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Research Article

Excess mortality during the SARS-CoV-2 pandemic in the City of Frankfurt/Main, Germany, in 2020 and 2021, adjusted for age trends and pandemic phases

Übersterblichkeit während der SARS-CoV-2-Pandemie in Frankfurt am Main, Deutschland, in den Jahren 2020 und 2021, unter Berücksichtigung des Alterstrends der Bevölkerung und der Pandemiephasen

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Abstract

Aims: Excess mortality during the SARS-CoV-2 pandemic has been studied in many countries. Accounting for population aging has important implications for excess mortality estimates. We show the importance of adjustment for age trends in a small-scale mortality analysis as well as the importance of analysing different pandemic phases for mortality in an urban population.

Methods: Population data for Frankfurt/Main for 2016–2021 were obtained from the Municipal Office of Statistics, City of Frankfurt/Main. Mortality data from 2016 to 2021 were provided by the Hessian State Authority. For standardized mortality ratios (SMR=observed number of deaths divided by the expected number of deaths), the expected number of deaths was calculated in two ways: For SMR_{crude}, the mean mortality rate from the years 2016–2019 was multiplied by the total number of residents in 2020 and 2021 separately. For $SMR_{adjusted}$, this procedure was performed separately for five age groups, and the numbers of expected deaths per age group were added.

Results: SMR_{crude} was 1.006 (95% CI: 0.980–1.031) in 2020, and 1.047 (95% CI: 1.021–1.073) in 2021. $SMR_{adjusted}$ was 0.976 (95% CI: 0.951–1.001) in 2020 and 0.998 (95% CI: 0.973–1.023) in 2021. Excess mortality was observed during pandemic wave 2, but not during pandemic waves 1 and 3.

Conclusion: Taking the aging of the population into account, no excess mortality was observed in Frankfurt/Main in 2020 and 2021. Without adjusting for population aging trends in Frankfurt /Main, mortality would have been greatly overestimated.

Keywords: SARS-CoV-2 pandemic, mortality, population, age-trend, pandemic phases

Zusammenfassung

Ziele: Die Übersterblichkeit während der SARS-CoV-2-Pandemie wurde in vielen Ländern untersucht. Die Berücksichtigung der Alterung der Bevölkerung hat wichtige Auswirkungen auf die Schätzung der Übersterblichkeit. Wir zeigen, wie wichtig die Berücksichtigung von Alterstrends in einer kleinmaßstäblichen Mortalitätsanalyse ist, und wie wichtig es ist, verschiedene Pandemiephasen für die Mortalität in einer städtischen Bevölkerung zu analysieren.

Methoden: Die Bevölkerungsdaten für Frankfurt am Main für die Jahre 2016 bis 2021 wurden vom Bürgeramt Statistik und Wahlen der Stadt Frankfurt am Main erhalten. Die Mortalitätsdaten 2016 bis 2021 wurden vom Hessischen Landesamt zur Verfügung gestellt. Für die Standardi-

sierte Mortalitätsratio (SMR=beobachtete Zahl der Sterbefälle geteilt durch die erwartete Zahl der Sterbefälle) wurde die erwartete Zahl der Sterbefälle auf zwei Arten berechnet: Für die SMR_{roh} wurde die mittlere Mortalitätsrate aus den Jahren 2016–2019 mit der Gesamtzahl der Bürger im Jahr 2020 bzw. 2021 multipliziert. Für die $SMR_{adjustiert}$ wurde dieses Verfahren für fünf Altersgruppen getrennt durchgeführt und die Zahlen der erwarteten Todesfälle pro Altersgruppe wurden addiert.

Ergebnisse: Die SMR_{roh} betrug 1,006 (95% CI: 0,980–1,031) im Jahr 2020 und 1,047 (95% CI: 1,021–1,073) im Jahr 2021. Die $SMR_{adjustiert}$ betrug 0,976 (95% CI: 0,951–1,001) und 0,998 (95% CI: 0,973–1,023) im Jahr 2021. Eine Übersterblichkeit wurde während der Pandemiewelle 2 beobachtet, nicht jedoch während der Pandemiewellen 1 und 3.

Schlussfolgerung: Unter Berücksichtigung der Alterung der Bevölkerung wurde in den Jahren 2020 und 2021 in Frankfurt am Main keine Übersterblichkeit beobachtet. Ohne Anpassung an die Alterung der Bevölkerung in Frankfurt am Main wäre die Sterblichkeit stark überschätzt worden.

