

Global, regional, and national sex-specific burden and control of the HIV epidemic, 1990–2019, for 204 countries and territories: the Global Burden of Diseases Study 2019



GBD 2019 HIV Collaborators*



Summary

Background The sustainable development goals (SDGs) aim to end HIV/AIDS as a public health threat by 2030. Understanding the current state of the HIV epidemic and its change over time is essential to this effort. This study assesses the current sex-specific HIV burden in 204 countries and territories and measures progress in the control of the epidemic.

Methods To estimate age-specific and sex-specific trends in 48 of 204 countries, we extended the Estimation and Projection Package Age-Sex Model to also implement the spectrum paediatric model. We used this model in cases where age and sex specific HIV-seroprevalence surveys and antenatal care-clinic sentinel surveillance data were available. For the remaining 156 of 204 locations, we developed a cohort-incidence bias adjustment to derive incidence as a function of cause-of-death data from vital registration systems. The incidence was input to a custom Spectrum model. To assess progress, we measured the percentage change in incident cases and deaths between 2010 and 2019 (threshold >75% decline), the ratio of incident cases to number of people living with HIV (incidence-to-prevalence ratio threshold <0.03), and the ratio of incident cases to deaths (incidence-to-mortality ratio threshold <1.0).

Findings In 2019, there were 36.8 million (95% uncertainty interval [UI] 35.1–38.9) people living with HIV worldwide. There were 0.84 males (95% UI 0.78–0.91) per female living with HIV in 2019, 0.99 male infections (0.91–1.10) for every female infection, and 1.02 male deaths (0.95–1.10) per female death. Global progress in incident cases and deaths between 2010 and 2019 was driven by sub-Saharan Africa (with a 28.52% decrease in incident cases, 95% UI 19.58–35.43, and a 39.66% decrease in deaths, 36.49–42.36). Elsewhere, the incidence remained stable or increased, whereas deaths generally decreased. In 2019, the global incidence-to-prevalence ratio was 0.05 (95% UI 0.05–0.06) and the global incidence-to-mortality ratio was 1.94 (1.76–2.12). No regions met suggested thresholds for progress.

Interpretation Sub-Saharan Africa had both the highest HIV burden and the greatest progress between 1990 and 2019. The number of incident cases and deaths in males and females approached parity in 2019, although there remained more females with HIV than males with HIV. Globally, the HIV epidemic is far from the UNAIDS benchmarks on progress metrics.

Funding The Bill & Melinda Gates Foundation, the National Institute of Mental Health of the US National Institutes of Health (NIH), and the National Institute on Aging of the NIH.

Copyright © 2021 The Author(s). Published by Elsevier Ltd. This is an Open Access article under the CC BY 4.0 license.

Introduction

Millennium development goal 6 aimed to halt and reverse the spread of HIV/AIDS by 2015 and to achieve universal access to treatment by 2010.¹ Although the world fell short of these goals, over the past two decades, HIV deaths and incident cases declined substantially.² The sustainable development goals (SDGs) subsequently set a goal of ensuring healthy lives, which includes a promise by member states to end the AIDS epidemic as a public health threat by 2030.³ Assessing progress in the control of the HIV epidemic towards this aim, while remaining cognisant of sex-specific trends, is essential. Establishing this baseline before the indirect effects of the COVID-19 pandemic have been fully realised is also crucial, because

these effects might bear on the recalibration of future targets.^{4,5}

Measurable targets relating to incidence and deaths have been proposed to assess progress in HIV, but they have not been synthesised to provide a comprehensive assessment of HIV burden. The original 90-90-90 targets were proposed in 2014,⁶ and set out that by 2020, 90% of people living with HIV will know their HIV status, 90% of those who are aware of their HIV-positive status will have initiated antiretroviral therapy (ART), and 90% of those on treatment will be virally suppressed. However, improvements in these metrics might not necessarily reflect progress and data might be misreported;⁷ under-reporting presents a problem for any modelling effort

Lancet HIV 2021; 8: e633–51

This online publication has been corrected. The corrected version first appeared at thelancet.com/hiv on February 21, 2022

*Collaborators listed at the end of the paper

Correspondence to: Hmwe H Kyu, Institute for Health Metrics and Evaluation, University of Washington, Seattle, WA 98195, USA hmwekyu@uw.edu

Research in context

Evidence before this study

The Sustainable Development Goals aim to eliminate HIV and AIDS as a public health threat by 2030. HIV burden estimates are produced yearly by the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) in all countries, and UNAIDS in select countries, to help monitor progress. GBD 2017 assessed HIV and AIDS incidence, prevalence, and mortality, and coverage of antiretroviral therapy for 195 countries and territories. Although there are well documented declines in the generalised sub-Saharan African epidemic, case studies highlight acceleration of HIV incidence in key populations, including men who have sex with men, sex workers, and people who inject drugs. Against this changing epidemic, revised metrics and thresholds to measure progress related to incidence, prevalence, and deaths have been proposed by UNAIDS. These include percentage change in the number of incident cases and deaths since 2010 (>75% decrease), the incidence to prevalence ratio (<0.03), and the incidence to mortality ratio (<1.0).

Added value of this study

In the 2019 iteration of the GBD, we added nine new countries and territories, and updated HIV treatment and prevalence data. We also implemented a new model that allowed estimation of a transmission rate from age and sex specific HIV prevalence surveys in high-burden settings instead of relying

on aggregate information. Additionally, we implemented a new method to account for bias in underlying antenatal care clinic-sentinel surveillance data that accounts for site location. We describe sex differences, and, for the first time, assess progress according to established metrics. Incident cases and deaths in males and females approached parity in 2019, reflecting declines in the female-dominated epidemic in sub-Saharan Africa. Despite this progress, countries and territories were not on track to meet thresholds related to reductions in incidence, prevalence, incidence-to-mortality ratio (IMR), or incidence-to-prevalence ratio (IPR).

Implications of all the available evidence

Sub-Saharan Africa continues to have the greatest burden of HIV, although our findings corroborate increasing concern about trends in HIV incidence outside this region. Although declines in incident cases and deaths in sub-Saharan Africa drove sex parity globally, challenges in engaging at-risk groups, including young women and key populations, are known in sub-Saharan Africa and other regions. These communities could be of increasing relative importance in curbing HIV in the future. Progress was inconsistent across regions and did not meet proposed thresholds. Decomposing the IMR and IPR in future analyses will allow policy makers to better understand the patterns in progress and design more targeted and hopefully increasingly-successful programmes.

that relies on treatment coverage to inform disease-burden estimates. Several more measurable metrics were agreed upon at a meeting convened by UNAIDS in 2017.⁸ These metrics include percentage reduction in HIV incidence (75% reduction set as the threshold for 2010–20), percentage reduction in AIDS-related deaths (75% reduction set as the threshold for 2010–20), the ratio of the number of incident cases to prevalent cases (incidence-to-prevalence ratio [IPR] set to a threshold of <0.03), and the ratio of number of incident cases to deaths among people living with HIV (incidence-to-mortality ratio [IMR] set to a threshold of <1.0; appendix, section 2.2, p 4). Together, these metrics can be used to provide a current epidemiological picture of HIV, but to our knowledge they have not been measured for all countries and territories.

In addition to assessing broad trends, understanding changes over time in the sex-specific burden of the HIV epidemic is crucial. Changes in the relative burden for males and females are evident, although research on this has been scarce.^{9–11} Although in sub-Saharan Africa women face a disproportionate burden,¹¹ males in Europe and the USA faced a concentrated epidemic early on. In southeast Asia, concurrent epidemics among men who have sex with men (MSM), female sex workers, and people who inject drugs emerged.¹² The HIV burden is also emerging in the super-regions of north Africa and

the Middle East, and central Europe, eastern Europe, and central Asia, where incidence is rising among certain populations, such as MSM.^{13,14} Understanding the sex-specific burden will provide better insight into current and future populations at risk.

Renewed focus on understanding differing HIV burden and trends among populations is necessary to achieving global targets for eliminating HIV as a public health threat by 2030. This study uses results from the Global Burden of Diseases, Injuries, and Risk Factors Study (GBD) 2019 to assess HIV burden in 204 countries and territories and across seven GBD super-regions from 1990 to 2019. The research aims to systematically assess trends in the HIV burden by sex and to measure progress towards SDGs. This manuscript was produced as part of the GBD Collaborator Network in accordance with GBD protocol.

Methods

Overview

GBD is a systematic, scientific effort to quantify the comparative magnitude of health loss caused by diseases and injuries by age, sex, and location over time. Compared with our previous iteration,¹⁵ GBD 2019 included nine additional locations, for a total of 204 countries and territories, and provided estimates from 1990 to 2019. The study also included a new model, the

See Online for appendix

estimation and projection package age-sex model (EPP-ASM). The conceptual and analytical framework for GBD 2019, its hierarchy of causes, and detailed methods have been published elsewhere.^{16–18} Here we describe the specific methods used in GBD 2019 for analysing the burden of HIV (appendix, section 2.1, p 4). The study is compliant with the Guidelines for Accurate and Transparent Health Estimates Reporting (also known as GATHER);¹⁹ data and code for GBD 2019 HIV estimation process are available online. As part of GBD, seven super-regions were defined as follows: high income; sub-Saharan Africa; southeast Asia, east Asia, and Oceania; south Asia; north Africa and the Middle East; Latin America and the Caribbean; and central Europe, eastern Europe, and central Asia (appendix, section 2.3, figure S2, p 6).

Modelling strategy

We grouped countries and territories on the basis of availability of different types of data to use unique modelling strategies that capitalise on the best available data in each country. Group 1 included countries and territories with HIV-prevalence data from antenatal care clinics or representative population-based seroprevalence surveys (ie, 48 countries in total, including several in sub-Saharan Africa and in the Dominican Republic, Haiti, India, Papua New Guinea, and Sudan). Group 2 included the remaining 156 countries, which generally had data on HIV deaths, except for 33 countries with no data on HIV deaths. The groups were further divided on the basis of peak prevalence with or without registration-data completeness (appendix, section 2.3, figure S1, p 6).

To estimate sex-specific HIV burden and trends for countries and territories in group 1, we improved the published version of EPP-ASM.²⁰ To augment this model, we first developed and included an offset term applied to antenatal care data that accounts for site location. This term captures the difference between the prevalence in a given antenatal care-site year and the national prevalence in that year (appendix, section 2.5.2, p 10). Second, to obtain results for all ages, we developed and implemented a paediatric model (for those aged <15 years) within EPP-ASM; the published version only provided results for adults. This model was based on the paediatric component originally in Spectrum,²¹ the model used by many national programmes and UNAIDS to estimate the annual status of the HIV epidemic, incorporating child-treatment inputs and demographics. Finally, we derived priors for the incidence-rate ratios that were used to split larger age groups into smaller ones within the population projection. Simple linear models of observed survey prevalence against year informed our priors for the change of ratios over time and intercepts (appendix, section 2.5.2, p 11).

India was a modelling exception to other group 1 countries because we sought to use available data from antenatal care sentinel surveillance and from the

sample registration system (SRS) on HIV deaths. We used an in-house version of the original estimation and projection package²² to estimate incidence and prevalence on the basis of data on antenatal care. We then used data on SRS deaths to inform age and sex patterns in incidence and deaths via cohort incidence bias adjustment (CIBA). Spectrum was used for final estimates.

For all countries in group 2, we developed CIBA with a modified version of Spectrum to estimate age and sex-specific HIV burden and trends. CIBA is a demographic cohort model that addresses the general scarcity of reliable data on incidence that could provide a gold-standard incidence to use as input for the Spectrum model. CIBA instead aims to derive a plausible incidence from more-reliable data on HIV deaths. We selected the incidence to input from estimates available as part of public-use files or the incidence estimated as part of a past GBD cycle that best minimised the ultimate bias between data from Spectrum deaths and reported deaths. To create an adjustment factor, we determined the ratio of Spectrum deaths to vital statistics deaths for each year. Age and sex specific incidence cohorts were defined by year of infection. The cohort that would have produced those deaths was scaled by this factor using the cohort-survival estimates derived from Spectrum (appendix, section 2.5.4, p 12). We provide a flowchart and full description of models, improvements, and additional adjustments (appendix, section 2.5, figure S3, p 9).

Input data

Country-specific inputs that are common across the modelling strategies included data on demographic estimates and intervention coverage reported to UNAIDS, such as ART and prevention of mother-to-child transmission. Rates of disease progression and HIV-free mortality (ie, the expected background mortality not caused by HIV), required for both models were also inputs for all countries and territories.¹⁸ Model-specific inputs for countries and territories in group 1 for which EPP-ASM was used included population-representative HIV seroprevalence surveys and antenatal care data that were also adjusted to be population representative. For countries and territories in group 2, we used adjusted vital registration data (appendix, section 2.4, p 7).

Estimating uncertainty

All the models were run 1000 times to create 1000 draws from which 95% uncertainty intervals (UIs) were derived, with the 2.5th and 97.5th percentile draws as the upper and lower bounds. On-ART and off-ART mortality were modelled separately. To propagate uncertainty, one draw was randomly selected each time EPP-ASM and Spectrum were run. We drew treatment inputs from a uniform distribution on each draw to ensure adequate uncertainty was captured.

For more on the **data and code** for GBD 2019 HIV estimation see <http://ghdx.healthdata.org/gbd-2019>

Assessing epidemic trends and progress

Sex-specific burden was assessed using the ratio of male-to-female incident cases, deaths, and people with HIV. Progress was measured using the UNAIDS metrics.⁸ We derived the percentage change in number of incident cases and deaths using case counts in 2019 versus 2010.

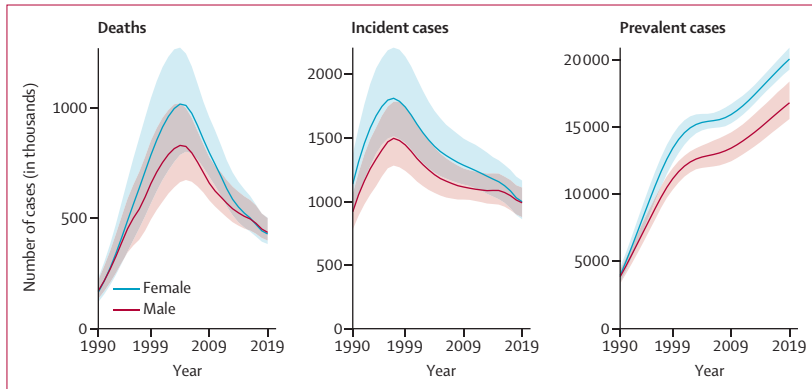


Figure 1: Global HIV burden 1990–2019

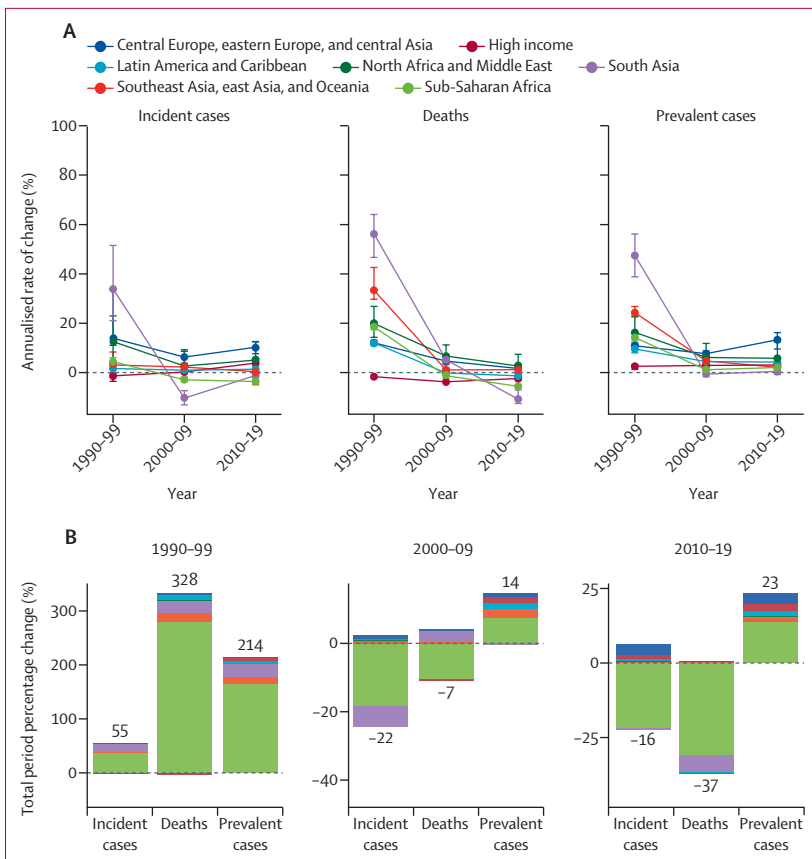


Figure 2: Change in HIV burden by GBD super-region for both sexes combined, by decade, from 1990 to 2019 (A) Annualised rate of change: derived as the mean yearly percentage change averaged over the given time period. (B) Total percentage change: the labelled numbers are the global percentage change in each measure over the given time period. Each bar shows the proportion and direction of change attributable to each super-region. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

$$\text{Percent change}_c = \frac{(Y_{2019} - Y_{2010}) \times 100}{Y_{2010}}$$

Y is either the total number of incident cases or the total number of deaths and c is the location. The IPR and IMR for 2010 and 2019 were also derived. IPR was measured using incident cases for all ages and both sexes combined over prevalent cases for all ages and both sexes combined. The IMR for 2010 and 2019 were measured as the number of incident cases over the total number of deaths from any cause among people living with HIV. Uncertainty for each measure was similarly derived using draw-level results from the modelling processes.

