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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

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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.

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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

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.

See Online for appendix

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

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 package[22] 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).

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

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.

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.

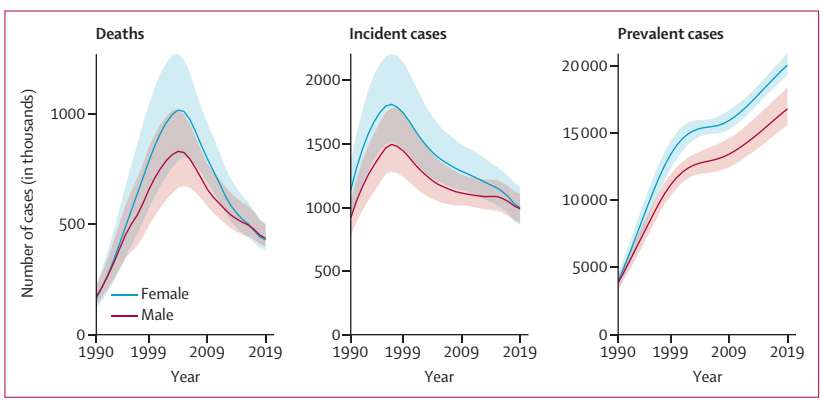

Figure 1: **Global HIV burden 1990–2019**

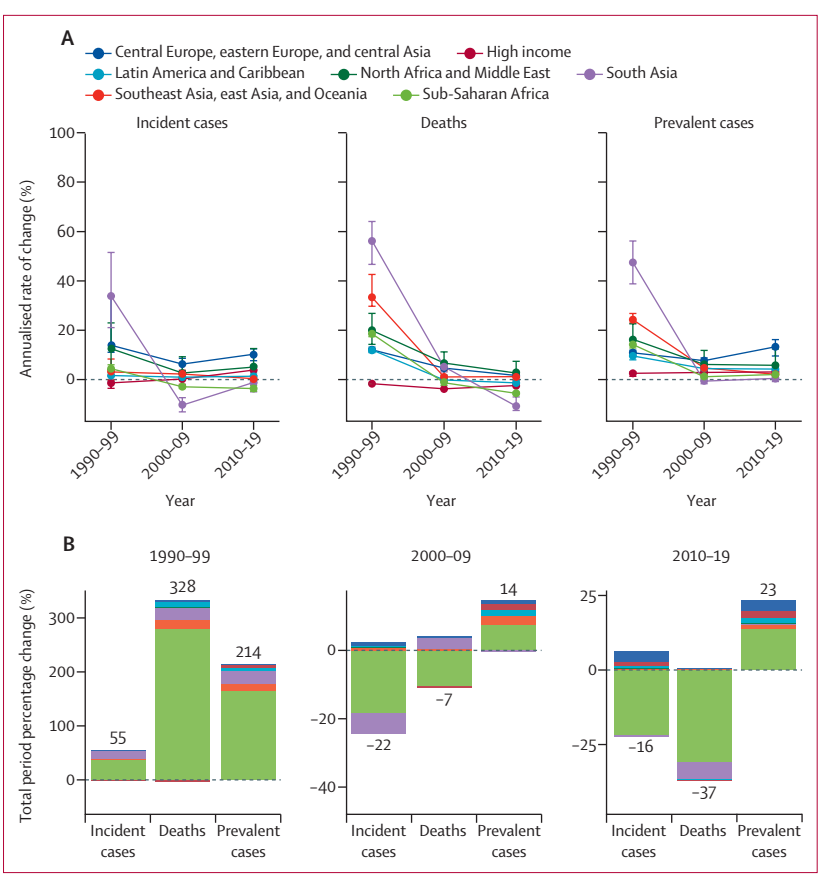

Figure 2: **Change in HIV burden by GBD super-region for both sexes combined, by decade, from 1990 to 2019**
(A) Annualised rate of change: derived as the mean yearly percentage change averaged over the given time period. (B) Total percentage change: the labelled numbers are the global percentage change 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