Schlüsselwörter: SARS-CoV-2 Pandemie, Sterblichkeit, Bevölkerung, Alterstrend, Pandemiephasen

Introduction

The first cases of SARS-CoV-2 occurred in China by the end of 2019. In Germany, the first case was registered in January 2020. On 1 Febuary 2020, the first returnee with SARS-CoV-2 arrived in Frankfurt/Main via airplane [1]. As of 31 August 2020, 2,665 people with SARS-CoV-2 infections had been reported in Frankfurt, 69 of which were registered as deceased [2]. By the end of 2021 in Frankfurt/Main, 70,825 persons infected with SARS-CoV-2 had been registered, and up to 7,230,304 in Germany [3].

The number of registered cases is strongly influenced by test availability and test regime. Both parameters affect not only the reported number of people infected with SARS-CoV-2, but also the case fatality rate [4], [5], [6], [7], [8], [9]. For the reported cases of death – in contrast to the automated laboratory SARS-CoV-2 reporting system – an additional registration is required. Therefore, underreporting cannot be ruled out, especially in the case of high volumes of reports. However, the registration data does not distinguish between patients dying *of* or *with* SARS-CoV-2. Accordingly, data on mortality from COVID-19 have only limited informative value. Given limited test availability or a restrictive test regime, the case fatality rate might be overestimated, whereas if registration of deaths with SARS-CoV-2 is incomplete, the mortality of COVID-19 might be underestimated. This limits the assessment of SARS-CoV-2-associated mortality [4], [5], [10], [11].

These methodological limitations do not apply when considering all-cause mortality [4], [5], [8], [9], [12], [13], [14]. However, it is not possible to extrapolate mortality from COVID-19 from total mortality.

Results on excess mortality during the SARS-CoV-2 pandemic vary greatly not only between countries but also within individual countries, depending on the method of analysis [12]. Results on excess mortality strongly depend on whether the aging of the population is taken into account. The importance of age standardization is also evident in analyses by Levitt et al., who estimate an excess mortality of 2.7% for Germany with age standardization for the years 2020 and 2021 combined, and 6.4% without age standardization [12].

These methodological comparisons have so far been published at the country level. This study presents a small-scale analysis of mortality in the City of Frankfurt/Main, Germany. While Frankfurt/Main is considered a “young city” due to marked population growth through birth and immigration, there is also a strong increase in elderly and especially the very old; e.g., the number of 80- to 84-year-olds rose by 24.6% between 2016 and 2020.

The aim of our study was to investigate excess mortality in the City of Frankfurt/Main during the pandemic (2020 and 2021). Moreover, we examined how strongly the adjustment for age trends in a small-scale mortality analysis affects excess mortality results. Finally, we aimed to analyze excess mortality during the different pandemic phases. Hence, we not only analyzed the pandemic years 2020 and 2021 in total, but also the different pandemic waves and the phases between them.

Methods

Population data for Frankfurt/Main for 2016–2021 were taken from the annual reports of the Municipal Office of Statistics, City of Frankfurt/Main [15]. The data refer to 31 December of each year. To calculate the SMRs, mid-year populations were used, which were obtained as the average of the population figures of two consecutive years for 31 December. The data on death cases were compiled by the Hessian Statistical Office (HSL) and made available to the state health office (HLPUG), which provided the data to the authors. The data included death reports only

of people residing in Frankfurt who had died in the state of Hesse. For each death case, sex, age and date of death was available. Reports of SARS-CoV-2 infections were taken from the RKI (Robert Koch Institute) database [3]. They are available as cases per reporting week and year for different age groups (5-year intervals). The definition of the different waves in Germany was taken from a publication by the RKI: Wave 1 calendar week (CW) 10 to 20/2020; Wave 2 CW 40/2020 to 8/2021; Wave 3 CW 9 to 23/2021; Wave 4 CW 31 to 51/2021 [16].

In this study, two kinds of SMRs (standardized mortality ratios) with 95% confidence intervals were estimated: a crude SMR (SMR_{crude}) and an age-adjusted SMR ($SMR_{adjusted}$).

For SMR_{crude}, mortality rates for 2016–2019 were calculated by dividing the total number of deaths by the city's total mid-year population for each year. The mean of the four mortality rates was multiplied by the total city population in 2020 and 2021 separately to give the expected number of deaths for 2020 and 2021. SMR_{crude} was estimated by dividing the observed total number of deaths in Frankfurt for each year, 2020 and 2021, by the expected number of deaths for the corresponding year.

For $SMR_{adjusted}$, mortality rates for 2016–2019 were calculated separately for five age groups (0–29, 30–59, 60–69, 70–79, ≥80 years) for each year. Each age-specific mean mortality rate was multiplied by the population of the corresponding age group in each of the years 2020 and 2021 to give the expected number of deaths for 2020 and 2021 for each age group. The total number of expected deaths for each of the years 2020 and 2021 was obtained by adding the expected numbers of deaths for the five age groups. This total number of expected deaths was the denominator of $SMR_{adjusted}$.

