CONCEPTUALISING, DESCRIBING, AND ANALYSING THE IMPACTS OF STRUCTURAL DETERMINANTS ON HIV TRANSMISSION AMONG SEXUAL AND GENDER MINORITIES

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List of acronyms and abbreviations

AIDS – Acquired Immune Deficiency Syndrome

ACASI – audio computer-assisted self-interview

AUDIT-C – alcohol use disorders identification test, consumption questions

aRR – adjusted risk ratio

ART – antiretroviral therapy

CASI – computer-assisted self-interview

CDC – US Centers for Disease Control

CI – confidence interval

CrI – credible interval

GEE – generalised estimating equations

GLMM – generalised linear mixed-effects model

FSW – female sex workers

FTFI – face-to-face interview

HIV – human immunodeficiency virus

HPTN – HIV Prevention Trials Network

ILGA – International Lesbian, Gay, Bisexual, Trans and Intersex Association

IMAGE – Interventions with Microfinance for AIDS and Gender Equity

IPD – individual participant data

IPERGAY – Intervention Préventive de l'Exposition aux Risques avec et pour les Gays

IPV – intimate partner violence

LGBT+ – lesbian, gay, bisexual, transgender, and other people whose identities do not fit typical binary notions of male and female, or use other categories to describe their sexual or gender identity

MSM – men who have sex with men

MSW – male sex workers

OR – odds ratio

PAF – population attributable fraction

PARTNER – Partners of People on ART – A New Evaluation of the Risks

PHQ-9 – Patient Health Questionnaire, 9 question version

PLHIV – people living with HIV

PR – prevalence ratio

PEP – post-exposure prophylaxis

PrEP – pre-exposure prophylaxis

PWID – people who inject drugs

RCT – randomised controlled trial

RDS – respondent driven sampling

RR – risk ratio

SCMM – sequential conditional mean models

SGM – sexual and gender minority

STI – sexually transmitted infection

TGW – transgender women

tPAF – transmission population fraction

UI – uncertainty interval

US – United States

UNAIDS – Joint United Nations Programme on HIV/AIDS

VMMC – voluntary medical male circumcision

WHO – World Health Organization

Abstract

Over recent decades, global progress in reducing HIV incidence has been notable, yet significant barriers remain, particularly for key populations, including sexual and gender minorities (SGM) such as men who have sex with men (MSM) and transgender women (TGW). Key populations face increased risks of HIV due to intersecting biobehavioural and structural determinants including stigma, discrimination, violence, and criminalisation. In Africa, 31 countries criminalise SGM partnerships, and SGM are frequently victims of stigma, discrimination, and violence. These push SGM to the margins of society and hinder access to HIV services. In 2021, the Joint United Nations Programme for HIV/AIDS (UNAIDS) set new global 95-95-95 targets to "End AIDS" by 2030 by increasing HIV testing, treatment, and viral suppression to 95% each across all populations. To support these, concurrent societal enablers goals (the 10-10-10) were adopted. These aim to reduce the proportion of countries with punitive laws, PLHIV and key populations facing stigma and discrimination, and women and key populations experiencing violence to less than 10% each by 2025. Whereas the 95-95-95 targets were guided by mathematical models of HIV, the impact of the 10-10-10 on HIV is harder to ascertain. To better guide policy and monitor progress, quantitative evidence on structural determinants and their impacts on HIV among SGM could be strengthened. My thesis aims to fill these gaps by conceptualising how to model structural determinants, describing HIV epidemiology among SGM, and analysing the impact of some structural determinants on HIV incidence among SGM.

In my first manuscript, I conceptualised pathways from structural determinants to HIV via sexual and health-seeking behaviors that mediate the relationship. I conducted a scoping review of transmission dynamics models that considered such pathways. Only 17 models have done this, and most used simple assumptions about pathways, simulated few mediators, and relied on cross-sectional data to inform the structural determinants parameters. Using this, I developed a methodological framework to guide the inclusion of structural determinants in HIV models, identifying the data needed to improve models going forward.

In my second manuscript, I systematically reviewed and meta-analysed trends in the proportion of SGM across Africa accessing HIV testing and treatment, and trends in HIV incidence, providing an exhaustive description of HIV epidemiology among SGM there. I pooled

data from 152 studies in 31 countries (2003-2020). Despite higher HIV testing and treatment over time, viral suppression and HIV incidence did not appear to change. I estimated that in 2020, 1 in 5 SGM living with HIV were not virally suppressed, while incidence was 27-199 times higher than among men in the total population, depending on region.

In my third manuscript, I meta-analysed individual-level data from three cohort studies of SGM in Africa (2015-2018): *Anza Mapema*, *HPTN 075*, and *CohMSM*. Using data on 1,590 SGM not living with HIV in 7 countries and sequential conditional mean models, I found links between sexual and gender minority violence (SGM violence) reported at baseline and moderate-to-severe depressive symptoms at any follow-up visit (RR=1.5, 95%CI: 1.1-1.9), between SGM violence reported during follow-up and depression at the same visit (RR=1.9, 1.5-2.4), and between depression and hazardous drinking at the same visit (RR=1.3, 1.1-1.5).

My thesis findings have implications for global HIV prevention among key populations. They provide a framework to improve the next generation of mathematical models of structural determinants, show that SGM continue to share a disproportionate HIV burden, and that reducing violence could support the mental health of SGM and HIV prevention. Addressing structural determinants among SGM may help achieve global HIV targets.

Resumé

Au cours des dernières décennies, des progrès substantiels ont été réalisés dans la réduction de l'incidence du VIH dans le monde. Malgré ces avancées, des obstacles importants à la prévention et le traitement du VIH persistent, en particulier pour les populations clés, notamment les hommes ayant des rapports sexuels avec d'autres hommes (HSH) et les femmes transgenre (FTG). Ces personnes sont confrontées à un risque accru de contracter le VIH et de le transmettre en raison de déterminants bio-comportementaux et structurels, notamment la stigmatisation, la discrimination, la violence, de même que la criminalisation des relations sexuelles entre hommes. En Afrique, 31 pays criminalisent toujours les rapports sexuels entre personnes de même sexe. Des enquêtes montrent que les HSH sont fréquemment victimes de stigmatisation, de discrimination et de violence. Ces facteurs marginalisent les HSH et entravent leur accès aux services essentiels de prévention et traitement du VIH. En 2021, le Programme commun des Nations Unies sur le VIH/sida (ONUSIDA) a fixé de nouveaux objectifs mondiaux 95-95-95 qui permettront de « *mettre fin au sida* » d'ici 2030 en augmentant le dépistage du VIH, le recours au traitement et la suppression virale à 95 % dans toutes les populations. Pour soutenir ces cibles, des moyens d'actions sociaux (c.-à-d. les objectifs 10-10-10) visant à réduire les expériences de stigmatisation, de discrimination et de violence à moins de 10 % parmi les populations clés d'ici 2025 ont été adoptés. Les objectifs 95-95-95 ont été guidés par des modèles mathématiques, mais estimer l'impact de la réalisation des 10-10-10 est ardu. Les données probantes sur l'impact des déterminants structurels sur HIV chez les HSH doivent être renforcées. Ma thèse vise à combler ces lacunes en conceptualisant comment inclure les déterminants structurels dans les modèles mathématiques, en décrivant l'état actuel de l'épidémiologie du VIH chez les HSH et en analysant l'impact de certains déterminants structurels sur l'incidence du VIH chez les HSH.

Dans mon premier manuscrit, j'ai conceptualisé les chaînes causales –des déterminants structurels à l'acquisition du VIH– via les comportements sexuels et de santé qui modèrent cette relation. J'ai effectué une revue de la portée de 17 modèles mathématiques de dynamique de transmission qui ont pris en compte ces chaînes. Sur cette base, j'ai développé un cadre méthodologique pour guider l'inclusion des déterminants structurels dans les modèles du VIH, en identifiant les données nécessaires pour informer la prochaine génération de modèles.

Dans mon deuxième manuscrit, j'ai mené une revue systématique et performé une méta-analyse pour décrire les tendances temporelles sur la proportion d'HSH en Afrique accédant les services de dépistage et de traitement du VIH. J'ai également méta-analyser les tendances d'incidence du VIH, fournissant une description exhaustive de l'épidémiologie du VIH chez les HSH de la région. J'ai regroupé les données de 152 études menées dans 31 pays (2003-2020). Malgré l'augmentation du dépistage du VIH et de la couverture du traitement antirétroviral au fil du temps, j'ai estimé qu'un HSH sur cinq vivant avec le VIH n'avait pas de suppression virale en 2020, tandis que les taux d'incidence étaient 27 à 199 fois plus élevés que chez les hommes de la population totale, selon la région.

Dans mon troisième manuscrit, j'ai effectué une méta-analyse des données individuelles issues de trois études de cohorte prospectives sur les HSH et les femmes transgenres en Afrique (2015-2018): *CohMSM, HPTN 075* et *Anza Mapema*. En analysant les données de 1,590 participants non séropositifs dans 7 pays à l'aide de modèles séquentiels conditionnels moyens, j'ai trouvé des liens entre l'expérience de la violence envers les minorités sexuelles et de genre (violence SGM) rapportée à l'inclusion et des symptômes dépressifs modérés à sévères à n'importe quelle visite de suivi (RR=1,5, IC à 95%: 1,1-1,9), entre la violence SGM rapportée pendant le suivi et la dépression lors de la même visite (RR=1,9; IC à 95%: 1,5-2,4), ainsi qu'entre la dépression et la consommation excessive d'alcool lors de la même visite (RR=1,3, IC à 95%: 1,1-1,5).

Les résultats de ma thèse ont des implications importantes pour les politiques globales de prévention du VIH parmi les populations clés. Ils fournissent un cadre pour améliorer la prochaine génération de modèles mathématiques afin d'évaluer les impacts des déterminants structurels, montrent que les HSH continuent de porter une charge disproportionnée du VIH et que la réduction de la violence et l'amélioration de la santé mentale des HSH pourraient soutenir la prévention du VIH. S'attaquer aux déterminants structurels chez les HSH pourrait aider à atteindre les objectifs mondiaux de lutte contre le VIH.

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My thesis explores how structural determinants affect HIV risk among sexual and gender minorities. First and foremost, I therefore want to extend my gratitude to everyone involved in the studies that made the work in my thesis possible. This includes the dedicated researchers who conducted the studies in Africa and, most importantly, the sexual and gender minority participants who generously shared their experiences and time, often at great personal risk. Your bravery and contribution are at the heart of this work. I hope this research helps contribute to creating a world where sexual and gender minorities can live authentically and with dignity, free from stigma, discrimination, and violence.

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Contribution to original knowledge

The research in this thesis is original and provides new evidence on structural determinants and their relationship with HIV among SGM. Specifically, my first manuscript updates our understanding of how structural determinants might be linked to HIV outcomes and provides novel conceptual and methodological frameworks and recommendations for improved analyses of these factors. My second and third manuscripts implement some of these recommendations. Manuscript 2 fills evidence gaps on time trends and disparities in HIV incidence, and engagement with testing and the HIV treatment cascade – knowledge of status, treatment and care, viral suppression – among SGM in Africa. Finally, Manuscript 3 provides new estimates of the impacts of sexual and gender minority violence on depression, hazardous drinking, condom use, and HIV acquisition among SGM in cohort studies and is one of the first studies estimating longitudinal effects of structural determinants among SGM in Africa.

The following three manuscripts are presented in my thesis:

[1] Stannah J, Flores Anato JL, Pickles M, Larmarange J, Mitchell KM, Artenie A, Dumchev K, Niangoran S, Platt L, Terris-Presthold F, Singh A, Stone J, Vickerman P, Phillipps A, Johnson L, Maheu-Giroux M, Boily M-C. (2024) From conceptualising to modelling structural determinants and interventions in HIV transmission dynamics models: a scoping review and methodological framework for evidence-based analyses. *BMC Medicine*. 22(1): 404.

[2] Stannah J, Soni N, Lam JK, Giguère K, Mitchell KM, Kronfli N, Larmarange J, Moh R, Nouaman M, Kouamé GM, Boily M-C, Maheu-Giroux M. (2023) Trends in HIV testing, the treatment cascade, and HIV incidence among men who have sex with men in Africa: a systematic review and meta-analysis. *The Lancet HIV*. 10(8): E528-E542.

[3] Stannah J, Knight J, Sandfort T, Laurent C, Otieno FO, Larmarange J, Coulaud P-J, Mudhune V, hamilton e, Cummings V, Spire B, Reynolds D, Dadabhai S, Okall D, Dembélé-Keita B, Sagaon-Teyssier L, Panchia R, Boily M-C, Maheu-Giroux M. (2024) The effect of sexual and gender minority violence on depression, hazardous drinking, condom use, and HIV acquisition: an individual participant data meta-analysis of the *CohMSM*, *HPTN 075*, and *Anza Mapema* cohort studies in Africa (Submitted.)

In addition to these papers, I co-authored eight other articles (including two as first author) during my PhD. These are included below for reference:

[1] Stannah J, Dale E, Elmes J, Staunton R, Beyrer C, Mitchell KM, Boily MC. (2019) HIV testing and engagement with the HIV treatment cascade among men who have sex with men in Africa: a systematic review and meta-analysis. *The Lancet HIV*. 6(11): e769-87.

[2] Stannah J, Silhol R, Elmes J, Owen B, Shacklett BL, Anton P, McGowan I, van der Straten A, Dimitrov D, Baggaley RF, Boily MC. (2020) Increases in HIV incidence following receptive anal intercourse among women: A systematic review and meta-analysis. *AIDS and Behavior*. 24: 667-81.

[3] Silhol R, Coupland H, Baggaley RF, Miller L, Staadegaard L, Gottlieb SL, **Stannah J**, Turner KM, Vickerman P, Hayes R, Mayaud P. (2021) What is the burden of heterosexually acquired HIV due to HSV-2? Global and regional model-based estimates of the proportion and number of HIV infections attributable to HSV-2 infection. *JAIDS Journal of Acquired Immune Deficiency Syndromes*. 88(1): 19-30.

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[5] Silhol R, Anderson RL, Stevens O, **Stannah J,** Booton RD, Baral S, Dimitrov D, Mitchell KM, Donnell D, Bershteyn A, Brown T. (2024) Measuring HIV acquisitions among partners of key populations: estimates from HIV transmission dynamic models. *JAIDS Journal of Acquired Immune Deficiency Syndromes*. 95(1S): e59-69.

[6] Stevens O, Sabin K, Anderson RL, Garcia SA, Willis K, Rao A. McIntyre AF, Fearon E, Grard E, Stuart-Brown A, Cowan F, Degenhardt L, **Stannah J**, Zhao J, Hakim AJ, Rucinski K, Sathane I, Boothe M, Atuhaire L, Nyasulu PS, Maheu-Giroux M, Platt L, Rice B, Hladik W, Baral S, Mahy M, Imai-Eaton JW. (2024) Population size, HIV prevalence, and antiretroviral therapy coverage among key populations in sub-Saharan Africa: collation and synthesis of survey data, 2010–23. *The Lancet Global Health*. 12(9): e1400-12.

[7] Stevens O, Anderson R, Stover J, Teng Y, **Stannah J**, Silhol R, Jones H, Booton RD, Martin-Hughes R, Johnson L, Maheu-Giroux M. (2024) Comparison of empirically derived and model-based estimates of key population HIV incidence and the distribution of new infections by Population Group in Sub-Saharan Africa. *JAIDS Journal of Acquired Immune Deficiency Syndromes*. 95(1S): e46-58.

[8] Pickles M, Mountain E, Bhattacharjee P, Kioko J, Musimbi J, Musyoki H, Gichangi P, **Stannah J**, Maheu-Giroux M, Becker M, Boily MC. (2024) Exploratory analysis of the potential impact of violence on HIV among female sex workers in Mombasa, Kenya: a mathematical modelling study. *BMC Medicine*. 22(1): 1-17.

Contribution of authors

Manuscript 1: James Stannah, Jorge Luis Flores Anato, Michael Pickles, Joseph Larmarange, Kate M Mitchell, Adelina Artenie, Kostyantyn Dumchev, Serge Niangoran, Lucy Platt, Fern Terris-Prestholt, Aditya Singh, Jack Stone, Peter Vickerman, Andrew Phillips, Leigh Johnson, Mathieu Maheu-Giroux, Marie-Claude Boily.

I conceptualised the study with my supervisors, Dr Mathieu Maheu-Giroux and Prof Marie-Claude Boily, my committee member Dr Joseph Larmarange, and with Dr Kate Mitchell – an epidemiologist with expertise in modelling HIV prevention among MSM. I conducted the scoping review, charted all studies and synthesised the information, with assistance from Jorge Luis Flores Anato. I then developed the conceptual and methological frameworks and drafted the initial manuscript. Dr Mike Pickles, Dr Adelina Artenie, Dr Jack Stone, Dr Peter Vickerman, Dr Andrew Phillips, and Dr Leigh Johnson are mathematical modellers with decades of experience between them modelling HIV and other infectious disease transmission among key populations. Dr Konstantyn Dumchev is an epidemiologist and Scientific Director at the Ukrainian Institute of Public Health Policy, with experience researching substance use and HIV in Ukraine. Dr Serge Niangoran is a HIV biostatistician with Programme PAC-CI in Côte d'Ivoire. Dr Lucy Platt is an epidemiologist whose research focuses on improving the health of marginalised populations including PWID and FSW. Dr Terris-Prestholt is an economist with UNAIDS with experience evaluating HIV prevention interventions. Aditya Singh is the India lead for the Johns Hopkins University School of Medicine's HIV programme ACCELLERATE and has experience managing and implementing domestic and donor-supported HIV intervention programmes for key populations in India. All coauthors provided substantive edits to the manuscript and read and approved the final version prior to submission for publication.

Manuscript 2: James Stannah, Nirali Soni, Jin Keng Stephen Lam, Katia Giguère, Kate M Mitchell, Nadine Kronfli, Joseph Larmarange, Raoul Moh, Marcellin Nouaman, Gérard Menan Kouamé, Marie-Claude Boily, Mathieu Maheu-Giroux.

I conceptualised this review and planned the analyses with my supervisors Dr Mathieu Maheu-Giroux and Prof Marie-Claude Boily, and my thesis committee member Dr Joseph Larmarange. I performed the literature search with Jin Keng Stephen Lam and Nirali Soni. We independently conducted all stages of study screening and extracted the study data. Dr Katia

Giguère is an epidemiologist with experience modelling the UNAIDS 95 targets, who double checked the data extraction with Nirali Soni. I conducted all the analyses, interpreted the results and drafted the initial manuscript, with guidance from my supervisors. Dr Nadine Kronfli is a clinician whose research focuses on increasing engagement along the HIV treatment cascade for marginalised populations. Dr Raoul Moh is the executive director of the Programme PAC-CI in Côte d'Ivoire. Drs Marcellin Nouaman and Gérard Menan Kouamé are epidemiologists at Programme PAC-CI. They made substantial contributions to the interpretation of the results and edited the manuscript. All authors had full access to all data in the study and read and approved the final version of the manuscript.

Manuscript 3: James Stannah, Jesse Knight, Theo Sandfort, Christian Laurent, Fredrick O Otieno, Joseph Larmarange, Pierre-Julien Coulaud, Victor Mudhune, erica hamilton, Vanessa Cummings, Bruno Spire, Doeriyah Reynolds, Duncan Okall, Bintou Dembélé-Keita, Luis Sagaon-Teyssier, Ravindre Panchia, Sufia Dadabhai, Marie-Claude Boily, Mathieu Maheu-Giroux.

I conceptualised the individual participant data meta-analysis with my supervisors, Dr Mathieu Maheu-Giroux and Prof Marie-Claude Boily, and my thesis committee member Dr Joseph Larmarange. Dr Jesse Knight is a mathematical modeller with expertise in assessing how common assumptions in HIV models influence their outputs, who provided guidance during the longitudinal data analyses. Fredrick Otieno is the principal investigator of the *Anza Mapema* study, and Dr Duncan Okall is a collaborator. Dr Christian Laurent is the principal investigator of the *CohMSM* study, and Dr Pierre-Julien Coulaud, Dr Bruno Spire, Dr Luis Sagaon-Teyssier, and Bintou Dembélé-Keita are collaborators. Dr Theo Sandfort is the principal investigator of the *HPTN 075* study, and Victor Mudhune, erica hamilton, Vanessa Cummings, Doeriyah Reynolds, Ravindre Panchia, and Sufia Dadabhai are collaborators. All authors made contributions to the interpretation of the results and manuscript.

1. Chapter 1: Introduction

1.1 Background

Acquired immunodeficiency syndrome (AIDS) was first identified in 1981 among gay men in the United States, with initial cases reported in cities such as Los Angeles, New York, and San Francisco.(1,2) Human immunodeficiency virus (HIV) was identified as its causative agent in 1983.(3) The early years of the AIDS crisis were characterised by pervasive stigma against sexual and gender minorities (SGM), which catalysed grassroots campaigns advocating for recognition, improved HIV prevention, and development of and access to effective AIDS treatment. These community-led efforts were instrumental in shaping the HIV responses in high-income countries.(4) In Africa, however, the predominant understanding of HIV transmission was through heterosexual contacts in the 1990s and even the 2000s. At that time, SGM in African countries were not explicitly included in local public health responses and policies.(5–8) To this day, the existence of SGM continues to be denied by political and other leaders in some countries.

When antiretroviral therapy (ART) first became available to treat HIV in 1996, only SGM in high income countries started accessing these life-saving treatments.(9) Although increased access since then has averted almost 21 million AIDS-related deaths, SGM and other key populations have not benefitted equally from improved treatment access such that a large burden of new HIV infections continues to fall upon these groups.(10) Key populations are groups particularly vulnerable to HIV acquisition and transmission, including SGM such as men who have sex with men (MSM), transgender women (TGW) and other transgender people, female sex workers (FSW), people who inject drugs (PWID), and incarcerated individuals, among others.(11) Members of key populations are at a greater risk of HIV acquisition and transmission due to intersecting biobehavioural and structural determinants, including criminalisation, stigma, discrimination, and violence that increase their vulnerability to HIV acquisition and are barriers to effective HIV prevention, treatment, and care.(12–14) In many regions, members of key populations have worse access to services than other people living with HIV (PLHIV).(15–18)

In 2021, the *Joint United Nations Programme on HIV/AIDS* (UNAIDS) put forwards the goal to "*End AIDS*" with ambitious objectives.(19) The 95-95-95 targets aim to increase to 95% the proportion of PLHIV aware of their status, those aware on treatment, and those on treatment achieving viral suppression, by 2025. Despite the initial focus on biomedical approaches to eliminate HIV as a public health threat, UNAIDS recognised the need to tackle the structural determinants that contribute to the spread of HIV. The 10-10-10 goals aim to reduce the proportion of countries with punitive laws and policies, the proportion of PLHIV and key populations experiencing stigma and discrimination, and the proportion of women and key populations experiencing violence to less than 10% each.(19) However, in Africa, 31 countries still criminalise same-sex sexual partnerships, and stigma is widespread.(8) SGM in Africa frequently report experiencing verbal, physical, and sexual violence perpetrated because of their sexual and gender identities or sexual behaviours (i.e., SGM violence).(20)

Pathways between structural determinants and risk and vulnerability to HIV for SGM are likely to be principally indirect, involving intermediate variables that mediate the effects of exposure. Structural determinants may deter SGM living with HIV from accessing the HIV treatment cascade: the steps from HIV testing through treatment necessary for achieving viral suppression and preventing onward transmission to sexual partners. The adverse mental health effects of stigma, discrimination, and violence may exacerbate sexual risk behaviours and make it harder to access condoms and other HIV prevention. Although qualitative studies have long acknowledged these impacts among SGM and other key populations, the pathways from structural determinants to HIV remain difficult to quantitatively assess.(21)

Since early in the AIDS pandemic, mathematical models – computer simulations of epidemics – have provided critical insights to inform global and local HIV responses.(22) Models have been used to estimate the basic reproduction number (R_0) of the virus in different populations, assess the influence of heterogeneity in sexual and other behaviours, and predict the effectiveness of HIV prevention approaches, such as early treatment initiation, treatment-as-prevention, and different PrEP strategies.(22–27) Mathematical models are useful, as they provide a framework for integrating information on individual characteristics, access to and effectiveness of HIV prevention and treatment, and population-level contact structures to generate a comprehensive understanding of how HIV spreads.(24) Models that incorporate estimates of the population-level impacts and individual-level effects of structural determinants

on HIV and other health outcomes could inform the development of structural interventions, although modelling of structural determinants is still in its infancy, and how best to incorporate structural determinants in models remains to be determined. A few modelling studies have attempted it using varied approaches and data sources: from cross-sectional studies to longitudinal ones that have estimated HIV incidence and sometimes collected information on structural determinants among SGM.(13,28) The availability of these modelling and observational studies allows me to address current knowledge gaps. My thesis seeks to understand how improving our understanding of structural determinants and their effects on HIV among SGM can improve mathematical models and help elucidate the potential population-level impacts of structural determinants and interventions on HIV transmission and acquisition among SGM.