Ethical approval

The University of Washington Institutional Review Board Committee approved GBD 2019 (approval number STUDY00009060). The study is approved until Dec 2, 2021.

Role of the funding source

The funders of the study had no role in study design, data collection, data analysis, data interpretation, or writing of the report.

Results

36·8 million (95% UI 35·1–38·9) people were living with HIV in 2019. Of these, 16·8 million (15·6–18·4) were male, and 20·1 million (19·3–20·9) were female. Over the 1990–2019 study period, the number of incident cases peaked globally in 1997 at 3·3 million (95% UI 2·8–4·0), whereas deaths peaked later, in 2004, at 1·8 million (1·5–2·2; figure 1). These estimates varied greatly by country and territory (appendix, section 2.7, figures S4A–C, pp 16–17), although sub-Saharan Africa had the highest number of incident cases, deaths, and people living with HIV in every study year. This region had 83·3% (95% UI 77·8–87·5) of the global number of incident cases, 78·5% (73·4–83·5) of the global number of deaths, and 74·1% (67·1–80·0) of the global number of people living with HIV in 1990. These numbers declined to 64·8% (58·6–70·4), 74·0% (70·7–77·2), and 70·7% (66·8–73·8), respectively, by 2019 (appendix, section 2.7, figure S5, p 17).

As of 2019, prevalent cases were continuing to rise globally, while incident cases and deaths were declining. Between 1990 and 1999, the global number of people living with HIV increased by an annual mean of 13·7% (95% UI 12·6–14·8) per year compared with 2·4% (2·0–2·7) per year in 2010–19. For incident cases, the fastest decline globally occurred in the decade between 2000 and 2009 (annualised rate of decline 2·7%, 95% UI 2·0–3·4), which came after the fastest decade of acceleration, between 1990 and 1999 (annualised rate of increase 5·1%, 3·9–6·5). By 2010–19, the number of incident cases also declined at a slower annual rate than

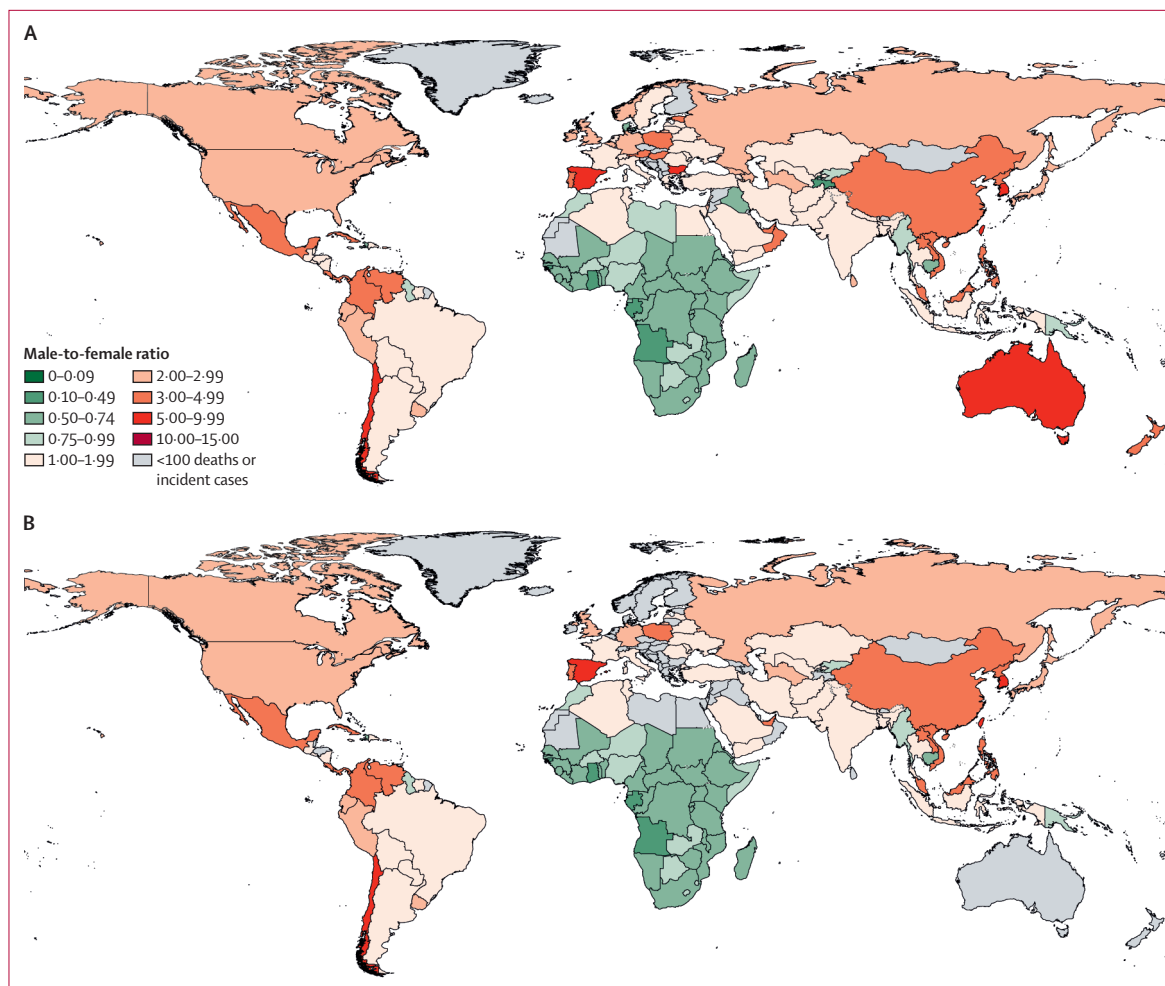


Figure 3: Male-to-female sex ratios for 204 countries and territories in 2019

Incident cases (A). Deaths (B) Countries and territories with fewer than 100 incident cases or deaths in 2019 were excluded from this calculation because of small burdens that drove high ratios that could not easily be interpreted.

deaths (mean decrease per year of 1.8%, 0.8–2.7, vs annual decrease of 5.2%, 4.5–5.7; figure 2).

The global numbers of male and female HIV incident cases and deaths approached parity in 2019, whereas prevalent cases remained disparate. In 2019, there were 0.99 new infections (95% UI 0.91–1.10) among males for every new infection among females, 1.02 HIV deaths (0.95–1.10) among males per HIV death among females (figure 3), and 0.84 males with HIV (0.78–0.91) per female with HIV (appendix, section 2.7, figure S5, p 17).

In 2019, sex differences varied considerably by super-region (appendix, section 2.7, figure S5, p 17). Ratios were the most skewed towards females in sub-Saharan Africa, at 0.68 new infections (95% UI 0.63–0.75) among males per infection among females and 0.84 deaths (95% UI 0.77–0.92) among males per death among females. High-income super-regions had the highest ratios of new infections among males per female

infection (2.42, 2.11–2.76) and deaths among males to deaths among females (2.83, 2.79–2.87).

By contrast to deaths and incident cases, the global number of males with HIV remained lower than the number of females with HIV in 2019. The global number of females with HIV increased faster than that of males with HIV between 1990 and 1999, at 14.7% (95% UI 13.4–16.1) per year versus 12.5% (11.5–13.8) per year. Between 2010 and 2019, however, females with HIV increased by a mean of 2.4% (2.0–2.8) per year, which was similar to the increase in males with HIV (increase per year of 2.3%, 2.0–2.7). At the super-region level, patterns in prevalent-case sex ratios were similar to those of incident cases and deaths (appendix, section 2.7, figures S6–8, pp 18–19).

The global number of HIV incident cases declined by 16.10% (95% UI –22.31 to –8.07) between 2010 and 2019, a change from 2.4 million (95% UI 2.2 to 2.7) new infections in 2010 to 2.0 million

(1·8 to 2·3) new infections in 2019. Between 2010 and 2019, the number of HIV deaths declined by 36·75% (−39·95 to −32·64), a change from 1·4 million deaths (1·2 to 1·6) in 2010 to 864 000 deaths (786 000 to 996 000) in 2019. Neither incidence nor deaths approached the desired 75% reduction target.

Between 2010 and 2019, the decline in incident cases was driven by trends in sub-Saharan Africa, where incident cases fell by 28·50% (95% UI 19·58 to 35·43).

On the other end of the spectrum was central Europe, eastern Europe, and central Asia, where incident cases increased by 107·45% (72·66 to 139·13) from 2010 to 2019, and the high-income super-region, where incident cases increased by 35·65% (3·38 to 55·91; table 1). We present country-level findings in a supplementary table (appendix, section 2.7, table S2, p 31).

Almost all super-regions contributed to the global decrease in deaths between 2010 and 2019, or showed

	IMR, 2010	IMR, 2019	IPR, 2010	IPR, 2019	Percentage change in deaths, 2010–19	Percentage change in incidence, 2010–19
Global	1·59 (1·53 to 1·65)	1·94 (1·76 to 2·12)	0·08 (0·07 to 0·09)	0·05 (0·05 to 0·06)	−36·75% (−39·95 to −32·64)	−16·10% (−22·31 to −8·07)
Central Europe, eastern Europe, and central Asia	2·82 (2·41 to 3·29)	4·76 (3·96 to 5·78)	0·15 (0·12 to 0·19)	0·11 (0·09 to 0·12)	6·85% (5·10 to 8·57)	107·45% (72·66 to 139·13)
High income	3·29 (2·45 to 4·17)	3·91 (2·65 to 4·98)	0·04 (0·03 to 0·05)	0·04 (0·03 to 0·05)	−20·26% (−21·02 to −19·55)	35·65% (3·38 to 55·91)
Latin America and Caribbean	2·25 (2·07 to 2·49)	2·61 (2·31 to 3·04)	0·09 (0·08 to 0·11)	0·07 (0·06 to 0·08)	−12·61% (−18·36 to −6·92)	11·75% (−1·82 to 23·47)
North Africa and Middle East	1·97 (1·27 to 3·18)	2·37 (1·48 to 4·19)	0·13 (0·10 to 0·17)	0·12 (0·08 to 0·17)	24·06% (−14·03 to 81·80)	52·40% (−2·87 to 172·14)
South Asia	0·73 (0·54 to 0·95)	1·40 (0·90 to 1·94)	0·06 (0·04 to 0·08)	0·05 (0·03 to 0·07)	−60·25% (−66·18 to −44·03)	−13·77% (−40·18 to 33·70)
Southeast Asia, east Asia, and Oceania	1·87 (1·62 to 2·23)	1·83 (1·6 to 2·19)	0·08 (0·07 to 0·01)	0·07 (0·06 to 0·08)	5·96% (−8·69 to 18·17)	4·91% (−7·40 to 16·76)
Sub-Saharan Africa	1·51 (1·46 to 1·57)	1·63 (1·44 to 1·82)	0·08 (0·07 to 0·01)	0·05 (0·04 to 0·06)	−39·73% (−42·36 to −36·49)	−28·50% (−35·43 to −19·58)

Data in parentheses are 95% uncertainty intervals. The IPR threshold was set as less than 0·03, and the threshold for the IMR was set to less than 1·0. The incidence and deaths threshold was at least a 75% reduction since 2010.⁸ GBD=Global Burden of Diseases, Injuries, and Risk Factors Study. IMR=incidence-to-mortality ratio. IPR=incidence-to-prevalence ratio.

Table 1: UNAIDS progress metrics by GBD super-region in 2010 and 2019

	1990		1999		2009		2019	
	Males	Females	Males	Females	Males	Females	Males	Females
Global								
Deaths	171 (135–221)	165 (121–230)	656 (493–850)	785 (566–1042)	658 (580–776)	796 (687–956)	435 (399–500)	428 (383–502)
Incident cases	920 (781–1060)	1140 (917–1370)	1450 (1240–1740)	1740 (1460–2140)	1110 (1020–1260)	1290 (1130–1490)	991 (878–1110)	999 (862–1170)
Prevalent cases	3870 (3350–4400)	3960 (3400–4550)	11 100 (10 300–11 900)	13 400 (12 300–14 400)	13 400 (12 400–14 600)	15 900 (15 300–16 700)	16 800 (15 600–18 400)	20 100 (19 300–20 900)
Central Europe, eastern Europe, and central Asia								
Deaths	4·56 (4·5–4·62)	1·32 (1·3–1·34)	12·7 (12·5–12·9)	3·16 (3·12–3·2)	18·5 (18·3–18·7)	6·69 (6·59–6·79)	19·3 (19–19·7)	8·39 (8·26–8·52)
Incident cases	11 (8·62–13·7)	2·77 (2·16–3·6)	29·2 (18·8–63·2)	10·8 (6·3–22)	45·8 (38·7–55·3)	22·4 (18·4–27·2)	112 (88·1–141)	53 (42·4–68·7)
Prevalent cases	72·6 (47·9–108)	16·2 (11·1–23·5)	170 (114–252)	51·5 (31·8–83·3)	333 (232–480)	145 (98·1–212)	1020 (837–1270)	520 (420–654)
High income								
Deaths	34·8 (34·5–35)	5·22 (5·17–5·28)	21·2 (21·1–21·4)	6·66 (6·61–6·71)	13·6 (13·5–13·6)	4·98 (4·94–5·02)	9·89 (9·79–9·99)	3·5 (3·46–3·54)
Incident cases	76·1 (55·6–98·9)	23·4 (15·7–33·2)	55·4 (39·6–70·2)	26·9 (17·9–35·8)	58·9 (37·8–82·5)	25·6 (16–36·3)	83·7 (49–118)	34·6 (19·9–50·6)
Prevalent cases	1080 (698–1520)	227 (137–338)	1250 (733–1850)	369 (210–555)	1570 (900–2280)	569 (322–827)	2060 (1210–2960)	811 (479–1160)
Latin America and Caribbean								
Deaths	12·7 (11·9–14·2)	5·13 (4·31–6·7)	30·1 (27–34·3)	17·5 (14·2–21·5)	29·9 (28·3–32·4)	17·8 (16–20)	27·0 (25·5–29·4)	14·9 (13·4–17)
Incident cases	59·2 (50·8–67·9)	34 (27·3–41·8)	64·1 (54·2–72·1)	43·3 (35·6–49·4)	72·3 (65–79·5)	42·9 (36·5–49·8)	89·9 (78·5–107)	44·8 (38–52·8)
Prevalent cases	247 (188–313)	115 (84·8–149)	505 (401–621)	306 (259–349)	771 (665–889)	483 (426–537)	1200 (1030–1410)	686 (603–772)

(Table 2 continues on next page)

	1990		1999		2009		2019	
	Males	Females	Males	Females	Males	Females	Males	Females
(Continued from previous page)								
North Africa and Middle East								
Deaths	0.406 (0.183–0.969)	0.313 (0.145–0.725)	1.87 (0.971–3.92)	1.78 (0.909–3.62)	3.67 (2.04–7.68)	3.6 (2.17–6.72)	4.72 (2.55–9.97)	4.72 (2.88–9.12)
Incident cases	1.98 (0.765–4.88)	2 (0.62–5.2)	5.69 (2.89–12.4)	5.72 (2.82–10.3)	7.7 (4.01–16.5)	7.44 (3.76–13.8)	11.8 (5.12–30)	12.3 (4.51–34)
Prevalent cases	9.23 (5.44–18)	7.16 (3.34–16.8)	31.4 (16–66.5)	31.9 (14.3–62.7)	60.1 (33.8–126)	58 (33–102)	103 (54.9–214)	101 (49.4–206)
South Asia								
Deaths	0.812 (0.445–1.71)	0.619 (0.43–1.04)	46.5 (34.3–64.6)	29.8 (22.5–40.7)	81 (69.8–96.9)	64.8 (54.2–77.8)	28.8 (22.8–47.3)	23.2 (18.8–35)
Incident cases	19 (7.51–38.8)	9.64 (3.89–19.4)	187 (148–231)	136 (109–167)	59.8 (38.3–91.2)	44.8 (29.1–68.3)	50.1 (28–94.7)	37.8 (22.1–66.5)
Prevalent cases	41.2 (23.6–74)	19.5 (11.4–34.3)	1100 (970–1250)	729 (644–822)	1100 (978–1290)	805 (718–911)	1130 (975–1440)	805 (700–984)
Southeast Asia, east Asia, and Oceania								
Deaths	3.28 (1.84–4.56)	1.73 (1.04–2.23)	41.2 (32.5–46.7)	21.6 (17.4–25.1)	49.1 (44.8–55.3)	26.5 (22.4–32.5)	53.8 (47.5–64.1)	26.0 (21.4–33.2)
Incident cases	69.3 (46.6–95.4)	30.9 (20.7–43.8)	77.4 (66.3–98)	48.5 (38.1–60.1)	110 (94.1–138)	54.6 (46.2–66.6)	120 (92.9–164)	49.2 (38.8–65.9)
Prevalent cases	134 (100–174)	58.4 (43.8–76.8)	769 (616–958)	441 (358–540)	1210 (941–1640)	707 (578–871)	1540 (1170–2260)	839 (675–1100)
Sub-Saharan Africa								
Deaths	115 (80–163)	151 (107–214)	502 (363–669)	704 (500–945)	462 (395–566)	672.0 (575–817)	292 (254–353)	348 (304–414)
Incident cases	683 (526–849)	1040 (805–1270)	1030 (835–1300)	1470 (1200–1840)	760 (658–900)	1090 (949–1280)	524 (436–640)	767 (636–930)
Prevalent cases	2290 (1900–2710)	3520 (2930–4070)	7320 (6480–8080)	11500 (10300–12500)	8390 (7950–8930)	13 200 (12700–13700)	9740 (9210–10 300)	16 300 (15 600–16 900)

Data in parentheses are 95% uncertainty intervals. GBD=Global Burden of Diseases, Injuries, and Risk Factors Study.