This procedure to estimate $SMR_{adjusted}$ was applied to all single waves and the intermediate phases (summer periods). Instead of whole years, only the calendar weeks of the respective waves (wave 1 to 4) and of the intermediate phases (between waves 1 and 2, and between waves 3 and 4) were taken into account. For wave 2, which lasted from CW 40/2020 to CW 8/2021, age-specific mean mortality rates were calculated by using the respective population on 31 December 2020.

Finally, weekly $SMR_{adjusted}$ for 2020 and 2021 in the total population and weekly SMRs for persons over 80 years of age were estimated by the procedure described above. In these analyses, age-specific weekly mortality rates for the years 2016 to 2019 were calculated and were used to calculate expected numbers of death for each calendar week. Weekly SMRs were estimated by dividing weekly observed numbers of deaths in each of the years 2020 and 2021 by the weekly expected numbers of death.

For both ways of calculating the number of expected deaths, we additionally estimated the difference between the observed number of deaths and the expected number of deaths for the years 2020 and 2021.

All analyses were also done separately by sex.

Results

SMR_{crude} was 1.006 (95% CI: 0.980–1.031) in 2020, and 1.047 (95% CI: 1.021–1.073) in 2021 (Table 1). SMR_{crude} was higher in men than in women in 2020 and in 2021. $SMR_{adjusted}$ was 0.976 (95% CI: 0.951–1.001) in 2020, and 0.998 (95% CI: 0.973–1.023) in 2021 (Table 2). $SMR_{adjusted}$ was higher in men than in women in 2020 and 2021. In 2020, the observed number of deaths was 148.5 lower than the expected number of deaths. In 2021, 12.1 fewer deaths were observed than expected.

Table 3 shows $SMR_{adjusted}$ for the different pandemic waves and for the intermediate phases during the summer weeks of 2020 and 2021, when incidences of SARS-CoV-2 were low. In waves 1 and 3, the number of observed death cases was –110.5 and –54.6 lower, respectively, than the expected number of death cases (wave 1 $SMR_{adjusted}$ 0.917; 95% CI: 0.866–0.969; wave 3 $SMR_{adjusted}$ 0.970; 95% CI: 0.925–1.015). In waves 2 and 4, the number of observed death cases was 273.9 and 80.4 higher, respectively, than the expected number of deaths (wave 2 $SMR_{adjusted}$ 1.106; 95% CI: 1.066–1.147; wave 4 $SMR_{adjusted}$ 1.033; 95% CI: 0.933–1.073).

Weekly $SMR_{adjusted}$ for the years 2020 and 2021 in comparison with the years 2016 to 2019 is shown in Figure 1 for the total population, and Figure 2 exhibits the SMR for the over-80-year-olds. Furthermore, SARS-CoV-2 seven-day reports per 100,000 of the respective population are also shown.

In the total population, registered infections peaked in wave 2 with 302/100,000 in CW 45/2020, in wave 3 with 208/100,000 in calendar week 17/2021 and 354/100,000 in calendar week 48/2021 during wave 4 (Figure 1). Peaks in $SMR_{adjusted}$ during the waves occurred in week 49/2020 with a $SMR_{adjusted}$=1.462 in the second wave, $SMR_{adjusted}$=1.352 in week 17/2021 (3rd wave) and an $SMR_{adjusted}$=1.352 in week 47/2021 (4th wave).

The highest registered weekly SARS-CoV-2 infection rates in the over 80-year-olds were twice as high as in the general population during the first wave, slightly higher than infection rates among the general population in the second wave at 310/100,000 (CW 46/2020), and lower than those of the general population in the following waves (Figure 2). In wave 2, $SMR_{adjusted}$ reached a maximum of 1.896 in week 49/2020. In 2021, maximum $SMR_{adjusted}$ were 1.393 (3rd wave; calendar week 17/2021) and 1.404 (4th wave, calendar week 49/2021).