1.2 Structure of this thesis

This manuscript-based thesis is organised around the following three objectives:

1) Conceptualise how structural determinants and their impacts on HIV acquisition and transmission through intermediate variables (mediators) could be included in dynamical mathematical models of HIV transmission to understand how structural determinants and their interventions could influence HIV epidemics.
2) Describe the current state of HIV epidemiology among men who have sex with men (MSM) in Africa and identify where barriers to HIV testing, treatment, and viral suppression exist.
3) Analyse the effects of exposure to sexual and gender minority verbal and/or physical violence on HIV incidence among SGM participants of three cohort studies in Africa.

My thesis is organised into seven chapters. Chapter 1 provides the introduction and objectives of the thesis. Chapter 2 is a literature review of HIV and structural determinants among SGM. Chapter 3 presents the methodological approaches taken, and a description of the main data sources. Chapter 4, 5, and 6 encompass my first, second, and third manuscripts, respectively. Finally, Chapter 7 discusses the findings of my manuscripts and contextualises efforts to address structural determinants for improving HIV prevention outcomes among SGM and other populations, in Africa and worldwide.

2. Chapter 2: Literature review

This chapter reviews HIV epidemiology, the importance of key populations, and HIV among sexual and gender minorities (SGM). I then describe structural determinants of HIV, including stigma, discrimination, and violence, and potential pathways linking structural determinants to HIV among SGM. Finally, I discuss structural interventions, and the remaining knowledge gaps.

2.1 HIV epidemics among key populations

The origins of HIV

The earliest cases of HIV are believed to have occurred at the beginning of the 20th century in western and central Africa, following the cross-species transmission of simian immunodeficiency viruses from African chimpanzees to humans.(29) HIV transmission among humans likely continued unrecognised for decades before being imported to Haiti, and then the USA, in the 1960-70s.(29)

Without treatment, HIV destroys CD4+ T-cells – white blood cells that play a central role in immune protection.(30,31) Typically, progression to AIDS occurs within 10 years of HIV acquisition, once CD4+ count has declined to a point where the immune system cannot fight back. Individuals with AIDS are susceptible to opportunistic infections and diseases such as opportunistic pneumonias, and rare malignancies, such as Kaposi's sarcoma, which were early indicators of AIDS recognised among men who have sex with men (MSM) in the 1980s.(1,32)

Initially, this cluster of symptoms now recognised as AIDS was referred to as the highly stigmatising "gay-related immune deficiency (GRID)" because it was wrongly thought to affect only gay men.(33) Exacerbating the odium this generated, the US Centers for Disease Control (CDC) caused controversy in 1982 when they notoriously described the "four H" groups most vulnerable to HIV as "homosexuals, heroin addicts, haemophiliacs, and Haitians". Although these groupings aimed to reflect the main modes of HIV transmission: sexual contacts (SGM), sharing of injection equipment (PWID), and blood transfusion (haemophiliacs), and the virus' migration route from Africa to North America (via Haiti), they immediately heightened stigma, discrimination, and racism towards members of these four groups.(34–36)

The earliest indication that HIV was spreading in Africa occurred in 1983 after Congolese immigrants to Belgium were diagnosed with AIDS.(37) Subsequent studies, starting in 1984, revealed a high prevalence of HIV in various settings, including Uganda, where a 1986 study found that over 35% of truck drivers were living with HIV and were presumed to have acquired HIV when buying sex.(37,38) Another study in 1986 identified a high prevalence of AIDS among female sex workers in Nairobi.(39) During the 1990s, new HIV acquisitions increased rapidly in Africa –initially spreading in eastern and central regions and then southern Africa– resulting in a sharp rise in HIV prevalence and associated morbidity and mortality. For instance, a cohort study in Uganda from 1989-90 found that HIV was responsible for 41% of adult deaths and over 70% of deaths among individuals aged 25-44 in the study.(40)

HIV prevalence continues to be high in Africa, although is highly heterogenous across regions and within countries. Generally, HIV prevalence has been higher in eastern and southern Africa compared to central and western Africa, and much lower in northern Africa.(41,42) Additionally, HIV prevalence is higher in urban areas than rural areas, and among those most vulnerable to HIV acquisition and transmission, known as key populations, who bear a disproportionate burden of HIV. (11,43,44) HIV surveillance and prevention programming for key populations including FSW has been a core component of the HIV response in Africa since the 1990s, although sexual and gender minorities (SGM) were not widely included in national HIV prevention programmes until the mid- to late 2000s.(5,45–47)

The role of key populations in HIV epidemics

Despite comprising a small proportion of their total national population, members of key populations often play crucial roles in the dynamics of HIV transmission. In 2021, members of key populations represented 70% of global new HIV infections.(48) Recently, it was estimated that approximately 7% of new HIV acquisitions in 2021 in sub-Saharan Africa were among SGM.(48,49) A key feature of the epidemics in sub-Saharan Africa is their diversity across settings, from what have been called “generalised” epidemics in eastern and southern Africa (with overall HIV prevalence >1%) to “concentrated” epidemics in central and western Africa.(50) In concentrated epidemics, HIV transmission primarily occurs within one or more sub-populations (e.g., key populations), characterised by an HIV prevalence of more than 5% within specific groups and less than 1% among the overall population, as indicated by the

prevalence among pregnant women attending antenatal clinics.(46,50) Under this framework, recommendations were that interventions in concentrated epidemic settings should aim to achieve high coverage among key populations, whereas in generalised epidemics interventions should target the general population.(51) However, the framework has been criticised for neglecting of the importance of key populations in HIV prevention.(52) Even in generalised epidemics, HIV prevalence may be disproportionately higher among key populations.(11) These "concentrated sub-epidemics" may contribute to the high HIV incidence in the total population, and reduce the effectiveness of population-based prevention.(52–55) For example, unmet prevention needs among SGM may contribute to ongoing HIV transmission at the population-level through their sexual partnerships with women. A recent systematic review found that between 23% and 58% of SGM in Africa also engage in sexual activity with women.(56) Focused interventions for SGM and other key populations therefore have the potential to reduce HIV transmission in the wider community regardless of HIV prevalence overall as well as to prevent HIV acquisition and transmission among SGM.(57).

2.2 HIV among sexual and gender minorities (SGM)

In this thesis, I use the term *sexual and gender minorities (SGM)* to refer to both *men who have sex with men (MSM)* and *transgender women (TGW)*. *Men who have sex with men (MSM)* is a term first introduced in 1992 to reflect a variety of sexual behaviours between men without referring to these men by their sexual orientation or gender identity.(17,58) The distinction was particularly important considering HIV's early mis-association with a gay sexual identity (as opposed to sexual behaviours), and because it emphasised that behaviours, not identities influence HIV risk.(17,21) MSM may include gay and bisexual men, heterosexual men who have sex with men, male sex workers, other men who have sex with men, and the traditional identities and terms for these men in different settings and cultures worldwide.(17) Women assigned male at birth but who identify and live as women are referred to as *transgender women (TGW)*. Historically, studies have often grouped MSM and TGW together due to shared sexual practices, such as receptive anal intercourse, and because the number of TGW participants recruited in SGM research has typically been small. However, TGW face unique vulnerabilities related to their gender that set them apart from MSM and necessitate distinct approaches to HIV prevention.(59) *Sexual and gender minorities (SGM)* has been suggested as a more inclusive

term, which can refer to both MSM and TGW.(60) It acknowledges the influence of sociopolitical contexts, addresses criticisms of the term MSM, which does not account for the diversity of identities that may have unique and important consequences for HIV vulnerability in different settings, and acknowledges the inclusion of TGW in many studies of MSM.(20,60) Women who have sex with women and transgender men are also SGM and experience structural barriers to HIV prevention, but the increased HIV risk for these groups has been less studied so far.(61,62)

Despite community, medical, and public health efforts going back many years, HIV prevalence and incidence remain disproportionately higher among SGM than men globally and particularly in sub-Saharan Africa, even in high-prevalence settings.(17,51,63) In 2022, the relative risk of acquiring HIV was 23 times higher for MSM than adults in the general population (aged 15-49), and 20 times higher for transgender people.(10,64) SGM are vulnerable to HIV acquisition partly because of the higher probability of HIV acquisition during receptive anal intercourse, which is estimated to be roughly 1% per-act (95%CI 0-3%) and 40% (95%CI 6-75%) per-partner.(65) Additionally, SGM may be both the insertive and receptive partner during sex.(66) Other individual-level risk factors for HIV acquisition among SGM have been well-documented and include condomless anal intercourse, a higher number of sexual partners, and using shared injection equipment.(4,17,67)

2.3 HIV prevention and treatment among SGM

The HIV prevention and treatment cascades

The HIV prevention and treatment cascades describe the steps in the continuum of care, providing a snapshot of the effectiveness of the healthcare system in preventing, diagnosing, and treating HIV (Figure 2.3.1).(68–70) For HIV prevention among SGM to be effective, SGM need to be made aware of their prevention needs, know about the existence of prevention methods, have access to them, and use them accurately (i.e., the prevention cascade).(70) Similarly, for HIV treatment and care to be impactful, SGM living with HIV need to test, be made aware of their status (i.e., diagnosed), linked to and enter care, and initiate and adhere to ART to achieve viral suppression (i.e., the treatment cascade; Figure 2.3.1).(68,71,72) However, at each step in

the cascades, individuals can be lost for several reasons, including the impact of structural determinants.

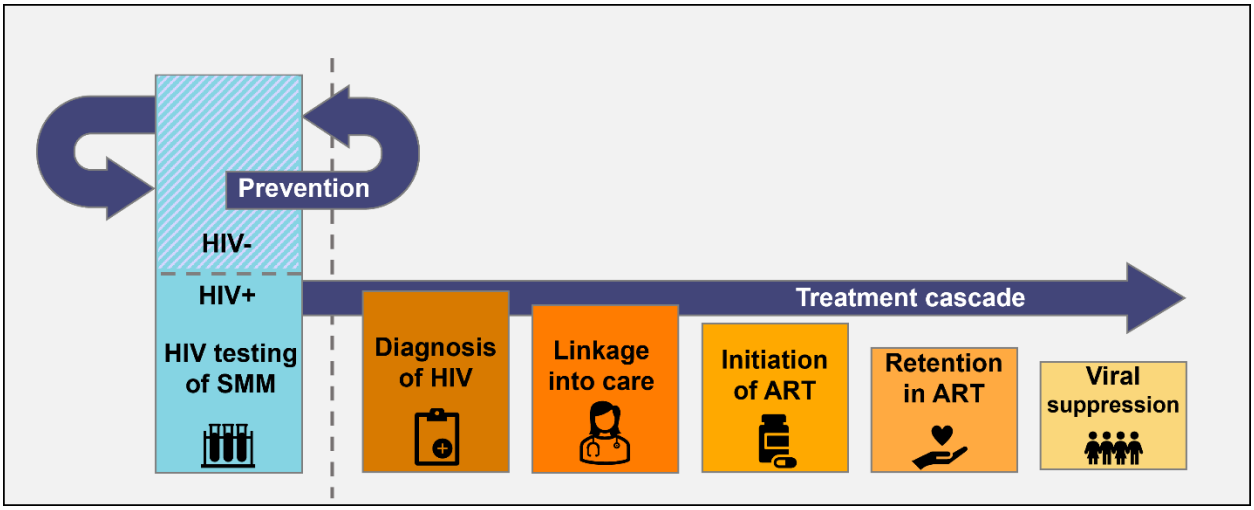

Figure 2.3.1. The HIV prevention and treatment cascade, from status-neutral HIV testing, to diagnosis, linkage to care, ART initiation and retention, and viral load suppression.

Behavioural prevention among SGM

In response to HIV, SGM have adopted various prevention strategies. Condom use is highly effective and may reduce the per-act risk of HIV acquisition during receptive anal intercourse by 78% compared with no condom use.(73,74). Despite this, condoms may not be the preferred prevention option as they can decrease perceived intimacy between sexual partners.(75) Further, lack of availability is a challenge to condom use for SGM in some settings, along with issues negotiating condoms with sexual partners, and condom slippage or breakage.(73,76,77) Other behavioral prevention strategies include seroadaptive practices such as serosorting, where individuals select HIV-concordant sexual partners, and seropositioning, which involves choosing sexual practices based on self and partner HIV status.(78,79) Voluntary medical male circumcision (VMMC) has also been considered in HIV prevention among SGM, although evidence of its effectiveness is mixed.(80,81) VMMC may prevent HIV acquisition during insertive but not receptive anal intercourse, meaning SGM who practice both may receive limited protection.(82)

Antiretrovirals for HIV treatment and prevention

ART first became available to treat HIV in 1996, after findings of its efficacy were presented at the Vancouver AIDS international meeting.(83) A combination of three antiretroviral medications was shown reduce the concentration of HIV in the blood to undetectable levels, leading to suppression of viral replication, enabling CD4+ counts to recover, preventing transition to AIDS.(31,84) Advances in HIV treatment and care since have led to dramatic reductions in HIV-related morbidity and mortality, significantly improving the quality and average life expectancy for PLHIV.(10) Today, with timely ART initiation, PLHIV on ART and virally suppressed can expect to live as long as those without HIV.(10)

Aside from saving lives, ART is also a powerful tool for preventing new HIV acquisitions. This was first recognised in 2008 in the 'Swiss statement'.(85) In 2011, the randomised controlled trial (RCT) HPTN 052, which followed over 1,600 heterosexual couples with one partner living with HIV for more than 10 years, found that ART reduced HIV transmissions to sexual partners by up to 96%.(86) Following these results, a strategy known as *Treatment as Prevention* (TasP), that recommended ART for all people living with HIV as early as possible regardless of CD4+ cell count, was adopted.(87) Three further studies, PARTNER, PARTNER2, and Opposites Attract, extended the findings of HPTN 052 to SGM couples, providing conclusive evidence to support U=U (undetectable=untransmissible) among SGM.(88–91) However, not everyone is benefitting equally from expanded access to ART, and it is increasingly recognised that biological and behavioural interventions alone may not be sufficient to halt HIV epidemics among SGM.(10)

More recently, other antiretroviral drugs have emerged as important components of HIV prevention among SGM. Post-exposure prophylaxis (PEP) is a four-week combination ART regimen started within 72 hours of potential exposure to HIV, to prevent seroconversion.(92) Pre-exposure prophylaxis (PrEP), on the other end, involves the provision of antiretroviral drugs prior to exposure to HIV. Since oral PrEP was introduced in 2012, it has drastically altered the HIV prevention landscape for SGM in some settings. The PROUD trial in the UK demonstrated that taking a combination of tenofovir and emtricitabine daily reduced HIV incidence among SGM by 86% (90%CI 64-96%).(93) Secondary analysis of the trial data, and analyses of the IPERGAY trial, suggest that when fully adherent, oral PrEP's effectiveness approaches 100% among SGM.(94–97) Very recently, results of a new trial for twice-yearly injectable lencapavir as PrEP among cisgender women found it gave 100% protection against HIV acquisition.(98)

2.4 Structural determinants of HIV among SGM

In 2023, over 9 million PLHIV were not receiving ART (out of 40 million PLHIV globally) and about 2 million on treatment were not virally suppressed.(10,64) If the current level of effort in the global HIV response is maintained, it is projected that by 2050, there will be 46 million PLHIV requiring ongoing treatment and care for HIV.(64) One reason HIV prevention and treatment efforts have not kept pace with new HIV acquisitions is insufficient focus on structural determinants of HIV. These are factors beyond an individual's control, including social, economic, political, legal, cultural, organisational, and physical factors that shape the diversity of HIV epidemics, helping to explain why HIV burden is higher in some countries, and within certain groups, than in others.(99,100) In many parts of the world, SGM face criminalisation, stigma, discrimination, violence, denial of HIV and other healthcare services, and exclusion from HIV prevention programmes.(8,33,101). For instance, stigma towards SGM has been linked to worse HIV testing uptake since the start of the global pandemic.(21) Other examples of structural determinants will differ by context but may include poverty, food insecurity, gender inequality, and inadequate access to education.(102–105) Structural determinants drive HIV transmission at the population-level by making it harder for individuals from certain groups to prevent HIV acquisition and transmission, and by limiting the availability, uptake, and consistent use of established prevention, treatment, and care services.(99)

Recent understandings of structural determinants of HIV among key populations have been informed by socio-ecological frameworks that encourage a focus on the interactions between structural determinants at different levels. The risk environment framework directs research to understand the social basis of drug-related harm and how structural determinants at macro- and micro-levels confer risk or protection among people who inject drugs (PWID), which has since been extended to FSW.(14,14,28,106) Another framework for FSW has further delineated how structural determinants operating at macrostructural, community organisation, and work environment levels intersect with downstream interpersonal and individual biological and behavioural determinants to affect HIV risk.(13,107)

Structural determinants in Africa

In Africa, 31 countries continue to criminalize sexual partnerships between SGM (Figure 2.4.1). Penalties for sex between men range from fines to long prison sentences, and even the

death penalty in some settings. An analysis of studies in 10 countries in western and central Africa between 2011 and 2020 found that HIV prevalence among SGM was approximately five times higher in criminalised settings that non-criminalised settings, 12 times higher in settings with recent prosecutions, and 10 times higher where SGM-related non-governmental organisations were blocked from registering or operating.(108)

Figure 2.4.1. Map of laws related to same-sex sexual partnerships between SGM in Africa. (Map generated using information from the International Lesbian, Gay, Bisexual, Trans, and Intersex Association (ILGA)(8))

Criminalisation exacerbates stigma, leading SGM to experience homophobia, exclusion, and in acute cases violence.(109) Stigma is the social process through which individuals or groups are labelled as different due to actual or perceived characteristics that are seen to deviate from social norms.(110) These labels are then associated with negative stereotypes, which are used to justify discrimination and lead to adverse outcomes for the targets of stigma. Stigma may be experienced in many different forms.(111) It may be enacted, perceived, anticipated, and/or internalised, and may occur in the community, within social and familial relationships, healthcare settings, and in the wider legal and political environments.(112) In an analysis of data among SGM from seven countries in western and southern Africa, 22% of SGM reported ever being afraid to seek healthcare and 18% had ever avoided healthcare for fear someone would learn they

have sex with men.(113) Emphasising how prevalent homophobic discrimination and violence is, 30% of SGM across the studies had ever been verbally harassed, 20% had ever been blackmailed, 12% had ever been physically hurt, and 10% had ever been raped, and the participants believed those experiences were related to the fact they have sex with men.(113) The prevalence of physical and verbal violence is generally high (>10% have ever experienced violence) in other studies of SGM in Africa, and may be higher among TGW compared to cisgender MSM.(114,115) In an analysis of eight African countries, TGW were 1.7 (95%CI 1.4-2.0) times more likely to have ever been beaten up and 2.0 (95%CI 1.6-2.4) times more likely to have ever been raped than cisgender MSM.(116) Other commonly cited examples of stigma include rejection and exclusion from relatives and peers, police harassment and abuse, fear to walk in public, among others.(113,117)

2.5 Current state of the policy landscape on structural determinants

Recent years have seen progress on LGBT+ rights in Africa in some countries with Namibia decriminalising same-sex relations in 2023, whereas Angola (2020), Botswana (2019), and Mozambique (2015) decriminalised several years earlier. Nevertheless, in some countries things are regressing. Nigeria introduced the Same-Sex Marriage Prohibition Act in 2014, which has since been linked to fear and avoidance of health care among SGM.(118) Uganda's 2023 Anti-Homosexuality Act allows the death sentence for certain types of consensual same-sex behaviours and has been upheld, despite international outcry.(119)

In 2015, the United Nations launched the Sustainable Development Goals, which recognised that ending HIV necessitates also tackling structural barriers including poverty, food and economic insecurity, lack of education, gender inequality, and access to justice.(120) In 2021, the UNAIDS Global AIDS Strategy 2021-2026 acknowledged that worsening inequalities were a key barrier to achieving global HIV prevention goals.(19) In response, the strategy called for bold action to tackle inequalities, announcing the ambitious 10-10-10 goals for societal enablers – social programmes, policies, and interventions that remove barriers to necessary HIV services.(121) The global strategy also committed to increasing community engagement in the delivery of HIV programmes, including those supporting societal enablers, which can increase uptake of HIV and other health services.(122) Nevertheless, to effectively tackle structural

barriers among SGM requires a clear understanding of how structural determinants influence HIV.

2.6 Pathways from structural determinants to HIV among SGM

Direct pathways

Some structural determinants may directly influence HIV risk. For instance, sexual violence directed at SGM may directly increase the risk of HIV acquisition, through increased probability of HIV transmission due to mucosal trauma.(123) In a study of SGM, those who reported ever have been raped by a man were over three times as likely to be living with HIV.(124) In another study in Malawi, SGM who had ever perpetrated rape were almost four times more likely to be living with HIV than non-perpetrators.(114)

Indirect pathways

Principally, however, structural determinants are likely to affect HIV acquisition and transmission risks through indirect causal pathways – those involving intermediate variables, or "mediators". Important mediators could differ by structural determinants, settings, and key populations. Studies have investigated indirect pathways to HIV acquisition among SGM involving mental health outcomes and sexual risk behaviours. Distal (i.e., upstream) structural determinants, including criminalisation of same-sex sexual partnerships and lower investment in HIV services for SGM are associated with greater experienced stigma.(125) Stigma, discrimination, and violence against SGM have been linked to depression(61,126–128), suicidal ideation(129,130), and substance use(20,128). Studies suggest these may be linked to HIV acquisition through mediators including a higher number of sexual partners and lower condom use, which are also linked to violence.(128,130) However, many studies are cross-sectional, which limits their ability to establish causality, due to potential confounding biases and the risk of reverse causation, which can obscure observed relationships.(131) Few longitudinal studies have investigated pathways. In the TRUST/RV368 cohort study in Nigeria, a path analysis – a form of structural equation modelling for mediation analysis – is one of the only longitudinal analyses to quantify pathways to HIV among SGM in Africa.(130) Stigma was measured as a categorical variable based on nine stigma indicators, and was linked to HIV acquisition through suicidal ideation and condomless sex with casual partners.(130) No studies have explored the

influence of the stigma indicators independently in Africa, including the effects of violence directed towards SGM because of their sexual and gender minority status (SGM violence).

