.01	0.83	0.57	0.37	0.34

Sources: Own elaboration from demographic data of UNITED NATIONS (2019) and data on Covid-19 deaths obtained from the sources indicated in Chart 1.

Notes:

1) Switzerland fees include Liechtenstein.

2) C.V. is the coefficient of variation, that is, a measure of dispersion calculated as the relationship between standard deviation and the mean.

The tables confirm that the mortality rates caused by Covid-19 are very different according to the age of the individuals affected by the disease. Table 1, which gathers information on a group of countries in which 49% of deaths were recorded in the world until 1/28/2021, indicates that, excluding the passage from 0 to 9 years to 10 to 19 years, the mortality rate grows in all these populations continuously and significantly from one range to the next[7]. The trend is so strong and accentuated that, taking values for all these countries, the mortality rate is more than 30 times higher among individuals aged 80 years or more than among those aged 40 to 49 years and, again, more than 30 times higher among those in this age group and those aged 0 to 19

[7] The only and yet partial exception is Canada. In the official statistics of this country, Covid-19 deaths of people under the age of 40 are not recorded.

years[8]. The disparity between mortality rates between those aged 60 and over and those under 60 is only slightly smaller (29 times).

Table 2

Covid-19 deaths until 28/1/2021 per Million Inhabitants by Heterogeneous Age Groups

India		Indonesia		Pakistan		Turkey	
Age range	Rate	Age range	Rate	Age range	Rate	Age range	Rate
0-17	4	0-5	8	0-19	1	0-1	7
18-25	8	6-18	6	20-29	9	2-4	1
26-44	39	19-30	26	30-39	19	5-14	2
45-60	233	31-45	61	40-49	65	15-24	4
60+	657	46-59	221	50-59	195	25-49	46
Total	112	60+	509	60-69	390	50-64	448
		Total	107	70-79	444	65-79	1,885
				80+	520	80+	4,791
				Total	52	Total	304
Chile		Ecuador		USA		Czech Republic	
Age range	Rate	Age range	Rate	Age range	Rate	Age range	Rate
0-29	18	0	53	0	12	0-14	0
30-39	92	1-4	7	1-4	2	15-24	3
40-49	236	5-9	8	5-14	2	25-34	22
50-59	762	10-14	4	15-24	15	35-44	50
60-69	2,114	15-19	11	25-34	61	45-54	157
70-79	5,172	20-49	195	35-44	178	55-64	720
80+	11,963	50-64	2,011	45-54	500	65-74	2,831
Total	951	65+	6,561	55-64	1,205	75-84	9,317
		Total	837	65-74	2,864	85+	23,334
				75-84	7,386	Total	1,489
				85+	20,800		
				Total	1,308		

Sources: Own elaboration from demographic data of UNITED NATIONS (2019) and data on Covid-19 deaths obtained from the sources indicated in Chart 1.

Although the exponential growth of mortality rates with age is observed in all countries, the relationship is less pronounced in developing countries than in developed countries in Europe and North America. In fact, in these countries, Covid-19 mortality is 5,000 or even 10,000 times higher among the elderly aged 80 years or more than among those under 20 years. This result is in line with the conclusions of COHEN et al. (2021), who, as early as April 2020, examined data on the distribution of deaths in Western Europe. However, among Latin American

[8] Those gradients are similar to those estimated by GUILMOTO (2020:7) from initial pandemic data for the US and eight European countries. Based on the data available until 5/15/2020, he estimated that Covid-19 mortality rates double every six years of age increase. According to the author, the usual relationship between general mortality and age, even after 35, is much less pronounced: the rate doubles at periods of just over 8 years.

countries the difference is smaller, reaching 500 times in the cases of Peru and Brazil[9]. The main determinant of this divergence is the higher mortality rates among the youngest observed in the poorest countries, but in extreme cases, there is also a particularly high mortality rate among the elderly in some rich countries[10]. The highest mortality rate depicted in Table 1 refers to the elderly aged 80 years or older from England and Wales. In this population, no less than one in 51 people died from Covid-19 from the onset of the pandemic until 1/28/2021[11]. In a country as severely affected by the pandemic as Mexico, this relationship is somewhat less dramatic: one death in every 108 people in this age group. In any case, the last column of Table 1 shows that the dispersion of mortality rates among countries is lower in the older age groups[12], different, in fact, from what O'DRISCOLL et al. (2021: 141) suggest, based on another methodology[13].

