

Epidemiological trends of HIV among individuals aged 15–54 years in South Africa from 2004 to 2025: a population-based, longitudinal cohort study

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Summary

Background South Africa has mounted the largest HIV prevention and treatment programme in history, delivering substantial gains in survival and prevention of new HIV infections; however, service disruptions and recent funding losses might jeopardise these successes. There is a scarcity of high-quality, population-based empirical evidence on key epidemic metrics needed to accurately gauge recent progress towards epidemic control in South Africa. We aimed to evaluate recent progress towards HIV epidemic control in South Africa by quantifying long-term trends in key epidemic control metrics in a large population-based cohort in rural KwaZulu-Natal, South Africa.

Methods In this population-based, longitudinal cohort study, we used prospectively collected HIV testing, sociodemographic, behavioural, and population viral load data from the Africa Health Research Institute (AHRI) health and demographic surveillance system in rural KwaZulu-Natal from 2003 to 2025. Population-based HIV surveys (encompassing individual health interview and HIV testing) take place annually in all consenting resident individuals aged 15 years or older. We used Poisson regression models to quantify trends in directly observed HIV incidence in repeat testers (aged 15–54 years) who had initially tested negative for HIV and subsequently received at least one valid HIV test result. We further analysed 11 rounds of population viral load testing conducted between 2011 and 2025. We used generalised estimating equations to quantify population viral suppression metrics and calculated trends in the incidence-to-prevalence ratio, a key metric for evaluating progress towards epidemic control.

Findings Between June 24, 2003, and May 22, 2025, across the population cohort, 59 806 (65·4%) of 91 367 contacted individuals aged 15–54 years consented to participate at least once in population-based HIV testing. Of those tested, 33 754 (56·4%) were female and 26 052 (43·6%) were male, with a median age of 26·7 years (IQR 19·3–39·1) at testing date. Among 42 662 participants who initially tested HIV negative and were recontacted, 29 702 (69·6%) underwent repeat HIV testing and were included in the incidence analysis. In this group, over 182 112 person-years of observation, we observed 4852 HIV seroconversions. From 2013 to 2018, overall annual HIV incidence rates declined by 52·2% in males and 36·9% in females. We found no evidence of a continued downward trend in HIV incidence between 2019 and 2025 among either females or males. After a period of substantial decline (from 2011 to 2018), population detectable viraemia increased significantly from 2019 to 2025 by 9·6 percentage points (95% CI 5·4–13·8), remaining an estimated 30·7 percentage points (95% CI 27·2–34·3) below the UNAIDS 95–95–95 population viral suppression target. The incidence-to-prevalence ratio decreased substantially across consecutive survey rounds, from 0·132 (95% CI 0·114–0·152) in 2006 to its lowest recorded value of 0·034 (95% CI 0·028–0·042) in 2022, representing an overall 74·2% decline. After 2022, the ratio stagnated above the epidemic control benchmark of 0·03.

Interpretation These epidemic metrics show that progress towards HIV epidemic control is faltering in KwaZulu-Natal, South Africa. The tools to reverse this trajectory are available; the challenge now is to ensure their sustained and effective implementation through coordinated action across research, policy, government, civil society, and international funding partners. We can, and we should, change course now if we want to achieve an AIDS-free generation in South Africa and the world.

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Introduction

Over the past two decades, the global HIV response has shown remarkable progress, with momentum growing towards the goal of ending the AIDS epidemic by 2030

(UN Sustainable Development Goal 3.3).¹ The scale-up of antiretroviral therapy (ART) and effective prevention strategies have driven estimated declines of 40% in the number of new HIV infections and 54% in the number of

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Research in context

Evidence before this study

HIV remains a major global health challenge, and South Africa continues to carry the world's heaviest burden of HIV infection. Over the past two decades, the global HIV response has made remarkable progress, with momentum growing towards the goal of ending the AIDS epidemic as a public health threat by 2030. However, this progress has been challenged by external events such as the disruptions caused by the COVID-19 pandemic, and more recently by growing instability in global HIV financing. We searched PubMed for empirical studies published between Jan 1, 2020, and June 30, 2026, using the search terms ((HIV[Title]) AND ("South Africa"[Title/Abstract]) AND (population-based[Title/Abstract] OR representative[Title/Abstract] OR longitudinal[Title/Abstract]) AND (incidence[Title/Abstract] OR epidemic control[Title/Abstract])). We also screened the reference lists of relevant articles and reports, with no language restrictions. However, we found no recent empirical population-based or representative studies reporting contemporary HIV incidence and other epidemic control metrics for the general population. Although several studies examined specific subgroups or analysed older datasets, there is no current empirical evidence to assess recent progress towards HIV epidemic control at the population level.

Added value of this study

This study provides a comprehensive assessment of HIV epidemic control in a hyperendemic rural South African

population. By analysing more than two decades (2003–25) of data from a population-based HIV testing platform, we showed that a composite view of key epidemic control indicators revealed stalling and reversal of progress that remain undetected in national estimates. These findings provide crucial evidence to guide the next phase of South Africa's HIV response amid shifting epidemiology and growing uncertainty in global HIV financing.

Implications of all the available evidence

Our findings show that progress across key HIV epidemic metrics has stalled (and in some cases begun to reverse) since 2019. Our findings challenge the expectation that South Africa is steadily advancing towards the UNAIDS 2030 targets. To change course, South Africa will need to expand tailored prevention options for diverse risk groups, strengthen antiretroviral therapy initiation and adherence to reduce detectable viraemia, and implement more flexible, patient-centred service delivery. Long-acting agents for prevention and treatment will also be vital for accelerating progress towards epidemic control. Without renewed political focus, the recent massive reduction in global financial support for the HIV response could further exacerbate the HIV epidemic trends we observe here, putting South Africa at risk of reverting to an HIV epidemic with high incidence and mortality.

