

BMJ Open Impacts of using different standard populations in calculating age-standardised death rates when age-specific death rates in the populations being compared do not have a consistent relationship: a cross-sectional population-based observational study on US state HIV death rates

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ABSTRACT

Objective To examine if the rankings of state HIV age-standardised death rates (SDRs) would be different if different standard populations (SPs) were used when age-specific death rates (ASDRs) in states being compared do not have a consistent relationship.

Design A cross-sectional population-based observational study.

Setting 36 states in the USA.

Participants Residents living in the 36 states.

Main outcome measures HIV SDR by state using two SPs, namely US2000 and US2020.

Results US HIV ASDR by state did not have consistent relationships. Of 36 states analysed, the HIV death rates of people aged 55–64 years were higher than people aged 45–54 years in 20 states; on the contrary, the HIV death rates of people aged 55–64 years were lower than people aged 45–54 years in 16 states. No change in ranking in 19 states and change in ranking in 17 states. Of the 17 states whose rankings changed, the rankings of 9 states calculated using US2000 were higher (lower SDR) than those calculated using US2020; in 8 states, the rankings were lower (higher SDR). The states with the greatest changes in rankings between US2000 and US2020 were Kentucky (12th and 9th, respectively) and Massachusetts (8th and 11th, respectively).

Conclusions Calculating SDR using elder SP (US2020) would disproportionately increase the SDR in states with peak HIV death rate in older adults than those used younger SP (US2000).

INTRODUCTION

Age standardisation of morbidity and mortality rates is a common epidemiological practice while comparing the populations with different age distribution in different

Strengths and limitations of this study

- This study examined the impacts of using different standard populations on the rankings of state age-standardised death rates (SDRs) when state age-specific death rates (ASDRs) do not have a consistent relationship.
- One of the limitations of this study was the use of 10-year intervals in calculating the SDRs.
- Another limitation was that the phenomena of inconsistent relationships in HIV ASDRs by state might not exist in other study years.
- This study did not explore possible impacts of using other methods of standardisation on the comparisons of HIV death rates by state.

jurisdictions or across periods. However, statistical literature has indicated that age standardisation is not appropriate when age-specific death rates (ASDRs) in the populations being compared do not have a consistent relationship.^{1–5} What does ‘consistent relationship’ in ASDR meanwhile examining the mortality trends? For example, if death rate of particular disease in older ages and younger age both showing increasing trends or decreasing trends, it is consistent relationship. However, if old ages showing increasing trends and younger ages revealing decreasing trends, the ASDRs do not have consistent relationships. The trend in the age-standardised death rates (SDRs) will reflect some sort of weighted average of the age-specific trends, where the weights depend on the standard population (SP) chosen. If a relatively young

Table 1 Summary of studies examined the use of different standard populations in calculating the age-standardised death rates

Author, year (Ref)	Standard population used	Main comparisons
Spiegelman, 1966 ⁶	US1940, US1950, US1960	Trends of 7 conditions (total, TB, diabetes, vascular lesion of CNS, CM, MVA, homicide)
Curtin, 1981 ⁷	US1940, US1970	Trends of 7 conditions (total, HD, cancer, resp. cancer, CVD, suicide, homicide)
Feinleib, 1992 ⁸	US1940, WHO World1975, WHO European, US1990, World Bank 2020 and 2050	Trends of 3 conditions (cancer, HD, accidents)
Kleinman, 1992 ⁹	US1940, US2050	Trends of 4 conditions (HD, cancer, stroke, lung cancer)
Rosenberg, 1992 ¹⁰	US1940, US1990	Trends of 5 conditions (total, cancer, resp. cancer, CVD, homicide)
Rothenberg, 1992 ¹¹	US1940, US1950, US1960, US1970, US1980, US1990, WHO WORLD, WHO UNIFORM and 16 constructed standards	Trends of 5 conditions (total, IHD, cancer, COPD, AD) and changes in rankings of states for IHD
Anderson, 1998 ¹²	US1940, US2000	Trends of 16 conditions (total, HD, cancer, CVD, COPD, accidents, pneumonia, diabetes, HIV, suicide, Cirrhosis, nephritis, homicide, sepsis, AD, atherosclerosis)
Ahmad, 2001 ¹³	WHO World, Segi, Scandinavian	Trends of circulatory disease mortality rates. Cross-sectional comparison of rankings of 23 countries for respiratory infection mortality rates
Sankoh, 2014 ¹⁴	WHO World, Segi, INDEPTH 2002 and 2013	Cross-sectional comparison of rankings of 16 countries 32 HDSS