An effort to generalize from the information gathered in these two tables allows us to infer three distinct patterns of Covid-19 mortality with a good degree of geographical coherence. In European countries and the US, overall mortality rates are high and the disparity in rates between age groups is extreme. In Latin American countries – and also in South Africa – overall rates are almost equally high, but the disparity in mortality conditions by age is smaller. In poor Asian countries, whereas the overall mortality rate is much lower, the relationship between age and mortality is less pronounced. Of course, there are intermediate situations, such as Turkey,

[9] A difference of the same order of magnitude is observed in Pakistan and Turkey (Table 2). In the Philippines, the disparity is rather smaller, below 300 times. Comparable information is not available for other poor Asian countries, but Table 2 suggests that the picture should be similar to that of the Philippines. In this country, therefore, that relationship between Covid-19 mortality rates among those over and under 60 is 18 times, higher than in India (12 times) and Indonesia (8 times). Alongside the specificities of each country, the data presented here confirm the hypothesis, at that time merely speculative, presented by GUILMOTO (2020: 7) that Covid-19 mortality rates could have a less pronounced relationship with age in Asian, African, and Latin American countries.

[10] This phenomenon is probably related to the higher proportion of elderly living in long-term care institutions, a situation that due to the gregarious nature of housing leads to greater vulnerability to contagion [CRIMMINS, 2020; EUROPEAN CENTRE FOR DISEASE PREVENTION AND CONTROL, 2020; O'DRISCOLL et al. 2021]. Indeed, COMAS-HERRERA et al. (2021: 21) showed that in a set of 22 developed countries the residents of those institutions corresponded, on average, to 0.73% of the population, but to no less than 41% of Covid-19 deaths. The proportion of elderly sheltered in those institutions who died of Covid-19 by mid-January 2021 reached percentages as high as 9.4% in Belgium, 7.9% in Spain, or 7.2% in the USA. Similar data are not available for developing countries, but at least in the Brazilian case, scarce estimates indicate that the portion of the population living in elderly shelters is in an order of magnitude below the value indicated above [CAMARANO & BARBOSA, 2016: 495; CAMARANO et al., 2011].

[11] The first death from Covid-19 recorded in the United Kingdom occurred on 3/5/2020.

[12] By the way, this helps explain why the overall mortality rate presents a lower dispersion than that observed in mortality rates by age group. In developed countries, overall mortality rates are completely dominated by the behaviour of deaths among the elderly. Not quite different general rates are generated in Latin American countries by a somewhat different process, in which simultaneously the significance of the elderly population is lower and higher mortality rates are recorded among the youngest.

[13]"*[While] we find a very consistent pattern in the relative risk of death by age for individuals younger than 65 years of age across countries and continents, (...) the observed relative risk of death in older individuals appears to be substantially more heterogeneous across locations.*"

as well as more or less important effects of national peculiarities, as in the case of Canada and Germany.

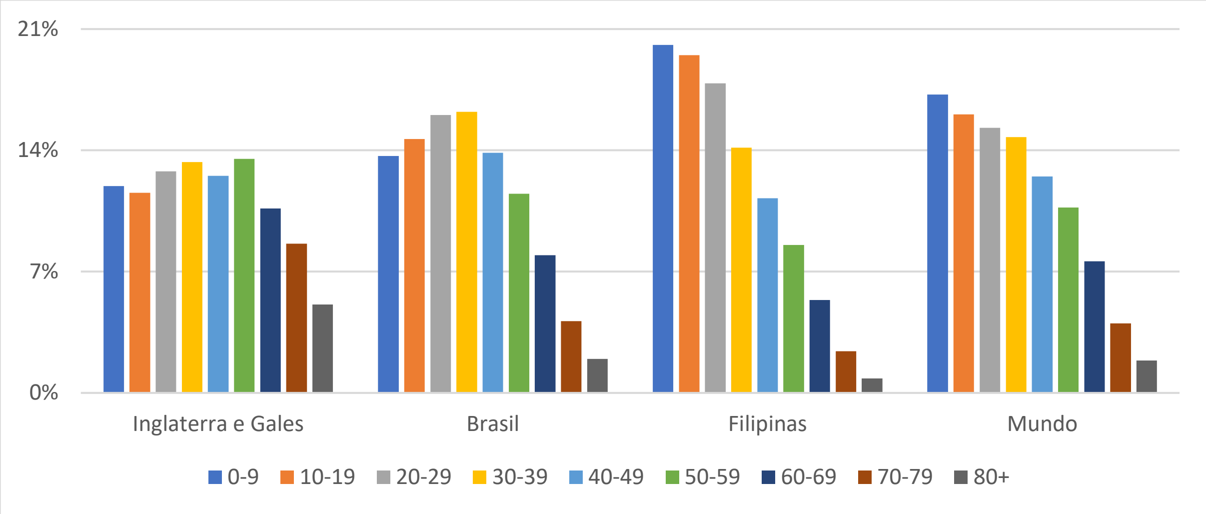
In a disease whose lethality is closely associated with age, the overall mortality rate in any population will depend not only on the mortality rates by age observed in it, but also on its age composition. Especially emblematic of this is the fact that the four countries in Table 1 with the highest overall mortality rates – England and Wales, Italy, Hungary, and Spain – are not among the four with the highest mortality rates in any of the age groups below 70 years, a list composed in all cases by Latin American countries or South Africa. On the other hand, in the age group of 80 years or more, three of the four highest rates are from developed countries, except for Colombia, which has the second highest mortality rate in this age group.