Structural determinants may also influence pathways to HIV transmission. SGM who experience stigma often report fear of seeking health care and avoid seeking services to prevent the disclosure of their sexual behaviours.(132–135) Studies suggest healthcare stigma is common among SGM in Africa and may reduce engagement with HIV testing to avoid stigmatisation.(136,137) This may delay diagnosis and initiation onto ART, which are critical steps of the treatment cascade. Stigma among SGM is also linked to lower ART adherence.(138)

2.7 Integrating structural determinants into HIV prevention strategies for SGM

Quantitative estimates of the population-level impacts and individual-level effects of structural determinants on HIV can inform prevention programming. Mathematical modelling of structural determinants in other key populations indicates that incorporating structural interventions into HIV prevention could improve HIV outcomes among SGM. For example, modelling based on studies from Canada, Kenya, and India suggested that eliminating violence by police, clients, and strangers could avert between 17-20% of new HIV acquisitions among FSW and clients within 10 years.(13) Mathematical modelling enables exploration of the population-level impacts of structural determinants and interventions and can address questions that are difficult to answer using randomised controlled studies (RCTs) or observational studies.(139) Previous recommendations for including structural determinants have primarily suggested including simple parameters, compartments, or changes to the transmission rate representing determinants including education, poverty, drug and alcohol use, and condom use.(140) Although a starting point, this approach does not account for heterogeneity among different groups, as the changes are applied uniformly across the entire population.(140) Methods to model structural determinants and quantify their impacts could therefore be improved.

2.8 Knowledge gaps

While the role of structural determinants in worsening HIV outcomes among SGM has been acknowledged since the early days of the AIDS epidemic, mostly due to qualitative studies, the quantitative evidence base on the effects of structural determinants on HIV epidemics among

SGM could be improved. First, mathematical models could play a key role in informing structural determinants-based HIV prevention programming for SGM. Models parameterised with robust empirical evidence – such as data on access to HIV testing and the treatment cascade, along with estimates of how exposure to structural determinants affects HIV acquisition – would enable a detailed understanding of the structural determinants driving HIV transmission and allow for the prediction of the impacts of structural interventions. However, key empirical evidence necessary to better inform models is very scarce. Nationally representative population-based surveys in Africa do not collect information on SGM. Key information such as uptake of HIV testing, treatment, and care therefore remain elusive. Additionally, quantitative estimates of the impacts of structural determinants on HIV acquisition among SGM are currently sparse. My thesis sought to provide some of this critical information.

3. Chapter 3: Methods

My thesis employs several different methodologies, including scoping and systematic reviews, conceptual frameworks, meta-analyses, meta-regressions, and longitudinal data analyses. In this chapter, I describe the main types of data synthesised, and provide an overview of the analytical approaches employed in each manuscript.

3.1 Data sources

The data sources used in my thesis include published mathematical modelling studies (Manuscript 1), surveys of SGM (Manuscript 2), and cohort studies of SGM (Manuscript 3). These data are detailed below.

3.1.1 Manuscript 1: Review of mathematical models

In my first manuscript, I elaborated a conceptual framework to guide mathematical modellers who want to develop and use dynamic models of HIV transmission that consider structural determinants and/or structural interventions and estimate their impacts on HIV acquisition and/or transmission. My conceptual framework was informed by a scoping review of HIV transmission dynamic modelling studies published between 1980 and 2023, by searching online databases (e.g., Medline, Embase), and searching the references of relevant studies.

Mathematical models are important to inform population-level HIV prevention programmes and interventions and can be valuable for estimating key epidemiological parameters.(22,141) The complex transmission dynamics of infectious diseases are best simulated using dynamic models.(22) These models can consider both the direct benefits of interventions (e.g., condoms, PrEP) to individuals using them but also the indirect effects to those not accessing prevention but who also become less likely to acquire HIV.(23,142) When combined with strong empirical data, mathematical models enable detailed understanding of factors driving disease transmission and projection of the course of epidemics under different conditions to explore numerous scenarios.(143) Mathematical models offer several advantages over empirical methods for investigating structural determinants. For instance, cohort studies of structural determinants would require large sample sizes to obtain precise estimates and may

need extended periods to observe the effects of different determinants. Issues such as loss to follow-up can also bias findings.(144)

Models can be broadly categorised into compartmental and individual-based models.(143) Compartmental models simplify HIV dynamics by stratifying the population into different compartments, such as susceptible, exposed, infected, and recovered (i.e., SEIR models). These models are often specified using a set of ordinary differential equations that describe transitions between the HIV states, which are solved numerically.(22) Instead of modelling groups, individual-based models simulate every individual in the population.(145) They can incorporate individual-level heterogeneity, such as partnership durations, concurrency, mobility between settings, and more.(146) Individual-based models also incorporate randomness into disease transmission.(145)

Models can incorporate heterogeneity by stratifying the population into sub-compartments that reflect different age groups (age-structured models), key populations, and behaviors (e.g., sexual activity classes).(143) In my first manuscript, I conceptualise how this could be extended to reflect the effects of structural determinants.

3.1.2 Manuscript 2: Review of empirical studies of SGM

My second manuscript systematically reviews the peer-reviewed literature on the epidemiology of HIV among SGM in African countries. Specifically, I leveraged cross-sectional and longitudinal studies that reported HIV testing, engagement with the HIV treatment cascade, and HIV incidence rates among SGM. I used these studies to estimate HIV treatment cascade access and HIV incidence in Africa. Cross-sectional studies analyse data from a population at a single or several points in time, while longitudinal studies, including cohort studies, observe a group of participants over time to track the occurrence of specific outcomes. I reviewed all studies conducted 1980 to 2023 that included information on HIV testing, knowledge of status, HIV treatment, care, viral suppression, or incident HIV acquisition among SGM in cross-sectional and longitudinal studies in Africa by searching online databases (e.g., Medline, Embase, Scopus, Global Health, Web of Science). Enrolling representative study populations of SGM is challenging and a range of methods are being employed. Common sampling methods

include convenience sampling, time-location sampling, snowball sampling, and respondent-driven sampling, among others. These are briefly described below.

Convenience sampling

Convenience sampling involves choosing participants based on their ease of accessibility, leading to samples that may not be representative of the wider SGM population.(147) In Africa, this may include recruiting SGM from venues such as bars, nightclubs, clinics, or online. Despite being practical, convenience sampling often fails to capture the full diversity of SGM communities.

Time-location sampling

Time-location sampling involves recruiting participants based on specific times and locations where SGM are known to meet, such as at nightlife venues or community spaces. Participants are randomly (or systematically) sampled at each time-location pair, and statistical adjustments are used to weight the analysis based on the inverse probability of inclusion (i.e., based on the location's size).(148) This method can reach a broader segment of SGM but may still miss individuals who do not visit these locations or who are less visible, potentially excluding certain subgroups of SGM.

Snowball sampling

Snowball sampling relies on existing participants to recruit peers from their social networks, making it particularly useful for populations without a clear sampling frame.(149) This method can effectively reach individuals who might be missed by other sampling methods but may also lead to bias due to the reliance on personal networks, leading certain subgroups of SGM to be over-represented and others to be under-represented.(150)

Respondent-driven sampling

Respondent-driven sampling (RDS) combines elements of snowball sampling with statistical techniques to manage biases and improve representativeness.(151–153) Participants recruit peers from their social networks while providing information on their recruitment patterns (usually linked coupons), and statistical adjustments are used to account for the non-random sampling, which weight participants based on their network sizes. RDS can enhance

representativeness among SGM populations, although it requires careful implementation and analysis to ensure unbiased results.(153)

3.1.3 Manuscript 3: Analyses of cohorts of sexual and gender minorities

In my third manuscript, I leveraged the individual participant data (IPD) from three cohorts of SGM, as described below. These were the *Anza Mapema* study (Kenya), *CohMSM* (Burkina Faso, Côte d'Iviore, Mali, Togo), and *HPTN 075* (Kenya, South Africa, Malawi).

The Anza Mapema Study

Between August 2015 and November 2017, the *Anza Mapema* study (Kiswahili for "Start Early") enrolled SGM in a prospective cohort study in Kisumu, Kenya, and followed up participants for quarterly HIV testing and behavioural interviews, for one year.(154) The primary aim of the study was to optimize regular HIV testing, linkage to care, and retention in HIV prevention and care among SGM in Kisumu, Kenya. Participants were recruited using snowball sampling and peer outreach at SGM hotspots. The final sample was comprised of 711 SGM, aged 18 or older, who self-reported anal or oral intercourse with a man in the previous six months, were not participating in another HIV intervention study, and who were residing in the study area. At baseline, 636 participants were not living with HIV who were included in our analysis in my third manuscript.

At each follow-up visit, participants completed audio computer-assisted self-interviews (ACASI), underwent HIV counselling and testing, completed a medical history and physical examination, and provided samples for STI testing. Questions on stigma and SGM violence were asked at baseline, then every six months.

The CohMSM Study (CohMSM ANRS 12324 – Expertise France)

The *CohMSM* study was a prospective, multi-country cohort study initiated in June 2015 in four western African countries: Burkina Faso (Ouagadougou), Côte d'Ivoire (Abidjan), Mali (Bamako), and Togo (Lomé).(155) SGM aged 18 or older who reported at least one instance of anal intercourse with a man in the previous three months were recruited and followed up every three months by a community-based organization providing HIV prevention, care, and support for SGM, for 30 months. The primary objective of *CohMSM* was to evaluate the effectiveness of a quarterly prevention package consisting of free clinical examination, HIV and other STI

testing, access to PEP, condoms, and lubricants, and individualised peer-led support. We had access to data on 782 participants between June 2015 and January 2018, of which 625 were not living with HIV at baseline and were included in our analysis in my third manuscript.

HIV and STI testing were conducted at baseline and each quarterly follow-up visit. Information on sociodemographic and behavioural information, including on stigma and SGM violence, were collected in standardised face-to-face interviews (FTFI) administered every six months.

The HIV Prevention Trials Network (HPTN) 075 Study

The HIV Prevention Trials Network (HPTN) 075 study was a prospective, multi-country cohort study conducted between 2015 and 2017 at four sites in three countries in eastern and southern Africa: Kenya (Kisumu), Malawi (Blantyre), and South Africa (Cape Town and Soweto).(156) Sites implemented their own recruitment strategies including peer outreach, snowball sampling, informational sessions about the study, peer-referral, and indirect recruitment via gay venues. Eligible participants were those aged 18-44 assigned male at birth, reporting anal intercourse in the previous three months by someone reported to be biologically male, and willing to undergo HIV testing. *HPTN 075* principally aimed to evaluate the feasibility of recruiting and retaining a cohort of adult SGM in HIV prevention and care. The final study population consisted of 401 participants, of whom 329 were not living with HIV at baseline and were eligible for our analysis in my third manuscript.

Participants attended quarterly follow-up visits that included behavioural assessments and HIV testing. Participants were primarily administered FTFIs but had the option to complete sensitive parts of the survey confidentially, if preferred. Participants also received STI testing during the study. Questions on stigma and SGM violence were administered at baseline, then every six months.

3.2 Methodologies used

3.2.1 Conceptual framework

In my first manuscript, I developed a conceptual framework to decipher how to mathematically model exposure to structural determinants and HIV risks (acquisition and

transmission). A conceptual framework is a structured approach to organising and visualising complex relationships between epidemiological variables that provides a systematic, coherent way of thinking about a problem.(157) They can guide epidemiological analyses, for example, by elucidating which variables to consider in models and whether to assess a direct or indirect effect.(157) I developed my conceptual framework by reviewing existing frameworks and mapping concepts from the literature on relationships between structural determinants and HIV, with support from mathematical modellers.(13,28,140,158–160) In the framework, I organised structural determinants and intermediate variables sequentially based on their proximity to HIV acquisition and transmission and refined the framework based on peer feedback.

3.2.2 Scoping review

My first manuscript also employed a scoping review of mathematical modelling studies of structural determinants. Scoping reviews assess the extent of literature on a topic by mapping existing studies, indicating the number available, and summarising their scope.(161) They are particularly useful for clarifying new concepts and exploring novel questions (i.e., when there may be few studies on the topic), along with examining how research has been conducted and identifying knowledge gaps.(162) I chose this method over other types of reviews because I anticipated finding limited studies and wanted to focus on understanding the methodologies employed in each study rather than their findings, which could elucidate how future modelling of structural determinants could be improved.

3.2.3 Systematic review

In my second manuscript, I used a systematic review of cross-sectional and longitudinal observational research on HIV testing, the HIV treatment cascade, and HIV incidence among SGM in Africa published since 1980 (i.e., the start of the global HIV pandemic). Systematic reviews are exhaustive investigations of a certain topic that attempt to appraise and synthesise all available studies. To conduct a systematic review, we first clearly define the research question and the inclusion and exclusion criteria for eligible studies. Then, a comprehensive literature search is performed using different databases and search strategies. The obtained studies are then screened and the ones that meet all eligibility criteria are summarised and their quality is appraised.

3.2.4 Meta-analysis of aggregate data

Following a systematic review, the studies can be summarised using meta-analytic methods. A meta-analysis enables the synthesis of quantitative information across multiple studies to produce evidence-based results.(163) Most meta-analyses are of aggregate data, where study estimates and their standard errors are generally obtained from publications and then pooled.(164) Typically, in aggregate data meta-analyses study estimates are combined using inverse-variance methods implemented with frequentist maximum likelihood estimation, which pools study estimates by weighting them according to their precision, or other methods, such as generalised linear mixed-effects models (GLMMs). Between-study heterogeneity is handled using random-effects models to account for variability in effect sizes between studies.(165) Alternatively, a fixed effects model could be used, which assumes a single common underlying effect size, but ignores study heterogeneity.(165)

3.2.5 Meta-regression

For my second manuscript, I used meta-regression analyses to estimate trends in HIV testing and treatment cascade outcomes, and HIV incidence, among SGM in Africa across regions, countries, and over time. Meta-regression is a method to explore heterogeneity that combines meta-analysis with linear regression to estimate whether there are linear associations between study characteristics (binary, continuous, and categorical variables) and outcomes of interest.(166,167) It is a more advanced method for exploring heterogeneity than traditional subgroup analysis and enables the investigation of multiple variables simultaneously.(168)

For my meta-regression, I used GLMMs.(169) GLMMs are a flexible alternative to inverse-variance methods that can incorporate correlated data structures, to account for multiple measurements from the same studies, countries, and settings.(170) GLMMs can also handle more complex models, including varying slopes and intercepts, and account for study-level covariates (e.g., study year, characteristics), which can provide more detailed insights into setting-specific trends and sources of heterogeneity. By “borrowing strength” from settings where data is abundant they can inform estimates in settings where data is sparse.(171,172) In Manuscript 2, I implemented meta-regression using GLMMs within a Bayesian framework, which offers advantages for hierarchical modelling when studies are heterogeneous.(173)

Bayesian methods produce posterior distributions of the pooled effect and associated variance terms. Estimates of uncertainty – credible intervals (CrI) – are obtained directly from these posteriors. These have a probabilistic interpretation (i.e., 95% probability of falling between two values), so are easily understood compared to the frequentist confidence interval.(171,174) Key benefits of a Bayesian approach include the ability to incorporate prior information, better performance with sparse or heterogeneous data, and in particular the flexibility in model specification.(171,175,176) Additionally, Bayesian meta-analysis appropriately accounts for uncertainty in the heterogeneity variance.(175)

3.2.6 Individual-participant data (IPD) meta-analysis

For my third manuscript, I used individual participant data (IPD) on exposure to violence among SGM in three prospective cohort studies in Africa. HIV incidence studies among SGM in Africa were identified using my systematic review in objective 2 and by using online data catalogues (e.g., PubMed) to search for newer studies published up to 2023. I contacted the principal investigators of all eligible studies about contributing data for this objective and three eligible studies shared their data.

Key advantages of IPD meta-analysis include that they can have greater power (as opposed to aggregated meta-analysis), they allow for standardisation of exposure, covariate, and outcome definitions across studies, and enable consistent adjustment for confounders across studies.(163,177,178) Additionally, they enable existing data to be used to explore new questions. Two competing approaches to IPD meta-analysis are one-stage or two-stage.(179) The two-stage approach is similar to the aggregate data meta-analysis, but with the advantages of IPD meta-analysis, described above. The IPD from each study are analysed separately, but using a common methodology, to obtain summary effect estimates and confidence intervals that are then combined using standard meta-analytic techniques. In the one stage approach, the IPD from all studies are analysed together in a single step, for instance using a hierarchical model.(177) The best approach is debated. Unless the sample size of most included studies are small or most studies experience few events, both approaches tend to closely agree.(178,180–182)

3.2.7 Analyses of longitudinal data

Estimating the effects of time-varying exposures using cohort data is a common problem in epidemiology. If there are time-varying confounders affected by previous exposure, standard regression methods can lead to bias. In my third manuscript, I employed sequential conditional mean models (SCMMs) using generalised estimating equations (GEE).(183) SCMMs enable the use of standard regression methods to estimate the effect of exposure on a subsequent outcome, by appropriately controlling for prior exposures, outcomes, and time-varying covariates, where applicable.(184) GEE is a method for longitudinal data analysis of repeated measures.(185) Alternatively, marginal structural models that use inverse probability of treatment weights to control for time-varying exposure and confounders could be used, or mixed-effects models, although SCMMs enable precise inferences, and are robust against model misspecification.(184) Causal mediation analysis is another method that enables detailed investigation of causal pathways, decomposing the total effect of exposure into direct and indirect effects.(186,187) However, to derive precise and valid estimates, it would require more studies or large sample sizes, as well as strict assumptions about the measurement of variables and confounding.

3.3 Ethics

In this thesis, I used existing studies and individual participant data to conduct secondary data analyses. All individual participant data were deidentified. Ethics approval was not required for my first and second manuscripts. Ethics approval for the individual participant data meta-analysis in my third manuscript was obtained from the McGill Faculty of Medicine Institutional Review Board in 2021.

4. Chapter 4: From conceptualising to modelling structural determinants and interventions in HIV transmission dynamics models

4.1 Preface to Manuscript 1

Mathematical models have played a crucial role in informing global and local HIV responses over the last 30 years.(22) Models that incorporate quantitative evidence on structural determinants and their effects on HIV acquisition and transmission among SGM could offer valuable insights into the likely population-level impact of structural interventions developed for SGM and other key populations. However, modelling the effects of structural determinants on HIV transmission dynamics in any population is still fairly new. In this manuscript, to understand how structural determinants have been represented in dynamic HIV transmission models, I conducted a scoping review of previous modelling studies that considered such structural determinants. Using the knowledge I learned from these previous approaches, I also developed recommendations to improve how practitioners conceptualise, develop, parameterise, and calibrate their mathematical models of structural determinants going forward. Importantly, I also discussed the types of data and analyses that are needed to strengthen the empirical evidence base of structural determinants and their impacts on HIV, which guided the analyses in my second and third manuscripts. The resulting article will be published by BMC Medicine and included in their upcoming special issue: "*Modelling the effects of structural interventions and social enablers on HIV incidence and mortality in sub-Saharan African countries*".

4.2 Manuscript 1: From conceptualising to modelling structural determinants and interventions in HIV transmission dynamics models: a scoping review and methodological framework for evidence-based analyses

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Abstract

Background

Including structural determinants (e.g., criminalisation, stigma, inequitable gender norms) in dynamic models of HIV transmission is important to help quantify their population-level impacts and guide implementation of effective interventions that reduce the burden of HIV and inequalities thereof. However, evidence-based modelling of structural determinants is challenging partly due to a limited understanding of their causal pathways and few empirical estimates of their effects on HIV acquisition and transmission.

Methods

We conducted a scoping review of dynamic HIV transmission modelling studies that evaluated the impacts of structural determinants, published up to August 28, 2023, using Ovid Embase and Medline online databases. We appraised studies on how the models represented exposure to structural determinants and causal pathways. Building on this, we developed a new methodological framework and recommendations to support the incorporation of structural determinants in transmission dynamics models and their analyses. We discuss the data and analyses that could strengthen the evidence used to inform these models.

Results

We identified 17 HIV modelling studies that represented structural determinants and/or interventions, including incarceration of people who inject drugs (number of studies [n]=5), violence against women (n=3), HIV stigma (n=1), housing instability (n=1), among others (n=7). Most studies (n=10) modelled exposures dynamically. Almost half (8/17 studies) represented multiple different exposure histories (e.g., current, recent, non-recent exposure). Exposures to structural determinants were often assumed to influence HIV indirectly by influencing mediators such as contact patterns, condom use, and antiretroviral therapy use. However, causal pathways' assumptions were sometimes simple, with few mediators explicitly represented in the model, and largely based on cross-sectional associations. Although most studies calibrated models using HIV epidemiological data, less than half (7/17) also fitted or cross-validated to data on the prevalence, frequency, or effects of exposure to structural determinants.

Conclusions

Mathematical models can play a crucial role in elucidating the population-level impacts of structural determinants and interventions on HIV. We recommend the next generation of models reflect exposure to structural determinants dynamically and mechanistically, and reproduce the key causal pathways, based on longitudinal evidence of links between structural determinants, mediators, and HIV. This would improve the validity and usefulness of predictions of the impacts of structural determinants and interventions.

Keywords

HIV, AIDS, structural factors, social determinants of health, structural interventions, mathematical modelling, causal pathways, mediation analysis, conceptual framework, key populations.

