# Adult HIV-1 incidence across 15 high-burden countries in sub-Saharan Africa from 2015 to 2019: a pooled analysis of nationally representative data

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## Summary

**Background** Harmonised population-based surveys with recent HIV-1 infection testing algorithms permit pooled cross-sectional estimation of HIV incidence across multiple countries. We aimed to estimate adult HIV-1 incidence rates and number of new infections by sex, age, and subregion in sub-Saharan Africa.

**Methods** We analysed data from 13 Population-Based HIV Impact Assessment (PHIA) surveys and two additional population-based surveys done between 2015 and 2019 in 15 sub-Saharan African countries. HIV-seropositive samples from adults aged 15–59 years were tested for recent HIV-1 infection by use of an algorithm consisting of the HIV-1 limiting antigen avidity enzyme immunoassay, HIV-1 viral load, and qualitative detection of antiretroviral agents. Data were pooled across countries; sampling weights were incorporated to represent all adults in the 15 national populations. Analyses accounted for the complex sample designs. HIV incidence rates, incidence rate differences, and number of new annual infections were estimated.

**Findings** Among 445 979 adults sampled, 382 had recent HIV-1 infection. The estimated HIV-1 incidence rate was 3·3 per 1000 person-years (95% CI 2·6–4·0) among women and 2·0 per 1000 person-years (1·2–2·7) among men (incidence rate difference 1·3 per 1000 person-years, 95% CI 0·3–2·3). Among adults aged 15–24 years, the incidence rate was higher for women (3·5 per 1000 person-years) than men (1·2 per 1000 person-years; difference 2·3, 95% CI 0·8–3·8), but infection rates were similar between sexes in all other age groups. The HIV-1 incidence rate was 7·4 per 1000 person-years (95% CI 5·0–9·7) in southern sub-Saharan Africa, 2·3 per 1000 person-years (1·7–2·9) in the eastern subregion, and 0·9 per 1000 person-years (0·6–1·2) in the western and central subregion. 689 000 (95% CI 546 000–833 000) new HIV cases were estimated annually among the 265 million susceptible adults (61·6% in women).

**Interpretation** HIV-1 incidence and number of new infections differed by age, sex, and subregion. Approaches for risk stratification are needed to guide comprehensive HIV-1 prevention.

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## Introduction

Sub-Saharan Africa has long been the epicentre of the HIV epidemic. Although it contained approximately 15% of the world's population in 2021,[1] it accounted for two-thirds of the 38·4 million people living with HIV globally.[2] Despite the disproportionate burden of HIV-1 in sub-Saharan Africa, national and regional estimates of HIV-1 incidence have primarily been based on mathematical models, which are sensitive to inputs and assumptions.[3,4] Although hundreds of HIV incidence estimates have been done in the region, the majority have been done among select populations with elevated HIV incidence and few have been nationally representative.[5] The absence of representative HIV-1 incidence estimates by age and sex is a crucial knowledge gap.

Since 2014, nationally representative household surveys have been done by the Population-Based HIV Impact Assessment (PHIA) project in sub-Saharan Africa to capture the state of the HIV epidemic in many high-burden countries that are supported by the President's Emergency Plan for AIDS Relief (PEPFAR).[6] These cross-sectional surveys include an HIV-1 recent infection testing algorithm to estimate national HIV-1 incidence.[7] Similar HIV-focused population-based surveys have been done in South Africa and Nigeria, with comparable methods.[8,9] For most countries, these surveys provide the first measured, empirical estimates of national HIV-1 incidence, and their common methodology allows for pooled estimates across sub-Saharan Africa. Although these surveys have been pooled together to answer many regional research questions, they have never been pooled to examine HIV-1 incidence rates and number of new infections. Pooling allows for regional and subregional estimates of HIV-1 by age and sex, something that was not possible in the national surveys owing to insufficient precision.

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## Research in context

### Evidence before this study

Regional and subregional estimates of HIV incidence, disaggregated by age and sex, are crucial to our ongoing understanding of the HIV epidemic in sub-Saharan Africa. However, until recently, such data have been limited to subnational populations, and have not been pooled at a regional or subregional level. We searched PubMed on Jan 5, 2022, for reviews and meta-analyses using the terms "HIV" AND "incidence" AND Africa. We identified a published systematic review synthesising empirical estimates of HIV-1 incidence in sub-Saharan Africa from 2010 to 2019, which coincided with our current report. The authors of the review used Medical Subject Headings terms for "HIV", "incidence", and "Africa", and included peer-reviewed articles in PubMed, Embase, Scopus, and OVID Global Health, as well as non-peer-reviewed Population-Based HIV Impact Assessment country reports. Their search identified work published between Jan 1, 2010, and July 23, 2019, and identified 236 studies. In most studies, HIV-1 incidence was higher among women than men, but overall incidence rates, HIV-1 incidence rate differences between females and males, and absolute number of infections were not estimated. In addition, most of these studies came from highly selected populations, such as adults from key populations (e.g. sex workers) or those enrolled in HIV-1 prevention trials, and thus over-represented high-incidence populations, and lacked broad external validity. The absence of representative empirical estimates of HIV-1 incidence and incidence rate differences by age and sex, fundamendal epidemiologic parameters, is a notable gap.

### Added value of this study

This is the first study to estimate HIV-1 incidence by age and sex across three subregions using nationally representative data from adults aged 15–59 years. Based on a large probability-based sample (n=445 979) from 15 countries representing 283 million adults from the general population, pooled annual HIV-1 incidence was higher among women (3·3 per 1000 person-years) than men (2·0 per 1000 person-years; incidence rate difference 1·3 per 1000 person-years, 95% CI 0·3–2·3). This difference was driven by the substantial difference in incidence by sex among 15–24-year-olds (difference 2·3, 95% CI 0·8–3·8). The overall estimated number of annual infections was substantial (N=689 000) and higher among women (61·6%) than among men (38·4%). Nearly half (46·8%) of all adult infections occurred among women aged 15–34 years, ages during which most childbearing occurs.