Figure 1 illustrates the differences in age profiles of populations by selecting three representatives from each of the groups of countries indicated above: England and Wales, Brazil, and the Philippines. In addition to a larger portion in the older age groups, the English population is divided among similar groups, at least for the population groups up to the age of 50. Age distribution is very different in the Philippines: participation in the total population drops continuously with age. Brazil, which has begun the demographic transition a few decades ago, is an intermediate case. It should be noted that given the population preponderance of countries with a similar profile to that of the Philippines, the age composition of the world population resembles this one more, albeit in an attenuated version.

Calculating adjusted mortality rates to compensate for the effect of differences in the age composition of populations is the main objective of this article. The results of those calculations, performed according to the methodology described in the previous section, are reported in Table 3, which gathers information on all 28 countries for which it was possible to obtain age-disaggregated mortality data. Immediately, we must emphasize that the success of the adjustment can be inferred from the correlation coefficients between, on the one hand, an indicator of population aging and, on the other hand, the crude and adjusted mortality rates. The correlation between the percentage of the population aged 60 and over and the crude rate is not only positive but also quite significant: 0.573. With the adjusted rate, the same indicator presents a very low correlation (-0.252).

Figure 1

Age Composition of World Population and Selected Countries (% of the Total Population)



Source: UNITED NATIONS (2019).

Table 3

Covid-19 Mortality Rates until 28/1/2021 Adjusted by Age Composition of World Population

Countries	Population data				Covid-19 deaths				
	Population Total (10^3)	Age range 60 or over	Age		Number of deceased	Mortality rate			
			Average	Mode		Crude	#	Adjusted	#
Mexico	128,933	11.2%	31	17	155,145	1,203	8	1,372	1
Peru	32,972	12.5%	32	0	40,272	1,221	7	1,284	2
South Africa	59,309	8.5%	29	5	43,105	727	20	1,085	3
Colombia	50,883	13.2%	33	26	52,913	1,040	15	1,050	4
Ecuador	17,643	11.0%	30	0	14,766	837	18	997	5
Brazil	212,559	14.0%	34	36	221,547	1,042	14	991	6
Argentina	45,196	15.5%	34	3	47,601	1,053	13	892	7
England and Wales	59,829	24.4%	41	32	97,581	1,631	1	741	8
USA	331,003	22.9%	39	27	433,067	1,308	4	738	9
Chile	19,116	17.4%	37	28	18,174	951	17	725	10
Hungary	9,660	26.8%	42	43	12,291	1,272	5	632	11
Czech Republic	10,709	26.2%	42	43	15,944	1,489	2	507	12
Italy	60,462	29.8%	45	50	87,381	1,445	3	496	13
Poland	37,847	25.9%	42	37	36,443	963	16	494	14
Spain	46,755	26.3%	44	43	57,806	1,236	6	484	15
Sweden	10,099	25.9%	41	28	11,520	1,141	10	460	16
France	65,274	26.8%	42	48	74,601	1,143	9	456	17
Switzerland	8,655	25.3%	42	53	9,308	1,075	12	431	18
Portugal	10,197	29.4%	45	47	11,608	1,138	11	400	19
Netherlands	17,135	26.6%	42	53	13,925	813	19	343	20
Ukraine	43,734	23.6%	41	33	23,469	537	22	331	21
Turkey	84,339	13.1%	33	7	25,605	304	24	314	22
Canada	37,742	24.9%	41	57	19,659	521	23	239	23
Germany	83,784	28.6%	44	55	55,883	667	21	229	24
Philippines	109,581	8.6%	28	7	10,552	96	27	142	25
India	1,380,004	10.1%	30	13	154,010	112	25	136	26
Indonesia	273,524	10.1%	31	5	29,331	107	26	123	27