Introduction

Structural determinants of HIV are the social, economic, political, cultural, organisational, and environmental factors that shape HIV acquisition and transmission risks across individuals and populations (Panel 1).[1-3] Socio-ecological frameworks have been applied to understand how such structural determinants influence HIV transmission dynamics among populations most vulnerable to HIV (i.e., key populations).[4,5] Key populations include people who inject drugs (PWID), sexual and gender minorities (SGM) including men who have sex with men (MSM) and transgender people, and female sex workers (FSW).[6] Inequitable access to essential resources such as education, employment, and health care, coupled with the criminalisation of certain behaviours, including sex work, drug use, and same-sex relationships concentrates HIV vulnerabilities within these groups.[4,7-9] This compounding effect is exacerbated by pervasive stigma, discrimination, racism, homophobia, and sexism.[10]

Recognising the importance of structural determinants, the *Global AIDS Strategy 2021-2026* includes the 10-10-10 targets.[10] These targets aim to reach <10% of key populations and people living with HIV (PLHIV) experiencing stigma and discrimination, <10% of women and key populations encountering gender-based inequalities and violence, and <10% of countries having punitive laws and policies that limit access to HIV-related services by 2025. The global strategy commits to supporting community-led organisations to deliver 60% of HIV programmes on societal enablers (structural interventions that improve the effectiveness of HIV services) including those to reduce stigma and discrimination, support enabling legal environments, and eliminate gender-based violence.[10] However, quantitative evidence of the population-level contribution of structural determinants and the impact of structural interventions on HIV and other outcomes is sparse (although increasing), partly because these impacts are often difficult to evaluate empirically.[11] Estimating the population-level impact of structural determinants is required to inform effective policies and interventions to mitigate their impacts on HIV outcomes. It builds the evidence base on their importance and can inform resource allocation – through complementary economic evaluations – tailored to the most important epidemic drivers. Mathematical models of HIV transmission that carefully triangulate information on structural determinants can provide a means to estimate their population-level impacts and quantitatively account for uncertainty in their individual-level effects, even with sparse observed data, to

generate evidence on the potential benefits of structural interventions.[12] A key benefit of these models is their ability to project non-linear dynamics, including both direct and indirect effects of structural determinants and interventions on HIV over relatively longer time horizons than statistical models when quantifying population-level impacts.

Transmission dynamic models that describe the acquisition and transmission of HIV have long been used to quantify the population-level impact of biomedical and behavioural interventions.[13-16] However, few mathematical models have so far considered structural determinants, in part due to the inherent complexity of incorporating these upstream factors, limited understanding of their causal pathways, and uncertainty in the benefits of associated interventions.[11] Unlike individual-level risk factors that directly influence HIV transmission, structural determinants influence HIV risks through multiple intervening mechanisms.[2,17] Given the importance of structural determinants, a new generation of evidence-based mathematical models are needed to better inform public health and decision-making on ending HIV/AIDS, and to evaluate the cost-effectiveness of different intervention strategies. These models need to explicitly represent structural determinants in a way that adequately captures the patterns of exposure and their influence on individual-level HIV risks through different causal pathways, while being firmly grounded in robust empirical evidence.

The overarching objective of this paper is to develop an evidence-based methodological framework to improve the design and analysis of dynamic HIV transmission models of structural determinants. Using our experience of modelling structural determinants[4,18-23] and a scoping review evaluating previous models that represented structural determinants of HIV, we develop recommendations for the next generation of models and data needs. Although our framework focuses on HIV, it can also be applied to other infectious diseases.

Conceptual framework: Causal pathways linking structural determinants to HIV in models

Structural determinants often have diffuse effects, in that exposure to structural determinants may impact multiple outcomes, through diverse causal pathways and mediators, which will differ by structural determinant and setting (see Panel 4.2.1 for definitions of key terms).[17] Exposure to some structural determinants may also increase exposure to other structural determinants (e.g., incarceration may increase exposure to stigma), and mediators and outcomes

may themselves impact future exposure to structural determinants (e.g., HIV acquisition leading to illness, loss of income, and financial hardships).[24,25] Transmission dynamics models allow us to reproduce these complex relationships.

Panel 4.2.1. Definitions of key terms used in this paper.

Transmission dynamics model: A model in which the force of infection changes over time due to direct and indirect effects from changes in the proportion of individuals living with transmissible HIV (i.e., virally unsuppressed). [26]

Basic reproduction number, $\mathcal{R}_0$: The average number of secondary transmissions from a person living with HIV in an otherwise completely susceptible population. If $\mathcal{R}_0 > 1$, HIV has the potential to spread in the population, whilst if $\mathcal{R}_0 < 1$, sustained HIV transmission is unlikely. Conceptually, it depends on the contact rate (c), the duration of time virally unsuppressed (D), and the transmission probability per contact (β). Other factors also affect $\mathcal{R}_0$, including population heterogeneity (vulnerability and exposure to HIV may vary across and within populations), and mixing patterns (how contact between groups varies, i.e., who mixes with whom). [27-30]

Force of infection, λ: The per capita incidence rate at which people susceptible in the population acquire infection. [26] It depends on the contact rate (c) (which can be conceptualised as accounting for mixing patterns by relevant population subgroups), the probability of transmission per effective contact (β), and the prevalence (I/N) of virally unsuppressed infection (I) among partners (N).

Structural determinants: The fundamental, foundational, underlying social, economic, political, cultural, organisational, and environmental determinants that affect HIV risks by shaping exposure patterns to risk and prevention factors (mediators) further downstream on the causal pathways. [1]

> **Distal structural determinants:** Macrolevel, aggregate structural determinants that affect whole populations, communities, or groups of individuals (e.g., key populations). [4,31,32] They affect exposure to individual-level proximate structural determinants. Examples include laws and policies such as those governing sex work, sex between men, and drug use, but also alcohol and tobacco advertising, systemic and institutionalised racism, and inequitable norms surrounding gender, sexual identity, and substance use.
>
> **Proximate structural determinants:** Structural factors experienced at an individual-level. [4,31,32] They are closer to and have more immediate effects on HIV risks. Examples include incarceration, stigma, discrimination, violence, housing instability, access, and availability of drugs.

Structural interventions: Interventions that promote the availability, accessibility, or acceptability of specific resources needed to prevent poor health outcomes or that reduce vulnerability to them. [33] They seek to mitigate the negative effects of structural determinants or prevent exposure to them (e.g., drug law reform that institutes drug treatment instead of incarceration). Structural interventions encompass both societal enablers and development synergies. [34] Societal enablers are social programmes, policies, and interventions that aim to remove barriers to accessing necessary health services. Examples include decriminalization (e.g., of sex work, sex between men, and drug use/possession), community mobilisation, stigma reduction, and other specific interventions including the Avahan intimate partner violence intervention in India or the integration of self-help groups to empower FSW within the national sex worker programme in Zimbabwe. [35,36]. Development synergies are investments in other sectors that can have positive effects on HIV outcomes (e.g., HIV incidence, treatment use, mortality). Examples include investments in education, employment practices, gender equality, legal reform, as well as specific economic empowerment interventions, such cash transfer interventions for women.

Exposure history: The specified duration of exposure as well as the time-varying intensities of exposure within different exposure periods (e.g., current, recent (<6 months), and non-recent (≥6 months) exposures). [37] Duration and time periods of exposure are usually based on the recall periods of the survey instruments that measure exposures, and intensities are based on the findings of analyses that assess the effects of exposure on causal pathways within those time periods.

Causal pathways: The chain of variables that causally link exposure to structural determinants and structural interventions to individual-level HIV risks.

> **Direct pathways:** Causal pathways not involving mediators. This may represent that the mediators on the causal pathways are unmeasured and therefore unobserved.
>
> **Indirect pathways:** Causal pathways that involve mediators.

Mediators: Intermediate variables on the causal pathways that link exposure to structural determinants and interventions to HIV risks. They are typically assumed or established as the main mechanisms through which exposure to structural determinants affects HIV vulnerabilities. Examples include the number of sexual or injecting partners, the frequency of sex or sharing injection equipment, inconsistent condom use, and access to and uptake of HIV prevention and treatment. Mediators may be observed or unobserved. The term 'mediator' to describe a variable is context specific. A variable that is a mediator on one causal pathway could be considered an independent exposure variable on another (e.g., pre-exposure prophylaxis (PrEP) use could be a mediator in analyses estimating the effect of exposure to HIV education on individual HIV acquisition risk and an exposure variable in analyses estimating the impact of PrEP use on HIV acquisition).

HIV outcomes: The last step in the causal pathways. These include HIV acquisition and onward HIV transmission, as well as individual-level HIV health outcomes such as HIV-related morbidity and mortality (e.g., disability-adjusted life years).

To model exposure to structural determinants, we need to translate the main features of exposures into their mechanistic components. This requires identifying and defining the patterns of exposure to the structural determinants that can be modelled, based on available evidence of their prevalence and frequency in the populations and settings of interest. We then need to simulate the main causal pathways, including mediators, needed to adequately reproduce the effects of exposure on HIV outcomes (Panel 4.2.1, Figure 4.2.1). Ideally, this requires strong empirical evidence on the causal pathways, including mediators, and the magnitudes and durations of causal effects (e.g., relative risks) linking structural determinants, mediators, and HIV outcomes.

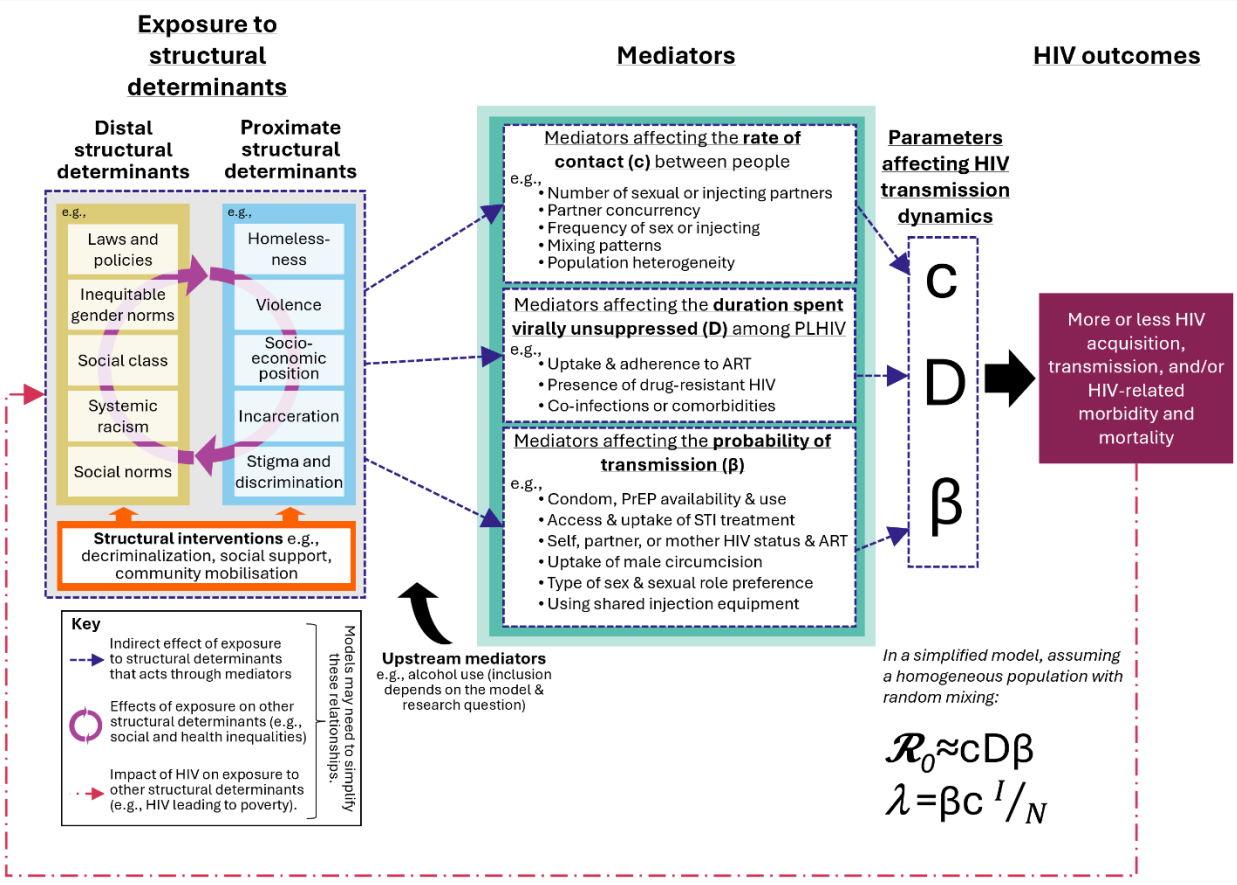

Figure 4.2.1. Conceptual framework illustrating the causal pathways connecting exposure to structural determinants to HIV transmission and population-level HIV outcomes, via mediators,

in dynamic mathematical models. Exposure to distal structural determinants such as laws and policies and proximate structural determinants such as stigma and discrimination (e.g., homophobia, racism, sexism, transphobia) impact HIV outcomes through their effects on intermediate variables (mediators). How exposure to structural determinants may impact HIV transmission within a modelled population can be conceptualised by considering the effects of exposure to structural determinants and interventions on key parameters that determine the basic reproduction number, $\mathcal{R}_0$, and the force of infection, l (i.e., HIV incidence). In a simplified model that assumed a homogeneous population and therefore random mixing patterns, these parameters include contact rates (c), transmission probabilities (b), and the duration spent virally unsuppressed among PLHIV (D). Important mediators to account for include those affecting these parameters. In a more realistic heterogeneous population and models with non-random mixing, additional complexity can be considered. The exact way in which this is modelled will differ by model. I/N = the prevalence of virally unsuppressed HIV among partners of those not living with HIV.

Structural determinants may be distal or proximate (Panel 4.2.1, Figure 4.2.1). [4,31,32,38] Distal structural determinants include macro-level aggregate exposures that affect whole populations, communities, or groups, such as laws and policies, social norms, and gender inequality. [4,31,32] Proximate structural determinants are individual-level consequences of distal exposures, such as incarceration, discrimination, and violence. [4,31,32] Some researchers advocate for focusing on proximate structural determinants, as they may be more easily modified by social programs and policies. [39] They may also be more easily measured and thus operationalised in models, and their evidence base may be stronger than for distal structural determinants. [5,7,40]

Models need to specify and quantify how exposure to structural determinants affects HIV outcomes, based on evidence of their effects. How these effects are captured in models will depend in large part on the model structure and the choice of mediators represented. In a simplified example modelling a homogeneous population with random mixing, important parameters that determine levels of HIV transmission include the probability of HIV transmission (b) per effective contact, the average duration of transmissibility among PLHIV (D; the time spent virally unsuppressed), and the contact rates between people (c; e.g., sexual or sharing injecting partners) (Figure 4.2.1). [26] Changes in these parameters influence the force of infection (l) and the basic reproduction number ($\mathcal{R}_0$) –concepts central to transmission dynamics models (Figure 4.2.1, Panel 4.2.1). In reality, populations are not homogeneous and both

population heterogeneity and mixing patterns by relevant population subgroups will impact $\mathcal{R}_0$ and l and intersect with structural determinants. [41,42]

Search methods and studies identified

To develop our framework and recommendations, we conducted a scoping review of HIV transmission dynamic modelling studies to appraise previous approaches. We included studies that modelled exposures to structural determinants and/or interventions, and their mediators, and estimated their impacts on HIV acquisition and onward transmission in any population and setting. We conducted the search on August 28, 2023, for studies published since January 1, 1980, using Ovid Embase and MEDLINE online databases (Text 4.4.1, Tables 4.4.1 and 4.4.2). We adopted a three-way classification to characterise studies: a) static approaches where the proportion of individuals exposed to the structural determinants and its effects on the assumed mediators and/or HIV acquisition or transmission risks were accounted for by applying fixed relative rates or probabilities to relevant model parameters influenced by the structural determinants; b) stratification-based approaches where the modelled population could experience one level of exposure, with some movement between exposed and non-exposed states; and c) stratification-based approaches with movement between multiple exposure history states (e.g., recent, non-recent). Our scoping review was reported using the PRISMA extension for scoping reviews (Table 4.4.6). [43] Additional details on the scoping review's methods are provided in Text 4.4.1.

We identified 17 modelling studies based on 13 models that assessed the impact of structural determinants and/or interventions on HIV (Table 4.2.1, Text 4.4.2, Table 4.4.3). Most studies modelled proximate structural determinants (number of studies [n]=12) [4,44-54] and/or structural interventions (n=14) [4,5,44,46-52,54-57], primarily affecting key populations including PWID (n=8) [5,46-48,50,53-55], FSW (n=5) [4,49,55-57], and SGM (n=3) [5,46,55]. Four models of PWID were not gender-stratified. [47,50,53,54] Studies were primarily published since 2015 (n=13) [4,44-48,50-55,58] and largely modelled settings in Western and Central Europe and North America (n=8) [4,5,44-47,49,57] and Eastern and Southern Africa (n=7) [4,5,49,51,52,57,58]. Seven studies modelled multiple settings in different regions, [4,5,49,53-55,57] including two studies that modelled 58 and 77 countries, respectively. [53,55] One study modelled hypothetical settings with moderate to high HIV prevalence. [50]

The modelling objectives of studies were primarily to estimate the impact of structural interventions on new HIV acquisitions (n=15) [4,5,44,46-52,54-58] or to assess the contribution of structural determinants to HIV epidemics (n=6) [4,45,48,51-53] (Table 4.2.1). Most studies estimated impacts by predicting the fraction of new HIV acquisitions occurring or averted under different scenarios (n=11; [4,5,44,45,47,49,51,54-57] Table 4.2.1).

Table 4.2.1. Characteristics of HIV mathematical modelling studies identified in our scoping review.

Reference	Type of model	Country	Population	Distal structural determinants	Proximate structural determinants	Structural interventions	Exposure histories represented	Additional exposure stratifications	Main mediators modelled	Main outcomes related to structural determinants/ interventions
a) Static approaches to representing exposure to structural determinants										
Stover et al., 2021[55]	Compart-mental (Goals)	77 countries	Heterosexual men and women, FSW, SGM, and PWID	Criminalisation of drug use and sex work, inequitable norms and attitudes about PLHIV	Internalised HIV stigma among PLHIV, violence among women	UNAIDS 10-10-10 (Decriminalisation of sex work and drug use, removing internalised HIV stigma, eliminating violence against women)	Not applicable	Not applicable	Not represented	No. cumulative HIV acquisitions over 10 years (2020-30) if UNAIDS 10-10-10 targets for 2025 are not achieved
Levy et al., 2021[51]	Compart-mental	Kenya	Heterosexual men and women	Inequitable norms and attitudes about PLHIV	Internalised, enacted, and perceived HIV stigma	Stigma reduction	Not applicable	Not applicable	ART use	No. annual HIV acquisitions over 13 years (2004-17) compared to scenarios with different prevalence and rates of stigma
Ronoh et al., 2020[58]	Compart-mental	Kenya	Heterosexual men and women aged 15-24	Positive and negative attitudes[a]	Positive and negative attitudes[a] affecting HIV testing, condom use, and ART use	Not modelled	Not applicable	Not applicable	Condom use, HIV testing, ART use	Change in HIV prevalence over 5 years (2018-23) comparing scenarios with different prevalence of positive and negative attitudes
Vassall et al., 2014[56]	Compart-mental	India	FSW	Criminalisation of sex work and policing practices, inequitable gender norms and attitudes towards sex workers	Stigma, discrimination, and violence against FSW	Community mobilisation and empowerment for FSW	Not applicable	Not applicable	Condom use	No. HIV acquisitions averted due to community mobilization over the first 7 years of Avahan (2004-11) comparing baseline to a scenario with no impact of community mobilisation on condom use

Wirtz et al., 2014[57]	Compart-mental (Goals)	Kenya, Thailand, Brazil, Ukraine	Heterosexual men and women, including FSW	Criminalisation/ regulation of sex work, lack of safe spaces for sex work, inequitable gender norms and economic opportunities for women, attitudes towards sex workers	Stigma and discrimination against FSW	Community empowerment for FSW	Not applicable	Not applicable	Condom use, ART effectiveness	No. HIV acquisitions averted over 5 years (2011-16) comparing scenarios with varied intervention coverage
Decker et al., 2013[49]	Compart-mental (Goals)	Ukraine, Kenya	FSW and non-FSW (gender-stratified)	Criminalisation/ regulation of sex work, inequitable gender norms and attitudes towards sex workers	Violence against FSW	Reducing violence against FSW	Not applicable	Not applicable	Condom use	Cumulative HIV acquisitions averted over 5 years (2011-16) comparing to scenarios with reduced prevalence of violence
Strathdee et al., 2010[5]	Compart-mental	Ukraine	PWID, including heterosexual men and women, bisexual SGM, and exclusive SGM	Criminalisation of drug use and policing practices	Police beatings among PWID (Ukraine)	Elimination of police beatings in Ukraine and scale-up of opioid agonist therapy, needle and syringe programmes, and ART	Not applicable	Opioid agonist therapy and needle and syringe programme status	Mediators not represented, but total effect of exposure on HIV was assumed to capture change in frequency of sharing injection equipment.	Percentage of HIV acquisitions averted over 5 years (2010-15) comparing baseline in each setting to scenarios with no police beatings
b) Stratification-based approaches to representing structural determinants, where the modelled population could experience one level of exposure, with some movement between exposed and non-exposed states										
Stone et al., 2022[53]	Compart-mental	58 countries	PWID (not gender-stratified)	Criminalisation of drug use, inequitable norms and attitudes about PWID, economic inequality	Housing instability among PWID	Not modelled	Not unstably housed, unstably housed	None	Mediators not represented, but total effect of exposure on HIV assumed to capture pathways involving injecting drug use	Global and country-level tPAFs of unstable housing among PWID over 10 years (2020-30) by comparing baseline for each setting to scenarios with no impact of unstable housing on HIV

Rigby and Johnson, 2017[52]	Individual-based	South Africa	Heterosexual men and women	Inequitable gender norms	Intimate partner violence against women	Violence reduction based on two interventions (IMAGE and SASA!)	No IPV in partnership, IPV in partnership. Once there is IPV, partnerships remain violent for their duration.	Relationship length, sexual risk behaviour group, predisposition and susceptibility to violence	Condom use, relationship dissolution, marriage rate, number of secondary partners, viral suppression, mixing patterns	HIV PAF of violence over 25 years (1990-2015) comparing baseline to a scenario with no IPV. Reduction in HIV incidence over 10 years (2015-25) due to both two interventions
c) Stratification-based approaches to representing structural determinants with multiple exposure histories										
Shannon et al., 2015[4]	Compart-mental	Canada, India, Kenya	FSW and clients	Criminalisation of sex work, inequitable gender norms and attitudes towards sex workers, and safety of sex work environment	Violence against FSW	Various hypothetical interventions including elimination of sexual violence, decriminalization of sex work, increasing safer sex work environments, community empowerment and outreach	Never, recent (<6 or 12 months), and non-recent (>6 or 12 months) client physical violence, client sexual violence, or police harassment. Type of violence and exposure history were setting-specific.	Work environment, PWID status (Canada), member of sex worker collective (India), binge drinking (Kenya)	Condom use	Percentage of cumulative HIV acquisitions averted over 7 years (2014-21) comparing baseline in each setting to various scenarios (e.g., setting violence rates to zero to simulate eliminating violence, removing the excess risk due to lower condom use among FSW ever exposed simulate counselling)
Ward et al., 2022[54]	Compart-mental	Belarus, Russia, Kazakhstan, Kyrgyzstan	PWID (not gender-stratified)	Criminalisation of drug use	Incarceration of PWID	Drug law reform	Never, currently, recently (<6 months) and non-recently incarcerated (>6 months).	PWID status, opioid agonist therapy status	Mediators not represented, but total effect of exposure on HIV assumed to capture change in frequency of sharing injection equipment, mixing patterns	Percentage of HIV acquisitions averted over 20 years (2020-40) comparing baseline to different scenarios (e.g., setting incarceration rates to zero to simulate decriminalisation, and opioid agonist therapy and ART scale-up)