Table 1: Mortality in Frankfurt/Main, Germany, 2020 and 2021, without adjustment for age trend of the population

	Deaths (observed)						Population						2020			2021		
	2016	**2017**	**2018**	**2019**	**2020**	**2021**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	$N_{exp\ deaths}$[a]	$Diff_{crude}$[b]	SMR_{crude}[c]	$N_{exp\ deaths}$[a]	$Diff_{cruded}$[b]	SMR_{crude}[c]
Both sexes	5,589	5,988	5,882	5,750	5,982	6,209	727,055	735,359	744,471	753,211	758,711	756,237	5949.24	33	1.006	5929.848	279	**1.047**
SMR 95CI															0.980–1.031			**1.021–1.073**
Males	2,719	2,955	2,874	2,849	3,008	3,145	360,803	364,857	369,375	373,680	376,411	375,006	2920.94	87	1.030	2910.037	235	**1.081**
SMR 95CI															0.993–1.067			**1.043–1.119**
Females	2,870	3,033	3,008	2,901	2,974	3,064	366,253	370,502	375,096	379,532	382,300	381,231	3028.317	–54	0.982	3019.849	44	1.015
SMR 95CI															0.947–1.017			0.979–1.051

Diff: difference; SMR: standardized mortality ratio; CI: confidence interval

[a] $N_{exp\ deaths}$ = expected number of deaths

[b] $Diff_{crude}$ = observed number of deaths minus number of expected deaths for the respective year

[c] SMR_{crude} = observed number of deaths divided by number of expected deaths for the respective year

[d] Example of calculation for expected number of deaths in 2020: ¼·(5589/727055+5988/735359+5882/744471+5750/753211) 758711=5949.24

Table 2: Mortality in Frankfurt/Main, Germany, 2020 and 2021, adjusted for age trend of the population

	Age	Deaths (observed)						Population						2020			2021		
		2016	2017	2018	2019	2020	2021	2016	2017	2018	2019	2020	2021	$N_{exp\ deaths}$[a] adjusted	$Diff_{adj}$[b]	SMR_{adj}[c]	$N_{exp\ deaths}$[a] adjusted	$Diff_{adj}$[b]	SMR_{adj}[c]
Both sexes	**0–29**	69	68	54	70	57	77	240,010	243,755	247,193	249,939	250,364	248,465	66.7	–9.7	0.855	66.2	10.8	1.164
	30–59	555	588	618	547	549	594	336,217	339,359	343,513	347,668	350,303	348,064	591.6	–42.6	0.928	587.9	6.1	1.010
	60–69	699	765	709	735	726	755	67,711	68,604	69,294	70,110	71,303	72,532	752.1	–26.1	0.965	765.0	–10.0	0.987
	70–79	1,311	1,426	1,257	1,275	1,270	1,368	52,360	51,919	51,816	51,617	51,394	50,834	1,303.6	–33.6	0.974	1,289.5	78.5	1.061
	≥80	2,955	3,141	3,244	3,123	3,380	3,415	30,758	31,723	32,655	33,878	35,348	36,343	3,416.5	–36.5	0.989	3,512.6	–97.6	0.972
	All ages	5,589	5,988	5,882	5,750	5,982	6,209	727,055	735,359	744,471	753,211	758,711	756,237	6,130.5	–148.5	0.976	6,221.1	–12.1	0.998
95% CI																0.951–1.001			0.973–1.023
Males	**0–29**	48	45	32	40	32	48	120,388	122,388	124,093	125,360	125,617	124,890	42.2	–10.2	0.759	41.9	6.1	1.144
	30–59	347	405	400	354	368	409	173,345	17,4495	176,382	178,334	179,444	177,851	384.7	–16.7	0.957	381.3	27.7	1.073
	60–69	432	475	467	459	471	461	32,470	32,922	33,307	33,831	34,571	35,299	478.1	–7.1	0.985	488.2	–27.2	0.944
	70–79	742	820	722	740	763	795	23,862	23,773	23,772	23,692	23,573	23,252	749.6	13.4	1.018	739.4	55.6	1.075
	≥80	1,150	1,210	1,253	1,256	1,374	1,432	10,739	11,279	11,823	12,464	13,206	13,715	1,390.3	–16.3	0.988	1,443.9	–11.9	0.992
	All ages	2,719	2,955	2,874	2,849	3,008	3,145	360,803	364,857	369,375	373,680	376,411	375,006	3,044.9	–36.9	0.988	3,094.8	50.2	1.016
95% CI																0.953–1.023			0.981–1.052
Females	**0–29**	21	23	22	30	25	29	119,622	121,367	123,101	124,579	124,747	123,575	24.5	0.5	1.022	24.2	4.8	1.196
	30–59	208	183	218	193	181	185	162,873	164,864	167,132	169,334	170,859	170,213	206.4	–25.4	0.877	205.6	–20.6	0.900
	60–69	267	290	242	276	255	294	35,241	35,682	35,987	36,280	36,732	37,234	275.8	–20.8	0.925	279.6	14.4	1.052
	70–79	569	606	535	535	507	573	28,499	28,147	28,045	27,925	27,821	27,583	554.5	–47.5	0.914	549.8	23.2	1.042
	≥80	1,805	1,931	1,991	1,867	2,006	1,983	20,019	20,444	20,833	21,414	22,142	22,628	2,033.6	–27.6	0.986	2,078.2	–95.2	0.954
	All ages	2,870	3,033	3,008	2,901	2,974	3,064	366,253	370,502	375,096	379,532	382,300	381,231	3,094.8	–120.8	**0.961**	3,137.4	–73.4	0.977
95% CI																**0.926–0.996**			0.942–1.011