### Implications of all the available evidence

The findings from this analysis, which included data that represent more than two-thirds of adult HIV-1 infections in sub-Saharan Africa, reinforce the evidence for gender differences in the HIV-1 epidemic, with women aged 15–34 years having the highest proportion of HIV-1 infections. Although consistent with modelled estimates and the findings described in the review above, the external validity of our results exceeds any previous empirical work.

By using data from the 15 PHIA and PHIA-like surveys done in sub-Saharan Africa from 2015 to 2019, we provide pooled estimates of annual adult HIV-1 incidence and the number of new HIV-1 infections by age and sex overall and within three subregions (western and central, eastern, and southern sub-Saharan Africa). We also calculated incidence-to-prevalence ratios (IPRs) to assess epidemic growth trajectories. Such estimates are essential for contextualising current UNAIDS prevention targets.[10]

## Methods

### Data sources

PHIA surveys are HIV-focused, cross-sectional, household surveys designed to estimate national HIV-1 incidence and, among those who are HIV-infected, national prevalence of viral load suppression.[11,12] We analysed all PHIA data that were publicly available as of Sept 30, 2022. Data came from 15 PHIA or PHIA-like surveys done in Cameroon (June, 2017, to February, 2018), Côte d'Ivoire (August, 2017, to March, 2018), and Nigeria (July to December, 2018) in western and central sub-Saharan Africa; Ethiopia (urban areas only, October, 2017, to April, 2018), Kenya (May, 2018, to March, 2019), Rwanda (October, 2018, to March, 2019), Tanzania (October, 2016, to June, 2017), and Uganda (August, 2016, to March, 2017) in eastern Africa; and Eswatini (August, 2016, to March, 2017), Lesotho (November, 2016, to May, 2017), Malawi (November, 2015, to August, 2016), Namibia (June to December, 2017), South Africa (December, 2016, to February, 2018), Zambia (March to August, 2016), and Zimbabwe (October, 2015, to August, 2016) in southern Africa. We refer to these 15 surveys as national surveys, even though Ethiopia's survey only represented the adult population in urban areas. 13 PHIA surveys were led by the respective countries' Ministries of Health and funded by PEPFAR with technical assistance from the International Center for AIDS Care and Treatment Program at Columbia University (New York, NY, USA) and from the US Centers for Disease Control and Prevention (CDC).[11] The fifth South African National HIV Prevalence, Incidence, Behaviour, and Communication Survey, 2017 (SABSSM-V),[8] was led by the Human Sciences Research Council with support from PEPFAR through the CDC. The Nigeria HIV/AIDS Indicator and Impact Survey (NAIIS)[9] was led by the Federal Ministry of Health with funding from PEPFAR and the Global Fund to Fight AIDS, Tuberculosis and Malaria, and technical assistance from the University of Maryland, Baltimore (MD, USA). All protocols were


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approved by ethics committees in each country and the institutional review boards at their respective institutions and by the CDC.

Each survey used a two-stage stratified cluster sample design. Data collection was done once over a 6–14-month period in each country, with annual estimates generated from each country's data collection period. Data were restricted to adults aged 15–59 years. Some surveys collected data from people aged 60 years or older, but because these data were not collected across all countries, these observations were excluded from this analysis. Adults aged 18 years and older provided informed consent. Adolescents aged 15–17 years old provided assent after a parent or guardian granted permission for an interviewer to approach the adolescent.[13] In 14 surveys, individuals who provided consent or assent completed an individual interview and provided venous blood for rapid HIV testing and measurement of HIV biomarkers.[14] SABSSM-V collected dried blood spots for HIV-1 biomarkers.[8]

## Outcomes

Samples from all consenting survey participants were tested for HIV-1 using each country's national HIV testing algorithm, done with household-based rapid tests and confirmatory laboratory testing.[14,15] HIV-1-positive individuals were classified as having recent infection according to the following algorithm: limiting antigen-avidity enzyme immunoassay (LAg) normalised optical density values of 1·5 or lower, viral load of at least 1000 copies per mL, and no qualitative evidence of common antiretroviral agents in each country's first-line and second-line regimens.[7] Other HIV-1-seropositive individuals whose plasma did not meet criteria for recent HIV-1 infection were classified as having long-term HIV-1 infection.

Pooled estimates of HIV-1 incidence and the number of new annual infections were estimated in the full population and also disaggregated by sex (male and female), age (15–24 years, 25–34 years, 35–44 years,