AIDS-related deaths since 2010.² Several high-burden countries, including Botswana, Eswatini, Lesotho, Namibia, Rwanda, Zambia, and Zimbabwe, are estimated to have reached the UNAIDS 95–95–95 targets (ie, 95% of people living with HIV should be diagnosed, 95% of those diagnosed with HIV should be receiving ART, and 95% of all those receiving ART should reach viral suppression), suggesting that ambitious epidemic goals are not only aspirational but achievable.² New prevention tools, such as long-acting injectable pre-exposure prophylaxis (PrEP), offer promising pathways for reaching global targets if effective interventions can be delivered and implemented at scale.^{3,4} These scientific and programmatic successes have fostered optimism that ending the global HIV epidemic is within reach, provided resources and political commitment can be sustained.⁵ This optimism has been challenged in recent years by disruptions in HIV services due to the COVID-19 pandemic⁶ and now by the emergence of a fragile and uncertain funding landscape. Projections warn that even small funding interruptions can trigger large numbers of new infections and AIDS-related deaths, whereas prolonged funding gaps can result in millions of additional deaths by 2030.⁷

South Africa sits at the centre of these global challenges; with 7·8 million people living with HIV and 170 000 new infections annually, it shoulders the world's heaviest

burden of HIV.² In response, the country has successfully mounted the largest ART programme in history globally, delivering dramatic gains in survival and HIV prevention.⁸ In rural KwaZulu-Natal, our group has documented steep reductions in HIV incidence and mortality over the past two decades, providing compelling evidence of progress towards epidemic control in South Africa.^{9,10} Yet, despite these achievements, the HIV epidemic in South Africa is evolving in ways that are not fully understood.⁹ The Sixth South African National HIV Prevalence, Incidence, Behaviour and Communication Survey in 2022 reported improvements compared with the previous survey, including rising HIV viral load suppression (defined as the proportion of people with HIV with plasma viral load <1000 RNA copies per mL) and declines in HIV incidence (based on prevalence of individuals with viraemia with low-avidity HIV antibodies, which are indicative of recent HIV acquisition).¹¹ However, national surveys are conducted once every 5 years in South Africa and do not have community-level granularity due to small sample sizes in individual communities. Since this 2022 survey, South African health authorities have noted rising cases of sexually transmitted infections, such as chlamydia and gonorrhoea.¹² There is a gap in the understanding of HIV epidemic trends since 2022 up until the onset of the funding crisis of 2025 and beyond, including whether

gains are being maintained across all groups, or whether progress is stalling after years of improvement. These uncertainties are particularly acute at a moment when the global HIV response faces unprecedented political and financial strain.¹³

Addressing these uncertainties requires data of exceptional scale and continuity. The Africa Health Research Institute (AHRI) population-based HIV testing platform in rural KwaZulu-Natal maintains one of the world's largest population-based cohorts with two decades of ongoing, longitudinal HIV data collection.¹⁴ This large cohort enables the tracking of epidemic dynamics at scale and with granularity (eg, by time period, age, sex, and geography) across a time period of profound change. In this study, we aimed to analyse more than two decades (2003–25) of population-based testing data from a hyperendemic setting in rural South Africa to characterise recent trends in HIV incidence, lifetime HIV acquisition risk, population viral load, and additional epidemic control metrics to assess the implications for sustaining progress towards HIV epidemic control. In the face of changing epidemiology and global funding uncertainty, these data provide crucial evidence to guide the next phase of South Africa's HIV response and to inform global strategies for reaching the end of the HIV epidemic.

Methods

Study design and participants

In this population-based, longitudinal cohort study, we used HIV testing data, sociodemographic and behavioural data, and population viral load data collected prospectively from the AHRI health and demographic surveillance system in rural KwaZulu-Natal, South Africa, between 2003 and 2025. The AHRI surveillance area covers 438 km² in uMkhanyakude District and includes a population of approximately 100 000 individuals.¹⁴ This setting is a high HIV-burden area and it is one of South Africa's 27 President's Emergency Plan for AIDS Relief (PEPFAR) priority districts, characterised by enhanced HIV testing and treatment programmes.¹⁵ Since June, 2003, every adult aged 15 years or older in this population has been eligible for population-based HIV testing. This testing enables routine follow-up of people without HIV over several years to observe individual HIV seroconversions, which is the gold standard for HIV incidence measurement. Population-based HIV surveys take place annually in all consenting resident individuals aged 15 years or older. Written informed consent was obtained from all participants before the individual health interview, which collects demographic, general health, and HIV-related information. Separate consent was obtained for HIV testing and dried blood spot collection. The interview was carried out at the same time as the HIV testing. For the present analysis, we included data from individuals aged 15–54 years. Ethics approval for data collection and use was obtained from the Biomedical

Research Ethics Committee of the University of KwaZulu-Natal, Durban, South Africa (BE290/16).

Procedures

Routinely collected data as part of the AHRI health and demographic surveillance system at the population level encompass a range of individual-level biomarkers, sexual behaviours, and knowledge of and attitudes towards ART, as well as verbal autopsies for determining causes of death. These population-based datasets have been integrated through unique identifiers with clinical records from the local public-sector ART programme, allowing for the evaluation of individual, household, and community-level exposure to ART.¹⁴ Field workers cover the entire study area systematically by going house to house, asking individuals to consent to HIV testing, irrespective of testing history or previous HIV status. After written informed consent is given, field workers obtain blood by fingerprick test following the guidelines outlined by UNAIDS and WHO for HIV testing technologies in surveillance.¹⁶ HIV status is then established through antibody testing done in the AHRI laboratories (Durban, South Africa) with HIV ELISA–immunoassay performed on dried blood spot using the Genscreen ULTRA HIV Ag-Ab enzyme immunoassay (Bio-Rad, Paris, France). Viral load measurements are performed subsequently in the AHRI laboratory by use of the Generic HIV Viral Load assay (Biocentric, Bandol, France). Laboratory extraction and quantification procedures, including the lower limit of detection of 1550 copies per mL, have been described previously.¹⁷ For this study, data extracted from the AHRI surveillance system included age, sex (self-reported; options provided were male or female), laboratory-derived HIV test result, and viral load measurements.