AD, Alzheimer's disease; CM, congenital malformation; CNS, central nervous system; COPD, chronic obstructive pulmonary disease; CVD, cerebrovascular disease; HD, heart disease; HDSS, health and demographic survey system; IHD, ischaemic heart disease; MVA, motor vehicle accidents.

SP is used, the trend in SDR may show a small increase or even a decrease; however, if a relatively old SP is used, the mortality trend of particular disease shows a much larger increase. Several empirical studies have illustrated possible effects on conclusions of the comparisons when different SPs were used.^{6–14} The SPs used and main comparisons in these studies are summarised in table 1.

Relatively few studies illustrated possible impacts on the SDRs while comparing different jurisdictions (countries or regions) with inconsistent relationship in ASDRs. What does 'consistent relationship' in ASDR meanwhile examining the differences in mortality rates between countries or regions? For example, if death rate of particular disease in older ages was higher than young ages in country A and country B, it is consistent relationship. However, if the death rate in old ages was higher than young ages in country A; yet, death rate in older ages was lower than young ages in country B, it is not consistent relationships. If a relatively young SP is used, the difference between SDR in country A and SDR in country B would be narrowed as the SDR in country B would be inflated. On the contrary, if a relatively older SP is used, the difference between SDR in country A and SDR in country B would be widened as the SDR in country A would be inflated.

Another principle of selecting the SP is that SP age distributions should be similar to those of the analysed populations.^{3 5} Xia *et al* indicated that the SP age distribution of US2000 differed substantially from that of the population with HIV and recommended restricting the SP to 18–84 years when using US2000 to analyse the population with HIV.¹⁵ Furthermore, the difference between the HIV SDRs and crude death rates varied across states. For example, the crude death rate was the same in Georgia and Maryland, which was 3.0; yet, the SDR was 2.9 in Georgia and 2.5 in Maryland, respectively (internet table 15).¹⁶ We hypothesised that the differences might be due to the inconsistent relationship in HIV ASDRs across states. We sought in this study to examine whether rankings of HIV SDR by state changed if different SPs with different age distribution are used.

METHODS

Data source

In this observational cohort study, the number of HIV deaths in each state and DC from 2015 to 2019 were collected using CDC WONDER (Wide-ranging Online Data for Epidemiologic Research of the Centers for Disease Control and Prevention).¹⁷ To reduce the number of cells in which the HIV death rate was zero while calculating the SDR, we merged years 2015 through 2019 and included only states in which the number of HIV deaths was larger than 100.

Data analysis

Because number of HIV deaths in some states in some age cells was zero, we employed nine age groups, namely ages 0–14, 15–24, 25–34, 35–44, 45–54, 55–64, 65–74, 75–84 and ≥85 years to calculate SDR. Xia *et al* recommended restricting the SP to 18–84 years¹⁵; nevertheless, the number of HIV deaths in people aged 15–17 years was minuscule in most states, we hypothesised that rankings would be the same between the SP age ranges of 15–84 and 18–84 years and between SP age ranges including all age groups and those including people aged 15–84 years. To test this hypothesis, we

Table 2 HIV crude death rates, age-standardised death rates (SDRs)* and rankings according to two standard populations by state, 2015–2019