| | Adults with recent HIV-1 | | Adults with long-term HIV-1* | | Adults without HIV-1† | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Unweighted (n=382) | Weighted (n=247 643) | Unweighted (n=28 790) | Weighted (n=17 202 334) | Unweighted (n=416 807) | Weighted (n=265 136 858) | Unweighted (n=445 979) | Weighted (n=282 586 835) |
| **Age, years** | | | | | | | | |
| 15–24 | 129 (33·8%) | 82 749 (33·4%) | 3154 (11·0%) | 1 860 271 (10·8%) | 152 705 (36·6%) | 100 848 640 (38·0%) | 155 988 (35·0%) | 102 791 659 (36·4%) |
| 25–34 | 139 (36·4%) | 96 854 (39·1%) | 8328 (28·9%) | 5 376 349 (31·3%) | 115 864 (27·8%) | 73 907 383 (27·9%) | 124 331 (27·9%) | 79 380 586 (28·1%) |
| 35–44 | 73 (19·1%) | 39 617 (16·0%) | 9521 (33·1%) | 5 678 793 (33·0%) | 79 054 (19·0%) | 49 038 308 (18·5%) | 88 648 (19·9%) | 54 756 718 (19·4%) |
| 45–59 | 41 (10·7%) | 28 424 (11·5%) | 7787 (27·0%) | 4 286 921 (24·9%) | 69 184 (16·6%) | 41 342 526 (15·6%) | 77 012 (17·3%) | 45 657 871 (16·2%) |
| **Sex** | | | | | | | | |
| Male | 116 (30·4%) | 94 300 (38·1%) | 8847 (30·7%) | 6 170 607 (35·9%) | 185 251 (44·4%) | 134 400 623 (50·7%) | 194 214 (43·5%) | 140 665 530 (49·8%) |
| Female | 266 (69·6%) | 153 343 (61·9%) | 19 943 (69·3%) | 11 031 726 (64·1%) | 231 556 (55·6%) | 130 736 234 (49·3%) | 251 765 (56·5%) | 141 921 304 (50·2%) |
| **Country** | | | | | | | | |
| Western and central | | | | | | | | |
| Cameroon, 2017–18 | 20 (5·2%) | 9974 (4·0%) | 908 (3·2%) | 470 618 (2·7%) | 24 015 (5·8%) | 12 623 850 (4·8%) | 24 943 (5·6%) | 13 104 442 (4·6%) |
| Côte d'Ivoire, 2017–18 | 5 (1·3%) | 1437 (0·6%) | 412 (1·4%) | 358 480 (2·1%) | 16 902 (4·1%) | 12 964 412 (4·9%) | 17 319 (3·9%) | 13 324 329 (4·7%) |
| Nigeria, 2018 | 44 (11·5%) | 29 030 (11·7%) | 2566 (8·9%) | 1 345 504 (7·8%) | 162 574 (39·0%) | 99 505 823 (37·5%) | 165 184 (37·0%) | 100 880 357 (35·7%) |
| Eastern | | | | | | | | |
| Ethiopia (urban), 2017–18 | 4 (1·0%) | 1447 (0·6%) | 589 (2·0%) | 371 389 (2·2%) | 17 970 (4·3%) | 12 003 099 (4·5%) | 18 563 (4·2%) | 12 375 934 (4·4%) |
| Kenya, 2018–19 | 11 (2·9%) | 12 803 (5·2%) | 1448 (5·0%) | 1 245 452 (7·2%) | 25 050 (6·0%) | 24 653 016 (9·3%) | 26 509 (5·9%) | 25 911 271 (9·2%) |
| Rwanda, 2018–19 | 8 (2·1%) | 1931 (0·8%) | 880 (3·1%) | 198 797 (1·2%) | 28 588 (6·9%) | 6 570 922 (2·5%) | 29 476 (6·6%) | 6 771 649 (2·4%) |
| Tanzania, 2016–17 | 33 (8·6%) | 25 721 (10·4%) | 1676 (5·8%) | 1 423 103 (8·3%) | 26 643 (6·4%) | 27 457 147 (10·4%) | 28 352 (6·4%) | 28 905 971 (10·2%) |
| Uganda, 2016–17 | 42 (11·0%) | 30 502 (12·3%) | 1667 (5·8%) | 1 136 718 (6·6%) | 26 332 (6·3%) | 17 510 780 (6·6%) | 28 041 (6·3%) | 18 678 000 (6·6%) |
| Southern | | | | | | | | |
| Eswatini, 2016–17 | 27 (7·1%) | 2047 (0·8%) | 2764 (9·6%) | 185 074 (1·1%) | 6768 (1·6%) | 483 023 (0·2%) | 9559 (2·1%) | 670 144 (0·2%) |
| Lesotho, 2016–17 | 35 (9·2%) | 3520 (1·4%) | 3164 (11·0%) | 302 333 (1·8%) | 8483 (2·0%) | 890 843 (0·3%) | 11 682 (2·6%) | 1 196 696 (0·4%) |
| Malawi, 2015–16 | 25 (6·5%) | 9958 (4·0%) | 2132 (7·4%) | 863 406 (5·0%) | 14 543 (3·5%) | 7 429 484 (2·8%) | 16 700 (3·7%) | 8 302 848 (2·9%) |
| Namibia, 2017 | 22 (5·8%) | 1594 (0·6%) | 2331 (8·1%) | 169 053 (1·0%) | 13 939 (3·3%) | 1 187 686 (0·4%) | 16 292 (3·7%) | 1 358 334 (0·5%) |
| South Africa, 2016–18 | 37 (9·7%) | 92 327 (37·3%) | 2617 (9·1%) | 7 084 464 (41·2%) | 11 954 (2·9%) | 28 024 507 (10·6%) | 14 608 (3·3%) | 35 201 298 (12·5%) |
| Zambia, 2016 | 41 (10·7%) | 15 255 (6·2%) | 2426 (8·4%) | 945 410 (5·5%) | 16 648 (4·0%) | 7 044 869 (2·7%) | 19 115 (4·3%) | 8 005 534 (2·8%) |
| Zimbabwe, 2015–16 | 28 (7·3%) | 10 097 (4·1%) | 3210 (11·1%) | 1 102 534 (6·4%) | 16 398 (3·9%) | 6 787 397 (2·6%) | 19 636 (4·4%) | 7 900 028 (2·8%) |

Data are number (%). Percentages may not sum to 100 because of rounding. *Individuals who had positive HIV-1 test results, but not biomarkers for recent HIV-1. †Includes 13 unweighted participants (6211 weighted) from Côte d'Ivoire who had positive HIV-2 test results and negative HIV-1 test results.

***Table:*** **HIV-1 status in the unweighted and weighted samples by age, sex, and subregion**

and 45–59 years), and subregion (western and central, eastern, and southern sub-Saharan Africa). Pooling was valid because the methodologies that gave rise to the data were similar and observations were appropriately weighted, such that each observation contributed appropriately to the overall estimates.

Incidence rates were estimated using a formula that includes the number of recent HIV-1 infections in the sample according to the LAg, viral load, and antiretroviral therapy algorithm; the number of susceptible individuals; the mean duration of recent infection (MDRI); the cutoff time for the assay; and the false recent rate (FRR).[16] Consistent with published reports, the FRR was assumed to be zero and the cutoff time was 365 days.[16–18] In 14 countries and in pooled estimates, the MDRI was assumed to be 130 days (95% CI 118–142), and in Uganda, it was assumed to be 153 days (127–178) owing to a higher prevalence of HIV-1 subtype D, which has a higher MDRI value.[19] The South African final report applied slightly different FRR and MDRIs, but we applied values used in the other PHIAs for consistency. From these assumptions, we estimated instantaneous HIV-1 incidence rates, expressed as cases per 1000 person-years, and incidence rate differences with corresponding 95% CIs.[16] To facilitate estimation of the number of new infections, incidence rate estimates were annualised to account for the changing susceptible population over time.