Diff: difference; SMR: standardized mortality ratio; CI: confidence interval

[a] $N_{exp\ deaths}$ = expected number of deaths

[b] $Diff_{adj}$ = observed number of deaths minus adjusted number of expected deaths for the respective year and age group

[c] SMR_{adj} = observed number of deaths divided by adjusted number of expected deaths for the respective year and age group

[d] Example of calculation for expected number of deaths for age group 0-29 in 2020: ¼ · (69/240,010 + 68/243,755 + 54/247,193 + 70/249,939) · 250,364 = 66.7

Table 3: Mortality in Frankfurt/Main, Germany, 2020–2021, adjusted for age trend of the population, during the four pandemic waves and during summer phases

	Age	Wave 1 CW 10 to 20/2020		Summer 2020 CW 24 to 30/2020		Wave 2 CW40/2020 to 8/2021		Wave 3 CW 9 to 23/2021		Summer 2021 CW 24 to 30/2021		Wave 4 CW 31 to 51/2021	
		$Diff_{adj}$[a]	SMR_{adj}[b]	$Diff_{adj}$[a]	SMR_{adj}[b]	$Diff_{adj}$[a]	SMR_{adj}[b]	$Diff_{adj}$[a]	SMR_{adj}[b]	$Diff_{adj}$[a]	SMR_{adj}[b]	$Diff_{adj}$[a]	SMR_{adj}[b]
Both sexes	**0–29**	–6.3	0.587	**3.1**	1.452	1.3	1.051	1.5	1.075	8.2	2.195	8.9	1.331
	30–59	–16.2	0.876	**1.9**	1.025	11.8	1.050	–6.6	0.962	29.4	1.394	17.9	1.077
	60–69	5.5	1.036	**–12.5**	0.862	6.6	1.021	–10.4	0.952	33.9	1.369	–8.4	0.973
	70–79	–1.2	0.996	**4.1**	1.026	54.8	1.100	25.6	1.066	24.8	1.160	41.7	1.086
	≥80	–92.2	0.876	**–5.4**	0.987	199.5	1.137	–64.7	0.937	–99.1	0.768	20.2	1.015
	All ages	–110.5	**0.917**	**–8.7**	0.988	273.9	**1.106**	–54.6	0.970	–2.8	0.996	80.4	1.033
95% CI			**0.866–0.969**		0.917–1.060		**1.066–1.147**		0.925–1.015		0.925–1.068		0.993–1.073
Males	**0–29**	–7.0	0.363	**3.9**	1.960	–1.6	0.902	0.5	1.037	0.9	1.232	4.8	1.294
	30–59	–7.8	0.909	**5.2**	1.107	5.3	1.034	6.8	1.059	1.6	1.034	22.9	1.154
	60–69	–6.3	0.936	**–8.6**	0.851	8.7	1.043	–18.4	0.872	8.2	1.140	–3.0	0.984
	70–79	3.0	1.017	**10.5**	1.120	35.4	1.113	11.0	1.047	10.7	1.124	24.7	1.089
	≥80	–57.9	0.810	**–10.5**	0.937	124.7	1.207	–18.4	0.956	–27.9	0.838	15.3	1.027
	All ages	–76.0	**0.887**	**0.5**	1.001	172.4	**1.134**	–18.5	0.980	–6.4	0.983	64.7	1.054
95% CI			**0.816–0.958**		0.899–1.104		**1.076–1.192**		0.916–1.044		0.882–1.084		0.996–1.111
Females	**0–29**	0.7	1.156	**–0.8**	0.713	2.9	1.324	1.0	1.157	7.2	3.599	4.2	1.384
	30–59	–8.3	0.813	**–3.2**	0.877	6.8	1.086	–13.2	0.770	27.9	2.066	–4.6	0.946
	60–69	11.3	1.212	**–4.1**	0.875	–3.0	0.975	7.1	1.098	25.4	1.757	–6.4	0.945
	70–79	–4.3	0.962	**–6.5**	0.907	19.4	1.082	14.8	1.095	14.1	1.205	17.1	1.082
	≥80	–36.2	0.917	**4.5**	1.018	71.6	1.084	–49.0	0.920	–72.0	0.718	0.4	1.001
	All ages	–36.7	0.944	**–10.1**	0.973	97.8	**1.075**	–39.3	0.956	2.7	1.007	10.7	1.009
95% CI			0.869–1.018		0.874–1.072		**1.019–1.132**		0.893–1.021		0.907–1.107		0.953–1.065