Table 2: Number of deaths, incident cases, and prevalent cases (thousands) globally and by GBD super-region, for both sexes combined, in 1990, 2000, 2010, and 2019

minimal change. The largest declines were again in south Asia and sub-Saharan Africa. Deaths in south Asia declined by 60.25% (44.03 to 66.18) from 2010 to 2019, whereas deaths in sub-Saharan Africa declined by 39.73% (36.49 to 42.36). Two super-regions, the high-income super-region and Latin America and the Caribbean, saw smaller declines, whereas the other three super-regions had modest increases (appendix, section 2.7, table S1, p 19, for country and super-region results). We present the number of deaths in each super-region for each decade (table 2).

At the national level, 40 (87%) of 46 countries in sub-Saharan Africa saw declines in deaths. The decline was greatest in Burundi (percentage change in deaths for 2010–19 was –72.77, 95% UI –77.50 to –65.43). In central Europe, eastern Europe, and central Asia, nine of 29 countries had more HIV deaths in 2019 than 2010. Only Georgia had an increase greater than 100%, although this was driven by low absolute numbers of deaths, with an increase of 174.52% (156.54–195.18), from eight deaths (8–9) in 2010 to 23 deaths (22–24) in 2019. In north Africa and the Middle East, 14 (67%) of 21 countries and territories had increases in mean

deaths. Most notably in this region, in Iran, deaths increased by 108.04% (52.23–189.15), from 565 deaths (486–646) in 2010 to 1180 deaths (852–1710) in 2019, whereas Turkey saw a 101.95% (60.34–144.22) increase, from 112 deaths (91–140) in 2010 to 226 deaths (182–265) in 2019. In southeast Asia, east Asia, and Oceania, deaths increased faster than incident cases (table 2), and although 12 countries showed declines over the decade, the remaining 22 countries had increases in deaths (appendix, section 2.7, table S1, p 19).

The global HIV IPR (number of new infections per person with HIV) was 0.05 (95% UI 0.05–0.06) in 2019, compared with 0.08 (0.07–0.09) in 2010, thus not reaching the proposed threshold of 0.03. The IMR (number of new infections per death among people with HIV) was 1.94 (1.76–2.12) in 2019 compared with 1.59 (1.53–1.65) in 2010, also not reaching the threshold of 1.0 (table 1).

Progress towards achieving these UNAIDS benchmarks was inconsistent between the different super-regions. In 2010, the high-income super-region had the highest IMR, at 3.29 (2.45–4.17), whereas central Europe, eastern Europe, and central Asia had the highest

in 2019 (4.76, 3.96–5.78). The lowest IMR in both 2010 and 2019 occurred in south Asia (0.73, 0.54–0.95, in 2010 and 1.40, 0.90–1.94, in 2019; table 1). By contrast to its high IMR, the high-income super-region had the lowest IPR in 2010 and 2019 (both years 0.04, 0.03–0.05), whereas north Africa and the Middle East (0.12,

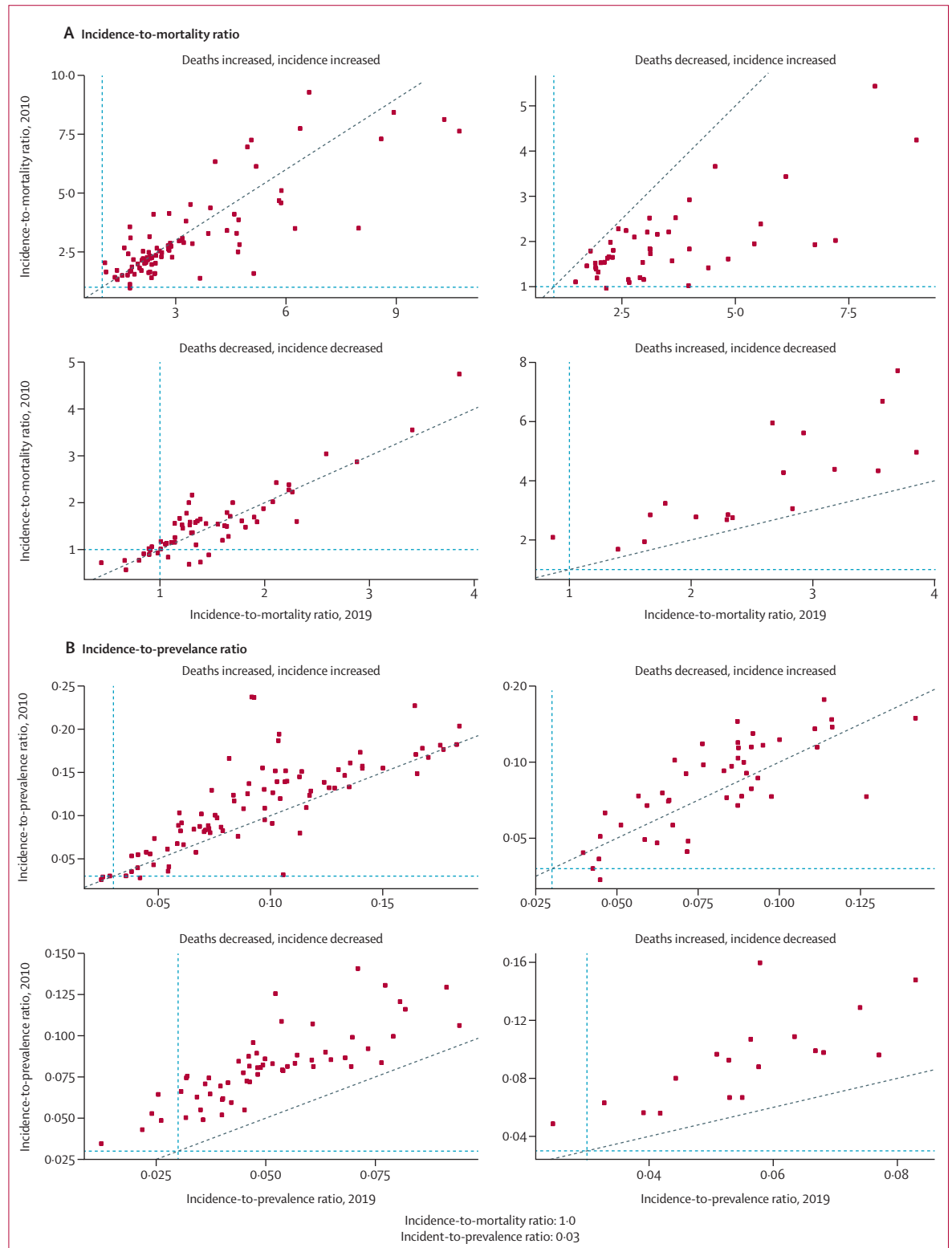


Figure 4: Incidence-to-mortality and incidence-to-prevalence ratios for 204 countries and territories in 2010 versus 2019, and direction of change from 2010 to 2019
The blue dotted lines represent UNAIDS thresholds (<1.0 for incidence-to-mortality ratio and <0.03 for incidence-to-prevalence ratio). Points to the left of the vertical line met the threshold in 2019, whereas points below the horizontal line met the threshold in 2010. Countries and territories are sorted into a directional change matrix for deaths and incidence on the basis of changes between 2010 and 2019.

0·08–0·17) and central Europe, eastern Europe, and central Asia (0·11, 0·09–0·12) had the highest IPRs in 2019 (table 1).

Changes in IMRs and IPRs were driven by different trends in the underlying measures within different countries (figure 4). The highest IMRs in 2019 were found primarily in locations where deaths decreased and incident cases increased since 2010 (nine of the ten countries and territories with the highest IMRs), whereas the lowest IMRs were in locations where both deaths and incident cases decreased (nine out of the ten with the lowest IMRs; appendix, section 2.7, table S5, p 60). Seven of the ten locations with the lowest IPRs in 2019 had both decreasing deaths and incident cases, whereas the remaining three locations had decreasing deaths and increasing incident cases. The top ten locations with the highest IPRs had increases in both deaths and incident cases between 2010 and 2019 (appendix, section 2.7, table S4, p 51).

Discussion

Globally, the number of HIV incident cases and deaths decreased over the past two decades, while the gap between incident cases and deaths in males and females shrank. Because of the high prevalence of HIV among females in sub-Saharan Africa, the number of people living with HIV remained higher in females than in males globally. The decreases in incident cases and deaths did not achieve a 75% decrease between 2010 and 2019; nevertheless, the IPR decreased between 2010 and 2019, approaching the UNAIDS benchmark of 0·03.⁸ The IMR, however, increased in nearly all super-regions over the same period, and no super-region approached the benchmark of 1·0. At the same time, the changes to IMR and IPR reflected different underlying trends in incidence and mortality. Our findings point towards an evolving epidemic and the need to consider alternative metrics to IMR and IPR for a complete picture of the epidemic to inform policy.

Large declines in incidence and deaths in sub-Saharan Africa drove growing global sex parity in these two measures. Females have a disproportionate HIV burden in sub-Saharan Africa because of vulnerabilities ranging from younger sexual debut, sexual transactions with older men, and sexual violence,²³ to biology that makes it easier for men to transmit to women, particularly when women are young.²⁴ Progress in sub-Saharan Africa coincided with global health funding available for HIV in the 2000s,²⁵ ART scale-up,²⁶ HIV/AIDS programmes that improved health-service delivery and infrastructure,²⁷ and prevention efforts.^{28,29} Despite the progress, sub-Saharan Africa still shares an overwhelming burden of HIV. The region does not meet the thresholds under study, and global investments have plateaued.²⁵ More granular work has also revealed heterogeneous patterns and changing HIV demographics within countries^{30,31} and the potential for subnational variation,³²

and highlights the ongoing dual burden with tuberculosis (unpublished). Elsewhere, males have a higher HIV burden, including in central Europe, eastern Europe, and central Asia and the high-income super-region, where the number of incident cases increased and the IMRs were highest in 2019. Injectable drug use has driven transmission through needles in eastern Europe and central Asia.³³

The ongoing epidemic in Africa, incidence growth, and failure to meet progress targets corroborate calls for the increasing importance of surveillance and engagement strategies targeting at-risk groups, including key populations. Although we did not seek to model key populations specifically, our finding, for instance, of sex parity in HIV burden in north Africa and the Middle East could be masking a hidden male epidemic thought to exist among MSM related to missing data and low testing.¹⁴ In sub-Saharan Africa, prevention efforts have not had great success in reaching, in particular, adolescents,³⁴ and key populations still face higher HIV risk and prevalence,³⁵ like elsewhere.^{12,36–38} Pre-exposure prophylaxis (PrEP) was associated with impressive incidence reductions, for example in MSM in Australia,³⁹ but PrEP often does not reach the entirety of the population it could target.^{40,41} Reducing the stigma and marginalisation that lower engagement in HIV prevention and treatment are thus essential to achieve global targets.^{42,43} Historically, affected communities initiated or propagated behavioural change that drove down HIV. The Sonagachi HIV/AIDS intervention in India, for instance, demonstrated the key role of brothels in its success among female sex workers.⁴⁴ Targeted government investment and programmes have also successfully supported reducing HIV infections in key populations.⁴⁵ For example, the Thai government almost managed to eliminate mother-to-child transmission through extensive monitoring, prevention, and treatment policy.⁴⁶ Failing to identify and engage at-risk populations inhibits the overall potential for progress.

To assess progress, metrics apart from IMR and IPR that do not rely primarily on changes to people with HIV might become increasingly relevant. The number of people with HIV can increase because of increasing incident cases or decreasing number of deaths as people live longer. Advances in and access to treatment have meant that life expectancies of people with HIV have approached those without HIV.⁴⁷ An IMR of greater than 1·0, indicating a growing number of people with HIV, could reflect progress as early deaths decline. Galvani and colleagues⁴⁸ also underscored scenarios in sub-Saharan Africa in which negative or positive changes could result in non-intuitive IMRs and IPRs. Relying on the size of the population of people with HIV could thus mask needed policy efforts that address the new challenges opened by longer lifespans for people with HIV.⁴⁹ The growing number of people with HIV in the long term also underscores the importance

of reducing the number of incident cases to constrain long-term ART costs for decades to come.⁵⁰ These factors are reflected in the US President's Emergency Plan for AIDS Relief (PEPFAR), which suggests that IMR only be used in settings with high ART coverage.⁵¹ As such, further decomposing changes in prevalence and the numerators and denominators of IMR and IPR becomes essential, rendering the metrics less useful in isolation.

The COVID-19 pandemic has the potential to complicate progress in controlling HIV epidemics, although research on this issue is scarce. People living with HIV do not seem to have higher susceptibility to severe COVID-19, although vulnerable social status in this population might put them at higher risk than the general population.⁵² There are also potential challenges related to treatment services, including timely access to care, continuing on treatment, and HIV testing.⁵³ One survey in China in February, 2020, found that about 64% of people living with HIV in Hubei province reported difficulty accessing antiretrovirals because of barriers.⁵⁴ In Kenya, there were concerning trends in turnaround times for HIV testing, numbers of tests, and clinical restructuring for COVID-19 mitigation.⁵⁵ There are, however, important efforts underway to mitigate these disruptions. In China, the Chinese National Centre for AIDS/STD Control and Prevention has worked to ensure people with HIV can collect medications.⁵⁶ In Kenya, the Ministry of Health allowed early refills for an extra 3 month supply of antiretrovirals.⁵⁷ Although these are just case studies, broader efforts through WHO, PEPFAR, UNAIDS, and the Global Network of People Living with HIV are working to this end.^{58–61}

Comparing GBD HIV estimates with those published by UNAIDS is useful. For the year 2019, we estimated 36·8 million (95% UI 35·1–38·9) people with HIV, 1·99 million (1·76–2·26) incident cases, and 864 000 (786 000–996 000) deaths, compared with the UNAIDS 2020 published estimates of 38·0 million (31·6–44·5) people with HIV, 1·7 million (1·2–2·2) incident cases, and 690 000 (500 000–970 000) deaths globally in 2019.⁶² Although the GBD estimate of people with HIV is the most similar, higher incidence and deaths are a reflection of several important differences in GBD methods compared with UNAIDS: we did an independent systematic review and synthesis model for on-treatment mortality and progression parameters that were important inputs in both Spectrum and EPP-ASM (appendix, section 2.5, p 9); we incorporated the CIBA process, which involves estimating incidence with mortality data; we used GBD population, fertility, births, and migration estimates in the population projection; and the modelling strategy across groups of countries for UNAIDS is more heterogeneous, with for example the Asian Epidemic Model in southeast Asia. Further, GBD provides two important advantages unavailable from UNAIDS, which include internally

consistent estimates with other causes of death and similar estimates across diseases.