Statistical analysis

We examined trends in HIV incidence by analysing data from individuals aged 15–54 years in the population cohort who underwent repeated testing over time. Each survey round was labelled as the year in which it finished. Disruptions related to the COVID-19 pandemic resulted in minimal HIV testing in 2020 and partial 2021 and 2022 testing rounds. These two partial rounds, spanning 2020–21 and 2021–22, were combined and labelled as the 2022 round, as previously described.¹⁸ Participants who had initially tested negative for HIV and subsequently received at least one valid HIV test result were included in the incidence analysis.¹⁹ Among these repeat testers, we identified those who HIV seroconverted during the observation period. Employing a uniform distribution, we assigned a random infection date within the interval between the latest negative test and the earliest positive test (referred to as the censoring interval). Subsequently, we censored the data at the latest negative test date (for those who remained HIV negative) or at the imputed infection date (for those who acquired HIV). This method

has the advantage of explicitly incorporating the uncertainty in incidence rates caused by intervals between testing rounds, as described previously.¹⁰ We estimated incidence rates per 100 person-years, and incidence rate ratios (IRRs) using Poisson regression models (appendix pp 2–3). We also assessed whether HIV incidence changed during the post-2018 period. Following our previous publication on HIV incidence trends in this population immediately preceding this period,⁹ we sought to assess subsequent trends in the context of evolving HIV prevention, testing, and treatment services, as well as broader changes in health-care delivery, including potential disruptions associated with the COVID-19 pandemic.⁶ We jointly compared annual incidence rates in 2022–25 with those observed in 2019 using pooled Wald tests derived from Poisson regression models. In addition, we directly compared the 2019 incidence rate with the pooled 2024–25 incidence estimate using a Wald test. Because incomplete

follow-up, with person-time censored at participants' most recent HIV test, makes final-year incidence estimates inherently unstable, we pooled the final two survey rounds for this comparison. To assess the uncertainty of our imputation procedure, we generated 300 datasets by imputing a random seroconversion date within the censoring period, using Rubin's rules, and computed the estimates and the 95% CIs.^{10,20} To address the possibility of potential biases from participant selection and to improve the robustness of our results, we applied inverse probability weighting in the Poisson regression models.²¹ Building on the methodology we used in previous studies,^{9,10} we estimated the inverse probability weights using the logistic regression model with the probability of non-participation regressed on the continuous variables of age, HIV prevalence in the homestead, and the time spent outside the study area.

To estimate the lifetime risk of acquiring HIV, we used a measure analogous to the total fertility rate, which quantifies the cumulative risk of HIV acquisition assuming that an individual was exposed to the relevant age-specific HIV incidence rates throughout their life course. Age-specific HIV incidence rates were calculated in the manner described previously. In the absence of competing mortality risks, we estimated the cumulative risk of acquiring HIV between age 15 years and age 54 years using a probabilistic approach that accounts for the time-dependent nature of infection risk, widely applied in epidemiological studies to estimate lifetime risk in dynamic populations. Instead of summing up annual incidence rates, which can overestimate the risk, we used a multiplicative survival-based method to model the cumulative probability of infection. This approach provides a more accurate estimate of cumulative HIV risk by incorporating the year-on-year probabilities of infection while ensuring that the cumulative probability remains bounded between 0 and 1. To assess uncertainty in our estimates, we computed 95% CIs using a bootstrap resampling approach. To generate reliable age-specific estimates of HIV incidence, we computed cumulative risk of infection across three periods: 2004–13, 2014–18, and 2019–25.

To assess trends in population-level HIV transmission potential we analysed viral load data from HIV-positive samples collected across 11 HIV survey rounds between 2011 and 2025 (appendix p 7). In 2019, additional dried blood spot samples were collected in the AHRI population (as part of the Vukuzazi study) by use of mobile clinic-based data collection; there was no duplication of viral load measurements in the data used.²² Detectable viraemia was defined as the proportion of people with HIV with a valid viral load measurement who had a detectable viral load (>1550 copies per mL). The proportion of the population with HIV transmission potential was calculated as HIV prevalence multiplied by detectable viraemia among people living with HIV. Detectable viraemia was

See Online for appendix

	Seroconversions		Person-years		Poisson incidence rate, infections per 100 person-years (95% CI)	
	Males	Females	Males	Females	Males	Females
Survey round*						
2004	49	122	2152	3171	2.23 (1.60–2.86)	3.87 (3.19–4.56)
2005	70	185	3335	4794	2.12 (1.62–2.61)	3.85 (3.30–4.41)
2006	81	225	3741	5448	2.20 (1.73–2.68)	4.18 (3.64–4.73)
2007	86	234	3856	5753	2.27 (1.79–2.74)	4.06 (3.54–4.59)
2008	91	238	3973	5937	2.23 (1.76–2.69)	3.97 (3.47–4.48)
2009	89	229	3864	5815	2.36 (1.88–2.84)	3.98 (3.47–4.49)
2010	86	234	3835	5822	2.26 (1.78–2.73)	4.08 (3.56–4.60)
2011	83	227	3810	5857	2.23 (1.75–2.70)	3.83 (3.33–4.33)
2012	83	234	3710	5679	2.25 (1.77–2.74)	4.13 (3.60–4.66)
2013	78	238	3844	5752	2.01 (1.56–2.45)	4.17 (3.64–4.70)
2014	69	238	3976	5818	1.73 (1.32–2.14)	4.09 (3.57–4.61)
2015	58	216	4104	5838	1.42 (1.05–1.78)	3.73 (3.23–4.22)
2016	50	187	4171	5867	1.25 (0.91–1.59)	3.18 (2.72–3.64)
2017	41	159	4089	5744	1.03 (0.72–1.34)	2.71 (2.28–3.14)
2018	37	142	3853	5427	0.96 (0.65–1.27)	2.63 (2.20–3.06)
2019	31	109	3595	4945	0.93 (0.61–1.24)	2.27 (1.85–2.69)
2022†	59	195	6836	9263	0.90 (0.58–1.22)	2.18 (1.76–2.61)
2023	37	103	3218	4439	1.15 (0.78–1.52)	2.29 (1.85–2.74)
2024	26	79	2619	3731	1.03 (0.64–1.42)	2.15 (1.68–2.62)
2025	11	43	1824	2607	0.61 (0.26–0.97)	1.70 (1.20–2.20)
Age group						
15–24 years	518	2065	38 656	44 225	1.33 (1.22–1.45)	4.74 (4.53–4.94)
25–34 years	488	1078	19 365	25 242	2.55 (2.32–2.77)	4.18 (3.93–4.44)
35–44 years	149	309	8724	17 062	1.70 (1.43–1.98)	1.77 (1.57–1.97)
45–54 years	60	185	7660	21 178	0.86 (0.66–1.07)	0.89 (0.76–1.02)
Total	1215	3637	74 405	107 707	1.65 (1.56–1.74)	3.39 (3.28–3.50)

*Each survey round was labelled as the year in which it finished. †Disruptions related to the COVID-19 pandemic resulted in minimal HIV testing in 2020 and partial 2021 and 2022 testing rounds; these two partial rounds, spanning 2020–21 and 2021–22, were combined and labelled as the 2022 round, as previously described.¹⁸

Table: Directly observed seroconversions, person-years of observation, and HIV incidence rate (per 100 person-years) among repeat testers in the incidence analysis, by age group, sex, and survey round

modelled as a binary outcome among people with HIV with valid viral load measurements. To evaluate trends over time, we fitted generalised estimating equation models with a binomial distribution and logit link function (appendix p 4). The models accounted for repeated measurements from the same individuals across survey rounds using an exchangeable correlation structure and were adjusted for age and survey round and stratified by sex. Odds ratios (ORs) and 95% CIs were derived from exponentiated regression coefficients by use of robust standard errors.