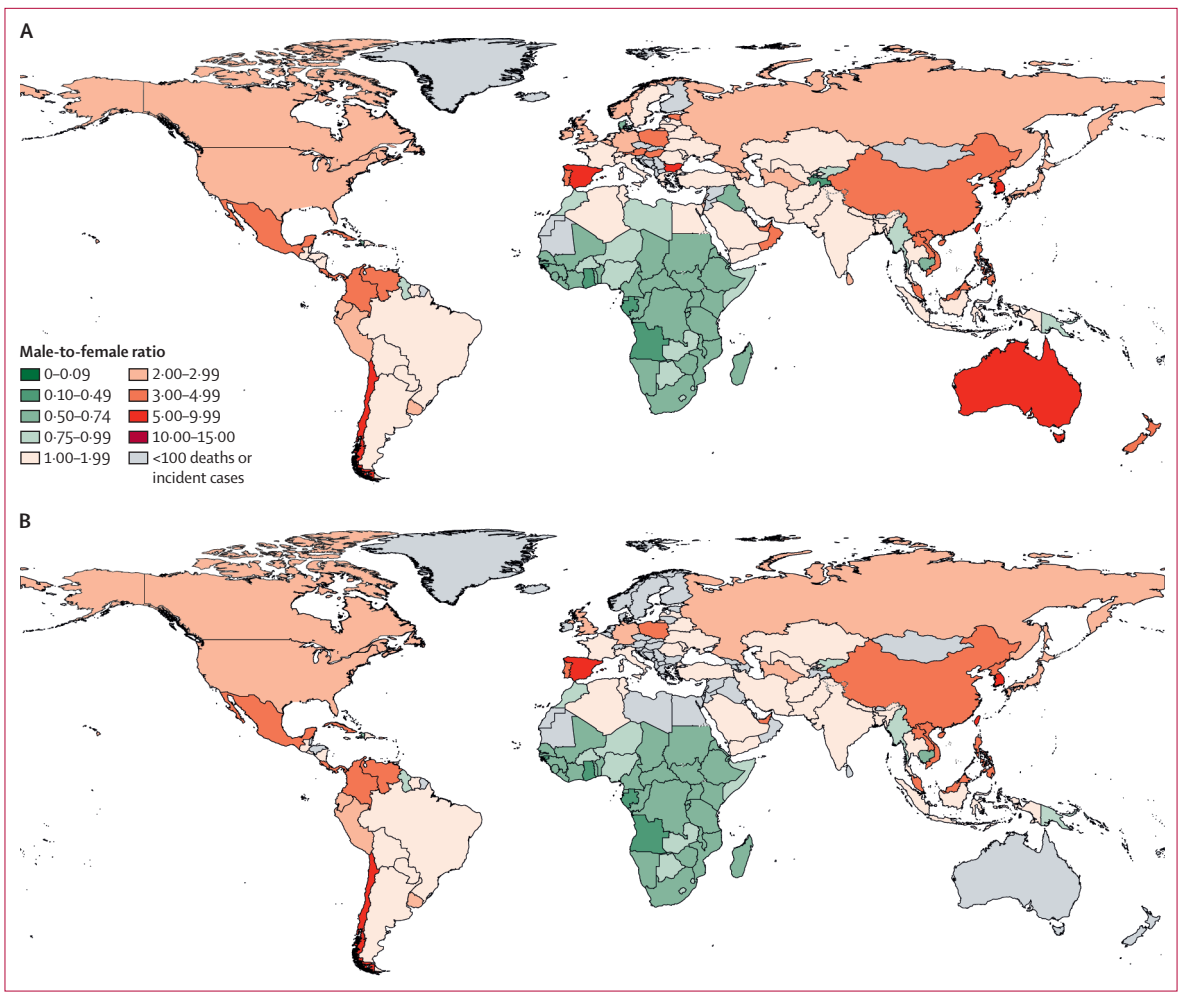

Figure 3: **Male-to-female sex ratios for 204 countries and territories in 2019**
Incident cases (A). Deaths (B) Countries and territories with fewer than 100 incident cases or deaths in 2019 were excluded from this calculation because of small burdens that drove high ratios that could not easily be 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,