This study has several limitations. The results of the cohort-incidence bias adjustment approach to incorporating vital registration data are sensitive to our initial incidence input to the first stage of Spectrum. Although we aimed to mitigate this problem by choosing the most plausible incidence option that yields deaths closest to more trustworthy vital registration data, there is a general scarcity of reliable data on incidence that could provide a gold-standard incidence input. Future work establishing the most likely incidence in a statistical framework could improve the selection of the incidence input relative to vital registration data and thus improve final burden estimates. The results are also affected by the limitations of the best data sources of countries and territories. Although GBD aims to make use of the best-available and most-recent data in different countries and territories, such data are prone to different biases related to sampling and modelling. Sex differences, for example, can be driven by modelling assumptions for which data are scarce or the dominant data source (case reports, vital statistics, or prevalence surveys) does not capture certain groups. We expect our incidence estimates might be too low in cases in which official data exclude certain population segments. Related to this issue, because of the scarcity of comprehensive data regarding HIV prevalence in gender non-conforming, intersex, and transgender individuals, a male-female binary was used in this research. Despite not having this data, HIV often disproportionately affects these populations, and this work is limited by the inability to provide estimates at a finer granularity of sex and gender identity. In countries and territories without data, our estimates rely on the assumption that regional means provide a good proxy for required treatment and other model inputs.¹⁶ Because countries and territories without data tend to have smaller HIV epidemics, we believe this assumption has limited consequences for regional or global estimates. Still, we might not be accurately capturing the epidemic in these locations if they are outliers in their region.

HIV incident cases and deaths decreased over the past two decades, while the number of people living with HIV continued to increase through 2019. The difference in the number of incident cases and deaths in males and females shrank whereas the number of females living with HIV remained higher than in males living with HIV in 2019. The largest decrease in incidence and deaths was in sub-Saharan Africa, where females also have a higher burden of HIV. Incidence increased the fastest in regions where HIV incidence concentrates in key populations, central Europe, eastern Europe, and central Asia, and the high-income super-region.

Although global trends in IPRs are decreasing, a sign of progress, IMRs were higher in more regions in 2019 than 2010, and did not meet benchmarks set by the

UNAIDS consensus. However, as the number of people with HIV expands because of declining deaths rather than increasing incidence, IMRs and IPRs might not be sufficient for measuring HIV progress. Estimating HIV burden and trends in different populations remains crucially important to provide policy makers with information to design effective control measures.

Contributors

Author contributions are listed in the appendix (pp 61–64). The corresponding author had full access to the data in the study and had final responsibility for the decision to submit for publication.

GBD 2019 HIV Collaborators

Deepa Jahagirdar, Magdalene K Walters, Amanda Novotney, Edmond D Brewer, Tahvi D Frank, Austin Carter, Molly H Biehl, Hedayat Abbastabar, E S Abhilash, Eman Abu-Gharbieh, Laith Jamal Abu-Raddad, Victor Adekanmbi, Daniel Adedayo Adeyinka, Qorinah Estiningtyas Sakilah Adnani, Saira Afzal, Soodabeh Aghababaei, Bright Opoku Ahinkorah, Sajjad Ahmad, Keivan Ahmadi, Sepideh Ahmadi, Ehsan Ahmadpour, Muktar Beshir Ahmed, Tarik Ahmed Rashid, Yusra Ahmed Salih, Addis Akilu, Tayyaba Akram, Chisom Joyqueenet Akunna, Hanadi Al Hamad, Fares Alahdab, Fahad Mashhour Alanezi, Ekaterina A Aleksandrova, Keyfalew Addis Alene, Liaqat Ali, Vahid Alipour, Sami Almustanyir, Nelson Alvis-Guzman, Edward Kwabena Ameyaw, Hubert Amu, Catalina Liliana Andrei, Tudorel Andrei, Davood Anvari, Jalal Arablog, Olatunde Aremu, Judie Arulappan, Desta Deballkie Atnafu, Beatriz Paulina Ayala Quintanilla, Muluken Altaye Ayza, Samad Azari, Darshan B B, Maciej Banach, Till Winfried Bärnighausen, **Fabio Barra**, Amadou Barrow, Sanjay Basu, Shahrzad Bazargan-Hejazi, Habtamu Gebrehana Belay, Tezera Moshago Berheto, Woldelessassie Mequanint Bezabhe, Yihienew Mequanint Bezabih, Akshaya Srikanth Bhagavathula, Nikha Bhardwaj, Pankaj Bhardwaj, Kritika Bhattacharyya, Sadia Bibi, Ali Bijani, Catherine Bisignano, Obasanjo Afolabi Bolarinwa, Archith Boloor, Azizbek A Boltaev, Nikolay Ivanovich Briko, Danilo Buonsenso, Katrin Burkart, Zahid A Butt, Chao Cao, Jaykaran Charan, Souranshu Chatterjee, Soosanna Kumary Chattu, Vijay Kumar Chattu, Sonali Gajanan Choudhari, Dinh-Toi Chu, Rosa A S Couto, Richard G Cowden, Berihun Assefa Dachew, Omid Dadras, Amare Belachew Dagne, Saad M A Dahlawi, Xiaochen Dai, Lalit Dandona, Rakhi Dandona, José das Neves, Louisa Degenhardt, Feleke Mekonnen Demeke, Abebay Alemayehu Desta, Keshab Deuba, Deepak Dhamnetiya, Govinda Prasad Dhungana, Mostafa Dianatinasab, Daniel Diaz, Shirin Djalalinia, Linh Phuong Doan, Fariba Dorostkar, Hisham Atan Edinur, Andem Effiong, Sahar Eftekharezadeh, Maysaa El Sayed Zaki, Rajesh Elayedath, Muhammed Elhadi, Shaimaa I El-Jaafary, Ziad El-Khatib, Aisha Elsharkawy, Aklilu Endalamaw, Aman Yesuf Endries, Sharareh Eskandarieh, Ifeanyi Jude Ezeonwumelu, Sayeh Ezzikouri, Mohammad Farahmand, Emerito Jose A Faraon, Abidemi Omolara Fasanmi, Simone Ferrero, Lorenzo Ferro Desideri, Irina Filip, Florian Fischer, Morenike Oluwatoyin Folayan, Masoud Foroutan, Takeshi Fukumoto, Mohamed M Gad, Muktar A Gadanya, Abhay Motiramji Gaidhane, Tushar Garg, Reta Tsegaye Gayesa, Eyob Alemayehu Gebreyohannes, Hailay Abraha Gesesew, Abera Getachew Obsa, Keyghobad Ghadiri, Ahmad Ghashghaee, Syed Amir Gilani, Themba G Ginindza, Ionela-Roxana Glăvan, Ekaterina Vladimirovna Glushkova, Mahaveer Golechha, Harish Chander Gugnani, Bhawna Gupta, Sapna Gupta, Veer Bala Gupta, Vivek Kumar Gupta, Samer Hamidi, Senad Handanagic, Shafiqul Haque, Harapan Harapan, Arief Hargono, Ahmed I Hasaballah, Abdiwahab Hashi, Shoaib Hassan, Soheil Hassanipour, Khezay Hayat, Ileana Heredia-Pi, Kamal Hezam, Ramesh Holla, Praveen Hoogar, Mohammad Enamul Hoque, Mostafa Hosseini, Mehdi Hosseinzadeh, Mohamed Hsairi, Rabia Hussain, Segun Emmanuel Ibitoye, Bulat Idrisov, Kevin S Ikuta, Olayinka Stephen Ilesanmi, Irena M Ilic, Milena D Ilic, Seyed Sina Naghibi Irvani, M Mofizul Islam, Nahlah Elkudssiah Ismail, Ramaiah Itumalla, Ighogosa Osamuyi Iyamu, Roxana Jabbarinejad,

Vardhmaan Jain, Ranil Jayawardena, Ravi Prakash Jha, Nitin Joseph, Ali Kabir, Zubair Kabir, Rohollah Kalhor, Feroze Kaliyadan, Ashwin Kamath, Tanuj Kanchan, Himal Kandel, Getinet Kassahun, Patrick DMC Katoto, Gbenga A Kayode, Ermiyas Mulu Kebede, Haffe Kahsay Kebede, Himanshu Khajuria, Nauman Khalid, Ejaz Ahmad Khan, Gulfaraz Khan, Khaled Khatab, Min Seo Kim, Yun Jin Kim, Adnan Kisa, Sezer Kisa, Sonali Kochhar, Vladimir Andreevich Korshunov, Parvaiz A Koul, Sindhura Lakshmi Koulmane Laxminarayana, Ai Koyanagi, Kewal Krishan, Barthelemy Kuate Defo, G Anil Kumar, Manasi Kumar, Nithin Kumar, Alexander Kwarteng, Dharmesh Kumar Lal, Iván Landires, Savita Lasrado, Zohra S Lassi, Jeffrey V Lazarus, Jane Jean-Hee Lee, Yeong Yeh Lee, Kate E LeGrand, Christine Lin, Xuefeng Liu, Emilie R Maddison, Hassan Magdy Abd El Razek, Phetole Walter Mahasha, Azeem Majeed, Alaa Makki, Ahmad Azam Malik, Wondimu Ayele Manamo, Mohammad Ali Mansournia, Francisco Rogerlândio Martins-Melo, Seyede Zahra Masoumi, Ziad A Memish, Ritesh G Menezes, Endalkachew Worku Mengesha, Hayimro Edemealem Merie, Amanual Getnet Mersha, Tomislav Mestrovic, Peter Meylakh, Nour Mheidly, Ted R Miller, Andreea Mirica, Babak Moazen, Yousef Mohammad, Mokhtar Mohammadi, Arif Mohammed, Salahuddin Mohammed, Shafiu Mohammed, Modhurima Moitra, Ali H Mokdad, Mariam Molokhia, Mohammad Ali Moni, Ghobad Moradi, Yousef Moradi, Christine Mpundu-Kaambwa, Sumaira Mubarik, Sandra B Munro, Lillian Mwanri, Jean B Nachege, Ahamarshan Jayaraman Nagarajan, Aparna Ichalngod Narayana, Muhammad Naveed, Biswa Prakash Nayak, Sabina O Nduaguba, Sandhya Neupane Kandel, Georges Nguéfack-Tsague, Trang Huyen Nguyen, Molly R Nixon, Chukwudi A Nnaji, Jean Jacques Noubiap, Virginia Nuñez-Samudio, Thomas Elliot Nyirenda, Onome Bright Oghenetega, Andrew T Olagunju, Babayemi Oluwaseun Olakunde, Oluwatomi Funbi Owopetu, Mahesh P A, Jagadish Rao Padubidri, Smita Pakhale, Tarang Parekh, Fatemeh Pashazadeh Kan, Shrikant Pawar, Veincent Christian Filipino Pepito, Emmanuel K Peparh, Marina Pinheiro, Khem Narayan Pokhrel, Roman V Polibin, Richard Charles G Pollok, Maarten J Postma, Zahiruddin Quazi Syed, Amir Radfar, Raghu Anekal Radhakrishnan, Fakher Rahim, Vafa Rahimi-Movaghar, Shadi Rahimzadeh, Mosiur Rahman, Amir Masoud Rahmani, Pradhun Ram, Chhabi Lal Ranabhat, Priyanga Ranasinghe, Chyitra R Rao, Sowmya J Rao, Priya Rathi, David Laith Rawaf, Salman Rawaf, Lemma Demissie Regassa, Inayat ur Rehman, Andre M N Renzaho, Nima Rezaei, Omid Rezaehosseini, Mohammad Sadeq Rezaei, Aziz Rezapour, Rezaul Karim Ripon, Voilet Rodrigues, Denis O Roshchin, Godfrey M Rwegerera, Umar Saeed, Sahar Saeedi Moghaddam, Rajesh Sagar, KM Saif-Ur-Rahman, Marwa Rashad Salem, Mehmoosh Samaei, Abdallah M Samy, Milena M Santric-Milicevic, Satish Saroshe, Brijesh Sathian, Maheswar Satpathy, Monika Sawhney, Aletta Elisabeth Schutte, Allen Seylani, Masood Ali Shaikh, Mohammed Feyisso Shaka, Hina Shamshad, Morteza Shamsizadeh, Mohammed Shannawaz, Adithi Shetty, Jae Il Shin, K M Shivakumar, Jasvinder A Singh, Valentin Yurievich Skryabin, Anna Aleksandrova Skryabina, Ranjani Somayaji, Sergey Soshnikov, Emma Elizabeth Spurlock, Dan J Stein, Mu'awiyah Babale Sufiyan, Hooman Tadbiri, Birkneh Tilahun Tadesse, Eyayou Girma Tadesse, Animit Tagele Tamiru, Elvis Enowbeyang Tarkang, Nuno Taveira, Yohannes Tekalegn, Fisaha Haile Tesfay, Gizachew Assefa Tessema, Rekha Thapar, Marcos Roberto Tovani-Palone, Eugenio Traini, Bach Xuan Tran, Alexander C Tsai, Biruk Shalmeno Tusa, Saif Ullah, Chukwuma David Umeokonkwo, Bhaskaran Unnikrishnan, Sahel Valadan Tahbaz, Jorge Hugo Villafañe, Sergey Konstantinovich Vladimirov, Bay Vo, Avina Vongpradith, Giang Thu Vu, Yasir Waheed, Richard G Wamai, Guan Wang, Yanzhong Wang, Paul Ward, Ronny Westerman, Andrea Sylvia Winkler, Lalit Yadav, Seyed Hossein Yahyazadeh Jabbari, Taklo Simeneh Yazie, Siyan Yi, Vahit Yiğit, Birhanu Wubale Yirdaw, Naohiro Yonemoto, Chuanhua Yu, Ismaeel Yunusa, Mikhail Sergeevich Zastrozhin, Anastasia Zastrozhina, Zhi-Jiang Zhang, Alimuddin Zumla,

Joshua A Salomon, Jeffrey W Eaton, Mohsen Naghavi, Laura Dwyer-Lindgren, Haidong Wang, Stephen S Lim, Simon I Hay, Christopher J L Murray*, and Hmwe H Kyu*.

*joint last authors.