Finally, we also calculated the trends in the incidence-to-prevalence ratio, a sensitive metric used to assess progress towards epidemic control.²³ The incidence-to-prevalence ratio is the ratio of the total number of new HIV infections to existing infections in a particular population, providing an estimate of the number of new infections occurring over the lifetime of a person with HIV on ART. An incidence-to-prevalence ratio benchmark for epidemic control has generally been considered to be 0·03, which assumes that the average survival time of a person with newly acquired HIV on ART is 33 years.²³ HIV prevalence was calculated as the proportion of individuals with a valid HIV-positive test result out of all individuals tested for HIV during a round of population-based HIV testing. We calculated the incidence-to-prevalence ratio for each survey round by estimating the total number of new HIV infections among the estimated number of HIV-negative individuals among the eligible population in each survey round divided by the estimated total number of people living with HIV (ages 15–54 years) in each survey round. All analyses were conducted in R version 4.5.2.

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

Between June 24, 2003, and May 22, 2025, across the surveillance cohort, 59 806 (65·4%) of 91 367 contacted individuals aged 15–54 years consented to participate at least once in population-based HIV testing. Of those tested, 33 754 (56·4%) were female and 26 052 (43·6%) were male, with a median age of 26·7 years (IQR 19·3–39·1) at testing date. A median of 8512 (IQR 7423–9979) participants aged 15–54 years consented to HIV testing in each population-based survey round. Among 42 662 participants who initially tested HIV negative and were recontacted, 29 702 (69·6%) underwent repeat HIV testing and were included in the incidence analysis. In this group, over 182 112 person-years of observation, we observed 4852 HIV seroconversions between the 2004 and 2025 survey rounds (table). Across successive annual surveys, the cumulative proportion of all participants with at least one HIV test increased from 37·5% in 2005 to

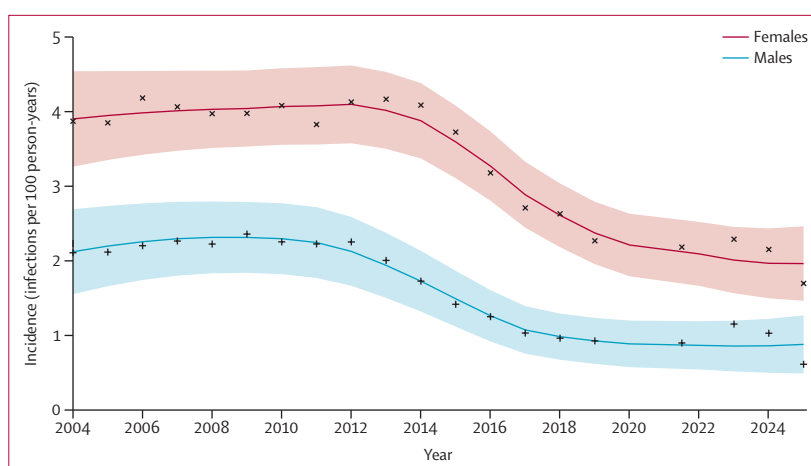
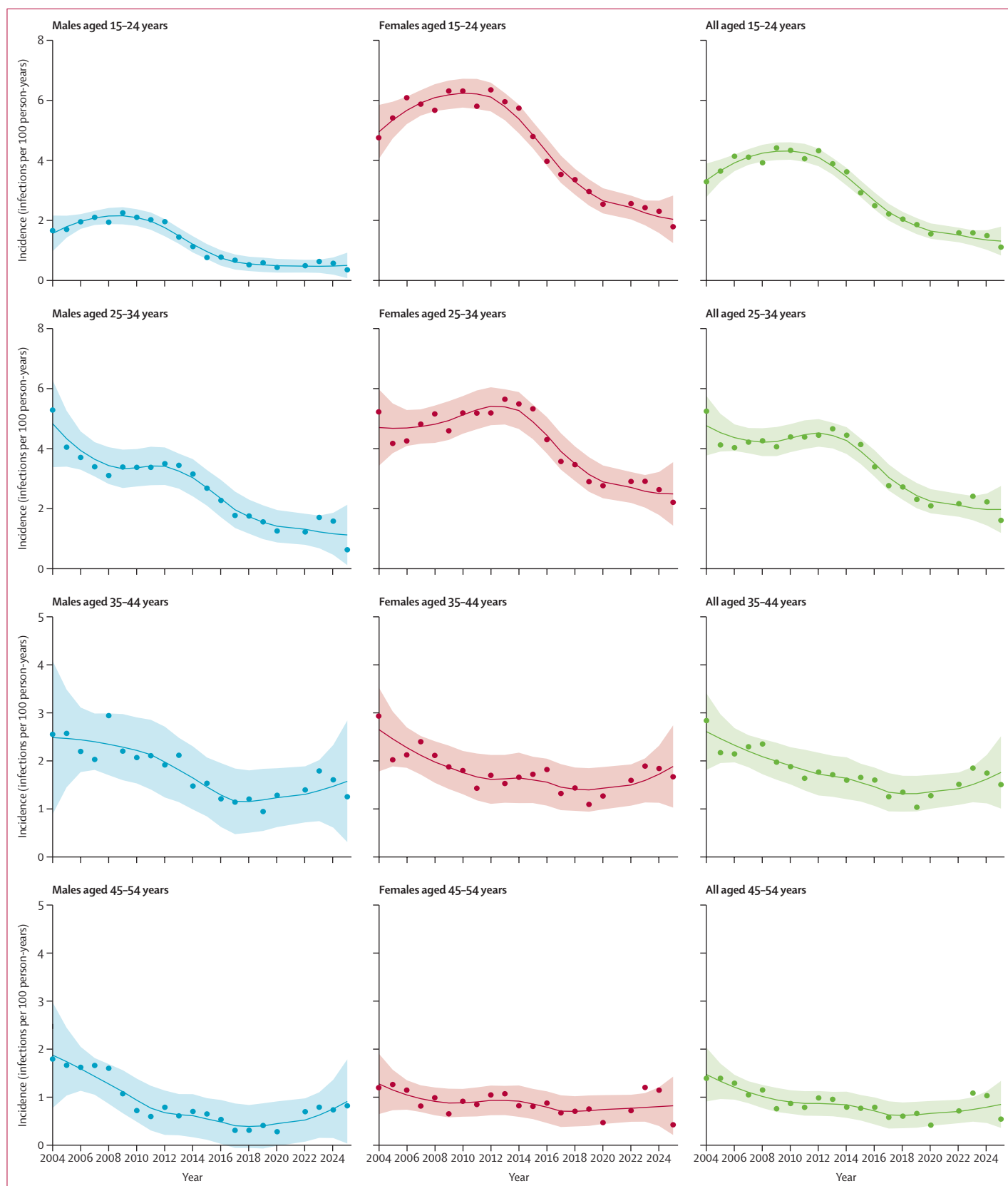