State	(1) Crude rate		(2) SDR_US2000		(3) SDR_US2020		Rank difference	
	Rate	Rank	Rate	Rank	Rate	Rank	(2)–(1)	(3)–(2)
USA	1.77		1.63		1.77			
Wisconsin	0.49	1	0.44	1	0.48	1	0	0
Minnesota	0.55	2	0.51	2	0.55	2	0	0
Kansas	0.78	3	0.74	3	0.82	3	0	0
Washington	0.84	4	0.76	4	0.85	4	0	0
Michigan	0.87	5	0.77	5	0.85	5	0	0
Colorado	0.88	6	0.82	6	0.90	6	0	0
Oregon	0.92	7	0.83	7	0.91	7	0	0
Ohio	1.02	8	0.96	10	1.01	8	+2	-2
Missouri	1.04	9	0.95	9	1.03	10	0	+1
Kentucky	1.05	10	1.00	12	1.03	9	+2	-3
New Mexico	1.08	11	1.01	13	1.10	13	+2	0
Massachusetts	1.09	12	0.91	8	1.06	11	-4	+3
Pennsylvania	1.14	13	0.99	11	1.10	12	-2	+1
Indiana	1.17	14	1.11	14	1.17	14	0	0
Arizona	1.26	15	1.23	17	1.30	16	+2	-1
Illinois	1.27	16	1.16	15	1.26	15	-1	0
Virginia	1.34	17	1.21	16	1.33	17	-1	+1
Oklahoma	1.46	18	1.43	19	1.52	18	+1	-1
Connecticut	1.62	19	1.31	18	1.53	19	-1	+1
Arkansas	1.64	20	1.59	21	1.65	20	+1	-1
California	1.65	21	1.54	20	1.70	21	-1	+1
Tennessee	1.92	22	1.82	23	1.89	22	+1	-1
North Carolina	1.95	23	1.76	22	1.93	23	-1	+1
Nevada	1.99	24	1.86	24	1.95	24	0	0
Alabama	2.08	25	2.02	27	2.07	25	+2	-2
Texas	2.11	26	2.09	28	2.23	27	+2	-1
Delaware	2.21	27	1.90	25	2.11	26	-2	+1
New Jersey	2.36	28	1.98	26	2.30	28	-2	+2
New York	2.50	29	2.18	29	2.47	29	0	0
South Carolina	2.73	30	2.53	30	2.69	30	0	0
Maryland	3.14	31	2.73	31	3.08	31	0	0
Georgia	3.21	32	3.06	32	3.25	32	0	0
Mississippi	3.33	33	3.28	33	3.40	33	0	0
Louisiana	3.61	34	3.51	35	3.63	35	0	0
Florida	3.71	35	3.31	34	3.57	34	0	0
DC	10.27	36	10.25	36	11.79	36	0	0

*Deaths per 100 000 persons
DC, District of Columbia.

compared the rankings of SDRs by state for the age range of 15–84 years with those for the age range of 18–84 years and the rankings of SDRs by state for the age range of 15–84 years with those for all ages in both US2000 and US2020.¹⁸

To visualise complex data relationships, we designed a dashboard to illustrate the patterns of HIV ASDR in each state and the differential effects of using US2000 and US2020 to derive SDRs.