We also estimated the HIV-1 IPR (ie, the ratio of the incidence rate to the prevalence in each country, expressed as a percentage). The IPR is a measure of epidemic growth, which tracks the number of new infections relative to the number of people living with HIV. UNAIDS projects that at an IPR of approximately 3·0% or less, an epidemic is expected to contract, though this is not an absolute threshold.[3]

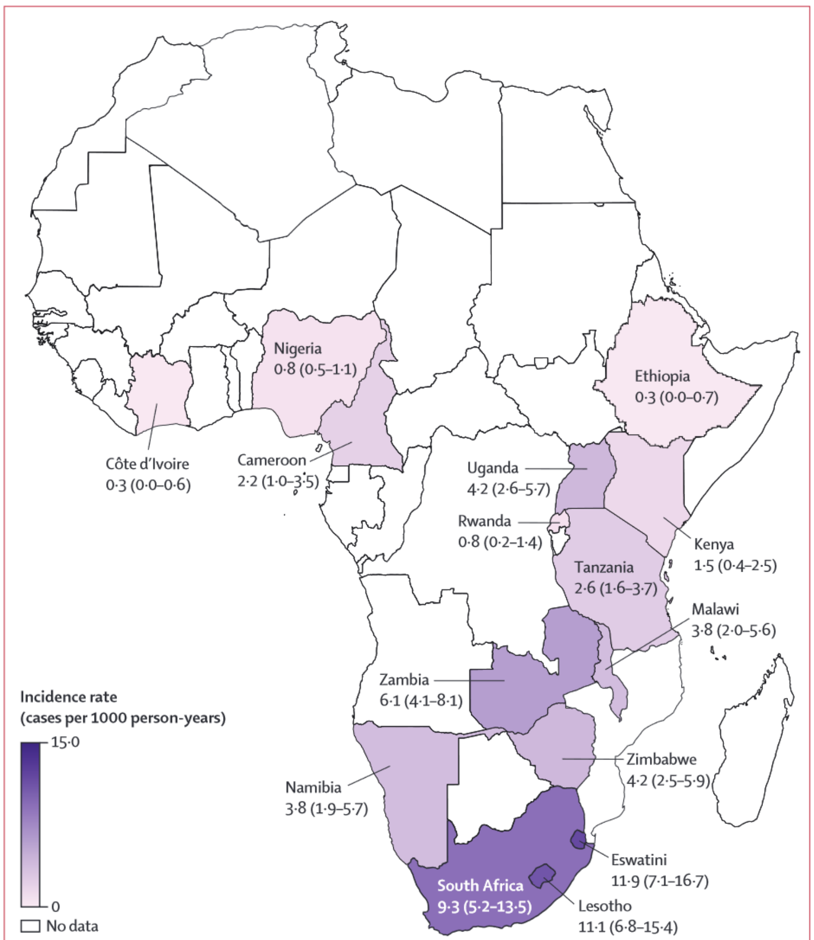


*Figure 1:* HIV incidence by country (cases per 1000 person-years)

## Statistical analysis

Within each country, sampling weights were computed to account for each individual's probability of selection, with adjustments for non-participation in the household-level survey, individual-level survey, and biomarker survey, and post-stratification adjustment to account for undercoverage. Post-stratification weights were benchmarked to the national population (in 14 countries) or urban population (in Ethiopia). PHIA data were pooled such that sampling weights summed to population totals by country, sex, and age group. To account for the complex two-stage sample design in each country, sampling weights for biomarker data were applied, and variances were estimated using Taylor series linearisation. Except for the unweighted estimates presented in the table, the sampling weights were applied for all analyses.[15]

Analyses were done in SAS version 9.4, R version 4.2.0, and SUDAAN Version 11 (RTI International, 2012). Country-level and pooled incidence rate and incidence rate difference estimates were computed using the inctools package in R. 15 population pyramids were created to visualise the population structure of 14 countries, the Ethiopia urban population, and the overall 15-country region. The number of new annual infections was estimated by multiplying the annualised incidence rates with the HIV-1 negative adult population estimated from the sample. Estimates of prevalence and IPRs were computed in SUDAAN. Variances for the estimated number of new infections and IPRs were approximated using methods described by Goodman for confidence interval construction.[20]


## Role of the funding source

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


## Results

The unweighted 15-country sample contained 445 979 adults aged 15–59 years and represented a weighted population of 283 million adults within this

age range (table). The cumulative weighted population was balanced between men (49·8%) and women (50·2%), with an expansive population pyramid shape (appendix) and younger age groups predominating: 36·4% of people were aged 15–24 years, 28·1% were aged 25–34 years, 19·4% were aged 35–44 years, and 16·2% were aged 45–59 years. Of the 283 million adults, 127 million (45·1%) lived in western or central sub-Saharan Africa, 93 million (32·8%) lived in the eastern subregion, and 63 million (22·2%) lived in the southern subregion.

Among the 283 million adults represented through these surveys, an estimated 93·8% (95% CI 93·6–94·1) were not living with HIV-1, 6·1% (5·8–6·3) had long-term HIV-1, and 0·1% (0·1–0·1) had recent HIV-1. Women accounted for the majority of recent HIV-1 infections (61·9%) compared with men (38·1%). Cumulatively, the two younger age groups (15–24 years and 25–34 years) accounted for 180 000 (72·5%) of the 248 000 recent HIV-1 infections compared with 68 000 (27·5%) for the two older age groups (35–44 years and 45–59 years). 135 000 (54·4%) of 248 000 recent infections occurred in southern sub-Saharan Africa, followed by 72 000 (29·2%) in the eastern subregion, and 40 000 (16·3%) in the western and central subregion.