CW: calendar week; Diff: difference; SMR: standardized mortality ratio; CI: confidence interval

[a] $Diff_{adj}$ = observed number of deaths minus adjusted number of expected deaths for the respective year and age group

[b] SMR_{adj} = observed number of deaths divided by adjusted number of expected deaths for the respective year and age group

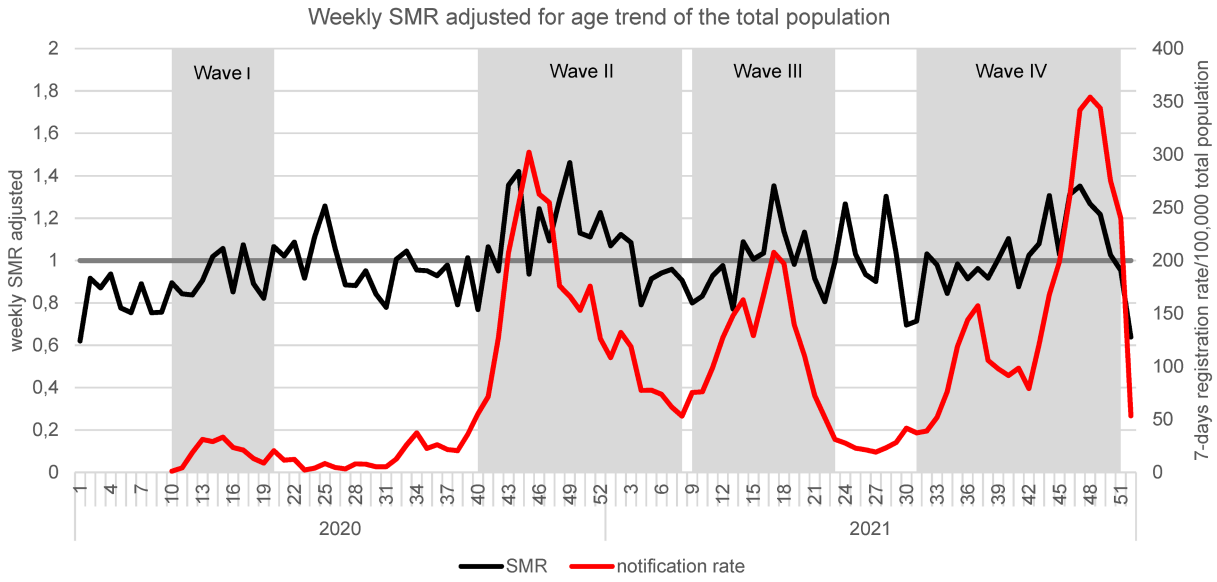

Figure 1: Age-adjusted weekly SMR and respective 7-day registration rates/100,000 in Frankfurt/Main in 2020 and 2021 for the whole population