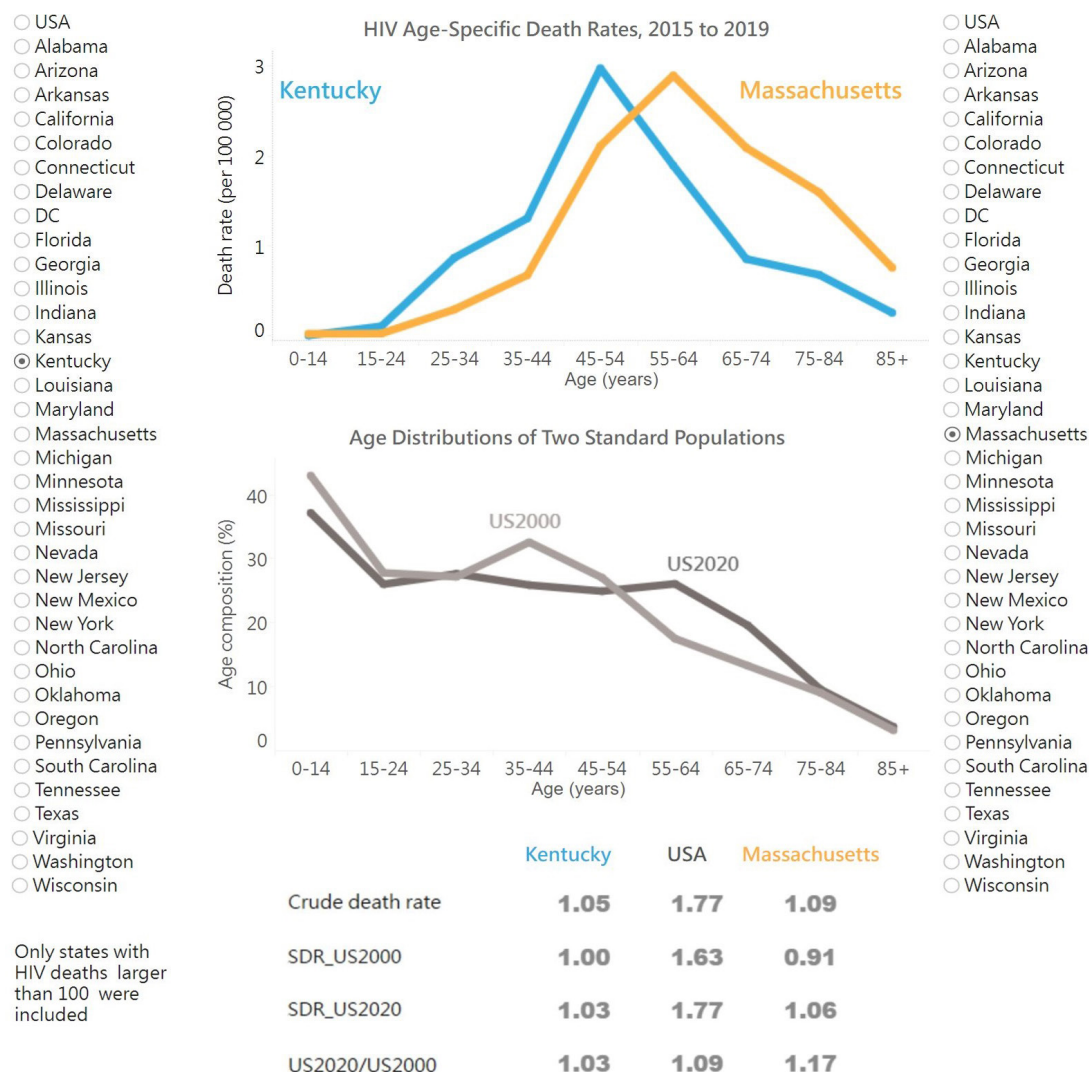


Figure 1 Age-specific HIV death rates in Kentucky and Massachusetts, 2015–2019, and age distribution of two standard populations (US2000 and US2020). Accessible at <https://public.tableau.com/app/profile/robert.lu//StateHIVdeathrates2015-2019/Dashboard>. SDR, standardised death rate.

Patient and public involvement

Patients were not involved in this study.

RESULTS

A total of 28 167 people died from HIV from 2015 to 2019 with 36 states reporting more than 100 HIV deaths. Only 10 people aged ≤ 14 years and 169 people aged ≥ 85 years were among the reported deaths. The rankings of SDRs by state were the same regardless of whether the SP was restricted to people aged ‘15–84 years’ or ‘18–84 years’ (online supplemental table 1) and whether the SP included ‘all ages’ or was restricted to ‘15–84 years’ between US2000 and US2020 (online supplemental table 2). Therefore, we present only the differences in SDRs and rankings with US2000_all ages and US2020_all ages as the SPs in the following sections.