See Online for appendix

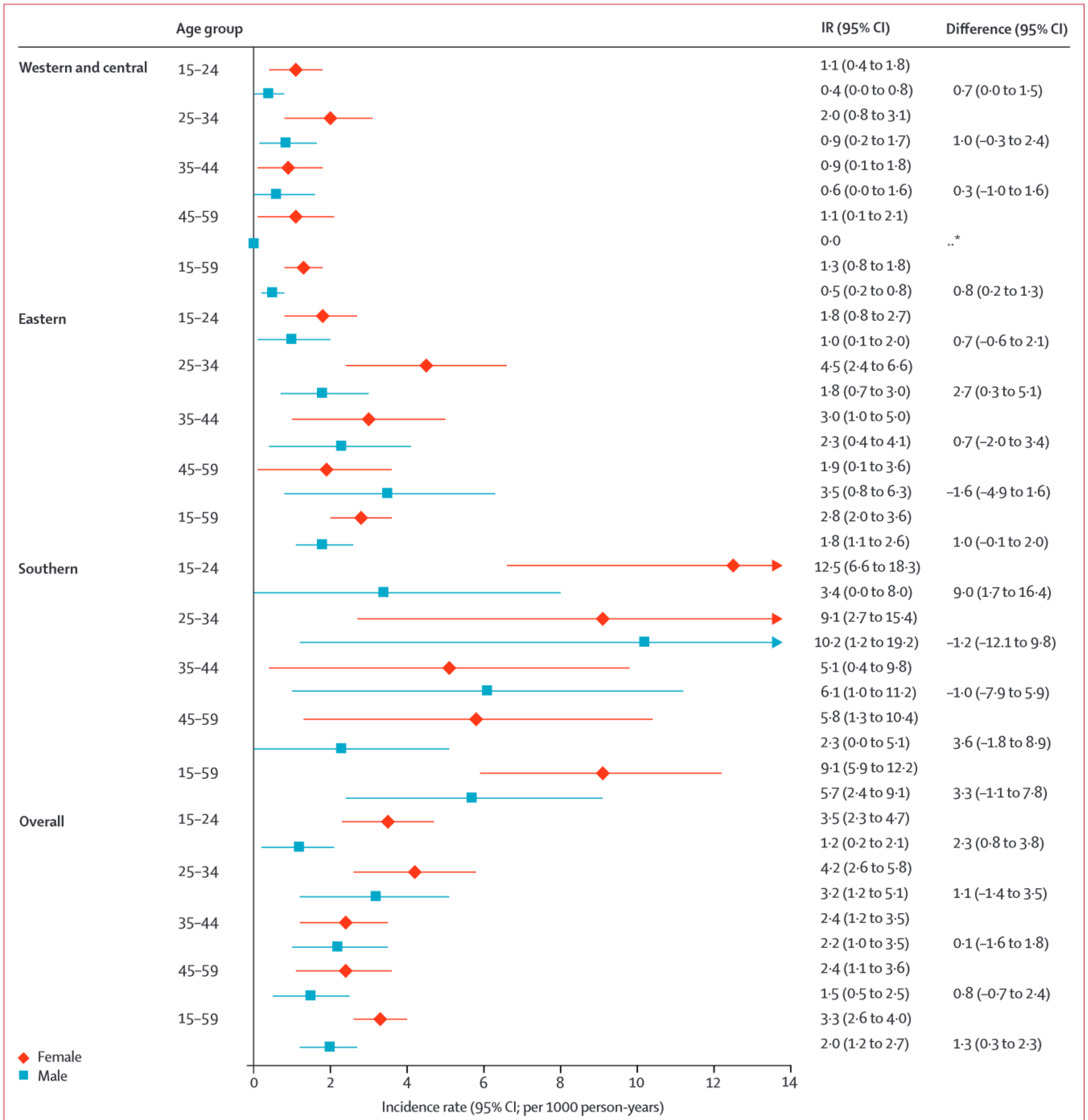


***Figure 2:*** **Pooled HIV-1 incidence rates by age, sex, and subregion**
IR=incidence rate. *No recent cases in this group.

In the pooled target population of 283 million adults aged 15–59 years, estimated HIV-1 incidence was 2·6 per 1000 person-years (95% CI 2·1–3·2). Results were similar for those aged 15–49 years: 2·7 per 1000 person-years (95% CI 2·1–3·3). HIV incidence differed by subregion: 0·9 per 1000 person-years (95% CI 0·6–1·2) in western and central sub-Saharan Africa, 2·3 per 1000 person-years (1·7–2·9) in the eastern subregion, and 7·4 per 1000 person-years (5·0–9·7) in the southern subregion. By country, HIV-1 incidence ranged from 0·3 per 1000 person-years in Cote d'Ivoire and Ethiopia-urban to 11·9 per 1000 person-years in Eswatini (figure 1).

Estimated pooled HIV-1 incidence was 3·3 per 1000 person-years (95% CI 2·6–4·0) among women and 2·0 per 1000 person-years (1·2–2·7) among men (figure 2). Among women, incidence was highest in the 25–34-year age group (4·2, 95% CI 2·6–5·8), although 95% CIs overlapped with the other three age groups (figure 2). Among men, incidence was also highest in the 25–34-year age group (3·2, 95% CI 1·2–5·1); however, 95% CIs overlapped with the other three age groups.

In sub-Saharan Africa overall, HIV-1 incidence was higher among women than men (incidence rate difference 1·3, 95% CI 0·3–2·3; figure 2). HIV-1 incidence was higher among women than men in the 15–24-year age group (difference 2·3, 95% CI 0·8–3·8), but incidence differences were similar in the other three age groups. Subregional variability existed in these point