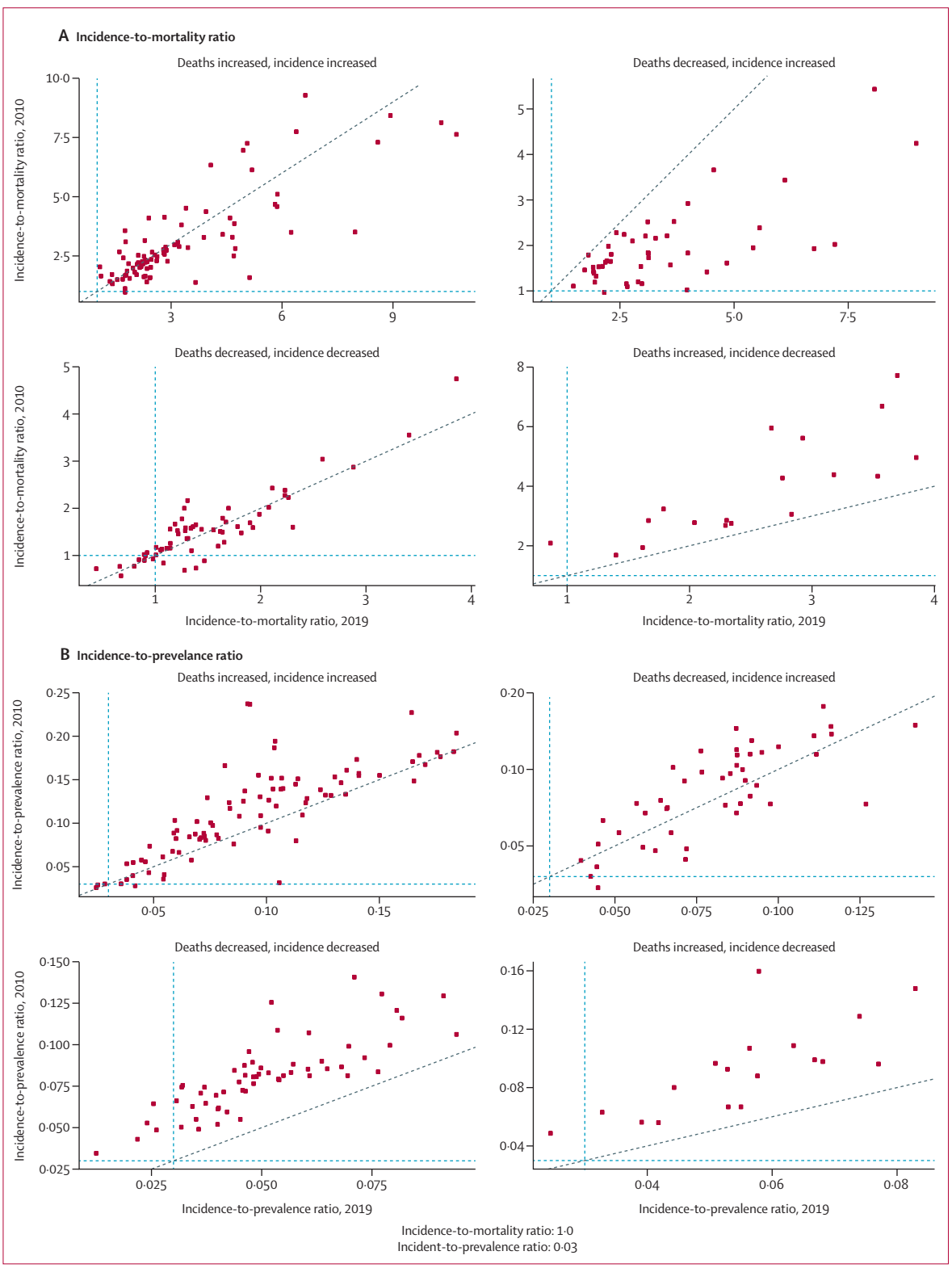

Figure 4: **Incidence-to-mortality and incidence-to-prevalence ratios for 204 countries and territories in 2010 versus 2019, and direction of change from 2010 to 2019**

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 colleagues[48] 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.

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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.

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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, Abbasifard M, et al. Global age-sex-specific fertility, mortality, healthy life expectancy (HALE), and population estimates in 204 countries and territories, 1950–019: 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, Bärnighausen 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, Perriëns 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, Wamicwe 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 Stuikyte 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, Elopre 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, Peerapatanapokin 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 Commnity 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).