US HIV ASDR by state did not have consistent relationships. Of 36 states analysed, the HIV death rates of people aged 55–64 years were higher than people aged 45–54

years in 20 states; on the contrary, the HIV death rates of people aged 55–64 years were lower than people aged 45–54 years in 16 states.

Table 2 lists the crude death rates, SDRs and state rankings using the US2000 and US2020 SPs. The SDRs calculated using US2000 were lower than the crude death rates in each state. However, the SDRs calculated using US2020 were lower than the crude death rates in 22 states and higher than the crude death rates in 14 states.

In 19 states, the SDR rankings were the same between those calculated using US2000 and US2020, and 15 of those states were among the highest and lowest SDRs: 7 states reported the lowest SDRs (ranking 1–7) and 8 states reported the highest SDRs (ranking 29–36). Among the 17 states whose rankings varied between the 2 SPs, the rankings calculated using US2000 were higher and lower than those calculated using US2020 in 9 and 8 states, respectively (table 2 lists absolute differences in rankings).

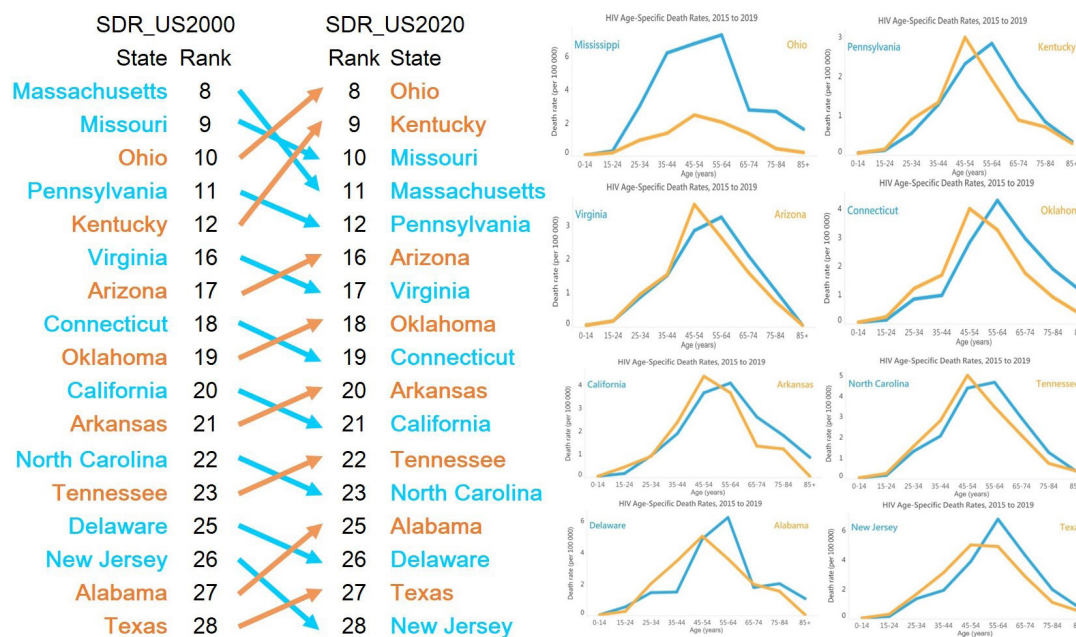


Figure 2 Changes in rankings of age-standardised death rates (SDRs) according to two standard populations (US2000 and US2020) and 2015–2019 HIV age-specific death rates of eight pairs of states with similar rates but different directions of ranking changes.