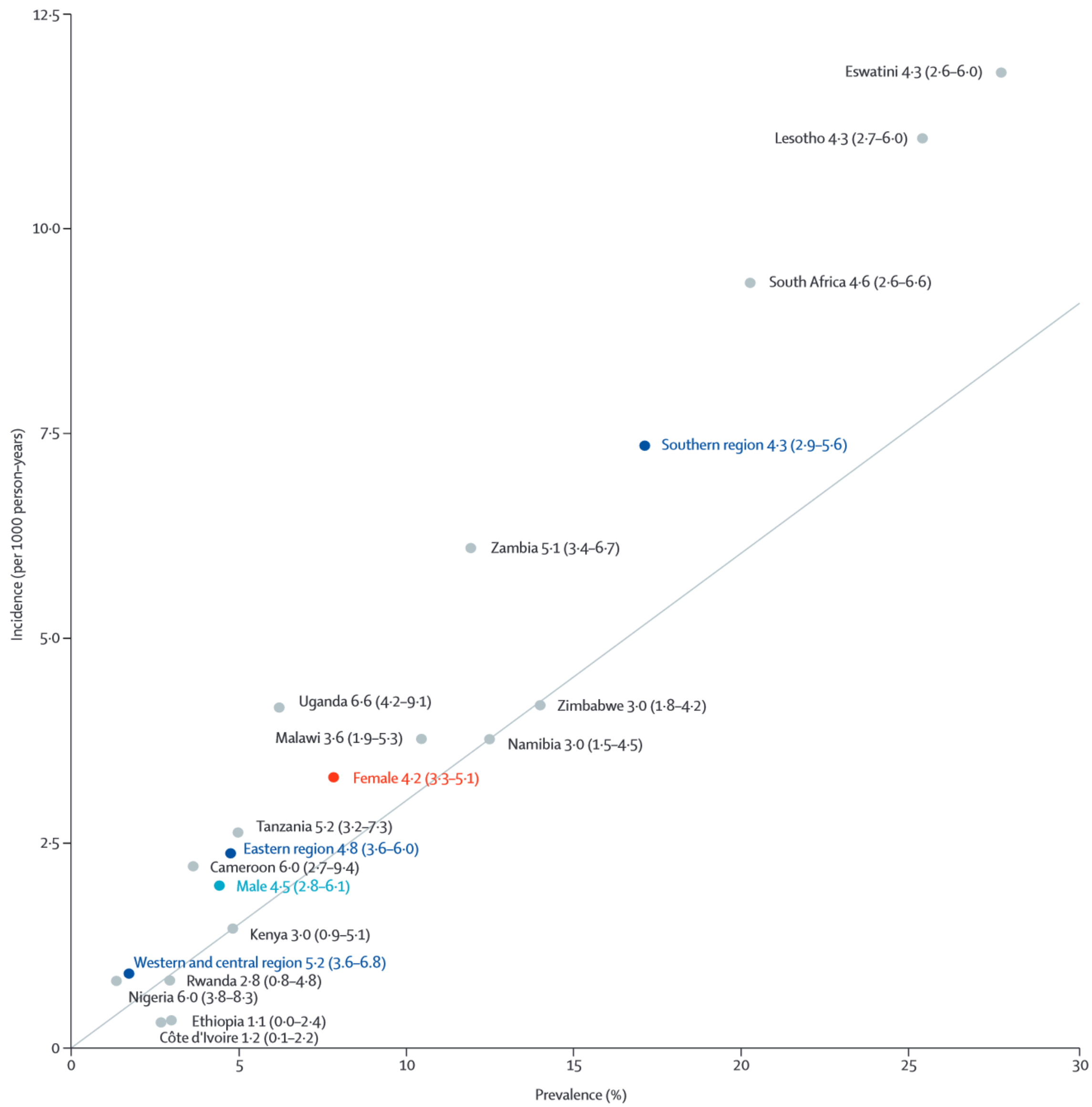


***Figure 3:*** **HIV incidence and prevalence by country and sex relative to the 3·0% transition benchmark (diagonal line)**



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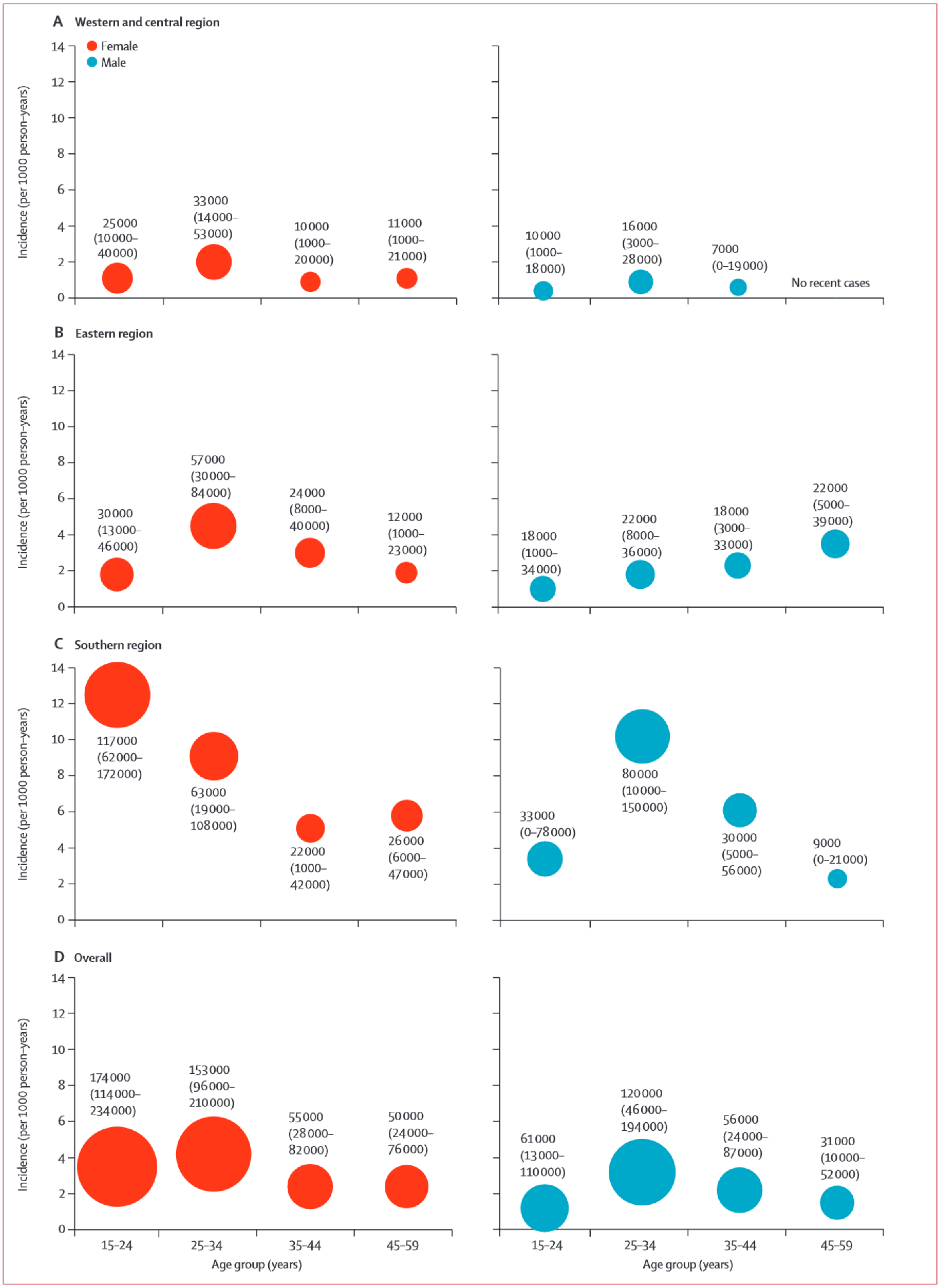