Adams et al., 2021[44]	Individual-based (TITAN model)	USA	African American men and women. Only men can be incarcerated.	Racial biases in arrests and sentencing, inequitable gender norms	Incarceration of African American men	Different PrEP prescription strategies for women with incarcerated male partners	Never, currently, recently (<6 months) and non-recently incarcerated (>6 months). Higher incarceration rates if previously incarcerated	Type of incarceration facility	Relationship dissolution, number of sexual partners, probability of current STI, ART use, mixing patterns	No. of cumulative HIV acquisitions averted over 10 years (2015-25) comparing baseline to different scenarios of PrEP scale-up among female partners of incarcerated men, and incarceration rates
Bernard et al., 2020[46]	Individual-based	USA	PWID, people who use drugs, SGM, and lower-risk heterosexuals (gender-stratified)	Criminalisation of drug use and possession	Incarceration of PWID	Jail diversion program for low-level drug offenders	Not incarcerated, currently in jail or prison, currently in drug court, currently in diversion program	Type of crime, jail further stratified by whether awaiting court or serving sentence	Mixing patterns, use of needle and syringe programmes, substance use disorder treatment, and ART, frequency of sharing, mixing patterns	Reduction in HIV incidence over 10 years (years not specified) by comparing baseline to a scenario with no jail diversion
Adams et al., 2018[45]	Individual-based (TITAN model)	USA	African American men and women. Only men can be incarcerated.	Racial biases in arrests and sentencing, inequitable gender norms	Incarceration of African American men	Not modelled	Never, currently, recently (<6 months) and non-recently incarcerated (>6 months). Higher incarceration rates if previously incarcerated	Type of incarceration facility	Relationship dissolution, number of sexual partners, probability of current STI, ART use, mixing patterns	No. cumulative HIV acquisitions averted among women over 10 years (2005-15) comparing baseline to a scenario with no incarceration

Borquez et al., 2018[48]	Compart-mental	Mexico	PWID (gender-stratified)	Criminalisation of drug use and possession	Incarceration of PWID and syringe confiscation by police	Drug law reform that institutes drug treatment instead of incarceration, compulsory abstinence programme	Incarceration: Never, current, recently (<6 months), non-recently incarcerated (>6 months) Syringe confiscation: confiscation (<6 months), no confiscation	Opioid agonist therapy status, rehabilitation (compulsory abstinence programme) status	Frequency of sharing, opioid agonist therapy use, mixing patterns	HIV PAF of incarceration and syringe confiscation over 18 years (2012-30) and 5 years (2012-17) comparing baseline to scenarios with no incarceration or impacts of recent incarceration and syringe confiscation to simulate full drug reform
Altice et al., 2016[47]	Compart-mental	Ukraine	PWID (not gender-stratified)	Criminalisation of drug use and possession	Incarceration of PWID	Stopping incarceration of PWID and scale-up of prison-based opioid agonist therapies	Never, currently, recently (<12 months), non-recently incarcerated (>12 months)	Opioid agonist therapy status	Mixing patterns. Other mediators not represented, but total effect of exposure on HIV assumed to capture change in frequency of sharing injection equipment	Percentage of HIV acquisitions averted and PAF of incarceration over 15 years (2015-30) comparing baseline to different scenarios (e.g., setting incarceration rates to zero, scaling up opioid agonist therapy, removing the excess risk if recently incarcerated)
Dolan et al., 2016[50]	Compart-mental	Hypothetical moderate and high-prevalence settings	PWID and non-PWID (not gender-stratified)	Criminalisation of drug use and possession	Incarceration of PWID	Reduced incarceration, scale-up of prison-based and post-release opioid agonist therapy, retention on ART post-release	Never, current, recently (<6 months), non-recently incarcerated (>6 months)	PWID status	Frequency of sharing injection equipment, mixing patterns	Percentage reduction in HIV incidence over 5 years (years not specified) and reduction in incarcerated PWID comparing baseline to scenarios with reduced incarceration rates)

ART=anti-retroviral therapy, FSW=female sex workers, IMAGE=Intervention with Microfinance for AIDS and Gender Equity, MSM=men who have sex with men, PAF=population attributable fraction, tPAF=transmission population attributable fraction, PWID=people who inject drugs, SGM=sexual and gender minorities, STI=sexually transmitted infection, TITAN= Treatment of Infection and Transmission in Agent-based Networks model.

Bolded structural determinants and interventions are those that were represented in models. For each, we also noted the distal and/or proximate structural determinants linked to the primary structural determinants and interventions modelled, which were not explicitly represented in any model.

[a] Positive attitudes represent e.g., confidentiality by health workers, adequate support structure at home and community, improved financial status. Negative attitudes represent e.g., religion, peer influence, perceived risk, stigma, poverty, caregivers' waning support, confidentiality breaches by health workers and others.

Structural determinants and interventions examined

Exposure to proximate structural determinants included incarceration of PWID (n=5) [46-48,50,54] and African American men (n=2) [44,45], client- and police-perpetrated violence against FSW (n=2) [4,49], intimate partner violence against women (n=1) [52], HIV stigma (n=1) [51], and housing instability among PWID (n=1) [53]. Few studies modelled distal exposures (Table 4.2.1, Table 4.4.3). [58] One study modelled "positive and negative attitudes" among Kenyan youth, which reflected a combination of proximate and distal exposures (e.g., health worker confidentiality, poverty, peer influences, stigma, and more). [58] The modelled structural interventions included reducing/eliminating incarceration of PWID (n=5) [46-48,50,54], reducing/eliminating violence against women and FSW (n=5) [4,5,49,52,55], community mobilisation and empowerment for FSW (n=3) [4,56,57], and HIV stigma reduction. [51] Most of these modelled several interventions or delivery strategies. One study considered the impacts of achieving the UNAIDS 10-10-10 targets. [55] Another modelled structural changes, including eliminating police beatings in Ukraine and preventing the transition from non-injecting drug use to injecting in Pakistan. [5] Six studies, five of which modelled incarceration, also modelled scale-up of biomedical interventions such as prison- or community-based opioid agonist therapy, PrEP, or ART for prisoners or their partners. [5,44,47,48,50,54]

Representations of exposure to structural determinants

The static representation category included studies that did not explicitly represent structural determinants (e.g., as compartments; n=7; Table 4.2.1a, Table 4.4.3). [5,49,51,55-58] For instance, Strathdee and colleagues modelled the impact of eliminating police beatings among PWID in Ukraine by comparing the baseline to a scenario with reduced sharing of injection equipment by a factor that was informed by empirical analyses showing greater sharing frequency if ever beaten by police and assuming that the reduction in sharing was due to the elimination of beatings. [5] Studies in this category included others that represented structural determinants as parameters that influenced HIV transmission or behaviours (n=3) [5,51,58], and studies using the Goals models (n=3). [49,55,57]

The stratification-based representation category included studies that stratified the population into mutually exclusive compartments or states, with transitions between them, to represent one current or recent exposure history to structural determinants (n=2; Table 4.2.1b,

Table 4.4.3) [52,53] or that represented multiple different exposure histories (n=8; Table 4.2.1c, Table 4.4.3) [4,44-48,50,54]. For example, Shannon and colleagues' model among FSW in Canada, Kenya, and India was the first to represent several structural determinants and exposure histories dynamically (Figure 4.2.2a provides a simplified adaption of their Vancouver model flowchart). [4] FSW transitioned between compartments of never, recent, and non-recent physical and sexual client violence and police harassment, that differed by settings. Similarly, all studies of incarceration represented multiple exposure histories (e.g., current, recent, non-recent incarceration; Table 4.2.1, Table 4.4.3). [44,45,47,48,50,54]

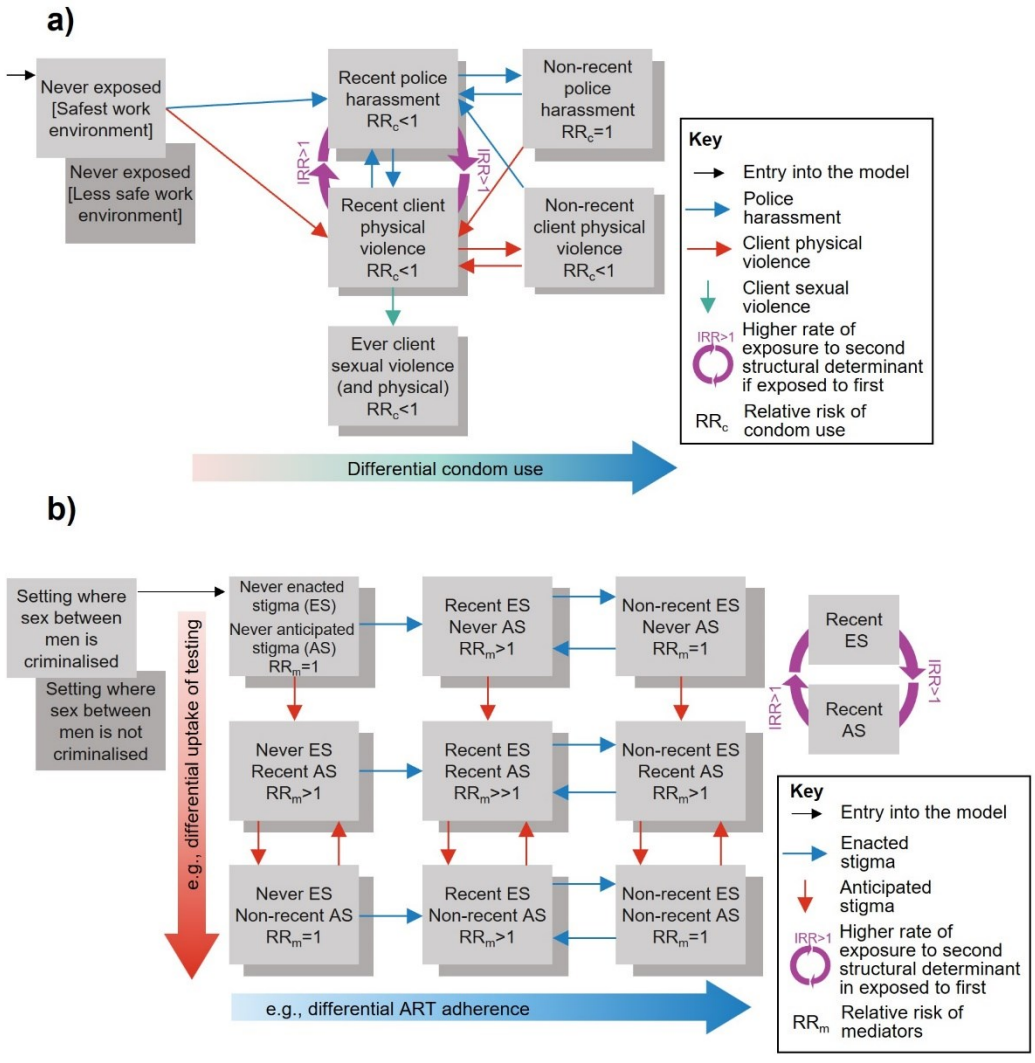

Figure 4.2.2. Dynamically representing exposure to structural determinants and their causal pathways in HIV models, with multiple different exposures and exposure histories. a) Model flowchart (adapted from Shannon et al., 2015) [4] showing how exposure to different

types of violence among female sex workers (FSW) in different work environments and their impacts on HIV were represented in their model, and b) a hypothetical model flowchart based on Shannon's approach representing how exposure to stigma among SGM in settings could be modelled. Evidence suggests that in settings where sex between men is criminalised, SGM experience more stigma. [59] Enacted stigma, such as denial of care, and anticipated stigma, such as fear of discrimination, are linked to lower and slower uptake of HIV testing and treatment. [60] These could be represented by stratifying the population based on type of stigma, and criminalisation of sex between men, with multiple exposure histories for stigma to reflect short and long-term effects of exposure on HIV risks, and interactions reflecting links between the different exposures (purple arrow, incidence rate ratio for exposure; IRR>1).

Dynamically representing structural determinants offers more flexibility to capture both long and short-term effects of exposure, including cumulative, gradual, waning, or lagged effects, by varying HIV risks associated with each exposure level. It also allows for the consideration of different rates of re-exposure. Granular exposure histories facilitate a wider range of interventions to be explored. For instance, Shannon's model differentiated the smaller impact of an intervention that reduces the incidence of violence versus an intervention that additionally removes the persisting negative effects of ever having been exposed. [4] It showed that tackling all forms of violence would have a greater impact on HIV given high levels of co-exposures and interactions. Other structural determinants could be modelled similarly (Figure 4.4.2b provides an example for stigma among SGM). Nevertheless, the stratification-based approach can be complex and data-intensive, making the static approach perhaps more practical for situations with sparse data, such as initial assessments. However, the stratification-based approach can also be simplified by using fewer stratifications.

Most studies represented the indirect effects of exposure to structural determinants through mediators related to sexual behaviours and HIV services access (Table 4.2.1). For instance, Shannon's study modelled the effects of exposure to violence on HIV through lower condom use, and feedback loops between the types of violence, since recent police harassment increased exposure to recent client violence and vice versa (Figure 4.2.2a). [4] The most common mediators across studies were contact patterns (n=8) [44-48,50,52,54], the frequency or number of sexual/injecting partners (n=9) [5,44-48,50,52,54], condom (n=6) [4,49,52,56-58], and ART (n=5) [44-46,51,58]. Some studies considered upstream mediators[54], such as binge drinking or harm reduction services. [4,46-48] Three studies among PWID (two on incarceration[47,54] and one on housing instability[53]), modelled both the total effect of exposure (by changing the transmission

probability among those exposed based on empirical estimates that implicitly captured indirect pathways involving injection drug use) and indirect effects through changes in mixing patterns (e.g., no contact between those in prison and the community; Table 4.2.1).

Use of empirical evidence

In all studies, empirical evidence was used to inform model development. The information used included the proportion of the population exposed to the structural determinants (n=9) [44-46,48-52,54], rates of exposure (n=5) [4,44,45,47,48,50,52,54], durations of exposure (n=7) [44-47,50,53,54], and estimates of the effect size of exposure to structural determinants or interventions on mediators or HIV risks (n=10) [4,5,44,45,48,50,52-57] (Table 4.4.4). All models were calibrated to different HIV outcomes (e.g., HIV prevalence, ART coverage) (Table 4.4.5). Seven studies also calibrated or cross-validated models using structural determinants data including the proportion exposed or exposure rates (n=4) [47,51-53], and the effect size of exposure on HIV or HIV prevalence or incidence stratified by exposure histories (n=4) [47,48,50,54] (Table 4.4.5).

Most model assumptions on structural determinants and their effects on mediators and HIV risks were based on empirical evidence –mostly from surveillance data or cross-sectional surveys, and largely from the same settings and risk populations modelled (Table 4.4.4). In these modelling studies, effects of exposures on mediators and HIV risks were based on various designs, each with limitations, including cross-sectional studies, cohort studies, trials, and some systematic reviews and meta-analyses, although these mostly included cross-sectional studies and sometimes pooled data from multiple settings. Single parameters were often informed by multiple sources (Table 4.4.4). Only one study (Shannon *et al.*) that represented structural determinants dynamically with multiple different exposure histories was informed by longitudinal data on the effects of exposure on its mediators (condom use) for all exposure histories, and only in one of the three settings modelled. [4] Cross-sectional effect sizes may limit the strength of evidence of a causal link, due to reverse causation. Data used to parameterise exposures, transitions, and effects were sometimes derived from different studies and settings, meaning that estimates informing the same model were not always based on standardized exposure definitions, potentially reducing external validity of some model findings. Few studies validated their model predictions for structural determinants against observed estimates, perhaps due to insufficient validation data. [4]

Methodological framework: Improving models of structural determinants and HIV

Given existing limitations, we propose a generalised framework of recommendations for modelling structural exposures and their causal pathways and discuss data needs for this next generation of models (Figure 4.2.3, Table 4.2.2). For simplicity, we focus on deterministic compartmental models, but the framework can also be applied to individual-based models.

Table 4.2.2. Recommendations for developing, analysing, and describing models of exposure to structural determinants and interventions.

Topic	No.	Recommendation to consider
1. General		
Structural determinants	1.1	Clearly define the structural determinant(s) of interest.
Population, setting, and time period	1.2	Specify the population group(s) exposed to the structural determinant, the setting(s) modelled, and the year(s) modelled.
Research objectives & research questions	1.3	Define i) the objectives of the modelling exercise (e.g., predicting the contribution of exposure to past epidemics and/or the impact of structural interventions on new transmissions) and ii) the research questions.
2. Exposure to structural determinants		
Exposure history	2.1	Consider reflecting different exposure histories (e.g., current, recent, and non-recent exposure) to account for short- and long-term exposure effects.
Additional stratifications	2.1a	Consider additional stratifications (e.g., different durations, frequencies, intensities, exposure environments, etc.) that could be needed to replicate the effects of exposure in the model.
Influence of past exposures	2.2	If relevant to the structural determinant, consider reflecting the influence of past exposures on future risks of exposure (e.g., reincarceration rates).
Co-exposures and inter-relationships	2.3	If modelling multiple structural determinants, consider representing interrelationships between them (i.e., interactions).
Influence of interventions	2.4	If modelling structural interventions, describe the interventions and explain how they are assumed to influence exposure to structural determinants (as defined above) or causal pathways (as described below).
3. Causal pathways and mediators		
Causal pathway overview	3.1	Represent the modelled direct and indirect causal pathways from exposure to mediators, and HIV risks in flowcharts.
Mediators	3.1a	Clearly define the mediators on indirect pathways.
Effect size estimates	3.2	Specify the magnitude of direct and indirect effects of structural exposures on mediators and/or HIV risks.
Intervention pathways	3.3	If modelling structural interventions, describe how they impact the causal pathways they intervene on.
4. Empirical evidence, model parameterization, and calibration		
Evidence-based	4.1	Ensure that causal pathways and mechanisms of interventions are evidence-based.

Topic	No.	Recommendation to consider
Parameterisation	4.2	Parameterise the model using data (point estimates and uncertainty ranges) on exposures, mediators, and their effects on HIV prevalence and/or incidence, preferably from the same settings and populations modelled.
Calibration	4.3	Calibrate the model using epidemiological as well as structural determinants data (point estimates and 95% confidence intervals), accounting for parameter uncertainty (e.g., using a Bayesian framework).
Qualitative and other sources of evidence	4.4	Consider whether model assumptions and causal pathways are also supported by qualitative evidence, social theory, and/or input from people with lived experiences.
5. Model outcomes, modelling scenarios, and validation		
Main model outcomes	5.1	Define the primary model outcomes (e.g., infections averted, PAF, tPAF, HIV prevalence or incidence) and secondary outcomes (e.g., impacts on other structural determinants or the mediators) and provide uncertainty ranges of model estimates.
Time horizons of outcomes	5.2	Determine the time horizon of analyses. Consider predicting outcomes over short (1 year), medium (2-10 years), and long (>10 years, lifetime, etc.) time horizons to understand short, medium, and long-term impacts of exposures and interventions.
Modelling scenarios	5.3	Specify the modelling scenarios, including counterfactuals, used to estimate model outcomes and address the primary (and secondary) research questions.
Sensitivity analyses	5.4	Use sensitivity analyses to explore how impacts change if short-term reductions in exposure are not sustained long-term.
Validation	5.5	Validate model estimates of the proportion exposed and individual- and population-level impacts of exposures, interventions, and mediators by comparing to empirical estimates that were not used for fitting.
PAF=population attributable fraction, tPAF=transmission population attributable fraction		

Recommendations

First, models should consider dynamic and granular representations of structural determinants within the model, while being cautious not to add complexity when there is not strong evidence to support it (Figure 4.2.3a). Models should represent the key dimensions of exposure, including exposure histories, duration, frequency, intensity, as well as co-exposures with other structural determinants and important feedback loops linking them. To connect exposure to HIV outcomes, the key causal pathways should be considered, including the mediators required to adequately capture the effects of exposure in the model.

When deciding on parameters related to structural determinants, it is important to weigh up the strengths and validity of available evidence and their relevance to the specific research question and context. Even if the model perfectly represents the mechanistic process linking structural determinants to HIV outcomes, using biased inputs, or inputs from different

populations and settings, could bias model outputs. [61] Ideally, modellers should consider evidence for effect modification, cumulative effects, and interactions. [62] If parameters are uncertain and the internal validity is weak, transparently conducting detailed uncertainty and sensitivity analyses is warranted. [63] In some instances, modellers may need to decide whether to try and incorporate uncertainty in the appropriate parameter value, explore assumptions in additional scenarios, or not to model the research question at all. Attention should be paid to the external validity (i.e., generalisability and transportability) of parameters. [64] At the fitting stage, data on HIV epidemiological and intervention outcomes should be used, ideally stratified by exposure history to the structural determinant. Efforts should be made to fit or validate model predictions to the prevalence of exposure to structural determinants, and levels of mediators by exposure history, if available and relevant. Ideally, the fitting method should allow uncertainty in parameter assumptions to be reflected (e.g., using a Bayesian framework), including uncertainty in estimates related to structural determinants. [26]

Finally, when conducting model analyses, the modelling scenarios, including the counterfactuals, used to assess the contribution of structural determinants to HIV incidence or to evaluate future changes due to introducing structural interventions should be clearly specified. Sensitivity analyses should be used to explore how impacts change if short-term reductions in exposure to structural determinants are not sustained long-term. [63] Data on HIV outcomes, mediators, and structural determinants not used at the fitting stage should be used to validate predictions, which can help indicate whether the model predicts the impact of structural interventions well or not. [65] Similarly, predictions from older models considering the same structural determinants could be compared to observed estimates, to identify strengths and weaknesses in their model structures and/or parameterisations that can inform newer models.