Kentucky and Massachusetts were the two states with most substantial changes in rankings. The rankings according to US2000 and US2020 were 12 and 9, respectively, for Kentucky and 8 and 11, respectively, for Massachusetts. **Figure 1** contrasts the pattern of ASDRs for Kentucky with those of Massachusetts and the age distributions of US2000 and US2020. We observed a peak in the proportion of people aged 55–64 years in US2020 SP (13.0%) compared with those in US2000 SP (8.7%), which would amplify the state differences in death rates of 55–64 years (2.89 in Massachusetts vs 1.89 in Kentucky) and resulted in a higher SDR in Massachusetts (1.06) than that in Kentucky (1.03).

Conversely, the proportion of people aged 35–44 years was peak in US2000 SP (16.3%) compared with those in US2020 SP (12.9%), which would amplify the state differences in death rates of 35–44 years (0.67 in Massachusetts vs 1.30 in Kentucky) and resulted in a lower SDR in Massachusetts (0.91) than that in Kentucky (1.00). The opposite conclusions of comparisons would be derived according to those using US2000 SP vs those using US2020 SP.

In the dashboard, users may select two states to compare the patterns of age-specific HIV death rates and assess the potential effects of US2000 and US2020 on SDRs (the dashboard can be accessed at <https://public.tableau.com/app/profile/robert.lu/viz/StateHIVdeathrates2015-2019/Dashboard>).

Figure 2 shows eight pairs of states with similar HIV death rates but different directions of their ranking changes according to the US2000 and US2020 SPs. For all eight states (Ohio, Kentucky, Arizona, Oklahoma, Arkansas, Tennessee, Alabama and Texas) for which the US2020 rankings were higher than the US2000 rankings,

the peak HIV ASDR occurred in the 45–54 years age group. By contrast, all nine states (Missouri, Massachusetts, Pennsylvania, Virginia, Connecticut, California, North Carolina, Delaware and New Jersey) for which their US2020 rankings were lower than their US2000 rankings, the peak HIV ASDR occurred in the 55–64 years age group.

DISCUSSION

The findings of this study indicate that the rankings of SDRs using US2000 SP in 17 states were different from those using US 2020 SP, which were owing to inconsistent relationship in ASDRs across states. Of 36 states analysed, the HIV death rates of people aged 55–64 years were higher than people aged 45–54 years in 20 states; on the contrary, the HIV death rates of people aged 55–64 years were lower than people aged 45–54 years in 16 states. SDRs calculated using an SP with an older age distribution (US2020) weigh the higher elderly death rate (death rate of 55–64 years age) more heavily. Similarly, the SDRs calculated using an SP with a younger age distribution (US2000) weigh the lower death rate for younger age groups (death rate of 45–44 years age) more heavily.

Besides the inconsistent relationship in ASDRs, two caveats of using SDRs should be noted. First, SDRs do not reflect the mortality risk of the ‘real’ population.^{3 12} The SDRs are not meaningful by themselves but should instead be used for comparing groups or examining temporal trends. Second, SDRs may obscure critical information. Anderson and Rosenberg employed age-specific cancer death rates from 1975 to 1995 to 3 age groups with large ranges to illustrate their point. The ASDRs for the youngest

age group decreased, whereas those for the oldest age group increased. Nevertheless, SDRs changed very little during this period. Changes in cancer SDRs do not reflect the divergent trends of ASDRs over time.¹²

Because of the aforementioned caveats, several scholars have emphasised that standardisation should not substitute a comparison of ASDRs.^{1 2 4} ASDRs may characterise the experiences (eg, morbidity or mortality) of the studied population. However, comparing sets of ASDRs between populations presents challenges. This study, for example, included 9 age groups across 36 states. One strategy to address these challenges is to use smaller number of broader age groups (<45 years, 45–64 years and ≥65 years) to reveal the diverse trends.^{8 9} Another strategy was the use of data visualisation to efficiently examining the comparisons. In the dashboard we designed (figure 1), users may compare the ASDRs of two states and visualise the effects of using two SPs to derive HIV SDRs without the use of large tables.