Figure 1: HIV incidence trends among males and females aged 15–54 years in the AHRI population cohort, 2004–25

Solid lines show LOESS-smoothed incidence trajectories and shaded areas are 95% CIs. The incidence point estimates are shown at the median testing date for each HIV survey round. AHRI=Africa Health Research Institute. LOESS=locally estimated scatterplot smoothing.

66·4% in 2010 and 80·3% in 2025 (appendix pp 5–6). From 2013 to 2018, overall annual HIV incidence rates declined by 52·2% in males and 36·9% in females. The initial decline in HIV incidence began around 2013 in males and 2015 in females. The most recent data reveal a stalling and in some cases a reversal of earlier progress, with HIV incidence rates plateauing in both males and females from 2019 to 2025 (figure 1). Comparing 2019 with the pooled 2024–25 estimate, HIV incidence in males was 0·93 infections per 100 person-years in 2019 and 0·86 per 100 person-years in 2024–25 (IRR 0·93, 95% CI 0·54–1·60), whereas in females, HIV incidence was 2·27 per 100 person-years in 2019 and 1·97 per 100 person-years in 2024–25 (IRR 0·87, 95% CI 0·63–1·21). When annual incidence rates in 2022–25 were jointly compared with those observed in 2019, we found no evidence of differences in HIV incidence among either females (global Wald test $p=0·705$) or males (global Wald test $p=0·683$), indicating that incidence remained stable during this period.

When decomposed by age and sex (figure 2), recent (2019–25) increases in HIV incidence, or an absence of decline, in the older age groups (age 35–54 years) offset the continued HIV incidence declines among the younger age groups (age 15–34 years). Overall HIV incidence declined from 3·32 (95% CI 2·96–3·68) new infections per 100 person-years in 2010 to 1·49 (1·26–1·72) per 100 person-years in 2024–25, a decline of 55%; however, this decline remains 35 percentage points lower than the UNAIDS target of 90% incidence reduction by 2030 relative to 2010.¹ HIV incidence estimates obtained from the inverse probability weighted regression (300 imputed datasets) to account for possible systematic differences in participation over the study period were similar to those from the primary analysis and did not have any material effect on our findings (appendix p 3).



Over the course of the study, cumulative risk of HIV acquisition by age 54 years also declined across both sexes but remained substantial in the 2019–25 period (figure 3). Given the age-specific HIV incidence rates observed in the 2004–13 period, an adolescent female aged 15 years would be facing a 75·3% (95% CI 67·8–82·7) cumulative risk of acquiring HIV by age 54 years (in the absence of competing risk of death) compared with a risk of 59·5% (52·3–66·6) for her male counterparts (figure 3A). During the 2019–25 period, the cumulative risk dropped substantially but nevertheless remained high at 53·0% (46·0–59·9) for females and 32·0% (26·3–37·8) for males (figure 3C). The greatest absolute sex disparity in cumulative risk of infection occurred in the 2014–18 period where cumulative risk differed by 29·6 percentage points by age 54 years.

Across 11 rounds of population viral load testing conducted between 2011 and 2025, we analysed a median of 2183 (IQR 1830–2789) HIV-positive samples per survey round. Between 2011 and 2018, population detectable viraemia dropped by 44·5% among males (from 74·9% in 2011 to 41·6% in 2018) and by 50·5% among females (from 69·9% to 34·6%; figure 4A; appendix p 7). Over the entire period (2011–25), population detectable viraemia remained consistently lower among females than males, with an average difference of 7·1 percentage points. After the initial steep decline between 2011 and 2018, population detectable viraemia increased from 2019 to 2025 by 10·1 percentage points in women (OR 1·59; $p<0\cdot0001$) and by 9·1 percentage points in men (OR 1·68; $p=0\cdot018$). Over this period among both sexes, population detectable viraemia increased by 9·6 percentage points (95% CI 5·4–13·8), remaining an estimated 30·7 percentage points (27·2–34·3) below the UNAIDS implied 95–95–95 population viral suppression target of 85·7%. Similarly, between 2011 and 2018, the proportion of the population with HIV transmission potential declined by 41·7% (from 12·6% in 2011 to 7·4% in 2018) in males and by 41·9% in females (from 23·6% to 13·7%). Between 2019 and 2025, the proportion of the population with HIV transmission potential decreased slightly by 1·7 percentage points in males but increased by 3·0 percentage points in females, remaining higher among females than males throughout the period (17·3% in females vs 9·8% in males in 2025), reflecting the persistently higher HIV prevalence among females (figure 4B).

The incidence-to-prevalence ratio showed a large decline from 2006 to 2018, after which levels began to stabilise (figure 5). The ratio decreased dramatically across consecutive survey rounds, falling from 0·132

(95% CI 0·114–0·152) in 2006 to its lowest recorded value of 0·034 (0·028–0·042) in 2022; this represents an overall 74·2% decline and approaches the 0·03 benchmark that