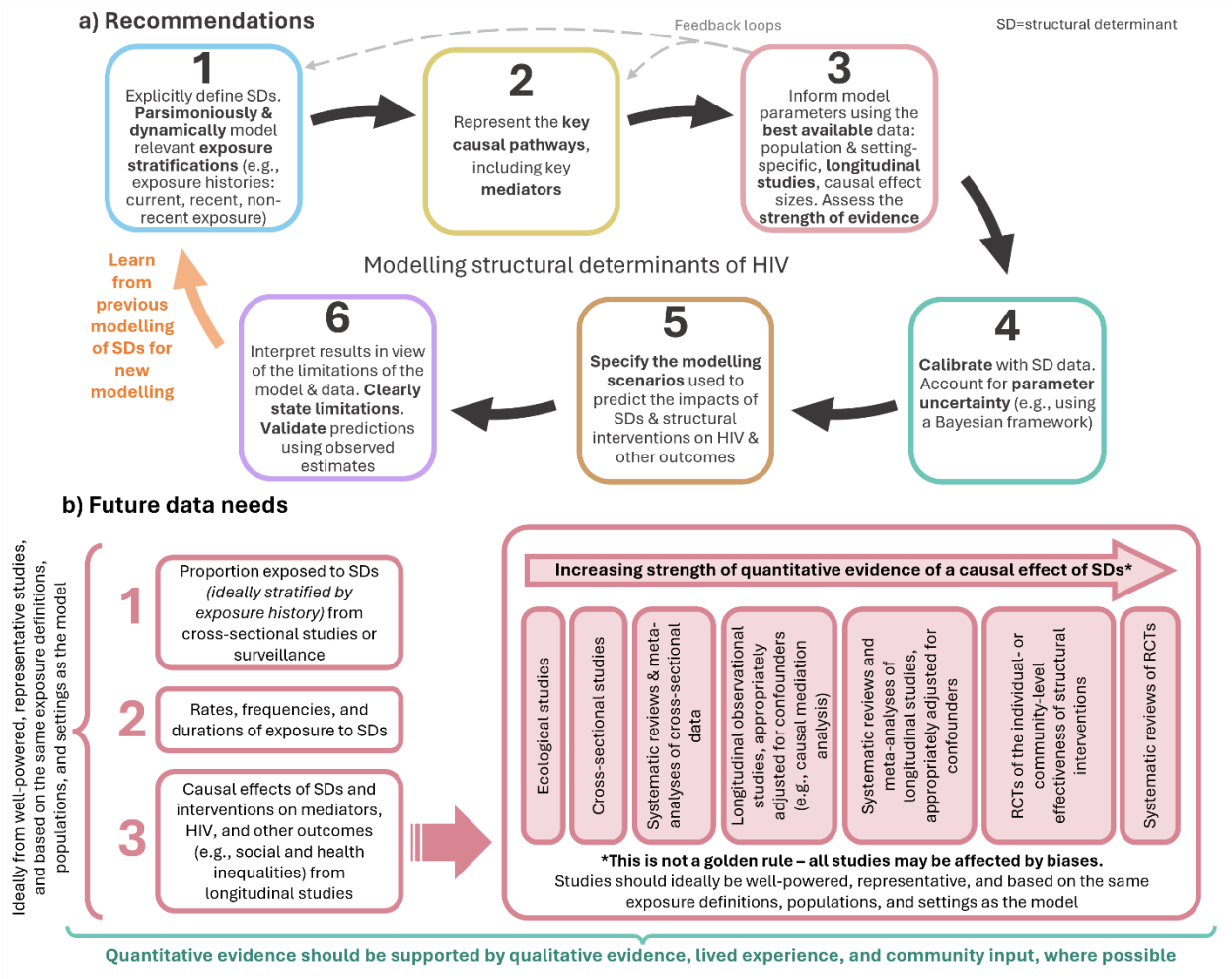

Figure 4.2.3. Methodological framework for modelling structural determinants. a) Recommendations for the next generation of models focused on structural determinants and HIV, and b) the future data needed to improve models of structural determinants, including the strength of quantitative evidence that could be used to inform the effects of exposures on mediators and HIV outcomes in models. SD=structural determinant.

Future data needs

Ultimately, the extent of model complexity will be determined by the research question and the availability of data on structural determinants, mediators, confounders, and HIV or other outcomes (Figure 4.2.3b). Our set of recommendations (Table 4.2.2, Figure 4.2.3a) can help outline data issues to consider. Ideally, exposures to specific structural determinants would be consistently measured to facilitate comparisons across studies and from the same settings and populations modelled. However, currently exposure measurements (i.e., the survey questions)

can vary considerably. For example, a global systematic review among sex workers and SGM in 2017 found that studies measuring stigma used various metrics that were not necessarily developed for the populations of interest and were largely not validated. [66] Additionally, most stigma measures among SGM addressed stigma based on sexual orientation rather than behaviour, limiting the generalisability of the measures to other settings where understandings of sexual orientation and identities may differ. Additional estimates of prevalence that reflect the different exposure histories are needed. These could come from cross-sectional studies and population surveillance exploring exposure over different recall periods. Furthermore, rates of exposure from longitudinal studies would be useful to inform models. In the absence of these, or if estimates from longitudinal studies may be limited (e.g., if there is substantial loss-to-follow-up), rates could be estimated by fitting the model to good cross-sectional data measured at different time points.

Despite increasing recognition of the importance of structural determinants for HIV transmission, estimation of the total effect of structural determinants on HIV outcomes has generally been overlooked in epidemiological analyses, except for socioeconomic status (e.g., income, education, employment). [67-69] Previously, many estimates have been based on cross-sectional studies and ecological analyses, which despite being useful, may have limited value for causal inferences given the risk for reverse causation, confounding, and ecological fallacy. [70] To improve the strength of evidence linking structural determinants, mediators, and HIV outcomes, causal analyses of longitudinal studies are needed (Figure 4.2.3b). A challenge is the potential abundance of confounding factors that may or may not be measured, but which may need to be adjusted for. [71] Ignoring this background heterogeneity could risk biasing the contribution of the structural determinant to HIV outcomes in the model. Empirical evidence (e.g., reviews of quantitative studies) can help identify the confounders to consider and directed acyclic graphs (DAGs) can help choose which to control for. [72] Estimates from path-specific inferences such as causal mediation analyses could be used to parameterise effect sizes. [73] Mediation analyses can be used to estimate causal estimands of exposure to structural determinants, including natural direct and indirect effects, path-specific effects, controlled direct effects, and proportions mediated, using longitudinal data (Text 4.4.3). [74] To improve the validity of model predictions, effect sizes should ideally be based on the same exposure definitions and settings as the other parameters (e.g., proportions exposed, exposure rates) that inform the model.

Although it may not be possible to randomise (at the individual or cluster-level) some structural determinants (e.g., criminalization), evidence on the causal effects and impacts of structural interventions should ideally come from randomised controlled trials (RCTs) –often considered the gold standard for causal inference analyses (Figure 4.2.3b). For example, there have been several RCTs of individual and community-level interventions to address inequitable gender norms. [75-82] However, even with RCTs, additional analyses might be needed to identify and quantify specific causal pathways. For example, RCT data has also been used in causal mediation analyses to estimate the effects of exposure to interventions on inequitable gender norms along specific pathways. [83,84]

Given the challenges associated with obtaining causal estimates, evidence on structural determinants and causal pathways should be complemented with information from additional sources, including qualitative evidence, social theory, and inputs and involvement in the research from people with lived experience, ideally from the same similar settings and populations as the ones modelled. [85] In our review, 11 of the studies that modelled specific settings included co-authors form those settings, however it was generally unclear if people with lived experienced from those settings were involved in the studies. Finally, modellers should aim for transparency in reporting the strengths of evidence on model assumptions related to structural determinants and attempt to triangulate all relevant data to help identify and quantify sources of uncertainty using distributions of parameter values.

Discussion

In this paper, we introduce conceptual and methodological frameworks to assist investigations of the population-level impacts of structural determinants on HIV outcomes, underpinned by a scoping review of previous models. Simultaneously, we advocate for strengthening the empirical evidence of the effects of structural determinants and interventions on HIV outcomes – an essential foundation for developing better models and prioritising interventions.

Previous models of structural determinants and interventions include notable efforts to represent structural determinants dynamically, with particularly complex representations of violence and incarceration, which were modelled in several studies with multiple exposures,

exposure histories, and additional stratifications. Our recommendations aim to build upon these to help the next generation of models represent structural determinants dynamically and mechanistically and to portray the important causal pathways and mediators to produce useful, evidence-based estimates of the impacts of structural determinants and interventions. These insights could be useful to inform policy decisions for resources allocation. [86] Further, our methodological framework supports transparency in reporting of methods and assumptions to facilitate comparisons in approaches and results across studies, which differed among the studies identified in our review.

Others have considered how to represent social and structural determinants in transmission dynamic models of infectious diseases. [71,87,88] Although our framework was principally developed to support the design of HIV models, our recommendations have broad applicability and can be readily extended to models of other infectious diseases that may face similar limitations. Indeed, a previous review of tuberculosis models also found few models that represented structural determinants (e.g., undernutrition, wealth), which were limited by simple exposure representations and causal pathways, an almost exclusive focus on proximate structural determinants, and a lack of evidence on the exposures from the necessary contexts. [88] More generally, we advocate a mechanistic approach with an emphasis on understanding and reproducing the key causal pathways, which is adaptable yet applicable to multiple and diverse structural determinants, mediators, and outcomes, in various contexts.

Conclusions

Increasingly, transmission dynamic models are being used to explore how exposures to structural determinants influence social and health inequalities, and how structural interventions might mitigate these impacts. Models informed by strong evidence on the causal pathways linking structural determinants and interventions to changes in HIV outcomes – through their direct and indirect effects on downstream mediators – can be used to estimate the contribution of structural determinants to HIV epidemics and to predict the impacts of structural interventions. Our recommendations for the next generation of models can help modellers think about how to model exposure to structural determinants and interventions dynamically and mechanistically to improve estimation of their impacts. Future research should prioritise longitudinal studies designed to estimate the causal effects of structural determinants on mediators and HIV over

suitable timeframes. This will not only contribute to a deeper understanding of structural determinants, but also facilitate greater use of models in exploring the impacts and economic feasibility of structural interventions, which will be critical in the next phase of the global HIV response.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Availability of data and materials

All information extracted and analysed during this study is included in this published article [and its supplementary information files].

Competing interests

JL reports grants from Unitaid and ANRS|MIE, consulting fees from Inserm, presidency of the scientific committee of ANRS|MIE evaluating projects submitted for funding, and membership of a scientific committee at Inserm, all outside the submitted work. KMM reports consulting fees from the University of North Carolina, and payments from Pfizer for teaching, all outside the submitted work. The other authors declare that they have no competing interests.

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Authors' contributions

JStannah, MM-G, and M-CB conceptualised the study. JStannah conducted the scoping review and drafted the initial manuscript. M-CB, MM-G, JLFO, MP, JL, KMM, AA, KD, SN, LP, FTP, AS, JStone, PV, AP, and LJ provided substantive edits to the manuscript. All authors read and approved the manuscript and agreed to submit for publication.

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4.4 Manuscript 1: Supplementary materials

Text 4.4.1. Additional scoping review methods

Search, screening, and data extraction

We first screened studies by title and abstract, then screened full texts for eligible studies. We included peer-reviewed studies that used transmission dynamic models (i.e., models in which the force of infection varies as a function of the prevalence of infection and therefore time) [1] to estimate the impacts of structural determinants and/or interventions on HIV transmission, in any population and setting. We excluded studies that did not model structural determinants or HIV, were "static" statistical models, did not estimate the impact of structural factors on HIV transmission (e.g., modelled incarceration but did not estimate its impact), that only modelled scale-up of biomedical interventions (e.g., pre-exposure prophylaxis (PrEP), antiretroviral therapy (ART)) or that were not in English.

From the included studies, we extracted information on key model characteristics including the type of model (i.e., compartmental or agent-based), year of publication, the populations modelled, and information on 1) whether structural factors were represented statically or dynamically, and whether they stratified by exposure history, 2) the mediators linking exposure to the structural determinant to HIV outcomes, 3) data related to the structural factors used to parameterise and calibrate the models, and 4) the main outcomes modelled and how impacts were estimated (i.e., modelling scenario definitions). We used this information to appraise how structural determinants and/or interventions were modelled, and what information and changes could improve future modelling of structural determinants.

Screening and data extraction were conducted by JS independently. Discrepancies were resolved by MM-G and M-CB.

Text 4.4.2: Additional results of scoping review

Search results

We identified 2510 publications, removed 401 duplicates and 2031 titles at the title and abstract screening stage, then assessed the eligibility of 78 full texts (Figure S1). Of these, we included 17 unique studies that used 13 unique models to assess the impact of structural factors and/or interventions on HIV transmission.

Text 4.4.3: Definitions of effects that can be estimated using causal mediation analysis[1]

Controlled direct effect: How much the HIV acquisition risk would have changed if everyone experienced the same level of a specific mediator, e.g., if everyone used condoms.

Natural direct effect: How much of the HIV acquisition risk due to a structural determinant is not mediated by a specific mediator, i.e., the effect of exposure through pathways that do not contain the mediator. As such it may represent both an actual direct effect of exposure on HIV acquisition risk, as well as indirect effects through unobserved or unmeasured mediators.

Natural indirect effect: How much of the HIV acquisition risk due to exposure to a structural determinant is mediated by a specific mediator, e.g., condom use.

Path-specific effect: How much of the HIV acquisition risk due to a structural determinant is mediated by an additional mediator (e.g., non-viral suppression of the male partner), beyond mediation by the first mediator (condom use).

Proportion mediated: The proportion of the total effect that is mediated through a specific mediator (or combination of mediators).

Table 4.4.1. Examples of structural determinants, societal enablers, and structural interventions identified in the UNAIDS Global AIDS Strategy 2021-2026[2] that are important for HIV transmission, and the mechanisms through which they impact HIV. Note that this is not a definitive list, and that further research is needed to determine the importance of these factors, and to determine and confirm the mechanisms, mediators, and pathways by which they influence HIV outcomes.

Structural determinant	Populations potentially impacted	Example societal enablers or structural interventions	Example mechanisms of impacting HIV outcomes
Stigma and discrimination	MSM, transgender and non-binary people, FSW, PWID, PLHIV, women & girls	Anti-discrimination laws. Public awareness campaigns. Sensitivity training for health care workers. Access to HIV self-testing. Integrating other social and health services (e.g., gender affirming care) into HIV services. Community mobilisation and peer support programmes.	Reduced access to HIV testing, treatment, and prevention. Mental health outcomes (depression, anxiety, low self-esteem). Substance use as a coping mechanism. Sexual behaviours.
Gender inequalities and gender-based violence	Women & girls, FSW, transgender and non-binary people	Investments in social protection and education for women & girls	Reduced access to education, economic opportunities, and health care. Inability to negotiate safe sex practices. Intimate partner violence, including sexual violence.
Punitive laws and policies	MSM, transgender and non-binary people, PWID, FSW, PLHIV, women & girls	Decriminalisation of same-sex behaviours, drug use, and sex work. Gender self-identification laws.	Reduced access to HIV testing, treatment, and prevention due to fear of legal repercussions. Lack of availability of harm reduction services, such as needle and syringe exchange programmes and opioid agonist therapy.
Poverty & inadequate living conditions	All	Universal health coverage. Integrated food and nutrition programmes and social protection interventions. Microfinancing interventions.	Reduced access to HIV testing, treatment, and prevention due to prioritising basic needs (e.g., food) over health care, which may be expensive. Late diagnosis and treatment. Survival sex work.

FSW=female sex workers, MSM=men who have sex with men, PLHIV=people living with HIV, PWID=people who inject drugs

Table 4.4.2a. Medline scoping review search terms and hits. The search was conducted on Monday August 28th, 2023.

	Hits	Search term
1	107772	exp HIV/
2	316769	exp HIV Infections/
3	78683	exp Acquired Immunodeficiency Syndrome/
4	534644	(HIV OR HIV1* OR HIV2* OR HIV-1* OR HIV-2*).af
5	109478	(human immun#deficiency virus OR human immun# deficiency virus).af
6	99687	(acquired immun#deficiency syndrome OR acquired immun# deficiency syndrome).af
7	470051	OR/ 1-6
8	357009	Models, Biological/
9	157616	Models, Theoretical/
10	211229	Computer Simulation/
11	1392	Patient-Specific Modeling/
12	32326	Monte Carlo Method/
13	31138	exp Stochastic Processes/
14	261917	((math* OR transmission OR dynamic* OR epidemi* OR compartmental OR deterministic OR individual OR individual#based OR agent OR agent#based OR network OR simulat*) ADJ3 model*).af
15	856907	OR/ 8-14
16	512494	exp Socioeconomic Factors/
17	100	Socioeconomic disparities in health/
18	19784	exp health status disparities/
19	9845	Ill-Housed Persons/
20	112973	exp Violence/
21	18365	Prisoners/
22	43876	Poverty/
23	12872	exp Social Discrimination/
24	12899	Social Stigma/
25	107730	((structural OR social) ADJ3 (determinant* OR factor* OR condition* OR cause* OR enabler* OR driver* OR exposure* OR risk*)).af
26	412263	(criminali#ation OR homeless* OR unstable housing OR housing instability OR incarceration OR prison* OR stigma OR discrimination OR violence OR poverty).af
27	988692	OR/ 16-26
28	**619**	**AND/ 7 & 15 & 27**

Table 4.4.2b. Embase scoping review search terms and hits. The search was conducted on Monday August 28th, 2023.

	Hits	Search term
1	220799	exp Human immunodeficiency virus/
2	426120	exp Human immunodeficiency virus infection/
3	154802	exp acquired immune deficiency syndrome/
4	491559	(HIV OR HIV1* OR HIV2* OR HIV-1* OR HIV-2*).af
5	512168	(human immun#deficiency virus OR human immun# deficiency virus).af
6	152857	(acquired immun#deficiency syndrome OR acquired immun# deficiency syndrome).af
7	655123	OR/ 1-6
8	140638	Mathematical model/
9	208325	Biological model/
10	96769	Theoretical model/
11	140067	Computer simulation/
12	7316	Population model/
13	208325	Biological model/
14	22033	Stochastic model/
15	387279	((math* OR transmission OR dynamic* OR epidemi* OR compartmental OR deterministic OR individual OR individual#based OR agent OR agent#based OR network OR simulat*) ADJ3 model*).af
16	800717	OR/ 8-15
17	1360451	exp socioeconomics/
18	86398	exp social aspect/
19	34630	exp health disparity/
20	13508	homelessness/
21	180604	exp Violence/
22	2725	Correctional facility/
23	57020	Poverty/
24	34558	exp Social Discrimination/
25	14790	Social Stigma/
26	127139	((structural OR social) ADJ3 (determinant* OR factor* OR condition* OR cause* OR enabler* OR driver* OR exposure* OR risk*)).af
27	525790	(criminali#ation OR homeless* OR unstable housing OR housing instability OR incarceration OR prison* OR stigma OR discrimination OR violence OR poverty).af
28	2041494	OR/ 16-27
29	**1891**	**AND/ 7 & 16 & 28**

Total from both databases = 2510
Total after removing duplicates = 2109
Duplicates = 401

Figure 4.4.1. PRISMA flowchart for the scoping review. Screening identified 17 unique modelling studies that used 13 different models to estimate the impact of structural determinants or interventions, including criminalisation and incarceration, stigma and discrimination, gender-based violence, homelessness, and education and empowerment.

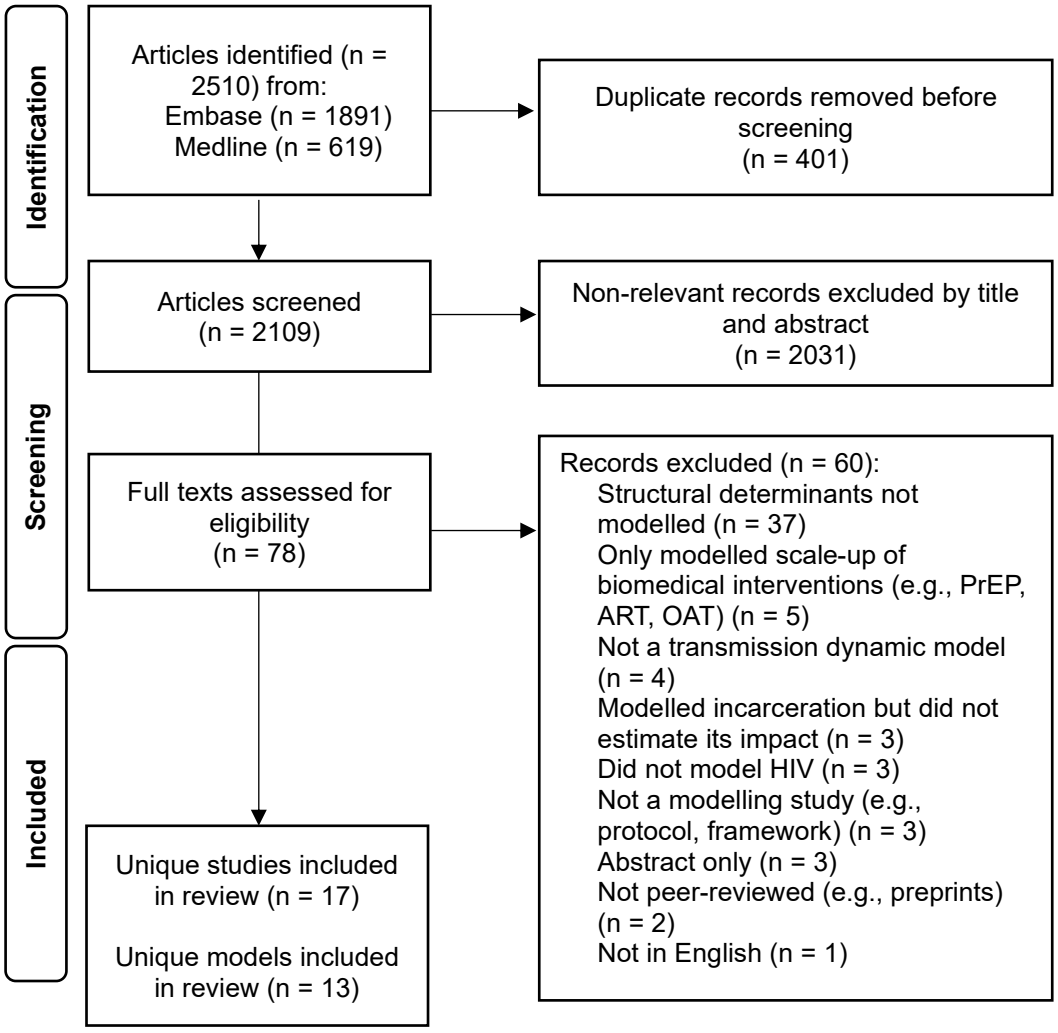

Table 4.4.3. Additional information on the modelling of structural determinants and interventions in the studies identified in the scoping review.

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
a) Static approaches to representing exposure to structural determinants						
Stover et al., 2021[3]	Compartmental (Goals)	Heterosexual men and women, FSW, MSM, and PWID	UNAIDS 10-10-10 (Decriminalisation of sex work and drug use, removing internalised HIV stigma, eliminating gender-based violence against women)	Estimate the impact of achieving the UNAIDS 2025 targets	Internalised stigma modelled by estimating maximum treatment cascade targets achievable without addressing stigma and applying these lower cascade targets to all countries. Access to justice modelled by applying set reduction in new infections among FSW over 10 years and attributing the reduction to access to justice. Violence modelled as reduction in linkage to HIV care and ART adherence. No movement between exposed and unexposed states but coverage (% exposed) was varied in modelling scenarios.	Societal enablers assumed to impact HIV indirectly (stigma and violence reduction) and directly (decriminalisation). Internalised stigma assumed to ↓ HIV testing, ART initiation, and adherence. Access to justice assumed to ↓ HIV transmission. Violence assumed to ↓ linkage to care and ART adherence.
Levy et al., 2021[4]	Compartmental	Heterosexual men and women	Internalised, enacted, and perceived HIV stigma and stigma reduction	Predict reductions in HIV infection through potential interventions that alter stigma over time.	Stigma modelled using parameter that changes over time, representing the proportion of the population with stigmatising views.	Stigma assumed to impact HIV indirectly through ↓ rates of ART use (uptake and discontinuation) among PLHIV.
Ronoh et al.,2020[5]	Compartmental	Heterosexual men and women aged 15-24	Positive and negative attitudes[a]	Estimate the effects of varying HIV testing, condom use, and ART adherence on HIV among youth in Kenya exposed to attitudes influencing disease control.	Positive and negative attitudes modelled as proportions that influence model parameters.	Positive and negative attitudes assumed to impact HIV indirectly: ↑ positive attitudes ↑ rates of condom use, HIV testing, and ART use. ↑ negative attitudes ↓ these rates.