Pakistan	220,892	6.7%	26	0	11,560	52	28	90	28

Sources: Own elaboration from demographic data of UNITED NATIONS (2019) and data on Covid-19 deaths obtained from the sources indicated in Chart 1.

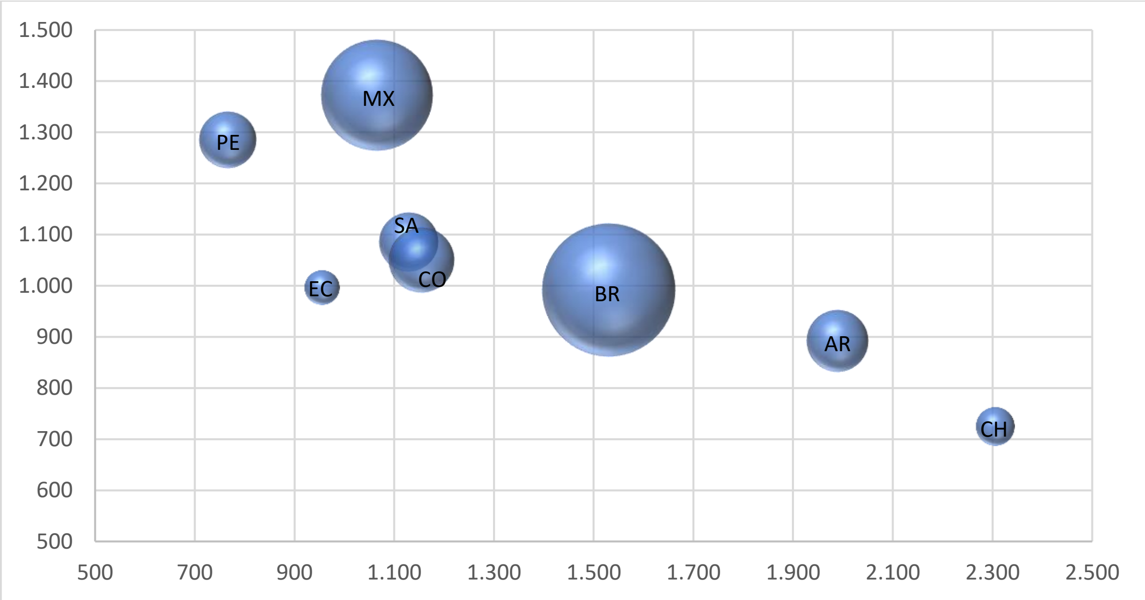
Due to the size of the differences in populations age profiles, it is not surprising that the values of these adjusted rates and, even more, the ranking that results from them differ greatly from the values of crude mortality rates and their respective ordering. Ranked by the adjusted rate, the seven countries with the highest mortality all belong to the group of Western developing countries, comprised of six Latin American countries and South Africa. Developed countries, such as England, the USA and Italy, which are at the top of the ranking of crude mortality rates, all rank below those seven countries. However, the internal organization of the group of countries at this stage of development does not undergo significant changes, which is explained by the similarity of the age profiles of their populations. Finally, it should be noted that the final positions of both rankings are occupied by those poorer Asian countries that, as already highlighted, have a much lower Covid-19 mortality rate than the Western countries covered in this study.

Based on Table 3, we can also calculate that the dispersion, measured by the coefficient of variation of the adjusted mortality rates, is greater than that of crude rates. This indicates that the crude rates converge because different phenomena are equalized: the higher mortality within each age group of some countries is compensated by a population which is younger and less susceptible to more severe cases. Alongside the disparity between the three groups of countries, the internal disparity counts on those groups. Indeed, the adjusted mortality rate in Mexico is 89% higher than in Chile, while in England and Wales it surpasses Germany by no less than 223%.