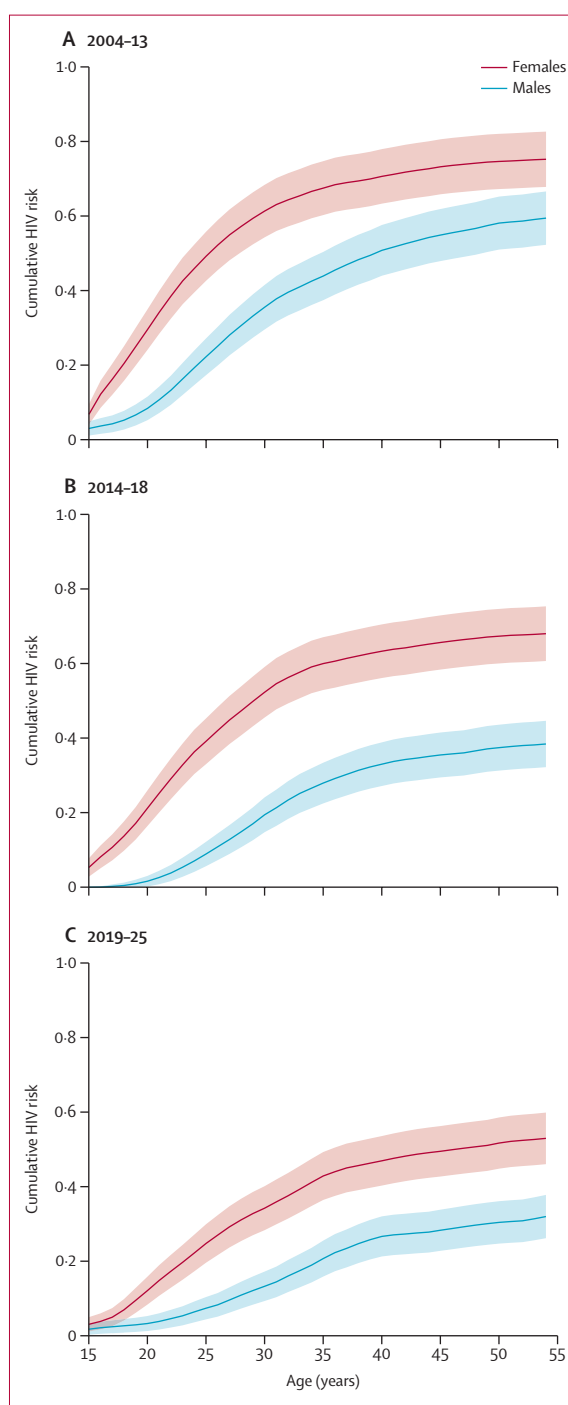


Figure 3: Cumulative risk of HIV acquisition by sex and time period in the AHRI population cohort
Panels show cumulative lifetime risk of HIV acquisition (from ages 15 years to age 54 years) estimated under observed age-specific incidence rates for three periods: 2004–13, 2014–18, and 2019–25. Shaded areas indicate 95% CIs. AHRI=Africa Health Research Institute.

Figure 2: Age-specific and sex-specific HIV incidence trends in the AHRI population cohort, 2004–25

Solid lines show LOESS-smoothed annual incidence trends and shaded areas are 95% CIs. Note that scales on y-axes differ between plots. AHRI=Africa Health Research Institute. LOESS=locally estimated scatterplot smoothing.

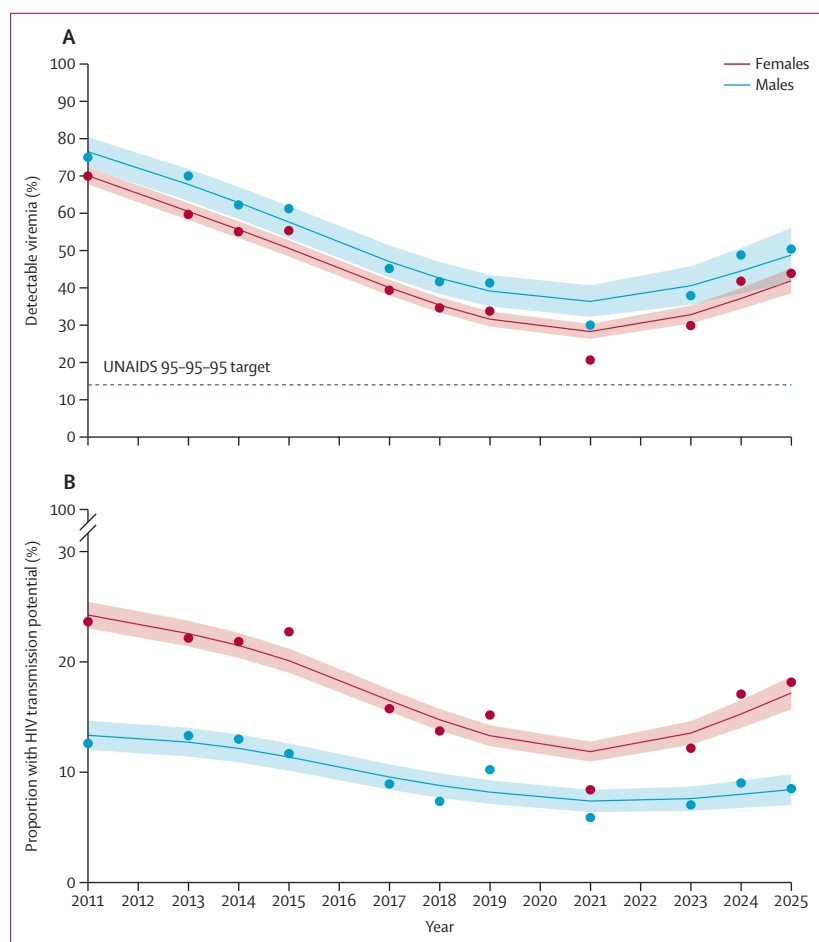


Figure 4: Population trends in detectable viraemia and proportion of the population with HIV transmission potential by sex in the AHRI cohort in rural KwaZulu-Natal, South Africa, 2011–25
 (A) Detectable viraemia was defined as the proportion of people with HIV with a valid viral load measurement who had a detectable viral load (>1550 copies per mL). (B) The proportion of all adults (with HIV and without HIV) in the population who can theoretically transmit HIV. Solid lines represent spline smoothed trends and shaded areas are 95% CIs. Note that scales on y-axes differ between plots. AHRI=Africa Health Research Institute.