***Figure 4:*** **Pooled HIV-1 incidence and estimated number of new infections by subregion, age, and sex**
Circle sizes are proportional to the estimated number of new infections. Number of new infections are shown as rounded number (95% CI).

estimates. In the southern subregion and western and central subregion, women had higher HIV-1 incidence than men in the 15–24-year age group, whereas in the eastern subregion, women had significantly higher HIV-1 incidence than men in the 25–34-year age group. Incidence rates were similar between women and men in the 35–44-year and 45–59-year age groups in all three subregions.

The IPR was 4·3% overall (95% CI 3·4–5·1): 4·2% (3·3–5·1) among women and 4·5% (2·8–6·1) among men. Regional estimates were similar: 4·3% (95% CI 2·9–5·6) in southern sub-Saharan Africa, 4·8% (3·6–6·0) in the eastern subregion, and 5·2% (3·6–6·8) in the western and central subregion (figure 3).

Among the 265 million HIV-1-negative adults in the target population, approximately 689 000 (95% CI 546 000–833 000) new HIV-1 infections were estimated to have occurred annually. The majority (61·6%) of these infections were estimated among women and 38·4% were among men (figure 4). Among women, three-quarters (75·7%) of new infections were concentrated in the two youngest age groups: 15–24 years (40·3%) and 25–34 years (35·5%). By contrast, 12·7% of new infections were in the 35–44-year group and 11·6% in the 45–59 years group. The large number of infections among these younger age groups was due to a combination of high incidence rates in these two age groups and the higher proportion of individuals in the younger versus older age groups. Among men, infections were highest in the 25–34 years age group (44·8%), compared with 22·9% in the 15–24 years group, 20·8% in the 35–44-year group, and 11·5% in the 45–59 years group.

The western and central region accounted for 45·1% of the target population, but only 16·2% of the HIV-1 infections (113 000, 95% CI 77 000–148 000). The southern region accounted for (22·2%) of the population, but 54·5% of new infections (378 000, 259 000–498 000). The eastern region contained (32·8%) of the population and a similar share (29·2%) of the new infections (203 000, 151 000–255 000).

Between the subregions, there was considerable heterogeneity in the estimated number of infections by age and sex, although all estimates were imprecise (figure 4). In the western and central subregion and the eastern subregion, women aged 25–34 years had the highest number of new infections (33 000 and 57 000, respectively). In the southern subregion, women aged 15–24 years had the highest number of new infections (117 000).

## Discussion

In 15 countries with high HIV-1 burden in sub-Saharan Africa, approximately three in every 1000 susceptible adults aged 15–59 years acquired HIV-1 annually during the study period. Incidence was lowest in west and central sub-Saharan Africa, higher in eastern Africa, and highest in southern Africa. Both HIV-1 incidence and the absolute number of new infections were higher for women than men in all three subregions. For both sexes, incidence peaked in the 25–34-year age group in the region overall, but there was substantial subregional heterogeneity. Women aged 15–34 years accounted for nearly half of the 689 000 adult HIV-1 infections that were estimated annually in these 15 countries during the study period.

Our study provides the largest empirical estimate of adult HIV-1 incidence by age, sex, and subregion so far. This is the first study to provide pooled, nationally representative HIV-1 incidence estimates across three subregions in sub-Saharan Africa by age and sex and to formally compare them. These findings are relevant to the 265 million HIV-negative adults living in 15 of the countries with the highest HIV-1 burden,[21] approximately half of the adults in sub-Saharan Africa in this age range. Several empirical estimates of HIV-1 incidence have been done, but none have been representative at such a large scale.[5]

Overall and within each subregion, HIV-1 incidence and the absolute number of new infections were substantially higher among women than men. These sex differences stem, in part, from age-disparate relationship structures, which are prevalent in sub-Saharan Africa[22] and lower rates of viral suppression among men living with HIV.[23] Although women had higher HIV-1 incidence and number of new infections in all three subregions, there were differences with respect to age of infection in women. In southern Africa, women aged 15–24 years accounted for the largest number of new infections and the highest incidence rate, whereas in the eastern region and the west and central region, women aged 25–34 years accounted for the largest number of new infections and the highest incidence rates.

Women aged 15–34 years (ie, ages during which most childbearing occurs) accounted for more than half of the new infections in these 15 countries. This observation—combined with high fertility rates[24] and elevated risk of vertical transmission during acute HIV-1 infection[25]—contributes to the paediatric HIV-1 burden in these settings. Focusing primary prevention efforts throughout this age group is crucial, not only for women's long-term health, but also for the health of their infants. Such efforts should include primary HIV prevention during pregnancy and breastfeeding, periods associated with elevated maternal HIV-1 incidence[25,26] and a growing proportion of new infant HIV-1 infections,[21] particularly in settings with high antiretroviral therapy coverage.[27]

The nature of HIV incidence in sub-Saharan Africa is paradoxical. On the one hand, HIV-1 incidence rates are higher than on any other continent.[21] The overall HIV-1 IPR point estimates in this study exceeded the 3·0% epidemic transition guidepost among both sexes and in all three subregions, suggesting slow epidemic growth, rather than contraction.[3] The estimated HIV-1

incidence rate in both men and women exceeded the 1 per 1000 person-years HIV epidemic transition benchmark, which guided the UNAIDS 90-90-90 targets.[28] Additionally, hundreds of thousands of HIV-1 infections are reported each year.[29] On the other hand, new infection remains a relatively rare event, with only an estimated three in every 1000 adults acquiring HIV annually according to our data.