A detailed interpretation of the discrepancy of adjusted mortalities observed among countries is beyond the scope of this article. Strictly speaking, except for the age profile of the populations, duly compensated for in the adjusted mortality rate, all factors that affect the incidence of the disease and its lethality influence those rates. A relevant finding of the research, however, is that at least in the case of the group of Western developing countries there is a clear inverse relationship between the level of health spending and the adjusted mortality rate. Such evidence is represented in Figure 2, which, in the horizontal axis, describes the current expenditure per capita on health – converted into dollars by the purchasing power parity exchange rate – and in the vertical axis, the adjusted mortality rate. The size of the spheres, in turn, reflects the absolute number of deaths in each country.

Figure 2

Relationship between Adjusted Covid-19 Mortality Rate and Per Capita Health Expenditure



Sources: Table 2 and WHO, Global Health Expenditures Database, https://apps.who.int/nha/database/ViewData/Indicators/em, accessed 20/2/2021.

Caption: AR = Argentina, BR = Brazil; CH = Chile, CO = Colombia, EC = Ecuador, MX = Mexico, PE = Peru, and SA= South Africa.

Note: The values of the current expenditure per capita on health refer to 2018, the last year with data available in the World Health Organzation database.

5. Conclusion

This article presents two main contributions to the analysis of the planetary spread of Covid-19. The first is the systematisation of data on mortality rates by age group for a set of 28 countries that, on 1/28/2021, concentrated 82% of deaths because of the disease. This is a valuable result in itself, since no source is known to have already published age-disaggregated information with the same geographical coverage. Based on them, we can infer whether the notorious growth of lethality with age is the same everywhere, an interrogation launched, for example, by VILLANI et al. (2020). As we have seen, there are important differences between countries and at least three patterns are discernible.

The second and most important contribution is the calculation of adjusted mortality rates based on mortality rates by age group and the age profile of populations. This adjustment was previously indicated by demographers who focused on the subject [QUEIROZ et al. 2020: 3689]. It is essential to filter the effect of disparities in age pyramids and to enable the appropriate use of mortality rates in assessing the success or failure of measures to address the pandemic [GOLDSTEIN & LEE, 2020: 5]. In fact, at least two previous studies have attempted to move in this direction. Notwithstanding, whether due to the broader spatial and temporal scope in relation to one of them [VILLANI et al., 2020] or to the methodologically more complete procedure in relation to the other [HEUVELINE & TZEN, 2021], we can argue that our results in this article offer important developments. From them, one can infer an international ranking of Covid-19 mortality very different from that based on crude rates. More than that, adjusted rates reveal that the "protective" effect of younger demographic profiles on populations in poorer countries [GUILMOTO, 2020: 8; DOWD et al, 2020: 9,697], at least in the case of several Latin American countries and South Africa, was not enough to prevent these countries from staging some of the more dramatic impacts of the pandemic. The primary explanation for this is the existence, identified in this article, of rather different mortality patterns by age in developing countries and, more specifically, the higher mortality in lower age groups.

We can see that the research method developed in this article is applicable in at least two different and relevant directions. The use on a subnational scale – states and municipalities, for example – would, in principle, illuminate comparisons between mortality rates in the same way that it did on an international scale. In addition, this endeavour can be updated over time and eventually expanded to other countries upon data availability. As the dynamics of the pandemic are still unfolding, the results may change substantially. Thus, the mere updating[14] of the calculations based on the total number of deaths recorded on May 21, 2021, would make Brazil climb four positions in the gloomy ranking of adjusted mortality rates, falling second only to Peru.

Conflict of Interests

The authors declare no conflict of interests.

Authors contributions

MP acted in the conception and planning of the article; in the bibliographic survey; in the literature review; in the search, tabulation, and processing of data; and in the final writing. EGC acted in the design and planning of the article; in the bibliographic survey; in the literature review; and in the critical review of the text.

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[14] Updates of this type run into an important methodological obstacle. One of the premises of the method used in this article is the stability of the distribution of deaths by age group from the day when disaggregated deaths by age are known in each country until a common base date for all countries. The beginning of the vaccination process and the prioritization to the older population make this hypothesis unsustainable, especially in the countries that have made the most progress in vaccination. However, as at the indicated date countries with adjusted mortality rates close to Brazil are all in relative early stages of vaccination, this caveat does not affect the validity of the comparison between them based on updated data.

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