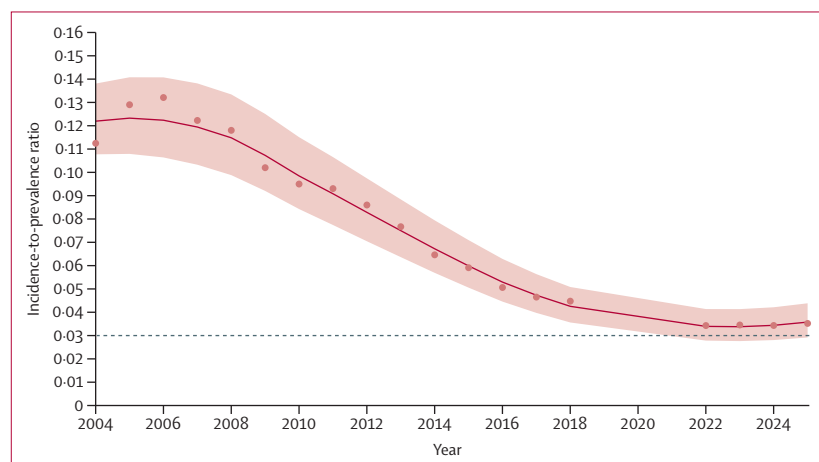


Figure 5: Population trends in the incidence-to-prevalence ratio in the AHRI population cohort, 2004–25
 Shaded areas are 95% CIs. The dashed horizontal line indicates the epidemic control benchmark of 0.03. AHRI=Africa Health Research Institute.

has been considered indicative of some level of epidemic control. After 2022, the index showed a modest increase, remaining above the epidemic control benchmark of 0.03.²³

Discussion

Our analyses of more than two decades of HIV testing data from a population cohort in rural South Africa reveal troubling trends in the state of the HIV epidemic. Although major strides have been made, our findings show that progress across three key HIV epidemic metrics has stalled (and in some cases begun to reverse) in recent years. Firstly, after steep reductions in incidence from 2013 to 2018, following the scale-up of ART and circumcision,^{10,24} incidence rates for both males and females showed little or no decrease from 2019 onwards. Although incidence trends have continued to decline in younger adults (age 15–34 years) since 2019, these gains have been offset by flattening and, in some cases, increasing trends in HIV incidence among older adults (age 35–54 years). Most new HIV infections are in females, and lifetime risk of infection in the 2019–25 period remains at over 50% for females. Between 2010 and 2025, the observed incidence decline was an estimated 35 percentage points lower than the UNAIDS target of 90% incidence reduction by 2030.¹ Moreover, HIV incidence in 2024–25 exceeds the functional elimination threshold of one infection per 1000 person-years²³ by about nine-fold in males and 20-fold in females. Secondly, population-level detectable viraemia increased between 2019 and 2025, after nearly a decade of steady improvement, and in 2025 was estimated at more than 30 percentage points lower than the implied 95–95–95 population viral suppression target of 85.7%. When evaluated in the context of the entire population, an estimated 8% of adult males and 18% of adult females (age 15–54 years) were theoretically capable of transmitting HIV in 2025, thus threatening the durability of treatment-as-prevention strategies. Finally, the incidence-to-prevalence ratio, which was steadily approaching the epidemic control benchmark of 0.03, has stalled above the benchmark.

The underlying causes of the loss of momentum (and in some cases reversal) observed across multiple epidemic indicators starting around 2019 are likely multifactorial. First, early gains reached during ART scale-up might have reached a saturation point in some populations, making further declines increasingly difficult to sustain as ongoing transmission becomes concentrated in harder-to-reach groups. At the same time, disruptions to HIV prevention and treatment services due to the COVID-19 pandemic likely widened gaps in treatment coverage and viral suppression.⁶ For example, in the same population as the present study, we have previously documented in a preprint a greater than two-fold increase in HIV-related mortality during the COVID-19 period, with a disproportionately greater rise among men than women.²⁵ Second, the ageing of the epidemic has shifted the burden of new infections towards increasingly older

adults, who might be less likely to perceive themselves at risk and remain underserved by existing prevention programmes. Rising HIV prevalence in older age groups²⁶ increases HIV exposure risk in these groups given the predominantly age-assortative sexual mixing patterns,²⁷ whereas targeted prevention programmes for younger adults (especially adolescent girls and young women) might have contributed to the greater declines observed in younger populations.²⁸ Finally, behavioural changes, including declines in condom distribution reported in some settings, might also have contributed by making earlier reductions in transmission more difficult to sustain.²⁹ Importantly, because our data extend to May, 2025, these findings are unlikely to reflect the effects of the January 2025 PEPFAR-related funding cuts and therefore provide a baseline against which future post-funding cut epidemic trends can be evaluated.

Our findings stand in contrast to estimates obtained from the 2022 *Sixth South African National HIV Prevalence, Incidence, Behaviour and Communication Survey*,¹¹ which reported declining incidence and improving population viral suppression (defined as >1000 copies per mL) nationally since the previous survey in 2017. Data from the AHRI population cohort showed no evidence of a decrease in HIV incidence between 2019 and 2024–25 and markedly lower population viral suppression (68·6% in 2023) than the KwaZulu-Natal provincial estimate from the 2022–23 national survey (86·8%).¹¹ These differences likely reflect the distinct methodologies and populations captured by the two data sources: national surveys provide broad, cross-sectional snapshots designed for provincial and national representativeness, whereas AHRI's population-based testing platform uses the gold-standard approach of the ongoing testing of a complete population to directly observe individual HIV seroconversions in repeat testers. This detailed follow-up can reveal gaps in treatment and persistent transmission risks that are masked in more aggregated national data. Notably, HIV incidence estimates in the national survey were based on an HIV incidence algorithm with a limited-antigen avidity assay combined with information on laboratory detection and self-reported ART use, HIV viral load, and previous HIV testing history.¹¹ In the AHRI population cohort, previous work by our group showed the population-level effects of ART and medical male circumcision scale-up on HIV incidence declines, but with persistent sex disparities and incomplete viral suppression.^{9,30} This study adds important new evidence by leveraging population-based data up to 2025, including observations both during and after the COVID-19 pandemic,⁶ and highlights a recent, unappreciated reversal in progress in South Africa's HIV response. Against this backdrop, despite 1·34 million oral PrEP initiations by late 2024 in South Africa,³¹ real-world uptake and adherence remain inadequate among those at highest risk, such as adolescent girls. In high-burden provinces such as KwaZulu-Natal, widespread discontinuation and inconsistent adherence of daily oral PrEP among

adolescents and young adults undermine its preventive potential.³¹

The principal strength of this study lies in its power to provide a longitudinal view of the HIV epidemic, spanning over two decades, through the AHRI population platform. Few other cohort studies combine annual, population-wide HIV testing and population-based viral load monitoring, allowing for measurement of true population-level HIV incidence through direct observation of seroconversions and assessment of detectable viraemia with fine resolution. An overarching strength of population-based cohort designs that enrol and prospectively follow up complete populations over decades is that they generate representative data on both disease outcomes and the evolving sociodemographic, behavioural, and community-level determinants of risk, irrespective of whether individuals choose to attend care. These designs therefore eliminate many of the biases commonly inherent in clinic-based studies and provide a strong foundation for robust assessment of population-level effects.