This paradox poses a challenge for reaching those in greatest need of pre-exposure prophylaxis (PrEP). UNAIDS has historically recommended PrEP to most adolescents and adults when HIV-1 incidence is 3 per 100 person-years (30 per 1000 person-years),[30] which is much higher than any of the incidence rates reported in this study. UNAIDS also recommended PrEP to individuals with sexually transmitted infections or more than one sexual partner in settings with HIV-1 incidence between 1 and 3 per 100 person-years.[10] We identified only two countries (Eswatini and Lesotho) and two age–sex groups in the southern region (women aged 15–24 years and men aged 25–34 years) that had HIV-1 incidence rates above 1 per 100 person-years, although estimates were imprecise. However, the majority of infections occurred outside of these two countries and age–sex groups. In 2021, WHO challenged these guidelines as too restrictive,[31] a view supported by our findings.

Approaches are still needed to identify adults across all three subregions at highest risk for HIV-1 acquisition who would benefit most from PrEP. Although risk assessment tools have been developed to assist with HIV-1 risk stratification, none have been created using nationally representative data, and most have been focused on select populations in a small number of countries.[32] Building upon the current analysis, we plan to develop a set of risk assessment tools that can be used to identify clinics and individuals in greatest need of PrEP.

Our analysis has strong internal and external validity. Methodological strengths include rigorous and comparable survey sampling methods implemented across countries, high participation rates at each survey stage, appropriate weighting techniques in the pooled sample, and a validated recent HIV-1 testing algorithm to measure HIV-1 incidence.[7,18] Furthermore, our analysis contains one of the largest numbers of new infections so far.

Longitudinal cohort studies are considered the gold standard for estimation of HIV incidence. Estimation of incidence on the basis of recent infection testing algorithms has important cost and feasibility advantages over cohort studies,[33] but also some limitations. This algorithm includes several assumptions: the LAg cut-point is appropriate, the MDRI is accurate, and the FRR is zero when viral load and antiretroviral drugs are included.[7] This method will overestimate or underestimate HIV incidence if these parameters are inaccurate. However, LAg-based HIV incidence algorithms have been validated against longitudinal measures,[18] enhanced with the antiretroviral drug detection,[7] and recommended by WHO.[34]

Although these pooled data represent one of the largest samples of recent or incident cases in a single dataset, imprecision remains a limitation. Although the pooled dataset included almost 446 000 individuals, only 382 had recent HIV-1 infection (<0·1%). Each survey was designed to provide national estimates of HIV-1 incidence, rather than estimates by age, sex, or subnational areas. However, when pooled across sub-Saharan African subregions, estimates of HIV-1 incidence by age and sex were possible. This ability to examine trends by age and sex across subregions is an important contribution of our pooled analysis.

This analysis included data from surveys done in 15 PEPAR-supported countries that had publicly available datasets on or before Sept 30, 2022. As such, these results are not generalisable to the entire sub-Saharan Africa region. Specifically, they do not represent many lower-burden countries that do not receive PEPFAR support or PEPFAR-supported countries that did not conduct PHIA surveys. Our results should not be generalised to the entire continent, but rather to the 15–59-year adults in the 15 countries included in our analysis. According to UNAIDS estimates,[35] these countries account for more than two-thirds of HIV infections in sub-Saharan Africa during this period and approximately half of the population in this age group.

For practical reasons, data were collected only once in each country between 2015 and 2019, with most data collected in 2016–18. These datasets were pooled together despite minor differences in the timing of data collection. Across the 2015–19 period, slight annual variations in incidence and number of new infections probably occurred, but such estimates were beyond the scope of this analysis. Although this analysis did not include such trends, PHIA is designed to track temporal trends, with second-wave data collection completed in Eswatini, Lesotho, Malawi, Uganda, and Zimbabwe, and a subsequent wave of SABSSM now underway in South Africa. Comparing trends over time is a key next step.

Despite substantial progress in testing and treatment, the HIV-1 epidemic in these high-burden countries persists, infecting hundreds of thousands of adults each year.[29] Clarity around the patterns of HIV-1 incidence by subregion, age, and sex are key for identifying adults at greatest risk of HIV-1 acquisition and linking them to well designed comprehensive HIV prevention programmes. Such identification and linkage are essential for reaching the UNAIDS fast-track target of ending the HIV epidemic as a public health threat by 2030.[36]

#### Contributors

NER, BES-S, MGH, and BHC conceptualised the overall study and were responsible for acquisition of funding. JJ, MEC, and SM and KZ conceptualised and oversaw data collection for the parent studies

(PHIAs, NAIIS, and SABSSM, respectively). BES-S and ML analysed the data, oversaw the development of the table and figures, and accessed and verified the underlying data. All authors reviewed and edited the final manuscript and approved the final submission. NER and BES-S were responsible for the decision to submit for publication.

**Declaration of interests**

LS-C received funding from ViiV Healthcare to support travel to an adolescents and HIV workshop in 2022. MY received grant funding and an honorarium payment from the National Institutes of Health (NIH). NAS-A received funding from the NIH and a grant from ViiV Healthcare. JJ served on the Roche Diagnostics Scientific Advisory Board in April 2022. BHC received a consulting fee from UNICEF. All other authors declare no competing interests.

**Data sharing**

The Nigeria data were publicly available from the NAIIS Data Archive portal: https://nadanaiis.nascp.gov.ng. The data for the SABSSMV were requested from the Human Sciences Research Council: https://hsrc.ac.za. The data for the remaining 13 PHIA surveys were publicly available upon request from the PHIA website, housed at ICAP, Columbia University: https://phia.icap.columbia.edu/.

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