Several limitations should be noted in interpreting the findings of this study. First, because of small number of HIV deaths in some states and the number of deaths in many age groups would be zero, we used 10-year intervals to calculate SDRs, which might be different from those using 5-year intervals. Second, we did not examine if inconsistent relationship in ASDRs existed in years other than 2015–2019 in the USA. Third, we did not explore possible impacts of using other methods of standardisation on the comparisons of HIV death rates by state such as indirect method, comparative mortality rate, life-table death rate (Brownlee), equivalent average death rate (Yule) and cumulative rate (Day).^{1 4}

In conclusion, the practice of age standardisation of morbidity and mortality rates to compare temporal trends and jurisdiction differences is commonplace in public health. Nonetheless, many researchers are unaware that standardisation is not appropriate when ASDRs do not have a consistent relative relationship across populations being compared. We have shown in this study that HIV ASDRs by state are inconsistent across age groups and across states. Consequently, the use of different SPs with different age distribution would result in different conclusions on the comparisons of HIV SDRs by state. In this situation, it is recommended that researchers could report comparisons of ASDRs alongside the SDRs.

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Patient consent for publication Not applicable.

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Supplementary Tables

Supplementary Table 1. State HIV age-standardized death rates (SDRs) and rankings, comparison between 15 to 84 and 18 to 84-year-old standard populations (US2000 and US2020), 2015 to 2019

Supplementary Table 2. State HIV age-standardized death rates (SDR) and rankings, comparison between all ages and 15 to 84-year-old standard populations (US2000 and US2020), 2015 to 2019

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Supplementary Table 1. State HIV age-standardized death rates (SDRs)* and rankings, comparison between 15 to 84 and 18 to 84-year-old standard populations (US2000 and US2020), 2015 to 2019

State	US2000 15 to 84		US2000 18 to 84		US2020 15 to 84		US2020 18 to 84	
	SDR	Rank	SDR	Rank	SDR	Rank	SDR	Rank
USA	2.11		2.31		2.33		2.33	
Wisconsin	0.57	1	0.63	1	0.63	1	0.63	1
Minnesota	0.66	2	0.72	2	0.72	2	0.72	2
Kansas	0.96	3	1.05	3	1.07	3	1.08	3
Washington	0.98	4	1.08	4	1.11	4	1.11	4
Michigan	1.00	5	1.10	5	1.12	5	1.12	5
Colorado	1.06	6	1.17	6	1.18	6	1.18	6
Oregon	1.07	7	1.18	7	1.19	7	1.19	7
Massachusetts	1.16	8	1.28	8	1.38	11	1.38	11
Missouri	1.23	9	1.36	10	1.36	10	1.36	10
Ohio	1.24	10	1.36	9	1.33	8	1.34	8
Pennsylvania	1.28	11	1.41	11	1.44	12	1.45	12
Kentucky	1.29	12	1.41	12	1.35	9	1.35	9
New Mexico	1.31	13	1.44	13	1.46	13	1.46	13
Indiana	1.43	14	1.57	14	1.54	14	1.55	14
Illinois	1.49	15	1.64	15	1.65	15	1.66	15
Virginia	1.57	16	1.73	16	1.76	17	1.76	17
Arizona	1.60	17	1.76	17	1.72	16	1.72	16
Connecticut	1.69	18	1.86	18	2.00	19	2.00	18
Oklahoma	1.85	19	2.03	19	2.00	18	2.01	19
California	1.99	20	2.18	20	2.22	21	2.23	21
Arkansas	2.07	21	2.26	21	2.18	20	2.20	20
North Carolina	2.28	22	2.50	22	2.55	23	2.55	23
Tennessee	2.36	23	2.59	23	2.48	22	2.49	22
Nevada	2.40	24	2.62	24	2.55	24	2.57	24
Delaware	2.45	25	2.67	25	2.76	26	2.78	26
New Jersey	2.56	26	2.82	26	3.02	28	3.03	28
Alabama	2.63	27	2.89	27	2.73	25	2.74	25
Texas	2.70	28	2.97	28	2.93	27	2.94	27
New York	2.81	29	3.08	29	3.24	29	3.25	29
South Carolina	3.26	30	3.59	30	3.53	30	3.54	30
Maryland	3.51	31	3.87	31	4.03	31	4.03	31
Georgia	3.95	32	4.34	32	4.27	32	4.29	32
Mississippi	4.23	33	4.65	33	4.46	33	4.47	33
Florida	4.28	34	4.70	34	4.68	34	4.70	34
Louisiana	4.55	35	4.97	35	4.79	35	4.83	35
DC	13.32	36	14.56	36	15.57	36	15.57	36