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
Vassall et al., 2014[6]	Compartmental	FSW	Community mobilisation and empowerment for FSW	Estimate the cost-effectiveness of community mobilisation and empowerment interventions in the Avahan programme in India	Community mobilisation and empowerment modelled by assuming that a fraction of the total increase in condom use due to Avahan was due to community mobilisation and empowerment, based on empirical analyses, removing this fraction in simulations, and attributing the reduction to community mobilisation and empowerment.	Community mobilisation and empowerment assumed to ↑ FSW condom use with clients.
Wirtz et al., 2014[7]	Compartmental (Goals)	Heterosexual men and women, including FSW)	Community empowerment for FSW	Estimate the impact of scale-up of a community empowerment intervention among FSW	Modelled as the proportion of the population exposed. No movement between states, but coverage (% exposed) was varied in modelling scenarios.	Empowerment assumed to impact HIV indirectly through ↑ condom use and ↑ effectiveness of ART among FSW exposed to empowerment intervention.
Decker et al., 2013[8]	Compartmental (Goals)	FSW and non-FSW (gender-stratified))	Violence against FSW and reducing violence	Estimate the impact of reducing violence against FSWs on HIV epidemics in Ukraine and Kenya	Modelled as the proportion of FSW exposed to violence.	Violence among FSW assumed to impact HIV indirectly through ↓ condom use during vaginal sex and ↓↓ condom use during anal sex among FSW exposed to violence and ↑ HIV transmission probability through condomless anal than vaginal sex.
Strathdee et al., 2010[9]	Ccompartmental	PWID, including heterosexual men and women, bisexual MSM, and exclusive MSM [b]	Elimination of police beatings in Ukraine and scale-up of OAT, NSPs, and ART	Characterise how certain structural changes could potentially affect proximate risk determinants and influence HIV epidemics among PWID	Beatings not explicitly modelled, but a scenario with reduced sharing of injection equipment based on empirical analyses of reduced sharing if ever exposed to violence was modelled, and the reduction was assumed to be attributed to eliminating violence. **Additional stratifications:** OAT and NSP status (currently, not on OAT/NSPs)	Beatings assumed to impact HIV indirectly through ↑ sharing of non-sterile injection equipment.
b) Stratification-based approaches to representing structural determinants, where the modelled population could experience one level of exposure, with some movement between exposed and non-exposed states						

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
Rigby and Johnson 2017[10]	Individual-based	Heterosexual men and women	Intimate partner violence against women and violence reduction based on two interventions (IMAGE and SASA!)	Identify causal pathways and confounders that play an important role in the IPV-HIV relationship and estimate which interventions can reduce HIV incidence by reducing IPV.	IPV = sexual or physical violence, at partnership level. **No. IPV states:** 2 (no IPV in partnership, IPV in partnership). Once there is IPV, partnerships remain violent for their duration. **Movement between states:** yes, one-way (no IPV → IPV). **Additional stratifications considered:** **Partnership level:** partnership type (married <2 years, married >2 years, short-term, sex worker-client. IPV can only occur only in married and short-term partnerships). **Individual level:** **Men and women:** sexual behaviour group (high risk [concurrent and sex-worker client partnerships possible] vs low risk [monogamous only]). **Men:** predisposition for violence (violent vs not; IPV can only occur if man predisposed to violence. ↑probability of being violent if high risk). **Women:** "susceptibility factor" (number 0-1 randomly assigned to women to account for extra heterogeneity e.g., due to self-esteem, mental health. ↑susceptibility = ↑IPV rate).	IPV affects HIV indirectly. Mediators were varied in different model scenarios that explored different causal pathways. **Mediators[c]:** ↓condom use, ↑relationship dissolution, ↓marriage rate (short-term relationships), ↑secondary partners (women only), and ↓viral suppression (women only), in violent partnerships. Men and women in violent partnerships therefore both have ↑HIV acquisition risk.
Stone et al., 2022[11]	Compartmental	PWID (not gender-stratified)	Housing instability among PWID	Estimate global and national % of incident HIV among PWID due to housing instability	**No. unstable housing states:** 2 (stably, unstably housed in the past year). **Movement between states:** yes. Fixed rate determined by average duration PWID are unstably housed.	Unstable housing impacts HIV directly. ↑ HIV transmission risk if unstably housed.
c) Stratification-based approaches to representing structural determinants with multiple exposure histories						

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
Shannon et al., 2015[12]	Compartmental	FSW and clients	Violence against FSW and various hypothetical interventions including elimination of sexual violence, decriminalisation of sex work, increasing safer sex work environments, community empowerment and outreach	Estimate infections averted through structural changes in regions with concentrated and generalised epidemics, and high HIV prevalence among FSW	**No. violence states:** **Canada:** 6 (never, recent (<6 months) and non-recent (>6 months) police harassment, recent (<6 months) and non-recent (>6 months) physical violence, ever client sexual violence). **India:** 5 (never, recent <12 months) and non-recent (>12 months) client violence, recent (<6 months) and non-recent (>6 months) fear of condom confiscation). **Kenya:** 3 (never, recent (<12 months) client sexual violence, non-recent (>12 months) client sexual violence). **Movement between violence states:** yes. In Canada, recent client physical violence must occur before client sexual violence. Once in ever client sexual violence compartment, FSW remain there. **No. work environment states:** 3. FSW assigned to 1 of 3 fixed work environments, from least to most safe. Options differ by setting. **Canada:** street, informal indoor venues, formal sex work establishments. **India:** home, street, brothel. **Kenya:** bar, street, home. **Movement between work environment states:** no. Work environments were fixed in the baseline scenario (although transitions were possible in other modelling scenarios). **Additional stratifications considered:** **Canada only:** PWID status (FSW who ever injected drugs have ↓ condom use). **India only:** sex worker collectivisation (members of sex work collectives have ↑ condom use). **Kenya only:** binge drinking (FSW who binge drink have ↑ rate of sexual violence, ↑ number of clients, and ↓ condom use)	Violence affects HIV indirectly. **Mediators:** **All settings:** ↑ condom use and ↓ risk of violence in safer worker environments. **Canada:** recent police harassment, recent and non-recent client physical violence, and ever client sexual violence ↓ condom use. ↑risk of recent police harassment if exposed to recent client physical violence, and vice versa. No effect of non-recent police harassment on condom use. **India:** recent client violence and recent fear of condom confiscation ↓ condom use. No effect of non-recent client violence or non-recent fear of condom confiscation on condom use. **Kenya:** recent client sexual violence ↓condom use. No effect of non-recent client sexual violence on condom use. A fraction of all FSW is exposed to FSW outreach, which ↑condom use.

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
Ward et al., 2022[13]	Compartmental	PWID (not gender-stratified)	Incarceration of PWID and drug law reform	Estimate the cost-effectiveness of shift from criminalising drug users to a public health approach with scale up of OAT and ART	**No. incarceration states:** 4 (never, current, recent (<6 months), non-recent (>6 months). **Movement between states:** yes. ↑ incarceration rate if previously incarcerated. **Additional stratifications:** OAT status (↓ reincarceration rate if on OAT), current and ex-injectors (only current PWID experience incarceration).	Incarceration affects HIV directly. ↑transmission risk among PWID recently released than never or non-recently incarcerated. Transmission risk while currently incarcerated can be ↑ or ↓ depending on setting.
Adams et al., 2021[14]	Individual-based (TITAN model)	African American men and women. Only men can be incarcerated.	Incarceration of African American men and different PrEP prescription strategies for women with incarcerated male partners	Estimate the potential reduction in HIV transmission among women attributable to making PrEP accessible to women affected by partner incarceration.	Same as above. Incarceration rates are also higher for men living with HIV and current PWID.	Same as above. Incidence and prevalence are also higher among MSMW.
Bernard et al., 2020[15]	Individual-based (network model)	PWID, people who use drugs, MSM, and lower-risk heterosexuals (gender-stratified)	Incarceration of PWID and jail diversion program for low-level drug offenders	To assess the health benefits and cost-effectiveness of a jail diversion program for low-level drug offenders	**No. incarceration states:** 5 (currently in drug court, currently incarcerated in jail or prison, currently in diversion program, or not incarcerated). Men and women. **Movement between states:** yes. **Additional stratifications:** type of crime (misdemeanor vs felony; misdemeanor = variable length jail stay, felony = jail prior to trial followed by release, jail, or prison. If misdemeanor PWID can enroll in diversion program, otherwise enter jail), jail further stratified by whether awaiting court proceeding or serving sentence.	Incarceration impacts HIV indirectly. No HIV transmission in jail. Post-release, PWID less likely to be in NSPs, SUDT, and ART. Jail diversion program and drug court ↓ % of PWID, which ↓ HIV transmissions.

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
Adams et al., 2018[1]	Individual-based (TITAN model)	African American men and women. Only men can be incarcerated.	Incarceration of African American men	Determine which mediators of male incarceration are most important for HIV acquisition among women, which could be targets for intervention.	**No. of incarceration states:** 4 (never, currently incarcerated, recently released (*<6 months*) and non-recently released (*>6 months*)). Men only. **Movement between states:** yes. ↑ incarceration rates if previously incarcerated **Additional stratifications considered:** type of facility (↓ incarceration rates and ↑ duration of current incarceration in prisons vs jails). Incarceration rates and durations were fixed over time.	Incarceration affects HIV indirectly. **Mediators:** **Men**: ↑ probability of relationship dissolution while incarcerated. ↑ number of sexual partners, ↑ probability of current STI, and ↑ probability of ART dropout for all men recently released. **Women** (*only applies if main partner incarcerated*): a fraction have ↑ number of sexual contacts throughout partner's incarceration or for 6 months after the relationship ends, if it ends whilst he is incarcerated.
Borquez et al., 2018[16]	Compartmental	PWID (gender-stratified)	Incarceration of PWID and syringe confiscation by police and drug law reform that institutes drug treatment instead of incarceration, compulsory abstinence programme	To investigate the past and future effect of drug law reform in 2012 that instituted drug treatment instead of incarceration on HIV incidence	**No. incarceration states:** 4 (never, current, recent (<6 months), non-recent (>6 months). Men and women. **Movement between states**: yes. ↑ incarceration rates if previously incarcerated **No. syringe confiscation states:** 2 (syringe confiscation in the past 6 months, no syringe confiscation in the past 6 months) **Additional stratifications:** exposure to drug treatment (OAT) or rehabilitation (compulsory abstinence programs, CAP).	Incarceration and syringe confiscation affect HIV directly. ↑ HIV transmission risk among PWID recently incarcerated and with recent syringe confiscation. No interaction between structural determinants.
Altice et al., 2016[2]	Compartmental	PWID (not gender-stratified)	Incarceration of PWID and stopping incarceration of PWID and scale-up of prison-based opioid agonist therapies	Assess the long-term contribution of incarceration to HIV transmission among PWID and the impact of eliminating incarceration and scaling up	**No. incarceration states:** 4 (never, current, recent (<12 months), and non-recent (>12 months)). **Movement between states:** yes. ↑ incarceration rate if previously incarcerated. **Additional stratifications:** OAT status (on OAT vs off OAT)	Incarceration affects HIV directly. ↑ HIV acquisition rate among PWID previously (recently and non-recently) than never or currently incarcerated; ↑↑ acquisition rate among PWID recently than non-recently incarcerated. (implicitly assumed ↑ is due to ↑ frequency of sharing

Reference	Type of model	Population	Structural determinants and/or intervention	Objectives	Details of exposure to structural determinants and interventions	Key causal pathways, mediators, and assumptions
				prison-based OAT		injection equipment). OAT assumed to ↓HIV infectivity and susceptibility by 50% (mechanism unspecified).
Dolan et al., 2016[17]	Compartmental	PWID and non-PWID (not gender-stratified)	Incarceration of PWID and reduced incarceration, scale-up of prison-based and post-release OAT, retention on ART post-release	Model the contribution of incarceration to HIV incidence in PWID and examine the effects of reduced incarceration, prison-based OAT, and post-release ART retention	**No. incarceration states:** 4 (never, current, recent (<6 months), and non-recent (>6 months)) **Movement between states:** yes. **Additional stratifications:** Sharing status (non-PWID, PWID who do not share syringes [never sharers & temporary sharers while incarcerated], PWID who share syringes),	Incarceration affects HIV indirectly. **Mediators:** Syringe sharing only occurs between PWID who share syringes. ↑↑ % of PWID share syringes whilst currently than recently incarcerated, equal and ↓↓ % among those never & non-recently incarcerated. ↓ART if recently than currently incarcerated. **Also:** ↓risk of reincarceration and ↓HIV acquisition rate on OAT.
ART=antiretroviral therapy, CAP=compulsory abstinence programme, FSW=female sex workers, IPV=intimate partner violence, MSM=men who have sex with men, MSMW=men who have sex with men and women, NSP=needle and syringe programme, PLHIV=people living with HIV, OAT=opioid agonist therapy, PrEP=pre-exposure prophylaxis, PWID=people who inject drugs, STI=sexually transmitted infection, SUDT=substance use disorder treatment, ↑=increases, ↓=decreases.						

Table 4.4.4. Empirical evidence used to parameterise models of exposure to structural determinants.

Reference	Parameter	Fixed or calibration-based	Type of empirical evidence used
a) Static approaches to representing exposure to structural determinants			
Stover et al., 2021[2]	Treatment cascade targets in absence of progress on stigma	Fixed	Estimated using evidence from cross-sectional study, nested case-control study, systematic review and meta-analysis
	Reductions in new infections in countries that criminalise sex work and drug injection	Fixed	Estimated from modelling studies
	Reductions in new infections due to a global programme to prevent IPV	Fixed	Estimated from cohort studies, modelling, WHO data
Levy et al., 2021[3]	Proportion of the population with stigmatising views of HIV/AIDS in 2003, 2008, and 2014 (based on data on the proportion of women who answered at least two of three questions in a stigmatising manner)	Fixed	Estimated from surveillance data
Ronoh et al., 2020[4]	Negative and positive attitude rates influence HIV testing, condom use, and ART	Fixed	Assumed or estimated, source unclear
Vassall et al., 2014[5]	Percentage change in condom use due to community mobilisation and empowerment	Fixed	Estimated from Avahan large-scale targeted HIV prevention intervention
Wirtz et al., 2014[6]	Impact of empowerment intervention on condom non-use	Fixed	Estimated from WHO reports
Decker et al., 2013[7]	Prevalence of violence against FSWs	Fixed	Cross-sectional studies, surveillance data, Sex Worker Advocacy Network (SWAN) report,
Strathdee et al., 2010[8]	Reduction in use of non-sterile equipment without police beatings (Ukraine model)	Fixed	Estimated from a cohort study in 3 cities in Ukraine
b) Dynamic approaches to representing structural determinants with only recent or current exposure history			
Rigby and Johnson, 2017[9]	Ratio of probability of violent predispositions in high-risk men vs low-risk men	Fixed	Cross-sectional study
	Probability of violent disposition, high-risk men	Calibration-based	Fitted
	Annual rate of IPV, by relationship duration	Fixed	Fitted
	OR for not using a condom in violent vs non-violent relationships	Fixed	Estimated from cross-sectional study, retrospective cohort study, RCT
	Probability of forced female sexual debut	Fixed	Estimated from surveillance data, cross-

Reference	Parameter	Fixed or calibration-based	Type of empirical evidence used
			sectional studies, and review
	Reduction in marriage rate in violent short-term relationships	Fixed	Assumed
	Increase in rate of relationship dissolution in violent relationships	Fixed	Cohort study
	Increase in rate of acquiring secondary partners among women experiencing IPV	Fixed	Assumed
	Reduction in viral suppression among women on ART experiencing IPV	Fixed	Systematic review and meta-analysis
Stone et al., 2022[10]	Relative increase in HIV transmission risk if unstably housed	Calibration-based	Systematic review and meta-analysis of studies globally
	Average duration of unstable housing	Calibration-based	Cohort studies in the US, UK, Canada, Australia
c) Dynamic approaches to representing structural determinants with multiple different exposure histories			
Shannon et al., 2015[11]	RR of inconsistent condom use due to violence, by violence type and exposure history (Canada model)	Calibration-based	Cohort study
	Time to violence in years by setting, work environment, PWID status, type of violence and exposure history (Canada model)	Calibration-based	Cohort study (Canada)
	Proportion of FSW in different work environments in each setting	Calibration-based	Analysis of IBBA data, cross-sectional studies, systematic review and meta-analysis
	IRR of experiencing recent police harassment if experienced recent client physical violence, vs no police harassment (Canada model)	Calibration-based	Cohort study
	IRR of experiencing recent client physical violence if experienced recent police harassment, vs no client physical violence (Canada model)	Calibration-based	Cohort study
	Time to recent physical and sexual violence (India model)	Calibration-based	Cross-sectional studies
	Time to recent police confiscation, by work environment and sex worker collective status (India model)	Calibration-based	Analysis of IBBA data
	IRR of violence if in sex work collective vs not in collective, by violence type (India model)	Calibration-based	Assumed
	RR of inconsistent condom use due to recent condom confiscation (6 months) and last year client violence (India model)	Calibration-based	IBBA analysis
	IRR of sexual violence if binge drinker (Kenya model)	Calibration-based	Cross-sectional study
	Time to violence if non-binge drinking FSW (Kenya model)	Calibration-based	Cross-sectional study
	RR of inconsistent condom use from binge drinking (Kenya model)	Calibration-based	Cross-sectional study

Reference	Parameter	Fixed or calibration-based	Type of empirical evidence used
	RR of inconsistent condom use from recent client sexual violence (Kenya model)	Calibration-based	Cross-sectional studies
Ward et al., 2022[12]	Proportion ever incarcerated	Fixed	Cross-sectional studies
	Proportion currently incarcerated	Calibration-based	Assumed
	Average number of times incarcerated if ever incarcerated	Fixed	Cross-sectional surveys
	Average duration of incarceration	Calibration-based	Cross-sectional surveys
	Incarceration and re-incarceration rates	Calibration-based	Fitted
	RR for HIV transmission risk if recently incarcerated compared to not in prison	Calibration-based	Systematic review and meta-analysis
Adams et al., 2021[13]	Proportion incarcerated in 2005	Fixed	Estimated from surveillance data
	Annual probability of incarceration for PWID	Fixed	Surveillance data
	HIV prevalence ratio for incarcerated vs non-incarcerated men	Fixed	Surveillance data
	Rates of incarceration, by type of facility and prior offense	Fixed	Surveillance data
	Sentence lengths, by type of facility and prior offense	Fixed	Surveillance data
	Proportion tested for HIV upon incarceration	Fixed	Surveillance data
	Proportion of PLHIV inmates on ART while incarcerated	Fixed	Systematic review of mostly surveillance data
	Proportion of main relationships that dissolve during incarceration	Fixed	Cross-sectional studies
	Number of partners at start of high-risk period	Calibration-based	Fitted
	Cumulative number of new partners over 6 months	Calibration-based	Fitted
	Increase in HIV acquisition risk due to current STI	Fixed	Cross-sectional study and prospective cohort study
	Proportion of PLHIV inmates retained on ART 6 months post-release	Fixed	Systematic review of mostly surveillance data
Bernard et al., 2020[14]	Proportion incarcerated in prison (rather than jail)	Fixed	Surveillance data
	Proportion currently incarcerated, by PWID status, age, sex, ethnicity	Fixed	Surveillance data
	Sentence lengths, by type of facility	Fixed	Surveillance data
	Weekly probability of crime, by age, PWID status, sex, ethnicity	Fixed	Surveillance data
	Fraction of crimes that are felonies, and that result in incarceration or release after trial	Fixed	Surveillance data
	Fraction of misdemeanors that result in transitions to non-drug using population through drug court	Fixed	Surveillance data

Reference	Parameter	Fixed or calibration-based	Type of empirical evidence used
	Multiplier for criminal activity if in diversion programme	Fixed	Estimated from non-randomised controlled evaluation
	Multiplier for joining and leaving community programmes if in diversion programme	Calibration-based	Control variable
	Fraction of misdemeanours that result in entry to the diversion programme	Calibration-based	Control variable
Adams et al., 2018[15]	Proportion incarcerated in 2005	Fixed	Estimated from surveillance data
	Rates of incarceration, by type of facility and prior offense	Fixed	Surveillance data
	Sentence lengths, by type of facility and prior offense	Fixed	Surveillance data
	Proportion tested for HIV upon incarceration	Fixed	Surveillance data
	Proportion of PLHIV inmates on ART while incarcerated	Fixed	Systematic review of mostly surveillance data
	Mean number of sex partners for men during 6-months post-release or women with incarcerated partners	Fixed	Longitudinal qualitative study
	Proportion of PLHIV inmates retained on ART 6 months post-release	Fixed	Systematic review of mostly surveillance data
	Probability of ART initiation for those who discontinued post-release	Fixed	Estimated from systematic review of mostly surveillance data
Borquez et al., 2018[16]	Proportion exposed to syringe confiscation in the past 6 months at baseline	Calibration-based	Cohort study
	Proportion exited prison in the past 6 months among PWID at baseline	Calibration-based	Cohort study
	Proportion of PWID incarcerated prior to starting injecting	Calibration-based	Fitted
	Primary incarceration rate	Calibration-based	Fitted
	Reincarceration rate	Calibration-based	Cohort study
	Relative change in the proportion of recent receptive sharing among recently released from prison vs never or not recently incarcerated	Calibration-based	Cohort study
	Relative change in the proportion of recent receptive sharing among recently exposed vs unexposed to police syringe confiscation	Calibration-based	Cohort study
	Relative change in the proportion of recent receptive sharing among PWID ever vs never exposed to compulsory abstinence program	Calibration-based	Cohort study
	RR of injecting HIV acquisition among PWID on OAT vs no OAT	Calibration-based	Systematic review and meta-analysis
	Rate of OAT cessation	Fixed	Cohort study, modelling

Reference	Parameter	Fixed or calibration-based	Type of empirical evidence used
Altice et al., 2016[17]	Duration of incarceration	Calibration-based	Cross-sectional study
	Proportion initiating injecting, by incarceration exposure history (informed by single estimate of proportion of people never incarcerated prior to injecting)	Calibration-based	Cross-sectional study
	Incarceration and re-incarceration rates	Calibration-based	Fitted
Dolan et al., 2016[18]	Proportion incarcerated, by PWID status	Calibration-based	Surveillance data
	Proportion of PWID who share syringes in and out of prison	Calibration-based	Reviews, modelling
	Annual number of injections among incarcerated and non-incarcerated PWID	Calibration-based	Modelling, cross-sectional studies, cohort study, cross-over experimental study,
	Proportion of recently released PLHIV who do not discontinue ART during post-release period	Calibration-based	Cohort studies, systematic review, modelling
	Proportion of injections shared, non-incarcerated	Calibration-based	Modelling
	Ratio of injections that are shared in prison vs non-incarcerated	Calibration-based	Assumed
	Proportion of PWID never incarcerated	Calibration-based	Cross-sectional study, systematic review
	Duration of incarceration and post-release period, by PWID status	Calibration-based	Surveillance data, cross-sectional study, cohort studies
	Rate of reincarceration, by PWID status	Calibration-based	Cohort study, systematic review

ART=antiretroviral therapy, FSW=female sex workers, IBBA=integrated behavioural and biological assessment, IPV=intimate partner violence, IRR=incidence rate ratio, OAT=opioid agonist therapy, OR=odds ratio, PLHIV=people living with HIV, PWID=people who inject drugs, RCT=randomised controlled trial, RR=relative risk, STI=sexually transmitted infection, WHO=World Health Organization

Table 4.4.5. Data on HIV epidemiology and structural determinants used to calibrate the models.