However, this study is not without limitations. Firstly, potential biases might arise if there are systematic differences in participation by subgroups with different risk profiles over time. In the AHRI cohort, 69·6% of those observed to be HIV negative and recontacted were subsequently retested. To address the possibility of bias affecting our findings, we applied inverse probability weighting in the Poisson regression models. These resulting incidence estimates varied little from the estimates reported in our primary analysis, strengthening the robustness of our findings. Moreover, it is unlikely that any existing testing bias could simultaneously and consistently shift all metrics (and their derivatives) in the same direction at a similar crucial juncture in a manner that does not disrupt their internal epidemiological coherence; nevertheless, we cannot completely exclude this possibility. As noted previously, dried blood spot samples were also collected via a separate community-based survey within the same population.²² However, the 2018 and 2019 population viral load results differed by only 0·4%; therefore, this temporary shift in testing methodology did not materially affect our viral load trajectory findings.

Secondly, tracking some epidemic metrics over the long term has sometimes been critiqued because of the difficulty of disentangling the influence of demography and other changes on the overall trend.²³ These potential effects, however, would not bias our findings during the most recent period where changes in the population would be small. Moreover, the use of a metric such as the cumulative risk of infection is robust to changes in the composition of the population over time because the metric calculates cumulative HIV risk for an individual across the life course.³² Thus, the use of complementary methods and metrics, each with their own strengths and potential weaknesses when used in isolation, provides a

more coherent combined picture, enhancing the robustness and concordance of our findings. Finally, our findings reflect epidemiological trends in one high-burden rural community, and these trends might not generalise to South Africa. Indeed, our group has shown remarkable spatial heterogeneity in HIV outcomes both locally within this population³³ as well as variations nationally.³⁴ Nevertheless, the size and continuity of this cohort in the country's most severely affected region provide some of the most robust real-world evidence available on the trajectory of the HIV epidemic over time that might not be evident from large-scale national surveys.

Taken together, our findings challenge the narrative that South Africa is steadily progressing towards epidemic control and has continued to move closer to the UNAIDS 2030 targets.¹ Rather, data from one of the world's largest population-based HIV cohorts provide early warning signs that the current HIV response will not suffice to drive the epidemic towards low levels of endemicity. Considering the shifting epidemiology and political will and the recent reduction or elimination of international assistance, South Africa should look beyond 2030 and prepare itself for the next several decades of public health response. First, South Africa should implement robust prevention options to cater for different risk groups. Consistent with our previous work,³⁵ this research has shown an increasing trend in HIV incidence in adults aged 35–44 years, whereas many prevention efforts focus on younger adults. This shift in age of peak HIV incidence towards increasingly older adults means that individuals are becoming vulnerable to acquiring HIV throughout the life course, thus contributing to the unacceptably high cumulative risk of infection of greater than 50% in females by age 54 years. These findings underscore the need for a broader demographic approach to HIV prevention, with interventions tailored to different age groups and transmission dynamics. Indeed, our previous work in this setting,^{27,36} and elsewhere in KwaZulu-Natal,³⁷ supports the observation that the dominant HIV transmission pathway for young women aged 15–30 years is from slightly older men aged 30–35 years, whereas for men aged 30–34 years the largest source of infection is from women in a similar age group. Second, the recent increase in population-level detectable viraemia, particularly in 2023–25, underscores the need for redoubled efforts in initiating and maintaining effective ART. To maximise the benefit of treatment as prevention, flexible health systems and patient-centred care models could help to minimise treatment interruptions. Third, the fragility of global health funding highlights the urgency of securing robust domestic health financing. Without stable funding, even small interruptions in HIV treatment and prevention programmes risk undoing decades of progress. For example, we recently quantified the effects of HIV treatment services in South Africa

after disruptions to US global health assistance had resulted in a net HIV treatment loss of 94881 patients (–3.9% between fiscal year 2024 and fiscal year 2025) at PEPFAR-supported sites.³⁸ Finally, population-based HIV testing platforms remain crucial for understanding and monitoring the HIV response. Cohorts such as the AHRI platform offer important insights into how the epidemic shifts beneath the surface and provide empirical data needed to recalibrate HIV prevention strategies.

Our study provides a stark warning on prevailing HIV trends in rural South Africa, where ground is being lost in the fight against the HIV epidemic. Novel ways of increasing population viral suppression are needed, alongside primary prevention through services such as voluntary male medical circumcision, provision of condoms, treatment of genital ulcerative diseases, expanded PrEP method mix, and social and behavioural interventions to reduce vulnerability and stigma. As the HIV epidemic continues to evolve, priority populations and response strategies should also change to reach sustained epidemic control. Without renewed political focus, the recent massive reduction in global financial support for the HIV response could further exacerbate the HIV epidemic trends we observe here, putting South Africa at risk of reverting to an HIV epidemic with high incidence and mortality.

Contributors

FCT conceptualised and designed the study, secured funding, provided resources, supervised the project, and led the writing and editing of the manuscript. EO conducted the statistical analyses of the HIV incidence data and contributed to drafting the manuscript. MO conducted the statistical analyses of the population viral load data and contributed to drafting the manuscript. KH and DG were responsible for data curation and data access. AD oversaw and contributed to the statistical methodology. FCT, KHT, MO, and EO drafted the first version of the manuscript. PM, MI, DC, AB, TB, AT, H-YK, and HM contributed to interpretation of the findings and critically reviewed the manuscript. All authors reviewed and approved the final version of the manuscript. EO and MO have accessed and verified the data. All authors had access to the data and were responsible for the decision to submit the manuscript for publication.

Declaration of interests

KHT was supported by the National Institute of Allergy and Infectious Diseases of the National Institutes of Health (K01AI193303). All other authors declare no competing interests.

Data sharing

The datasets used in this study have been deposited in the Africa Health Research Institute (AHRI) data repository (<https://data.ahri.org/index.php/home>). To access the licensed datasets, the applicant must agree to the terms and conditions of use by completing an application for access to a licensed dataset. This request will be reviewed by the AHRI Data Release Committee, who can decide to approve the request, to deny access to the data, or to request additional information from the applicant.

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