*Deaths per 100 000 persons

Supplementary Table 2. State HIV age-standardized death rates (SDR)* and rankings, comparison between all ages and 15 to 84-year-old standard populations (US2000 and US2020), 2015 to 2019

State	US2000 All Ages		US2000 15 to 84		US2020 All Ages		US2020 15 to 84	
	SDR	Rank	SDR	Rank	SDR	Rank	SDR	Rank
USA	1.63		2.11		1.77		2.33	
Wisconsin	0.44	1	0.57	1	0.48	1	0.63	1
Minnesota	0.51	2	0.66	2	0.55	2	0.72	2
Kansas	0.74	3	0.96	3	0.82	3	1.07	3
Washington	0.76	4	0.98	4	0.85	4	1.11	4
Michigan	0.77	5	1.00	5	0.85	5	1.12	5
Colorado	0.82	6	1.06	6	0.90	6	1.18	6
Oregon	0.83	7	1.07	7	0.91	7	1.19	7
Massachusetts	0.91	8	1.16	8	1.01	8	1.38	11
Missouri	0.95	9	1.23	9	1.03	9	1.36	10
Ohio	0.96	10	1.24	10	1.03	10	1.33	8
Pennsylvania	0.99	11	1.28	11	1.06	11	1.44	12
Kentucky	1.00	12	1.29	12	1.10	12	1.35	9
New Mexico	1.01	13	1.31	13	1.10	13	1.46	13
Indiana	1.11	14	1.43	14	1.17	14	1.54	14
Illinois	1.16	15	1.49	15	1.26	15	1.65	15
Virginia	1.21	16	1.57	16	1.30	16	1.76	17
Arizona	1.23	17	1.60	17	1.33	17	1.72	16
Connecticut	1.31	18	1.69	18	1.52	18	2.00	19
Oklahoma	1.43	19	1.85	19	1.53	19	2.00	18
California	1.54	20	1.99	20	1.65	20	2.22	21
Arkansas	1.59	21	2.07	21	1.70	21	2.18	20
North Carolina	1.76	22	2.28	22	1.89	22	2.55	23
Tennessee	1.82	23	2.36	23	1.93	23	2.48	22
Nevada	1.86	24	2.40	24	1.95	24	2.55	24
Delaware	1.90	25	2.45	25	2.07	25	2.76	26
New Jersey	1.98	26	2.56	26	2.11	26	3.02	28
Alabama	2.02	27	2.63	27	2.23	27	2.73	25
Texas	2.09	28	2.70	28	2.30	28	2.93	27
New York	2.18	29	2.81	29	2.47	29	3.24	29
South Carolina	2.53	30	3.26	30	2.69	30	3.53	30
Maryland	2.73	31	3.51	31	3.08	31	4.03	31
Georgia	3.06	32	3.95	32	3.25	32	4.27	32
Mississippi	3.28	33	4.23	33	3.40	33	4.46	33
Florida	3.31	34	4.28	34	3.57	34	4.68	34
Louisiana	3.51	35	4.55	35	3.63	35	4.79	35
DC	10.25	36	13.32	36	11.79	36	15.57	36

*Deaths per 100 000 persons