Affiliations

Institute for Health Metrics and Evaluation (D Jahagirdar PhD, M K Walters BS, A Novotney MPH, E D Brewer BS, A Carter MPH, C Bisignano MPH, K Burkart PhD, X Dai PhD, Prof L Dandona MD, Prof R Dandona PhD, Prof L Degenhardt PhD, L Dwyer-Lindgren PhD, K S Ikuta MD, K E LeGrand MPH, C Lin BS, E R Maddison BS, M Moitra MPH, Prof A H Mokdad PhD, M R Nixon PhD, E E Spurlock BA, A Vongpradith BA, J W Eaton PhD, Prof M Naghavi MD, H Wang PhD, Prof S S Lim PhD, Prof S I Hay FMedSci, Prof C J L Murray DPhil, H H Kyu PhD), Department of Health Metrics Sciences, School of Medicine (K Burkart PhD, Prof R Dandona PhD, L Dwyer-Lindgren PhD, Prof A H Mokdad PhD, Prof M Naghavi MD, H Wang PhD, Prof S S Lim PhD, Prof S I Hay FMedSci, Prof C J L Murray DPhil, H H Kyu PhD), Division of Allergy and Infectious Diseases (K S Ikuta MD), Department of Global Health (S Kochhar MD), School of Social Work (J J Lee PhD), Department of Medicine (R Somayaji MD), University of Washington, Seattle, WA, USA; Vagelos College of Physicians and Surgeons (T D Frank MPH), Columbia University Medical Center, New York, NY, USA; Division of Data, Analytics, and Delivery for Impact (M H Biehl MPH), WHO, Geneva, Switzerland; Advanced Diagnostic and Interventional Radiology Research Centre (H Abbastabar PhD), Multiple Sclerosis Research Centre (S Eskandarieh PhD), School of Public Health (M Farahmand PhD), Department of Epidemiology and Biostatistics (Prof M Hosseini PhD, M Mansournia PhD), Paediatric Chronic Kidney Disease Research Centre (Prof M Hosseini PhD), Department of Psychiatry (R Jabbarinejad MD), Metabolomics and Genomics Research Centre (F Rahim PhD), Sina Trauma and Surgery Research Centre (Prof V Rahimi-Movaghar MD), Research Centre for Immunodeficiencies (Prof N Rezaei PhD), Non-Communicable Diseases Research Centre (S Saeedi Moghaddam MSc), Tehran University of Medical Sciences, Tehran, Iran; Department of Botany (E S Abhilash PhD), Sree Narayana Guru College Chelannur, Kozhikode, India; Clinical Sciences Department (E Abu-Gharbieh PhD), Mass Communication Department (A Makki PhD), University of Sharjah, Sharjah, United Arab Emirates; Department of Health-Care Policy and Research, Weill Cornell Medical College in Qatar, Doha, Qatar (Prof L J Abu-Raddad PhD); Department of Population Medicine, Cardiff University, Cardiff, UK (V Adekanmbi PhD); Department of Community Health and Epidemiology, University of Saskatchewan, Saskatoon, SK, Canada (D A Adeyinka MPH); Department of Public Health, Federal Ministry of Health, Abuja, Nigeria (D A Adeyinka MPH); Department of Midwifery, Karya Husada Institute of Health Sciences, Kediri, Indonesia (Q E S Adnani PhD); Department of Midwifery, Auckland University of Technology, Auckland, New Zealand (Q E S Adnani PhD); Department of Community Medicine, King Edward Memorial Hospital, Lahore, Pakistan (Prof S Afzal PhD); Department of Public Health, Public Health Institute, Lahore, Pakistan (Prof S Afzal PhD); Mother and Child Care Research Centre (S Aghababaei PhD), Faculty of Nursing and Midwifery (S Aghababaei PhD), Department of Midwifery (S Masoumi PhD), Hamadan University of Medical Sciences, Hamadan, Iran; The Australian Centre for Public and Population Health Research, University of Technology Sydney, Sydney, NSW, Australia (B O Ahinkorah MPH, E K Ameyaw MPhil); Foundation University Medical College, Foundation University Islamabad, Islamabad, Pakistan (S Ahmad PhD, Prof Y Waheed PhD); Lincoln Medical School, Universities of Nottingham and Lincoln, Lincoln, UK (K Ahmadi PhD); School of Advanced Technologies in Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran (S Ahmadi PhD); Infectious and Tropical Diseases Research Centre, Tabriz University of Medical Sciences, Tabriz, Iran (E Ahmadpour PhD); Department of Epidemiology (M B Ahmed MPH), School of Pharmacy (H K Kebede MSc), Jimma University, Jimma, Ethiopia; Australian Centre for Precision Health, University of South Australia, Adelaide, SA, Australia (M B Ahmed MPH); Department of Computer Science and Engineering, University of Kurdistan Hewler, Erbil, Iraq

(T Ahmed Rashid PhD); Database Technology Department (Y Ahmed Salih PhD), College of Informatics (Y Ahmed Salih PhD), Sulaimani Polytechnic University, Sulaymaniyah, Iraq; Department of Medical Laboratory Sciences (A Aklilu MSc), Department of Biomedical Sciences (E G Tadesse MSc), Arba Minch University, Arba Minch, Ethiopia; School of Mathematical Sciences (T Akram PhD), School of Pharmaceutical Sciences (R Hussain PhD), University of Science Malaysia, Penang, Malaysia; Department of Public Health, The Intercountry Centre for Oral Health for Africa, Jos, Nigeria (C J Akunna DMD); Department of Public Health, Federal Ministry of Health, Garki, Nigeria (C J Akunna DMD); Geriatric and Long-Term Care Department (H Al Hamad MD, B Sathian PhD), Rumailah Hospital (H Al Hamad MD), Hamad Medical Corporation, Doha, Qatar; Mayo Evidence-based Practice Center, Mayo Clinic Foundation for Medical Education and Research, Rochester, MN, USA (F Alahdab MSc); Environmental Health Department (S M A Dahlawi PhD), Forensic Medicine Division (Prof R G Menezes MD), Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia (F M Alanezi PhD); International Centre for Health Economics, Management, and Policy, National Research University Higher School of Economics, St Petersburg, Russia (E A Aleksandrova PhD, P Meylakhs PhD); Faculty of Health Sciences (K A Alene MPH), School of Public Health (B A Dachew PhD, T R Miller PhD, G A Tessema PhD), Curtin University, Perth, WA, Australia; Wesfarmers Centre of Vaccines and Infectious Diseases, Telethon Kids Institute, Perth, WA, Australia (K A Alene MPH); Department of Biological Sciences, National University of Medical Sciences, Rawalpindi, Pakistan (L Ali PhD); Health Management and Economics Research Centre (V Alipour PhD, J Arabloo PhD, S Azari PhD, A Ghashghae BSc, M Hosseinzadeh PhD, A Rezapour PhD), Department of Health Economics (V Alipour PhD), Department of Medical Laboratory Sciences (F Dorostkar PhD), Student Research Committee (A Ghashghae BSc), Minimally Invasive Surgery Research Centre (A Kabir MD), Iran University of Medical Sciences, Tehran, Iran (F Pashazadeh Kan BSN); College of Medicine, Alfaisal University, Riyadh, Saudi Arabia (S Almustanyir MD, Prof Z A Memish MD); Research and Innovation Centre (Prof Z A Memish MD), Ministry of Health, Riyadh, Saudi Arabia (S Almustanyir MD); Research Group in Hospital Management and Health Policies, Universidad de la Costa, Barranquilla, Colombia (Prof N Alvis-Guzman PhD); Research Group in Health Economics, University of Cartagena, Cartagena, Colombia (Prof N Alvis-Guzman PhD); Department of Population and Behavioural Sciences, University of Health and Allied Sciences, Ho, Ghana (H Amu PhD, E E Tarkang PhD); Cardiology Department, Carol Davila University of Medicine and Pharmacy, Bucharest, Romania (C Andrei PhD); Department of Statistics and Econometrics, Bucharest University of Economic Studies, Bucharest, Romania (Prof T Andrei PhD, I Glăvan PhD, A Mirica PhD); Department of Parasitology (D Anvari PhD), Paediatric Infectious Diseases Research Centre (Prof M Rezaei MD), Mazandaran University of Medical Sciences, Sari, Iran; Department of Parasitology, Iranshahr University of Medical Sciences, Iranshahr, Iran (D Anvari PhD); Department of Public Health, Birmingham City University, Birmingham, UK (O Aremu PhD); Department of Maternal and Child Health, Sultan Qaboos University, Muscat, Oman (J Arulappan DSc); Department of Health System and Health Economics (D D Atafu MPH), Department of Internal Medicine (Y M Bezabih MD), Department of Nursing (A B Dagne MSc), Department of Medical Laboratory Sciences (F M Demeke MSc), Department of Paediatrics and Child Health Nursing (A Endalamaw MSc), Department of Reproductive Health and Population Studies (E W Mengesha MPH), Bahir Dar University, Bahir Dar, Ethiopia (W M Bezabih BSc); The Judith Lumley Centre (B Ayala Quintanilla PhD), School of Psychology and Public Health (M Islam PhD), La Trobe University, Melbourne, VIC, Australia; San Martin de Porres University, Lima, Peru (B Ayala Quintanilla PhD); Department of Pharmacology and Toxicology (M A Ayza MSc), Department of Epidemiology (H A Gesesew PhD), School of Public Health (F H Tesfay PhD), Mekelle University, Mekelle, Ethiopia; Kasturba Medical College, Mangalore (D B B MD, R Holla MD, A Kamath MD, J Padubidri MD, P Rathi MD, Prof B Unnikrishnan MD) Prof B Unnikrishnan MD), Centre for Bio Cultural Studies

(P Hoogar PhD), Manipal College of Dental Sciences (Prof A I Narayana PhD, Prof R A Radhakrishnan PhD), Department of Community Medicine (C R Rao MD), Manipal Academy of Higher Education, Manipal, India (A Kamath MD); Department of Hypertension, Medical University of Lodz, Lodz, Poland (Prof M Banach PhD); Polish Mothers' Memorial Hospital Research Institute, Lodz, Poland (Prof M Banach PhD); Heidelberg Institute of Global Health, Heidelberg University, Heidelberg, Germany (Prof T W Bärnighausen MD, B Moazen MSc); T H Chan School of Public Health (Prof T W Bärnighausen MD, I Yunusa PhD), Center for Primary Care (S Basu PhD), Harvard University, Boston, MA, USA; Academic Unit of Obstetrics and Gynaecology (F Barra MD), Department of Neurosciences, Rehabilitation, Ophthalmology, Genetics, Maternal, and Child Health (Prof S Ferrero PhD), University Eye Clinic (L Ferro Desideri MD), University of Genoa, Genoa, Italy; Department of Public and Environmental Health, University of The Gambia, Brikama, The Gambia (A Barrow MPH); Epidemiology and Disease Control Unit, Ministry of Health, Kotu, The Gambia (A Barrow MPH); School of Public Health (S Basu PhD), Department of Primary Care and Public Health (Prof A Majeed MD, Prof S Rawaf MD), WHO Collaborating Centre for Public Health Education and Training (D L Rawaf MD), Department of Infectious Disease Epidemiology (J W Eaton PhD), Imperial College London, London, UK; Department of Psychiatry, Charles R Drew University of Medicine and Science, Los Angeles, CA, USA (Prof S Bazargan-Hejazi BEP); Department of Psychiatry and Biobehavioral Sciences, University of California Los Angeles, Los Angeles, CA, USA (Prof S Bazargan-Hejazi BEP); Department of Midwifery (H G Belay MSc), Department of Pharmacy (T S Yazie MSc), Debre Tabor University, Debre Tabor, Ethiopia; HIV and TB Research Directorate, Ethiopian Public Health Institute, Addis Ababa, Ethiopia (T M Berheto MPH); University of Tasmania, Tasmania, VIC, Australia (W M Bezabhe BSc); One Health, University of Nantes, Nantes, France (Y M Bezabih MD); Department of Social and Clinical Pharmacy, Charles University, Hradec Kralova, Czech Republic (A S Bhagavathula PharmD); Institute of Public Health (A S Bhagavathula PharmD), Department of Medical Microbiology and Immunology (Prof G Khan PhD), United Arab Emirates University, Al Ain, United Arab Emirates; Department of Anatomy, Government Medical College Pali, Pali, India (Prof N Bhardwaj MD); Department of Community Medicine and Family Medicine (P Bhardwaj MD), School of Public Health (P Bhardwaj MD), Department of Pharmacology (J Charan MD), Department of Forensic Medicine and Toxicology (T Kanchan MD), All India Institute of Medical Sciences, Jodhpur, India; Department of Statistical and Computational Genomics, National Institute of Biomedical Genomics, Kalyani, India (K Bhattacharyya MSc); Department of Statistics, University of Calcutta, Kolkata, India (K Bhattacharyya MSc); Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan (S Bibi PhD, S Ullah PhD); Social Determinants of Health Research Centre, Babol University of Medical Sciences, Babol, Iran (A Bijani PhD); Department of Public Health Medicine, University of KwaZulu-Natal, Durban, South Africa (O A Bolarinwa MSc, T G Ginindza PhD); Department of Internal Medicine (A Bolor MD), Department of Community Medicine (N Joseph MD, N Kumar MD, R Thapar MD), Department of Obstetrics and Gynaecology (A Shetty MS), Manipal Academy of Higher Education, Mangalore, India; Department of Mental Health, Human Research and Development Centre, Bukhara, Uzbekistan (A A Boltaev MD); Department of Epidemiology and Evidence-Based Medicine (Prof N I Briko DSc, E V Glushkova PhD, V A Korshunov PhD, R V Polibin PhD), I M Sechenov First Moscow State Medical University, Moscow, Russia; Department of Woman and Child Health and Public Health, Fondazione Policlinico Universitario A Gemelli IRCCS (Agostino Gemelli University Polyclinic IRCCS), Rome, Italy (D Buonsenso MD); Global Health Research Institute, Università Cattolica del Sacro Cuore, Roma, Italy (D Buonsenso MD); School of Public Health and Health Systems, University of Waterloo, Waterloo, ON, Canada (Z A Butt PhD); Al Shifa School of Public Health, Al Shifa Trust Eye Hospital, Rawalpindi, Pakistan (Z A Butt PhD); Program in Physical Therapy, Washington University in St Louis, St Louis, MO, USA (C Cao MPH); Department of Microbiology and Infection Control, Medanta Medicity, Gurugram, India (S Chatterjee MD); Department of Public Health, Texila American University, Georgetown, Guyana (S Chattu PhD); Department of Medicine, University of Toronto, Toronto, ON, Canada (V Chattu MD); Global Institute of Public Health, Thiruvananthapuram, India (V Chattu MD); Department of Community Medicine, Datta Meghe Institute of Medical Sciences, Wardha, India (Prof S G Choudhari MD, Prof A M Gaidhane MD, Prof Z Quazi Syed PhD); Centre for Biomedicine and Community Health, VNU-International School, Hanoi, Vietnam (D Chu PhD); Department of Chemical Sciences (R A S Couto MD), Institute for Research and Innovation in Health (J das Neves PhD), Institute of Biomedical Engineering (J das Neves PhD), Department of Chemistry (M Pinheiro PhD), University of Porto, Porto, Portugal; Department of Psychology, University of the Free State, Park West, South Africa (R G Cowden PhD); Department of Epidemiology (B A Dachev PhD), Department of Surgical Nursing (A A Desta MSc), Department of Clinical Pharmacy (E Gebreyohannes MSc), School of Medicine (A G Mersha MD), Department of Midwifery (A T Tamiru MSc, B W Yirdaw MSc), University of Gondar, Gondar, Ethiopia; School of Public Health, Walailak University, Nakhon Si Thammarat, Thailand (O Dadras DrPH); Graduate School of Medicine, Kyoto University, Kyoto, Japan (O Dadras DrPH); Public Health Foundation of India, Gurugram, India (Prof L Dandona MD, Prof R Dandona PhD, G Kumar PhD, D K Lal MD); Indian Council of Medical Research, New Delhi, India (Prof L Dandona MD); National Drug and Alcohol Research Centre (Prof L Degenhardt PhD), School of Public Health and Community Medicine (Prof A E Schutte PhD), University of New South Wales, Sydney, NSW, Australia; National Centre for AIDS and STD Control, Save the Children, Kathmandu, Nepal (K Deuba DrPH); Department of Global Public Health, Karolinska Institute, Stockholm, Sweden (K Deuba DrPH); Department of Community Medicine, Dr Baba Sahib Ambedkar Medical College and Hospital, Delhi, India (D Dhannetiya MD, R P Jha MSc); Department of Microbiology, Far Western University, Mahendranagar, Nepal (G P Dhungana MSc); Department of Epidemiology and Biostatistics, Shahroud University of Medical Sciences, Shahroud, Iran (M Dianatinasab MSc); Department of Epidemiology, Shiraz University of Medical Sciences, Shiraz, Iran (M Dianatinasab MSc); Centre of Complexity Sciences, National Autonomous University of Mexico, Mexico City, Mexico (Prof D Diaz PhD); Faculty of Veterinary Medicine and Zootechnics, Autonomous University of Sinaloa, Culiacán Rosales, Mexico (Prof D Diaz PhD); Development of Research and Technology Centre, Ministry of Health and Medical Education, Tehran, Iran (S Djalalinia PhD); Institute for Global Health Innovations (L P Doan MSc, T H Nguyen MSc), Faculty of Medicine (L P Doan MSc, T H Nguyen MSc), Duy Tan University, Da Nang, Vietnam; School of Health Sciences (H A Edinur PhD), Universiti Sains Malaysia (University of Science Malaysia), Kubang Kerian, Malaysia; Centre Clinical Epidemiology and Biostatistics (A Effiong MB), School of Medicine and Public Health (A G Mersha MD), University of Newcastle, Newcastle, NSW, Australia; Division of Urology, Children's Hospital of Philadelphia, Philadelphia, PA, USA (S Eftekhazadeh MD); Reference Laboratory of Egyptian Universities-Cairo, Ministry of Higher Education and Scientific Research, Cairo, Egypt (Prof M El Sayed Zaki PhD); School of Behavioural Sciences, Mahatma Gandhi University of Medical Sciences and Technology, Kottayam, India (R Elayedath MSc); Faculty of Medicine, University of Tripoli, Tripoli, Libya (M Elhadi MD); Department of Neurology (S I El-Jaafary MD), Department of Endemic Medicine and Hepatogastroenterology (A Elsharkawy MD), Cairo University, Cairo, Egypt; World Health Programme (Z El-Khatib PhD), Université du Québec en Abitibi-Témiscamingue (University of Quebec in Abitibi-Témiscamingue), Quebec, QC, Canada; Public Health Department, St Paul's Hospital Millennium Medical College, Addis Ababa, Ethiopia (A Y Endries MPH); Institute for Health Science Research Germans Trias i Pujol, Autonomous University of Barcelona, Badalona, Spain (I J Ezeonwumelu MSc); IrsiCaixa AIDS Research Institute, Badalona, Spain (I J Ezeonwumelu MSc); Department of Virology, Pasteur Institute of Morocco, Casablanca, Morocco (S Ezzikouri PhD); Department of Health Policy and Administration, University of the Philippines Manila, Manila, Philippines (E A Faraon MD); Satcher Health Leadership Institute, Morehouse