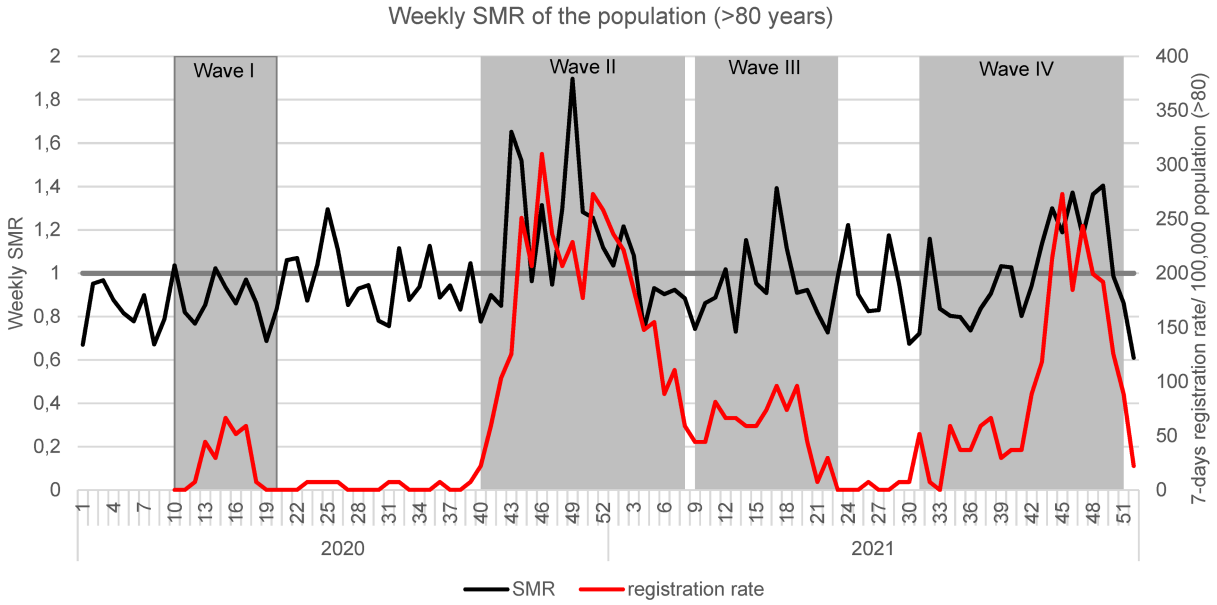

Figure 2: Weekly SMR and respective 7-day registration rates/100,000 in Frankfurt/Main in 2020 and 2021 for the over 80-year-old population

Discussion

No excess mortality ($SMR_{adjusted}$) was observed in Frankfurt/Main in the pandemic years 2020 and 2021 in total, encompassing the circulation of the Wuhan variant as well as the alpha and delta variants in Germany. When analyzing the different pandemic waves separately, excess mortality was seen in wave 2 – autumn/winter of 2020 – but not in waves 1, 3 and 4, in spring of 2020 and 2021, and autumn/winter of 2021, respectively.

In many countries, significant excess mortality was observed in the first half of 2020. Examples include 102.8% in England and Wales, 99% in Spain, 33.7% in France, 25.1% in Sweden and 25.1% in Italy by the end of August 2020 [11]. In Italy, excess mortalities between +48.8% and maximum 600% were reported in individual provinces and cities during the first wave – with great geographical and temporal heterogeneity [14], [17], [18]. In 2020 – with the first wave and the beginning of the second wave of the SARS-CoV-2 pandemic – excess mortality was somewhat lower in most countries, for example 3% in Sweden, 14.8% in Spain and 8.8% in Switzerland [8], [19]. All publications showed a strong increase in mortality in older age groups and, where analyzed, a higher mortality for men than for women.

In Germany, excess mortality was comparatively low with less than +1% in the first months of 2020 and until the end of 2020 [20], [21], [22]. Only during a few weeks in the first pandemic wave, excess mortality ranged from 3% to up to 15% – with substantial heterogeneity between

federal states as well as between individual counties within these states [9], [21].

Without adjustment for population age development, excess mortality$_{crude}$ in Frankfurt/Main presented within the range to be expected for Germany with +0.6% (SMR$_{crude}$ 1.006 (95% CI 0,980–1.031; +33 deaths) for 2020. However, adjustment for population age trends yielded a significant reduction of –2.4% in mortality$_{adjusted}$. (SMR$_{adjusted}$ 95% CI 0.951–1.001; –148.5 deaths). This change is consistent with the findings of other authors. For instance, Stang et al. reported an excess mortality of +3% (SMR 1.03) in wave 1 in the unadjusted model, with an excess mortality of –2% (SMR 0.98) after adjustment [9]. Gianicolo et al. found excess mortality of +43,835 in the unadjusted model (wave 1, Italy), which decreased to +33,035 after adjusting for population development [23]. The necessity of adjusting for population development was emphasized, especially when considering rapidly aging developed countries such as Germany, where the absolute number of people aged 80 or above increased by approximately 20% from 2016 to 2020. In the absence of adjustment for this development, mortality is necessarily overestimated [13]. The lack of adjustment for population development in many publications as well as in the mortality data published by the WHO in their country comparison was assessed critically [24]. Furthermore, in many countries – especially those with low incomes – there is generally no standardized recording of deaths, which further limits comparability between countries [7].

While in most studies only the mortality during the first wave or the combined mortality of the first and second wave were published, we present the mortality for all four pandemic waves until the end of 2021 and separately for the summer phases 2020 and 2021 with low SARS-CoV-2 incidence. In Frankfurt/Main, there was no excess mortality during the first wave – either in the total population or among the residents of the nursing homes in the city [25], [26]. In wave 2, however, there was significant excess mortality$_{adjusted}$ (+10.6%), which particularly affected the over 80-year-olds and, within this group, especially men (+20.7% men, +8.4% women). This correlates with an increase in the incidence of SARS-CoV-2 reporting in the overall population. Many nursing homes for the elderly experienced SARS-CoV-2 outbreaks, including fatalities, despite strict hygiene measures and intense contact restrictions. Rapid SARS-CoV-2 antigen tests were not yet sufficiently available everywhere at that time and vaccines were not available at all [26].