School of Medicine, Atlanta, GA, USA (A O Fasanmi PhD); School of Medicine (A O Fasanmi PhD), Department of Cardiology (P Ram MD), Emory University, Atlanta, GA, USA; Psychiatry Department, Kaiser Permanente, Fontana, CA, USA (I Filip MD); School of Health Sciences, A T Still University, Mesa, AZ, USA (I Filip MD); Institute of Gerontological Health Services and Nursing Research, Ravensburg-Weingarten University of Applied Sciences, Weingarten, Germany (F Fischer PhD); Department of Child Dental Health, Obafemi Awolowo University, Ile-Ife, Nigeria (Prof M O Folan FWACS); Department of Medical Parasitology, Abadan Faculty of Medical Sciences, Abadan, Iran (M Foroutan PhD); Department of Dermatology, Kobe University, Kobe, Japan (T Fukumoto PhD); Department of Cardiovascular Medicine (M M Gad MD), Department of Internal Medicine (V Jain MD), Lerner Research Institute (X Liu PhD), Cleveland Clinic, Cleveland, OH, USA; Gillings School of Global Public Health, University of North Carolina Chapel Hill, Chapel Hill, NC, USA (M M Gad MD); Community Medicine Department, Bayero University, Kano, Nigeria (M A Gadanya FMCPH); Department of Community Medicine, Aminu Kano Teaching Hospital, Kano, Nigeria (M A Gadanya FMCPH); Department of Radiology, King Edward Memorial Hospital, Mumbai, India (T Garg MBBS); Department of Nursing, Wollega University, Nekemte, Ethiopia (R T Gayesa MSc); Division of Pharmacy, University of Western Australia, Perth, WA, Australia (E Gebreyohannes MSc); College of Medicine and Public Health (H A Gesesew PhD, Prof P Ward PhD), Health and Social Care Economics Group (C Mpundu-Kaambwa PhD), Southgate Institute for Health and Society (F H Tesfay PhD), Flinders University, Adelaide, SA, Australia; School of Psychology (A Getachew Obsa MA), School of Public Health (W A Manamo MSc), Addis Ababa University, Addis Ababa, Ethiopia; Infectious Disease Research Centre (Prof K Ghadiri MD), Paediatric Department (Prof K Ghadiri MD), Kermanshah University of Medical Sciences, Kermanshah, Iran; Faculty of Allied Health Sciences (Prof S Gilani PhD), University Institute of Public Health (A A Malik PhD), The University of Lahore, Lahore, Pakistan; Afro-Asian Institute, Lahore, Pakistan (Prof S Gilani PhD); Health Systems and Policy Research, Indian Institute of Public Health, Gandhinagar, India (M Golechha PhD); Department of Microbiology (Prof H C Gugnani PhD), Department of Epidemiology (Prof H C Gugnani PhD), Saint James School of Medicine, The Valley, Anguilla; Department of Public Health, Torrens University, Melbourne, VIC, Australia (B Gupta PhD); Toxicology Department, Shriram Institute for Industrial Research, Delhi, India (S Gupta MSc); School of Medicine, Deakin University, Geelong, VIC, Australia (V Gupta PhD); Department of Clinical Medicine, Macquarie University, Sydney, NSW, Australia (Prof V K Gupta PhD); School of Health and Environmental Studies, Hamdan Bin Mohammed Smart University, Dubai, United Arab Emirates (Prof S Hamidi DrPH); WHO Collaborating Centre for HIV Strategic Information, University of Zagreb, Zagreb, Croatia (S Handanagic MD); Research and Scientific Studies Unit, Jazan University, Jazan, Saudi Arabia (S Haque PhD); Medical Research Unit (H Harapan PhD), Universitas Syiah Kuala (Syiah Kuala University), Banda Aceh, Indonesia; Department of Epidemiology, Universitas Airlangga, Surabaya, Indonesia (A Hargono Dr); Department of Zoology and Entomology, Al Azhar University, Cairo, Egypt (A I Hasaballah PhD); Department of Public Health, Jijiga University, Jijiga, Ethiopia (A Hashi PhD); Centre for International Health (S Hassan MPhil), Bergen Centre for Ethics and Priority Setting (S Hassan MPhil), University of Bergen, Bergen, Norway; Gastrointestinal and Liver Diseases Research Centre (S Hassanipour PhD), Caspian Digestive Disease Research Centre (S Hassanipour PhD), Guilan University of Medical Sciences, Rasht, Iran; Institute of Pharmaceutical Sciences, University of Veterinary and Animal Sciences, Lahore, Pakistan (K Hayat MS); Department of Pharmacy Administration and Clinical Pharmacy, Xian Jiaotong University, Xian, China (K Hayat MS); Centre for Health Systems Research, National Institute of Public Health, Cuernavaca, Mexico (Prof I Heredia-Pi DipSocSc); Department of Applied Microbiology, Taiz University, Taiz, Yemen (K Hezam PhD); Department of Microbiology, Nankai University, Tianjin, China (K Hezam PhD); NHMRC Clinical Trial Centre (M E Hoque PhD), Save Sight Institute (H Kandel PhD), University of Sydney, Sydney, NSW, Australia; Faculty of Medicine of Tunis, University Tunis El Manar, Tunis, Tunisia (Prof M Hsairi MPH); Department of Health Promotion and Education (S E Ibitoye MPH), Department of Community Medicine (O S Ilesanmi PhD), Department of Obstetrics and Gynaecology (O B Oghenetega MSc), University of Ibadan, Ibadan, Nigeria; Infectious Diseases Department, Bashkir State Medical University, Ufa, Russia (B Idrisov MD); Laboratory of Public Health Indicators Analysis and Health Digitalisation, Moscow Institute of Physics and Technology, Moscow, Russia (B Idrisov MD, S Soshnikov PhD); Department of Community Medicine (O S Ilesanmi PhD), Department of Total Quality Management (O F Owopetu MSc), University College Hospital, Ibadan, Nigeria; Faculty of Medicine (I M Ilic PhD, Prof M M Santric-Milicevic PhD), School of Public Health and Health Management (Prof M M Santric-Milicevic PhD), University of Belgrade, Belgrade, Serbia; Department of Epidemiology, University of Kragujevac, Kragujevac, Serbia (Prof M D Ilic PhD); Independent Consultant, Tabriz, Iran (S N Irvani MD); Department of Clinical Pharmacy, MAHSA University, Bandar Saujana Putra, Malaysia (Prof N Ismail PhD); Department of Health Management, University of Hail, Hail, Saudi Arabia (R Itumalla PhD); Knowledge Translation Program, Centre for Health Evaluation and Outcome Sciences, Vancouver, BC, Canada (I O Iyamu MD); School of Population and Public Health, University of British Columbia, Vancouver, BC, Canada (I O Iyamu MD); Department of Physical Medicine and Rehabilitation, Northwestern University, Chicago, IL, USA (R Jabbarinejad MD); Department of Physiology (R Jayawardena PhD), Department of Pharmacology (P Ranasinghe PhD), University of Colombo, Colombo, Sri Lanka; School of Exercise and Nutrition Sciences, Queensland University of Technology, Brisbane, QLD, Australia (R Jayawardena PhD); Department of Community Medicine, Banaras Hindu University, Varanasi, India (R P Jha MSc); School of Public Health, University College Cork, Cork, Ireland (Z Kabir PhD); Institute for Prevention of Non-communicable Diseases (R Kalthor PhD), Health Services Management Department (R Kalthor PhD), Qazvin University of Medical Sciences, Qazvin, Iran; Dermatology Department, King Faisal University, Hofuf, Saudi Arabia (F Kaliyadan MD); Sydney Eye Hospital, South Eastern Sydney Local Health District, Sydney, NSW, Australia (H Kandel PhD); School of Midwifery (G Kassahun MSc), Department of Paediatrics (B T Tadesse MD), Hawassa University, Hawassa, Ethiopia; Centre for Tropical Diseases and Global Health, Catholic University of Bukavu, Bukavu, Democratic Republic of the Congo (P D Katoto PhD); Department of Global Health, Stellenbosch University, Cape Town, South Africa (P D Katoto PhD, T E Nyirenda MD); International Research Center of Excellence, Institute of Human Virology Nigeria, Abuja, Nigeria (G A Kayode PhD); Julius Centre for Health Sciences and Primary Care (G A Kayode PhD), Institute for Risk Assessment Sciences (E Traini MSc), Utrecht University, Utrecht, Netherlands; Department of Public Health, Ambo University, Ambo, Ethiopia (E M Kebede MPH); Amity Institute of Forensic Sciences, Amity University, Noida, India (H Khajuria PhD, B P Nayak PhD); School of Food and Agricultural Sciences, University of Management and Technology, Lahore, Pakistan (N Khalid PhD); Department of Epidemiology and Biostatistics, Health Services Academy, Islamabad, Pakistan (E A Khan MPH); Faculty of Health and Wellbeing, Sheffield Hallam University, Sheffield, UK (K Khatib PhD); College of Arts and Sciences, Ohio University, Zanesville, OH, USA (K Khatib PhD); Department of Genomics and Digital Health, Samsung Advanced Institute for Health Sciences and Technology, Seoul, South Korea (M Kim MD); Public Health Center, Ministry of Health and Welfare, Wando, South Korea (M Kim MD); School of Traditional Chinese Medicine, Xiamen University Malaysia, Sepang, Malaysia (Y Kim PhD); School of Health Sciences, Kristiania University College, Oslo, Norway (Prof A Kisa PhD); Department of Global Community Health and Behavioral Sciences, Tulane University, New Orleans, LA, USA (Prof A Kisa PhD); Department of Nursing and Health Promotion, Oslo Metropolitan University, Oslo, Norway (S Kisa PhD); Global Health-Care Consulting, New Delhi, India (S Kochhar MD); Department of Internal and Pulmonary Medicine, Sheri Kashmir Institute of Medical Sciences, Srinagar, India (Prof P A Koul MD); Kasturba Medical College, Udupi, India (S Koulmane Laxminarayana MD); Biomedical Research Networking Centre for Mental Health Network (CIBERSAM), San Juan de Dios

Sanitary Park, Sant Boi de Llobregat, Spain (A Koyanagi MD); Catalan Institution for Research and Advanced Studies (ICREA), Barcelona, Spain (A Koyanagi MD); Department of Anthropology, Panjab University, Chandigarh, India (K Krishan PhD); Department of Demography (Prof B Kuate Defo PhD), Department of Social and Preventive Medicine (Prof B Kuate Defo PhD), University of Montreal, Montreal, QC, Canada; Department of Psychiatry (M Kumar PhD), School of Public Health (R G Wamai PhD), University of Nairobi, Nairobi, Kenya; Division of Psychology and Language Sciences (M Kumar PhD), Department of Infection (Prof A Zumla PhD), University College London, London, UK; Department of Biochemistry and Biotechnology, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana (A Kwarteng PhD); Unit of Genetics and Public Health (Prof I Landires MD), Unit of Microbiology and Public Health (V Nuñez-Samudio PhD), Institute of Medical Sciences, Las Tablas, Panama; Department of Public Health (V Nuñez-Samudio PhD), Ministry of Health, Herrera, Panama (Prof I Landires MD); Department of Otorhinolaryngology, Father Muller Medical College, Mangalore, India (S Lasrado MS); Robinson Research Institute (Z S Lassi PhD), Centre for Heart Rhythm Disorders (J Noubiap MD), School of Public Health (G A Tessema PhD), Adelaide Medical School (L Yadav PhD), University of Adelaide, Adelaide, SA, Australia; Barcelona Institute for Global Health, Barcelona, Spain (Prof J V Lazarus PhD); Department of Medicine (Prof Y Lee PhD), School of Medical Sciences (Prof Y Lee PhD), University of Science Malaysia, Kota Bharu, Malaysia; Department of Quantitative Health Science, Case Western Reserve University, Cleveland, OH, USA (X Liu PhD); Radiology Department, Egypt Ministry of Health and Population, Mansoura, Egypt (H Magdy Abd El Razek MD); Grants, Innovation, and Product Development Unit (P W Mahasha PhD), Risk and Resilience in Mental Disorders Unit (Prof D J Stein MD), South African Medical Research Council, Cape Town, South Africa (C A Nnaji MPH); Rabigh Faculty of Medicine, King Abdulaziz University, Jeddah, Saudi Arabia (A A Malik PhD); Campus Caucaia, Federal Institute of Education, Science and Technology of Ceará, Caucaia, Brazil (F R Martins-Melo PhD); Department of Statistics, Debre Markos University, Debre Markos, Ethiopia (H E Merie MSc); Clinical Microbiology and Parasitology Unit, Dr Zora Profozic Polyclinic, Zagreb, Croatia (T Mestrovic PhD); University Centre Varazdin, University North, Varazdin, Croatia (T Mestrovic PhD); The Center for Drug Use and HIV Research (P Meylakh PhD), School of Global Public Health (E K Peprah PhD), New York University, New York, NY, USA; Department of Communication and Journalism, Autonomous University of Barcelona, Barcelona, Spain (N Mheidly BA); Pacific Institute for Research & Evaluation, Calverton, MD, USA (T R Miller PhD); Institute of Addiction Research, Frankfurt University of Applied Sciences, Frankfurt, Germany (B Moazen MSc); Internal Medicine Department, King Saud University, Riyadh, Saudi Arabia (Y Mohammad MD); Department of Information Technology, Lebanese French University, Erbil, Iraq (M Mohammadi PhD); Department of Biology, University of Jeddah, Jeddah, Saudi Arabia (A Mohammed PhD); Department of Biomolecular Sciences, University of Mississippi, Oxford, MS, USA (S Mohammed MSc); Department of Pharmacy, Mizan-Tepi University, Mizan, Ethiopia (S Mohammed MSc); Health Systems and Policy Research Unit (S Mohammed PhD), Department of Community Medicine (M B Sufiyan MD), Ahmadu Bello University, Zaria, Nigeria; Department of Health-Care Management, Technical University of Berlin, Berlin, Germany (S Mohammed PhD); Faculty of Life Sciences and Medicine (M Molokhia PhD), School of Population Health and Environmental Sciences (Y Wang PhD), King's College London, London, UK; Department of Computer Science and Engineering, Pabna University of Science and Technology, Pabna, Bangladesh (M Moni PhD); Social Determinants of Health Research Centre (G Moradi PhD, Y Moradi PhD), Department of Epidemiology and Biostatistics (G Moradi PhD), Kurdistan University of Medical Sciences, Sanandaj, Iran; Department of Epidemiology and Biostatistics (S Mubarik MS, Prof C Yu PhD), School of Medicine (Z Zhang PhD), Wuhan University, Wuhan, China; Scientific Communications Department, Invitae, Boulder, CO, USA (S B Munro PhD); College of Medicine and Public Health, Flinders University, Adelaide, SA, Australia (L Mwanri PhD); Department of Epidemiology, University of Pittsburgh, Pittsburgh, PA, USA (Prof J B Nachega PhD); Department of Epidemiology (Prof J B Nachega PhD), Johns Hopkins University, Baltimore, MD, USA (H Tadbiri MD); Research and Analytics Department, Initiative for Financing Health and Human Development, Chennai, India (A J Nagarajan Mtech); Department of Research and Analytics, Bioinsilico Technologies, Chennai, India (A J Nagarajan Mtech); Department of Biotechnology, University of Central Punjab, Lahore, Pakistan (M Naveed PhD); Pharmaceutical Outcomes and Policy Department, University of Florida, Gainesville, FL, USA (S O Nduaguba PhD); Bupa Clemton Park, Bupa, Sydney, NSW, Australia (S Neupane Kandel BSN); Department of Public Health, University of Yaoundé I, Yaoundé, Cameroon (G Nguefack-Tsague PhD); School of Public Health and Family Medicine, University of Cape Town, Cape Town, South Africa (C A Nnaji MPH); European and Developing Countries Clinical Trials Partnership, European Commission, Cape Town, South Africa (T E Nyirenda MD); Department of Psychiatry and Behavioural Neurosciences, McMaster University, Hamilton, ON, Canada (A T Olagunju MD); Department of Psychiatry, University of Lagos, Lagos, Nigeria (A T Olagunju MD); Community Prevention and Care Services, National AIDS Control Committee, Abuja, Nigeria (B O Olakunde PhD); Department of Respiratory Medicine, Jagadguru Sri Shivarathreeswara Academy of Health Education and Research, Mysore, India (Prof M P A DNB); Department of Medicine, Ottawa Hospital Research Institute, Ottawa, ON, Canada (S Pakhale MD); Department of Health Administration and Policy, George Mason University, Fairfax, VA, USA (T Parekh MSc); Department of Genetics, Yale University, New Haven, CT, USA (S Pawar PhD); Centre for Research and Innovation, Ateneo De Manila University, Pasig City, Philippines (V F Pepito MSc); HIV and Mental Health Department, Integrated Development Foundation Nepal, Kathmandu, Nepal (K N Pokhrel PhD); Institute of Infection and Immunity, St George's University of London, London, UK (R C G Pollok FRCP); University Medical Centre Groningen (Prof M J Postma PhD), School of Economics and Business (Prof M J Postma PhD), University of Groningen, Groningen, Netherlands; College of Medicine, University of Central Florida, Orlando, FL, USA (A Radfar MD); Thalassaemia and Haemoglobinopathy Research Centre, Ahvaz Jundishapur University of Medical Sciences, Ahvaz, Iran (F Rahim PhD); Department of Natural Science, Middlesex University, London, UK (S Rahimzadeh MSc); Department of Population Science and Human Resource Development, University of Rajshahi, Rajshahi, Bangladesh (M Rahman DrPH); Future Technology Research Center, National Yunlin University of Science and Technology, Yunlin, Taiwan (A Rahmani PhD); Research Department, Policy Research Institute, Kathmandu, Nepal (C L Ranabhat PhD); Health and Public Policy Department, Global Centre for Research and Development, Kathmandu, Nepal (C L Ranabhat PhD); Department of Oral Pathology, Srinivas Institute of Dental Sciences, Mangalore, India (S Rao MDS); NIHR-Biomedical Research Centre (Prof A Zumla PhD), University College London Hospitals, London, UK (D L Rawaf MD); Academic Public Health England, Public Health England, London, UK (Prof S Rawaf MD); Department of Epidemiology and Biostatistics, Haramaya University, Harar, Ethiopia (L D Regassa MPH); Department of Pharmacy, Abdul Wali Khan University Mardan, Mardan, Pakistan (I Rehman PhD); School of Medicine (Prof A M N Renzaho PhD), Translational Health Research Institute (Prof A M N Renzaho PhD), Western Sydney University, Campbelltown, NSW, Australia; Network of Immunity in Infection, Malignancy, and Autoimmunity, Universal Scientific Education and Research Network, Tehran, Iran (Prof N Rezaei PhD); Department of Infectious Diseases, University of Copenhagen, Copenhagen, Denmark (O Reza Hosseini MD); Department of Public Health and Informatics, Jahangirnagar University, Dhaka, Bangladesh (R K Ripon MSPH); Nursing Department, Ireland Hospital, Abbeyleix, Ireland (V Rodrigues MSc); Department of Lifestyle Research and Public Health, NA Semashko National Research Institute of Public Health, Moscow, Russia (D O Roshchin PhD); Department of Internal Medicine, University of Botswana, Gaborone, Botswana (G M Rwegerera MD); Department of Research and Development, Islamabad Diagnostic Centre Pakistan, Islamabad, Pakistan (U Saeed PhD); Biological Production Division, National Institute of Health, Islamabad, Pakistan (U Saeed PhD); Department of Psychiatry, All India Institute of Medical Sciences, New Delhi, India

(Prof R Sagar MD); Health Systems and Population Studies Division, International Centre for Diarrhoeal Disease Research, Bangladesh, Dhaka, Bangladesh (K Saif-Ur-Rahman MPH); Department of Public Health and Health Systems, Nagoya University, Nagoya, Japan (K Saif-Ur-Rahman MPH); Public Health and Community Medicine Department, Cairo University, Giza, Egypt (M R Salem MD); Emergency Department, Brown University, Providence, RI, USA (M Samaei MD); Department of Entomology, Ain Shams University, Cairo, Egypt (A M Samy PhD); Department of Community Medicine, Mahatma Gandhi Memorial Medical College, Indore, India (S Saroshe MD); Faculty of Health and Social Sciences, Bournemouth University, Bournemouth, UK (B Sathian PhD); UGC Centre of Advanced Study in Psychology, Utkal University, Bhubaneswar, India (M Satpathy PhD); Udyam-Global Association for Sustainable Development, Bhubaneswar, India (M Satpathy PhD); Department of Public Health Sciences, University of North Carolina at Charlotte, Charlotte, NC, USA (M Sawhney PhD); The George Institute for Global Health, Sydney, NSW, Australia (Prof A E Schutte PhD); National Heart, Lung, and Blood Institute, National Institute of Health, Rockville, MD, USA (A Seylani BS); Independent Consultant, Karachi, Pakistan (M A Shaikh MD); School of Public Health, Dilla University, Dilla, Ethiopia (M F Shaka MPH); Research Institute of Pharmaceutical Sciences, University of Karachi, Karachi, Pakistan (H Shamsad PhD); Faculty of Caring Science, Work Life, and Social Welfare, University of Borås, Borås, Sweden (M Shamsizadeh MSc); Department of Community Medicine, BLDE University, Vijayapur, India (M Shannawaz PhD); College of Medicine, Yonsei University, Seoul, South Korea (Prof J Shin MD); Public Health Dentistry Department, Krishna Institute of Medical Sciences Deemed to be University, Karad, India (Prof K M Shivakumar PhD); School of Medicine, University of Alabama at Birmingham, Birmingham, AL, USA (Prof J A Singh MD); Medicine Service, US Department of Veterans Affairs, Birmingham, AL, USA (Prof J A Singh MD); Department No 16 (V Y Skryabin MD), Laboratory of Genetics and Genomics (Prof M S Zastrozhin PhD), Moscow Research and Practical Centre on Addictions, Moscow, Russia; Therapeutic Department, Balashiha Central Hospital, Balashikha, Russia (A A Skryabina MD); Department of Medicine, University of Calgary, Calgary, AB, Canada (R Somayaji MD); Institute for Leadership and Health Management, Sechenov First Moscow State Medical University, Moscow, Russia (S Soshnikov PhD); International Vaccine Institute, Seoul, South Korea (B T Tadesse MD); HIV Health Promotion Division, HIV/AIDS Prevention Research Network, Kumba, Cameroon (E E Tarkang PhD); University Institute Egas Moniz, Monte da Caparica, Portugal (Prof N Taveira PhD); Research Institute for Medicines, University of Lisbon, Lisbon, Portugal (Prof N Taveira PhD); Department of Public Health, Mada Walabu University, Bale Robe, Ethiopia (Y Tekalegn MPH); Department of Pathology and Legal Medicine, University of São Paulo, Ribeirão Preto, Brazil (M R Tovani-Palone PhD); Modestum LTD, London, UK (M R Tovani-Palone PhD); Clinical Epidemiology and Public Health Research Unit, Burlo Garofolo Institute for Maternal and Child Health, Trieste, Italy (E Traini MSc); Department of Health Economics, Hanoi Medical University, Hanoi, Vietnam (B X Tran PhD); Department of Psychiatry, Massachusetts General Hospital, Boston, MA, USA (A C Tsai MD); Mbarara University of Science and Technology, Mbarara, Uganda (A C Tsai MD); Department of Epidemiology and Biostatistics, Haramaya University, Haramaya, Ethiopia (B S Tusa MPH); Department of Community Medicine, Alex Ekwueme Federal University Teaching Hospital Abakaliki, Abakaliki, Nigeria (C D Umeokonkwo MPH); Clinical Cancer Research Centre, Milad General Hospital, Tehran, Iran (S Valadan Tahbaz PhD, S Yahyazadeh Jabbari MD); Department of Microbiology, Islamic Azad University, Tehran, Iran (S Valadan Tahbaz PhD); Clinical Research Department, IRCCS Fondazione Don Carlo Gnocchi, Milan, Italy (J H Villafañe PhD); Laboratory of Public Health Indicators Analysis and Health Digitalization, Moscow Institute of Physics and Technology, Dolgoprudny, Russia (S K Vladimirov PhD); Faculty of Information Technology, Ho Chi Minh City University of Technology, Ho Chi Minh City, Vietnam (B Vo PhD); Centre of Excellence in Behavioral Medicine, Nguyen Tat Thanh University, Ho Chi Minh City, Vietnam (G T Vu BA); Cultures, Societies and Global Studies, and Integrated Initiative for

Global Health, Northeastern University, Boston, MA, USA (R G Wamai PhD); School of Health and Sport Sciences, University of Brighton, Eastbourne, UK (G Wang PhD); Competence Centre of Mortality-Follow-Up of the German National Cohort, Federal Institute for Population Research, Wiesbaden, Germany (R Westerman DSc); Institute of Health and Society, University of Oslo, Oslo, Norway (Prof A S Winkler PhD); Department of Neurology, Technical University of Munich, Munich, Germany (Prof A S Winkler PhD); Research and Development Division, The George Institute for Global Health, New Delhi, India (L Yadav PhD); Saw Swee Hock School of Public Health, National University of Singapore, Singapore (S Yi PhD); Khana Centre for Population Health Research, KHANA, Phnom Penh, Cambodia (S Yi PhD); Department of Health Management, Süleyman Demirel Üniversitesi, Isparta, Turkey (V Yiğit PhD); Department of Neuropsychopharmacology, National Centre of Neurology and Psychiatry, Kodaira, Japan (N Yonemoto MPH); Department of Public Health, Juntendo University, Tokyo, Japan (N Yonemoto MPH); Department of Clinical Pharmacy and Outcomes Sciences, University of South Carolina, Columbia, SC, USA (I Yunusa PhD); Addictology Department (Prof M S Zastrozhin PhD), Paediatrics Department (A Zastrozhina PhD), Russian Medical Academy of Continuous Professional Education, Moscow, Russia; Center for Health Policy and Center for Primary Care and Outcomes Research (Prof J A Salomon PhD), Stanford University, Stanford, CA, USA.

Declaration of interests

S Afzal reports an unpaid leadership role as General Secretary for the Pakistan Society of Community Medicine and Public Health, working for prevention and advocacy of AIDS in families of HIV patients by providing advocacy and counseling services to the families, children, and partners of patients with AIDS and screening them for HIV in Pakistan, outside the submitted work. T Bärnighausen reports research grants from the European Union (Horizon 2020 and EIT Health), German Research Foundation (also known as DFG), US National Institutes of Health (NIH), German Ministry of Education and Research, Alexander von Humboldt Foundation, Else-Kröner-Fresenius-Foundation, the Wellcome Trust, the Bill & Melinda Gates Foundation, KfW, UNAIDS, and WHO; consulting fees for KfW on the OSCAR initiative in Vietnam; and participation on a Data Safety Monitoring Board or Advisory Board through the NIH-funded study Healthy Options (Principle Investigators Smith Fawzi, Kaaya), Chair, Data Safety and Monitoring Board, German National Committee on the Future of Public Health Research and Education, Chair of the scientific advisory board to the EDCTP Evaluation, Member of the UNAIDS Evaluation Expert Advisory Committee, National Institutes of Health Study Section Member on Population and Public Health Approaches to HIV/AIDS, US National Academies of Sciences, Engineering, and Medicine's Committee for the Evaluation of Human Resources for Health in the Republic of Rwanda under the President's Emergency Plan for AIDS Relief (also known as PEPFAR), University of Pennsylvania Population Aging Research Center External Advisory Board Member; and a leadership or fiduciary role in other board, society, committee, or advocacy group, paid or unpaid as Co-Chair of the Global Health Hub Germany (which was initiated by the German Ministry of Health), all outside the submitted work. J Eaton reports institutional support for the manuscript from the Gates Foundation, UNAIDS, and National Institutes of Health; grants or contracts from WHO, Gates foundation, and UNAIDS; consulting fees from WHO; and support for attending meetings or travel from WHO and UNAIDS, all outside the submitted work. I Filip reports financial support from Avicenna Medical and Clinical Research Institute, outside the submitted work. I Iyamu reports support for attending FHI 360 HIV prevention, care, and treatment training events in Nigeria, outside the submitted work. K Krishan reports non-financial support from UGC Centre of Advanced Study, CAS II, Department of Anthropology, Panjab University, Chandigarh, India, outside the submitted work. K LeGrand reports support for the present manuscript through payment to the institution (Institute for Health Metrics and Evaluation) from the Gates Foundation. M Postma reports a leadership or fiduciary role in other board, society, committee, or advocacy group, unpaid as member of UK's JCVI. O Reza Hosseini reports grants or contracts from the Research Foundation of

Rigshospitalet and the A P Møller Fonden; and support for attending meetings or travel from EACS 2019 Basel, all outside the submitted work. J Salomon reports support for the present manuscript through a research grant paid to the institution (Institute for Health Metrics and Evaluation) from the Gates Foundation. J Singh reports consulting fees from Crealta/Horizon, Medisys, Fidia, Two labs, Adept Field Solutions, Clinical Care Options, Clearview Health-Care Partners, Putnam Associates, Focus Forward, Navigant Consulting, Spherix, MedIQ, UBM LLC, Trio Health, Medscape, WebMD, and Practice Point Communications, the NIH, and the American College of Rheumatology; payment or honoraria for lectures, presentations, speakers bureaus, manuscript writing, or educational events from Simply Speaking; support for attending meetings or travel from OMERACT, an international organisation that develops measures for clinical trials and receives arm's-length funding from 12 pharmaceutical companies, when traveling biannually to OMERACT meetings; participation on a Data Safety Monitoring Board or Advisory Board as a member of the FDA Arthritis Advisory Committee; a leadership or fiduciary role in other board, society, committee, or advocacy group, paid or unpaid, with OMERACT as a member of the steering committee, with the Veterans Affairs Rheumatology Field Advisory Committee as a member, and with the UAB Cochrane Musculoskeletal Group Satellite Center on Network Meta-analysis as a director and editor; and stock or stock options in TPT Global Tech, Vaxart pharmaceuticals, Charlotte's Web Holdings, and previously owned stock options in Amarin, Viking, and Moderna pharmaceuticals, all outside the submitted work. D Stein reports personal fees from Lundbeck, Takeda, Johnson & Johnson and Servier, all outside the submitted work. A Tsai reports stipend for work as Editor-in-Chief of Social Science and Medicine, Mental Health from Elsevier. All other authors declare no competing interests.

Data sharing

To download the data used in these analyses, please visit the Global Health Data Exchange GBD 2019 data-input sources tool at <http://ghdx.healthdata.org/gbd-2019/data-input-sources>.