Wave 3 (CW 9–23/2021) was characterized by an increasing spread of the new alpha variant and at the same time by gradual relaxations of the restrictive pandemic measures. At that time, Frankfurt/Main presented an excess mortality$_{adjusted}$ of –3.0%, which was more pronounced among those over 80 years of age (–6.3%), as vaccine rollout in Germany had started at the end of 2020. In accordance with the recommendations of the German Commission on Vaccination (*Ständige Impfkommission*, STIKO), priority was given to vaccinating the very old (>80 years), people at high risk of severe COVID-19 disease and their caregivers, as well as physicians and nursing staff [27]. This needs to be considered when analyzing the change in mortality in this age group.

In the last quarter of 2021, there was another pandemic wave (wave 4) in Germany with SARS-CoV-2 infection rates higher than ever before. At that point, an adjusted excess mortality of +1.5% was recorded for the very old (over 80 years of age) in Frankfurt/Main. Although a large proportion of the older population had already been vaccinated twice by then, the numbers of breakthrough infections led to the STIKO recommending a third vaccination for those older than 70 in October 2021 and for all adults from November 2021 onwards [28], [29]. The potential effects of the vaccinations cannot be quantified precisely in view of other influencing factors (different virus variants, different public health measures, various biases, etc.).

When looking at the weekly Standardized Mortality Ratio (SMR), the excess mortality$_{adjusted}$ in wave 2 is clearly evident (Figure 1 and Figure 2), not only in the group of the very old but also in the overall population. In addition, after the end of wave 1, excess mortality$_{adjusted}$ is still noticeable, especially among those older than 80. One possible explanation for this could be a deterioration in the quality of medical care as a result of restrictive measures. In order to discuss this further, information about the quality of medical care in Germany (frequency of check-ups, etc.) during the SARS-CoV-2 pandemic is necessary.

Limitations and strengths

The Robert Koch Institute's (RKI) reporting data are subject to various biases, as follows. Test availability and testing regimes have a strong influence on the weekly SARS-CoV-2 reporting rate. Cases of death with or from SARS-CoV-2 depend on the reporting discipline of the physicians confirming the death and the work of the public health authorities. A differentiation between deaths from or with SARS-CoV-2 is not possible without a closer look at each individual case.

With regard to the proportion of detected virus variants and the definition of the pandemic waves, we refer to the nationwide data of the RKI. We cannot totally exclude possible regional deviations due to a lack of corresponding data.

Many of the studies published to date include only the first wave [9], [11], [14], [17], [18], the first 6 months of 2020 [21], [22], [23], the period from January to October 2020 [20] or the year 2020 as a whole [8], [13], [19], [30], [31], and therefore consider only phases in which the Wuhan variant was dominant. Only some publications went on to evaluate data up to 2021, when the alpha and delta variants were circulating and vaccine rollout had begun [5], [12], [32], [33], [34], [35], [36], [37]. The strength of our study is that it not only encompasses two complete pandemic years with the circulation

of the Wuhan variant of SARS-CoV-2 as well as the alpha and delta variants, but also analyzes the individual pandemic waves and the intermediate phases separately.

Conclusion

We analyzed data from two full years and four waves of the SARS-CoV-2 pandemic in Frankfurt/Main. The data provide a good overview of overall mortality in Frankfurt/Main, also taking into account the increasing age of the population. There was 0.6% excess mortality$_{crude}$ in 2020 (33 cases) and 4.7% excess mortality in 2021 (+279 cases). Taking into account the trend of increased aging within the population, excess mortality$_{adjusted}$ decreased to –2.4% (–148.5 cases) in 2020 and –0.2% (–12.1 cases) in 2021. This confirms the need for such an adjustment, especially in strongly aging societies.

No excess mortality was observed during the first and third waves of the pandemic. In the second wave, excess mortality adjusted for population development was +10.6% and +3.3% in the fourth wave. The excess mortality rate needs to be considered in relation to complex influencing factors (including virus variants, public health measures, etc.) and cannot be categorically attributed to COVID-19 infection or immunity in the population through previous infection or vaccination. For a more precise analysis of the causes of excess mortality, further analyses with individual data on the exact causes of death and medical histories would be required.

While Germany experienced excess mortality (adjusted for population trends) in 2020 and 2021 [12], the small-area analysis for the city of Frankfurt showed negative excess mortality. This underscores the importance of small-scale analyses for the proper information of the population and as a basis for the planning and control of local public health measures.

Notes

Competing interests

The authors declare that they have no competing interests.

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