Acknowledgments

L Abu-Raddad acknowledges the support of Qatar National Research Fund (NPRP 9-040-3-008) who provided the main funding for generating the data provided to the GBD-IHME effort. T Bärnighausen was supported by the Alexander von Humboldt Foundation through the Alexander von Humboldt Professor award, funded by the German Federal Ministry of Education and Research. S Bazargan-Hejazi was partly supported by the National Institute of Health (NIH) National Center for Advancing Translational Science UCLA CTSI (grant number UL1TR001881). L Degenhardt is supported by an NHMRC Senior Principal Research Fellowship (1135991) and a US NIH National Institute on Drug Abuse (NIDA) grant (R01DA1104470). NDARC, UNSW Sydney, is supported by funding from the Australian Government Department of Health under the Drug and Alcohol Programme. J Eaton was supported by the Bill & Melinda Gates Foundation (OPP1190661), UNAIDS, the National Institute of Allergy and Infectious Disease of the NIH under award numbers R01AI136664, and the MRC Centre for Global Infectious Disease Analysis (reference MR/R015600/1), jointly funded by the UK Medical Research Council (MRC) and the UK Foreign, Commonwealth, and Development Office (FCDO), under the MRC/FCDO Concordat agreement and is also part of the EDCTP2 programme supported by the European Union. V B Gupta acknowledges funding support from National Health and Medical Research Council (NHMRC), Australia. V K Gupta acknowledges support from NHMRC, Australia. S Haque is grateful to the DSR, Jazan University, Saudi Arabia for providing the access of the Saudi Digital Library for this study. P Hoogar would like to acknowledge the Centre for Bio Cultural Studies Directorate of Research, Manipal Academy of Higher Education, Manipal-Karnataka, India. Y J Kim's portion of this work was supported by the Research Management Centre, Xiamen University Malaysia (Np:XMUMRF-C6/ITCM/0004). S L Koulmane Laxminarayana acknowledges institutional support by Manipal Academy of Higher Education. K Krishan is supported by the UGC Centre of Advanced Study (phase 2), awarded to the Department of Anthropology, Panjab University, Chandigarh, India. M Kumar acknowledges grant FIC/NIH K43 TW010716-04. I Landires is member of the Sistema Nacional de

Investigación, supported by the Secretaría Nacional de Ciencia, Tecnología e Innovación, Panama. J Lazarus acknowledges support to ISGlobal from the Spanish Ministry of Science, Innovation, and Universities through the Centro de Excelencia Severo Ochoa 2019–23 programme (CEX2018-000806-S), and from the Government of Catalonia, Spain, through the CERCA programme. P Mahasha acknowledges grants, innovation, and product development from the South African Medical Research Council. P Meylahk's portion of this research was supported by the Russian Science Foundation (under grant project number 20-18-00307; the health of nation: the multidimensional analysis of health, health inequality, and health-related quality of life). M Molokhia is supported by the National Institute for Health Research Biomedical Research Centre at Guy's and St Thomas' National Health Service Foundation Trust and King's College London. J Nacheha is an infectious disease internist and epidemiologist and Principal Investigator of NIH/Fogarty International Center (grant numbers 1R25TW011217-01, 1R21TW011706-01, and 1D43TW010937-01A1). A Samy acknowledges support from a fellowship of the Egyptian Fulbright Mission programme. A Shetty acknowledges the support given by Kasturba Medical College Mangalore, Manipal Academy of Higher Education, Manipal. N Taveira's work is partially funded by Fundação para a Ciência e Tecnologia, Portugal, and Aga Khan Development Network, Portugal Collaborative Research Network in Portuguese speaking countries in Africa (project 332821690), and by the LIFE project (RIA2016MC-1615), and European and Developing Countries Clinical Trials Partnership. G Tessema was funded by the Australian National Health and Medical Research Council Investigator (grant number 1195716). B Unnikrishnan acknowledges Kasturba Medical College, Mangalore, Manipal Academy of Higher Education, Manipal. A Zumla acknowledges support from the European and Developing Countries Clinical Trials Partnership programme, Horizon 2020, and the European Union's Framework Programme for Research and Innovation (grants PANDORA-ID-NET, TESA-2, and CANTAM-2).

References

- 1 WHO. MDG 6: combat HIV/AIDS, malaria and other diseases. https://www.who.int/topics/millennium_development_goals/diseases/en/ (accessed July 9, 2020).
- 2 WHO. Global health sector response to HIV, 2000–2015: focus on innovations in Africa: progress report. Geneva: World Health Organization, 2015.
- 3 Nursing and the United Nations 2030 Agenda for Sustainable Development. Transforming our world: the 2030 agenda for sustainable development. In: Rosa W, ed. A new era in global health. New York, NY: Springer Publishing Company, 2017.
- 4 Hogan AB, Jewell BL, Sherrard-Smith E, et al. Potential impact of the COVID-19 pandemic on HIV, tuberculosis, and malaria in low-income and middle-income countries: a modelling study. *Lancet Glob Health* 2020; **8**: e1132–41.
- 5 Tamuzi JL, Ayele BT, Shumba CS, et al. Implications of COVID-19 in high burden countries for HIV/TB: a systematic review of evidence. *BMC Infect Dis* 2020; **20**: 744.
- 6 UNAIDS. 90-90-90: treatment for all. <https://www.unaids.org/en/resources/909090> (accessed Jan 8, 2021).
- 7 Haber NA, Lesko CR, Fox MP, et al. Limitations of the UNAIDS 90-90-90 metrics: a simulation-based comparison of cross-sectional and longitudinal metrics for the HIV care continuum. *AIDS* 2020; **34**: 1047–55.
- 8 Ghys PD, Williams BG, Over M, Hallett TB, Godfrey-Faussett P. Epidemiological metrics and benchmarks for a transition in the HIV epidemic. *PLoS Med* 2018; **15**: e1002678.
- 9 Magadi MA. Understanding the gender disparity in HIV infection across countries in sub-Saharan Africa: evidence from the Demographic and Health Surveys. *Sociol Health Illn* 2011; **33**: 522–39.
- 10 Okano JT, Blower S. Sex-specific maps of HIV epidemics in sub-Saharan Africa. *Lancet Infect Dis* 2016; **16**: 1320–22.
- 11 UNAIDS. Women and HIV: a spotlight on adolescent girls and young women. 2019. https://www.unaids.org/sites/default/files/media_asset/2019_women-and-hiv_en.pdf (accessed May 13, 2021).
- 12 Pendse R, Gupta S, Yu D, Sarkar S. HIV/AIDS in the south-east Asia region: progress and challenges. *J Virus Erad* 2016; **2** (suppl 4): 1–6.

- 13 Gökengin D, Oprea C, Uysal S, Begovac J. The growing HIV epidemic in Central Europe: a neglected issue? *J Virus Erad* 2016; **2**: 156–61.
- 14 Mumtaz GR, Riedner G, Abu-Raddad LJ. The emerging face of the HIV epidemic in the Middle East and North Africa. *Curr Opin HIV AIDS* 2014; **9**: 183–91.
- 15 Frank TD, Carter A, Jahagirdar D, et al. Global, regional, and national incidence, prevalence, and mortality of HIV, 1980–2017, and forecasts to 2030, for 195 countries and territories: a systematic analysis for the Global Burden of Diseases, Injuries, and Risk Factors Study 2017. *Lancet HIV* 2019; **6**: e831–59.
- 16 Vos T, Lim SS, Abbafati C, et al. Global burden of 369 diseases and injuries in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* 2020; **396**: 1204–22.
- 17 Murray CJL, Aravkin AY, Zheng P, et al. Global burden of 87 risk factors in 204 countries and territories, 1990–2019: a systematic analysis for the Global Burden of Disease Study 2019. *Lancet* 2020; **396**: 1223–49.
- 18 Wang H, Abbas KM, Abbasfard M, et al. Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950–2019: a comprehensive demographic analysis for the Global Burden of Disease Study 2019. *Lancet* 2020; **396**: 1160–203.
- 19 Stevens GA, Alkema L, Black RE, et al. Guidelines for accurate and transparent health estimates reporting: the GATHER statement. *Lancet* 2016; **388**: e19–23.
- 20 Eaton JW, Brown T, Puckett R, et al. The estimation and projection package age-sex model and the r-hybrid model: new tools for estimating HIV incidence trends in sub-Saharan Africa. *AIDS* 2019; **33** (suppl 3): S235–44.
- 21 Mahy M, Penazzato M, Ciaranello A, et al. Improving estimates of children living with HIV from the Spectrum AIDS Impact Model. *AIDS* 2017; **31** (suppl 1): S13–22.
- 22 Brown T, Bao L, Eaton JW, et al. Improvements in prevalence trend fitting and incidence estimation in EPP 2013. *AIDS* 2014; **28** (suppl 4): S415–25.
- 23 Righi MK, Orchowski LM, Kuo C. Integrated intimate partner violence and HIV interventions among adolescents in sub-Saharan Africa: a systematic review. *Trauma Violence Abuse* 2020; **21**: 643–59.
- 24 Griesbeck M, Scully E, Altfeld M. Sex and gender differences in HIV-1 infection. *Clin Sci* 2016; **130**: 1435–51.
- 25 Dieleman JL, Haakenstad A, Micah A, et al. Spending on health and HIV/AIDS: domestic health spending and development assistance in 188 countries, 1995–2015. *Lancet* 2018; **391**: 1799–829.
- 26 Tanser F, Barnighausen T, Grapsa E, Zaidi J, Newell M-L. High coverage of ART associated with decline in risk of HIV acquisition in rural KwaZulu-Natal, South Africa. *Science* 2013; **339**: 966–71.
- 27 Yu D, Souteyrand Y, Banda MA, Kaufman J, Perriens JH. Investment in HIV/AIDS programs: does it help strengthen health systems in developing countries? *Glob Health* 2008; **4**: 8.
- 28 Halperin DT, Mugurungi O, Hallett TB, et al. A surprising prevention success: why did the HIV epidemic decline in Zimbabwe? *PLoS Med* 2011; **8**: e1000414.
- 29 Green EC, Halperin DT, Nantulya V, Hogle JA. Uganda's HIV prevention success: the role of sexual behavior change and the national response. *AIDS Behav* 2006; **10**: 335–46.
- 30 Dwyer-Lindgren L, Cork MA, Sligar A, et al. Mapping HIV prevalence in sub-Saharan Africa between 2000 and 2017. *Nature* 2019; **570**: 189–93.
- 31 Local Burden of Disease HIV Collaborators. Subnational mapping of HIV incidence and mortality among adults ages 15 to 49 in sub-Saharan Africa, 2000–18. *Lancet HIV*; **8**: e363–75.
- 32 Holmes CB, Sikazwe I, Sikombe K, et al. Estimated mortality on HIV treatment among active patients and patients lost to follow-up in 4 provinces of Zambia: findings from a multistage sampling-based survey. *PLoS Med* 2018; **15**: e1002489.
- 33 LaMonaca K, Dumchev K, Dvoriak S, Azbel L, Morozova O, Altice FL. HIV, drug injection, and harm reduction trends in eastern Europe and central Asia: implications for international and domestic policy. *Curr Psychiatry Rep* 2019; **21**: 47.
- 34 Kharsany ABM, Karim QA. HIV infection and AIDS in sub-Saharan Africa: current status, challenges and opportunities. *Open AIDS J* 2016; **10**: 34–48.
- 35 Ortblad KF, Baeten JM, Cherutich P, Wamiciwe JN, Wasserheit JN. The arc of HIV epidemics in sub-Saharan Africa: new challenges with concentrating epidemics in the era of 90-90-90. *Curr Opin HIV AIDS* 2019; **14**: 354–65.
- 36 Sullivan PS, Satcher Johnson A, Pembleton ES, et al. Epidemiology of HIV in the USA: epidemic burden, inequities, contexts, and responses. *Lancet* 2021; **397**: 1095–106.
- 37 Stuijkyte R, Barbosa I, Kazatchkine M. Getting to grips with the HIV epidemic in Russia. *Curr Opin HIV AIDS* 2019; **14**: 381–86.
- 38 De Boni R, Veloso VG, Grinsztejn B. Epidemiology of HIV in Latin America and the Caribbean. *Curr Opin HIV AIDS* 2014; **9**: 192–98.
- 39 Holt M. Progress and challenges in ending HIV and AIDS in Australia. *AIDS Behav* 2017; **21**: 331–34.
- 40 Annequin M, Villes V, Delabre RM, et al. Are PrEP services in France reaching all those exposed to HIV who want to take PrEP? MSM respondents who are eligible but not using PrEP (EMIS 2017). *AIDS Care* 2020; **32**: 47–56.
- 41 Sullivan PS, Mena L, Elope L, Siegler AJ. Implementation strategies to increase PrEP uptake in the South. *Curr HIV/AIDS Rep* 2019; **16**: 259–69.
- 42 Wirawan DN. Stigma and discrimination: barrier for ending AIDS by 2030 and achieving the 90-90-90 targets by 2020. *PHPMA* 2019; **7**: 1.
- 43 Nyblade L, Mingkwan P, Stockton MA. Stigma reduction: an essential ingredient to ending AIDS by 2030. *Lancet HIV* 2021; **8**: e106–13.
- 44 Ghose T, Swendeman DT, George SM. The role of brothels in reducing HIV risk in Sonagachi, India. *Qual Health Res* 2011; **21**: 587–600.
- 45 Siraprapasiri T, Ongwangdee S, Benjarattanaporn P, Peerapattanapokin W, Sharma M. The impact of Thailand's public health response to the HIV epidemic 1984–2015: understanding the ingredients of success. *J Virus Erad* 2016; **2** (suppl 4): 7–14.
- 46 Thisyakorn U. Elimination of mother-to-child transmission of HIV: lessons learned from success in Thailand. *Paediatr Int Child Health* 2017; **37**: 99–108.
- 47 Marcus JL, Leyden WA, Alexeeff SE, et al. Comparison of overall and comorbidity-free life expectancy between insured adults with and without HIV infection, 2000–2016. *JAMA Netw Open* 2020; **3**: e207954.
- 48 Galvani AP, Pandey A, Fitzpatrick MC, Medlock J, Gray GE. Defining control of HIV epidemics. *Lancet HIV* 2018; **5**: e667–70.
- 49 Samji H, Cescon A, Hogg RS, et al. Closing the gap: increases in life expectancy among treated HIV-positive individuals in the United States and Canada. *PLoS One* 2013; **8**: e81355.
- 50 Gebo KA, Fleishman JA, Conviser R, et al. Contemporary costs of HIV healthcare in the HAART era. *AIDS* 2010; **24**: 2705–15.
- 51 PEPFAR. US President's Emergency Plan for AIDS Relief. Strategy for accelerating HIV/AIDS epidemic control (2017–2020). <https://www.state.gov/wp-content/uploads/2019/08/PEPFAR-Strategy-for-Accelerating-HIVAIDS-Epidemic-Control-2017-2020.pdf> (accessed Feb 28, 2021).
- 52 Brown LB, Spinelli MA, Gandhi M. The interplay between HIV and COVID-19: summary of the data and responses to date. *Curr Opin HIV AIDS* 2021; **16**: 63–73.
- 53 Jiang H, Zhou Y, Tang W. Maintaining HIV care during the COVID-19 pandemic. *Lancet HIV* 2020; **7**: e308–09.
- 54 Guo W, Weng HL, Bai H, et al. Quick community survey on the impact of COVID-19 outbreak for the healthcare of people living with HIV. *Zhonghua Liu Xing Bing Xue Za Zhi* 2020; **41**: 662–66 (in Chinese).
- 55 Lagat H, Sharma M, Kariithi E, et al. Impact of the COVID-19 pandemic on HIV testing and assisted partner notification services, western Kenya. *AIDS Behav* 2020; **24**: 3010–13.
- 56 UNAIDS. UNAIDS and China working together during the COVID-19 outbreak to ensure that people living with HIV continue to get treatment. https://www.unaids.org/en/resources/presscentre/pressreleaseandstatementarchive/2020/february/20200218_china_covid19 (accessed Jan 11, 2021).
- 57 Odhiambo F, Mulwa E, Ayieko J, et al. Implementation of HIV care in western Kenya during corona virus disease 2019 response. *AIDS* 2020; **34**: F1–2.

-
- 58 Global Network of People living with HIV (GNP+), International Community of Women Living with HIV, Global Network of Young People Living with HIV. Living with HIV in the time of COVID-19: report from a survey of networks of people living with HIV. 2020. https://gnpplus.net/wp-content/uploads/2020/07/BeyondLIVING_COVID-19_English.pdf (accessed March 3, 2021).
- 59 UNAIDS, Global HIV Prevention Coalition. Maintaining and prioritizing HIV prevention services in the time of COVID-19. 2020. https://www.unaids.org/sites/default/files/media_asset/maintaining-prioritizing-hiv-prevention-services-covid19_en.pdf (accessed March 3, 2021).
- 60 WHO. Coronavirus disease (COVID-19): HIV and antiretrovirals. Geneva: World Health Organization, 2020.
- 61 PEPFAR. US President's Emergency Plan for AIDS Relief. PEPFAR technical guidance in context of COVID-19 pandemic. 2021. <https://www.state.gov/wp-content/uploads/2021/02/02.24.21-PEPFAR-Technical-Guidance-During-COVID.pdf> (accessed March 3, 2021).
- 62 HIV.gov. Global Statistics. Nov 25, 2020. <https://www.hiv.gov/hiv-basics/overview/data-and-trends/global-statistics> (accessed Jan 11, 2021).