Reference	Calibration data related to HIV epidemiology	Calibration data related to structural determinants, interventions, and their effects
a) Static approaches to representing structural determinants		
Stover et al., 2021[2]	HIV prevalence, overall and by age from surveys, surveillance, and routine testing, probability of HIV transmission from systematic revewi and meta-analysis per act	None
Levy et al., 2021[3]	Adult population size, number of HIV infections, all-cause mortality, and percent treated from surveillance 2004-17	None
Ronoh et al., 2020[4]	HIV prevalence among youth in Kenya 1990-2013 from surveillance	None
Vassall et al., 2014[5]	HIV and STI prevalence from IBBA survey data for FSW and clients (2005/6, 2007, 2008, 2011), and the FSW HIV prevalence ratio between Round 1 and later rounds	None
Wirtz et al., 2014[6]	HIV prevalence among FSW from surveillance 2007-2010	None
Decker et al., 2013[7]	HIV prevalence among adults from surveillance 2008-2010	None
Strathdee et al., 2010[8]	HIV prevalence among FSW in Ukraine 2004-2008 from cross-over experimental study and surveillance	None
b) Dynamic approaches to representing structural determinants with only recent or current exposure history		
Rigby and Johnson, 2017[9]	HIV prevalence by age in South Africa in 2012	Proportion ever exposed to intimate partner violence and duration to onset of violence in relationships
Stone et al., 2022[10]	Calibrated to sampled values of HIV prevalence among PWID from a systematic review and meta-analysis	Calibrated to sampled values of the proportion of PWID unstably housed
c) Dynamic approaches to representing structural determinants with multiple different exposure histories		
Shannon et al., 2015[11]	HIV prevalence in Canada among FSW (2010-12) and among PWID FSW (1997, 2004, 2006), in India among FSW (2005, 2008, 2010) and clients (2007), and in Kenya among FSW (1989, 1993-5, 1996-2000, 2005-6) and among FSW who binge drink (2005-6), proportion of PLHIV on ART	No, but the model was cross-validated using data on the prevalence of violence

Reference	Calibration data related to HIV epidemiology	Calibration data related to structural determinants, interventions, and their effects
Ward et al., 2022[12]	HIV prevalence among PWID, coverage of OAT and ART, PWID population size, in different years in each setting	OR for HIV prevalence between PWID ever or never incarcerated, proportion of community PWID ever incarcerated, overall and by injecting duration, and the number of times prisoners (Kyrgyzstan) or community PWID (other settings) have been incarcerated, in different years in each setting
Adams et al., 2021[13]	HIV prevalence among men and women in the US in 2012 and 2010	None
Bernard et al., 2020[14]	HIV prevalence, awareness, and treatment, by PWID status in Washington	Rates of misdemeanor and felony arrests, number incarcerated in Washington
Adams et al., 2018[15]	HIV prevalence among men and women in the US in 2012 and 2010	None
Borquez et al., 2018[16]	HIV prevalence among PWID (2005, 2006), HIV incidence among PWID (2014), proportion of new infections attributable to sexual transmission (2006)	Proportion of PWID ever incarcerated, by duration of injecting and sex, HIV prevalence among ever incarcerated PWID, relative HIV prevalence among ever vs never incarcerated PWID, from baseline cohort data in Mexico in 2011
Altice et al., 2016[17]	ART coverage (2011, 2015)	HIV prevalence among PWID never and previously incarcerated PWID (2013) and currently incarcerated PWID (2011)
Dolan et al., 2016[18]	HIV prevalence among PWID	HIV prevalence among incarcerated PWID, HIV incidence in prison

ART=antiretroviral therapy, FSW=female sex workers, IBBA=integrated behavioural and biological assessment, OAT=opioid agonist therapy, OR=odds ratio, PWID=people who inject drugs, STI=sexually transmitted infection,

Table 4.4.6. Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) Checklist

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN
TITLE			
Title	1	Identify the report as a scoping review.	Title
ABSTRACT			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	Abstract
INTRODUCTION			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	Introduction (background)
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	Introduction (objectives)
METHODS			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	Not applicable
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	Scoping review
Information sources*	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	Scoping review, Table 4.4.2)
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	Table 4.4.2
Selection of sources of evidence†	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	Text 4.4.1

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN
Data charting process‡	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	Text 4.4.1
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	Text 4.4.1, Table 4.4.3
Critical appraisal of individual sources of evidence§	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	Scoping review Text 4.4.1
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	Scoping review Text 4.4.1
RESULTS			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	Figure 4.4.1
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Table 4.2.1, Table 4.4.3
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	Scoping review (structural determinants and interventions examined, representations, use of empirical data)
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Table 4.2.1, Tables 4.4.3-5
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	Scoping review (structural determinants and interventions examined, representations, use of empirical data), Table 4.2.1, Tables 4.4.3-5
DISCUSSION			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	Discussion

SECTION	ITEM	PRISMA-ScR CHECKLIST ITEM	REPORTED IN
Limitations	20	Discuss the limitations of the scoping review process.	Discussion
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	Discussion
FUNDING			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	Acknowledgements and declarations

JBI = Joanna Briggs Institute; PRISMA-ScR = Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews.
* Where *sources of evidence* (see second footnote) are compiled from, such as bibliographic databases, social media platforms, and Web sites.
† A more inclusive/heterogeneous term used to account for the different types of evidence or data sources (e.g., quantitative and/or qualitative research, expert opinion, and policy documents) that may be eligible in a scoping review as opposed to only studies. This is not to be confused with *information sources* (see first footnote).
‡ The frameworks by Arksey and O'Malley (6) and Levac and colleagues (7) and the JBI guidance (4, 5) refer to the process of data extraction in a scoping review as data charting.
§ The process of systematically examining research evidence to assess its validity, results, and relevance before using it to inform a decision. This term is used for items 12 and 19 instead of "risk of bias" (which is more applicable to systematic reviews of interventions) to include and acknowledge the various sources of evidence that may be used in a scoping review (e.g., quantitative and/or qualitative research, expert opinion, and policy document).

From: Tricco AC, Lillie E, Zarin W, O'Brien KK, Colquhoun H, Levac D, et al. PRISMA Extension for Scoping Reviews (PRISMAScR): Checklist and Explanation. Ann Intern Med. 2018;169:467–473. doi: 10.7326/M18-0850.

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5. Chapter 5: Trends in HIV testing, the treatment cascade, and HIV incidence among men who have sex with men in Africa

5.1 Preface to Manuscript 2

In the conceptual framework in my first manuscript, I posited that it is key for models to consider how structural determinants impact population-level HIV outcomes by affecting mediating variables on the causal pathways to HIV acquisition and transmission. For example, structural determinants such as criminalisation, stigma from health care workers, and fear of being disclosed as SGM may impede access to essential HIV services such as HIV testing and the treatment cascade. This could in turn increase the risk of HIV transmission to sexual partners of SGM living with HIV by delaying both diagnosis and initiation onto ART. Delays prolong the period during which PLHIV are able to remain virally unsuppressed, providing a route through which barriers to services may contribute to increased HIV incidence among SGM.

Comprehensively reviewing available data to estimate HIV burden, epidemic trends, and intervention coverage among SGM and other key populations is an important first and necessary step to inform robust models of HIV transmission. In my scoping review in Manuscript 1, seven models simulated pathways from structural determinants to HIV transmission via HIV services access, mostly reduced ART uptake, although none specifically addressed SGM populations. Information on HIV and gaps in HIV services access among SGM in Africa are not often collected in nationally representative population surveys. These data gaps make it challenging to track, prevent, and model new HIV acquisitions among SGM in Africa, which may explain why few studies have mathematically modelled structural determinants among SGM.(188) Without nationally collected data, observational studies –such as cross-sectional and cohort studies– can be valuable sources of this needed information.

Ideally, estimates of HIV burden and intervention coverage among SGM would be disaggregated among MSM and TGW. However, many observational studies among SGM report combined estimates only. TGW have typically been included in HIV research with MSM due to some shared sexual behaviours, yet experience unique vulnerabilities related to their gender identity and sexual networks that are distinct from MSM and warrant their own investigation.(189) Therefore, in my second manuscript, to address the inclusion of TGW in

MSM studies, I focused on including data specifically for MSM, where possible. I estimated disparities in HIV incidence and gaps in access to HIV testing and the HIV treatment cascade among MSM using a systematic review and meta-analysis of quantitative observational studies in Africa. The resulting article was published in *The Lancet HIV* (July 2023, Volume 10, Issue 8, DOI: https://doi.org/10.1016/S2352-3018(23)00111-X).

5.2 Manuscript 2: Trends in HIV testing, the treatment cascade, and HIV incidence among men who have sex with men in Africa: a systematic review and meta-analysis

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Summary

Background

Gay, bisexual, and other men who have sex with men (MSM) are disproportionately affected by HIV. In Africa, MSM face structural barriers to HIV prevention and treatment that increase their vulnerability to HIV acquisition and transmission, and undermine the HIV response. In this systematic review, we aimed to explore progress towards increases in HIV testing, improving engagement in the HIV treatment cascade, and HIV incidence reductions among MSM in Africa.

Methods

We searched Embase, MEDLINE, Global Health, Scopus, and Web of Science for cross-sectional and longitudinal studies reporting HIV testing, knowledge of status, care, antiretroviral therapy (ART) use, viral suppression, and HIV incidence among MSM in Africa published between Jan 1, 1980, and March 3, 2023. We pooled surveys using Bayesian generalised linear mixed-effects models, used meta-regression to assess time trends, and compared HIV incidence estimates among MSM with those of all men.

Findings

Of 9278 articles identified, we included 152 unique studies published in 2005–23. In 2020, we estimate that 73% (95% credible interval [CrI] 62–87) of MSM had ever tested for HIV. HIV testing in the past 12 months increased over time in central, western, eastern, and southern Africa (odds ratio per year [OR_{year}] 1·23, 95% CrI 1·01–1·51, n=46) and in 2020 an estimated 82% (70–91) had tested in the past 12 months, but only 51% (30–72) of MSM living with HIV knew their HIV status. Current ART use increased over time in central and western (OR_{year} 1·41, 1·08–1·93, n=9) and eastern and southern Africa (OR_{year} 1·37, 1·04–1·84, n=17). We estimated that, in 2020, 73% (47–88) of all MSM living with HIV in Africa were currently on ART. Nevertheless, we did not find strong evidence to suggest that viral suppression increased, with only 69% (38–89) of MSM living with HIV estimated to be virally suppressed in 2020. We found insufficient evidence of a decrease in HIV incidence over time (incidence ratio per year 0·96, 95% CrI 0·63–1·50, n=39), and HIV incidence remained high in 2020 (6·9 per 100 person-years, 95% CrI 3·1–27·6) and substantially higher (27–199 times higher) than among all men.

Interpretation

HIV incidence remains high, and might not be decreasing among MSM in Africa over time, despite some increases in HIV testing and ART use. Achieving the UNAIDS 95-95-95 targets for diagnosis, treatment, and viral suppression equitably for all requires renewed focus on this key population. Combination interventions for MSM are urgently required to reduce disparities in HIV incidence and tackle the social, structural, and behavioural factors that make MSM vulnerable to HIV acquisition.

Funding

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Introduction

Globally, gay, bisexual, and other men who have sex with men (MSM) and other key populations experience a disproportionate burden of HIV.[1] Key populations are individuals who are vulnerable to HIV acquisition and transmission and who experience unmet HIV prevention needs. In 2021, members of key populations and their sexual partners accounted for 70% of new annual HIV acquisitions globally and 21% occurred among MSM.[1]

Globally, MSM may be up to 28 times more likely to acquire HIV compared to heterosexual men.[1] Vulnerabilities to HIV can be partly explained by sexual behaviours, but the sociocultural and political contexts in which MSM live are important drivers of these vulnerabilities. Today, MSM face criminalization in 70 countries, including 31 in Africa.[2] In many settings, they are marginalized for their sexual identities and behaviours and face violence, stigma, and discrimination.[1-4] These punitive and discriminatory norms and laws often impede access to primary HIV prevention and the treatment and care cascade, exacerbating susceptibilities to HIV acquisition and transmission. To "End AIDS", the Global AIDS Strategy 2021-2026 calls for equitable and equal access to HIV services, as well as breaking down legal and societal barriers to HIV prevention, treatment, and care.[5]

In 2021, an estimated 18% of new annual HIV acquisitions in Central and Western Africa occurred among MSM, compared to 3% in Eastern and Southern Africa, where epidemics are more generalized.[1] Despite this, HIV prevalence is much higher among MSM than the general population in all regions of Africa, highlighting the need for contextualized approaches to HIV prevention, and MSM-focused interventions across epidemic typologies.[1]

As with other key populations, MSM can be unsuccessfully engaged, and nationally representative data on HIV service utilization and incidence are not available in Africa. This poses challenges to evaluating progress towards ending AIDS. The UNAIDS 95-95-95 targets for 2025 call for 95% knowledge of status among those living with HIV, 95% treatment coverage among those diagnosed, and 95% viral suppression among those on treatment.[5] Increasingly, dedicated surveys are being carried out to collect such indicators among MSM in Africa and to identify barriers and improve uptake of services to reduce new acquisitions.

Research in Context

Evidence before this study

Key populations, including gay, bisexual, and other men who have sex with men (MSM) are at increased risk of acquiring and transmitting HIV. Sociocultural and political contexts in some African countries and elsewhere can exacerbate these HIV vulnerabilities. Few studies have comprehensively and systematically characterized MSM's HIV burden and their engagement in the treatment and care cascade in this region, partly because nationally representative data on HIV incidence and HIV service utilization among this group are not available. This limits our understanding of progress towards achieving HIV epidemic control and ending AIDS in Africa. We searched Embase, Medline, Scopus, Global Health, and Web of Science, for studies published between Jan 1, 1980, and Mar 3, 2023, reporting HIV testing, knowledge of status, engagement in care, antiretroviral treatment (ART) coverage, viral suppression, and HIV incidence among MSM in Africa, using search terms for HIV, MSM, and Africa. We included peer-reviewed cross-sectional and longitudinal studies in any language. Most reviewed studies were carried out in one single site, often located in urban areas. One systematic review and meta-analysis from 2018 found that, between 2004-2017, HIV testing had increased, but that levels of diagnosis, current ART use, and viral suppression were too low to attain the previous UNAIDS 90-90-90 targets for 2020. A recent synthesis of MSM surveys estimated that in 2021, 2 in 5 MSM living with HIV were not reached by ART, but did not estimate time trends. HIV incidence in sub-Saharan Africa was systematically reviewed in 2021, but only five incidence rates among MSM were included, and MSM were excluded from analyses of temporal and geographic incidence trends.

Added value of this study

Our new comprehensive systematic review is informed by data from 152 independent studies from 31 countries, spanning close to two decades, and including 31 studies reporting HIV incidence. By considerably improving the temporal and geographical coverage of the previous reviews, we were able to also examine time trends in key outcomes. Our findings suggest that HIV testing among MSM has generally increased over time, reaching 82% of MSM in the past 12 months in 2020, along with current ART use among MSM living with HIV, which is estimated to have reached 73% in 2020, with some variations between Central/Western Africa (78%) and Eastern/Southern Africa (67%). However, increases in viral suppression over time were inconclusive and, in 2020, only 69% of MSM living with HIV in Africa were virally suppressed. We found no evidence of decreases in HIV incidence over time. Estimated incidence remained high in 2020, at 6.9 new HIV acquisitions per 100 person-years, and substantially higher than among all men in Eastern/Southern Africa (27 times higher) and Central/Western Africa (199 times higher).

Implications of all the available evidence

Levels of HIV testing, knowledge of status, and current ART use have improved among MSM in Africa over time, however viral suppression remains low and estimated HIV incidence among MSM remains persistently high – many times higher than that of all men – without strong evidence that it is decreasing. MSM in Africa remain highly vulnerable to HIV acquisition and HIV-related mortality and morbidity, undermining the Global AIDS Strategy to end AIDS. Realizing the UNAIDS 95-95-95 targets and reducing disparities in HIV incidence requires urgent efforts to strengthen community-led prevention efforts, including enabling environments and combination interventions tailored to the prevention needs of MSM.

A previous systematic review and meta-analysis of HIV testing and the HIV treatment cascade from 2004-2017 among MSM in Africa reported that levels of diagnosis, treatment, and viral suppression were too low to achieve the previous UNAIDS 90-90-90 targets for 2020.[6] Here, we update and substantially expand on this previous review to improve our understanding of temporal trends in HIV testing, knowledge of status, care, treatment coverage, and viral suppression, and HIV incidence among MSM, and to evaluate progress towards achieving the new UNAIDS 95-95-95 targets for 2025 and ending HIV among MSM in Africa.

Methods

Search strategy and data extraction

We searched Web of Science, Scopus, and Ovid Embase, MEDLINE, and Global Health online databases for articles reporting HIV testing, knowledge of status, engagement in care, antiretroviral therapy (ART) use, viral suppression, or HIV incidence among MSM in Africa, published from January 1st, 1980, up to March 3rd, 2023, using search terms for HIV, MSM, and Africa (Table 5.4.1).

We first screened articles by title and abstract, and then screened full texts for eligible studies. We included peer-reviewed cross-sectional or longitudinal studies that were conducted in any African country. We excluded conference abstracts, posters, and presentations, review articles, mathematical modelling studies, qualitative studies, and policy analyses. We did not exclude studies based on language. We searched the bibliographies of reviews and full texts for further relevant articles.

From the included studies, we extracted or calculated the following outcomes:

1) proportions of MSM who self-reported ever testing for HIV;

2) proportions of MSM who self-reported testing for HIV in the past 3, 6, and 12 months;

3) proportions of MSM living with HIV (confirmed with a biomarker) who knew they were living with HIV (from self-reports only or complemented with biomarkers, hereafter referred to as HIV aware MSM);

4) proportions of MSM living with HIV who self-reported engagement in care (as defined by the authors of each included study)

5) proportions of MSM living with HIV or HIV aware MSM, who were currently on ART (from self-reports or biomarkers)

6) proportions of MSM living with HIV, HIV aware MSM, or MSM currently on ART who were virally suppressed (confirmed with viral load testing and based on viral thresholds defined by the authors of each included study);

7) HIV incidence rates among MSM.

We also extracted information on participants (e.g., study population, age), study characteristics (e.g., study design, region of Africa, country, study years), and indicators of study quality (e.g., sampling methods, definitions of MSM employed by studies, and interview methods).

When multiple articles reported observations of the same outcome from the same study, we extracted the observation derived from the largest sample size. For studies that included transgender women (TGW), where possible, we included observations among MSM only, otherwise we used the aggregate observation reported. For studies conducted in multiple countries, we extracted observations for each country separately, if reported; otherwise, we used the aggregate observation but did not assign it a specific country. For studies conducted in multiple sub-national regions of a single country, we extracted only the aggregate observation. In studies of HIV incidence that reported multiple incidence rates over consecutive non-overlapping follow-up periods, we included these, otherwise we considered only the incidence rate covering the total follow-up period. In studies that reported them, we included weighted observations that accounted for sampling method (e.g., respondent-driven sampling, cluster, or time-location sampling) over crude observations (Text 5.4.1).

Screening and data extraction were conducted by three independent reviewers (JS, NS, and JKSL). Discrepancies were resolved by KG. This systematic review and meta-regression analysis were completed according to PRISMA guidelines.[7]

Data analyses

To pool observations and obtain region- and country-level estimates of HIV testing, stages in the HIV treatment cascade, and HIV incidence over time, we performed meta-regression analyses using Bayesian generalized linear mixed-effects models. Outcomes needed a minimum of 10 survey observations to be pooled. We chose a Bayesian multilevel framework because MSM survey estimates are heterogenous, data are sparse geographically, and few countries have several surveys.[6] In our models, we included study-level random intercepts, nested within country and region, allowing us to improve the accuracy and precision of estimates in settings with fewer observations.[8] To assess time trends, we used the mean-centered calendar year (or year and month for HIV incidence) as a continuous variable (using the midpoint year of each study), with random slopes by country, nested within regions. To assess the influence of criminalisation, we further included the legal status of partnerships between men in the country when the study was conducted as a binary variable. We classified regions as Central/Western, Eastern/Southern, and Northern Africa based on UNAIDS' classifications.[1] If both Central and Western Africa or Eastern and Southern Africa had >10 survey observations, we included those regions separately in our analyses.

We modelled proportions of ever and recent HIV testing, knowledge of status, ART use, and viral suppression using a binomial likelihood. We standardized proportions of viral suppression to a viral threshold of <1000 copies per mL before pooling (Text 5.4.2).[9] For HIV incidence rates, we used a Poisson likelihood with log(person-time) as an offset. We used non-informative prior distributions on the model parameters and elicited weakly informative prior distributions on the group-level variance parameters of the random effects and assessed model convergence using trace plots and R-hat diagnostics (Text 5.4.3). We obtained posterior distributions using Hamiltonian Monte Carlo, implemented in Stan,[13] and summarized using medians and 95% credible intervals (CrI).[13] We weighted pooled estimates by the estimated number of MSM in each country, using only the countries with available data (Text 5.4.4). Due to uncertainties in population size estimates, we assumed the same proportion of MSM in each

country.[10-12] We reported time trends for countries with observations from at least three different time points. Finally, we compared our estimates of knowledge of status, current ART use, and viral suppression among MSM living with HIV, and HIV incidence with year-matched UNAIDS estimates for all men.[14]

We assessed the risk of bias in included studies by appraising studies according to five criteria covering the appropriateness of the sampling method to recruit a representative sample of MSM, statistical adjustment for complex survey design (e.g., sampling weights in studies using RDS, cluster, or time-location sampling), the representativeness of the MSM participants based on studies' eligibility criteria, the inclusion of transgender women as MSM in surveys, and the risk of misclassification in ascertaining study outcomes (Text 5.4.5). Studies received a score ranging from 0-5 for each outcome reported, representing higher (score 0-1), moderate (score 2-3), and lower (score 4-5) risk of bias in reported study outcomes. We assessed publication bias using funnel plots.

Analyses were conducted in R, version 4.2.0, using the "brms" and "rstan" packages.[15,16]

Role of the funding source

The funder had no role in study design, data collection, analysis, interpretation, or preparation of the manuscript. All authors had full access to all the data in the study and had final responsibility for the decision to submit for publication.

Results

Search results

We identified 20,789 publications and, after removing 11,511 duplicates, and 8,156 publications at the title and abstract screening stage, we assessed the eligibility of 1,122 full texts (Figure 5.2.1). We identified four additional articles from bibliographies of relevant articles. Overall, we included 238 articles from 152 unique studies, nearly doubling the number of studies identified in a previous systematic review (Figure 5.4.1).[6]

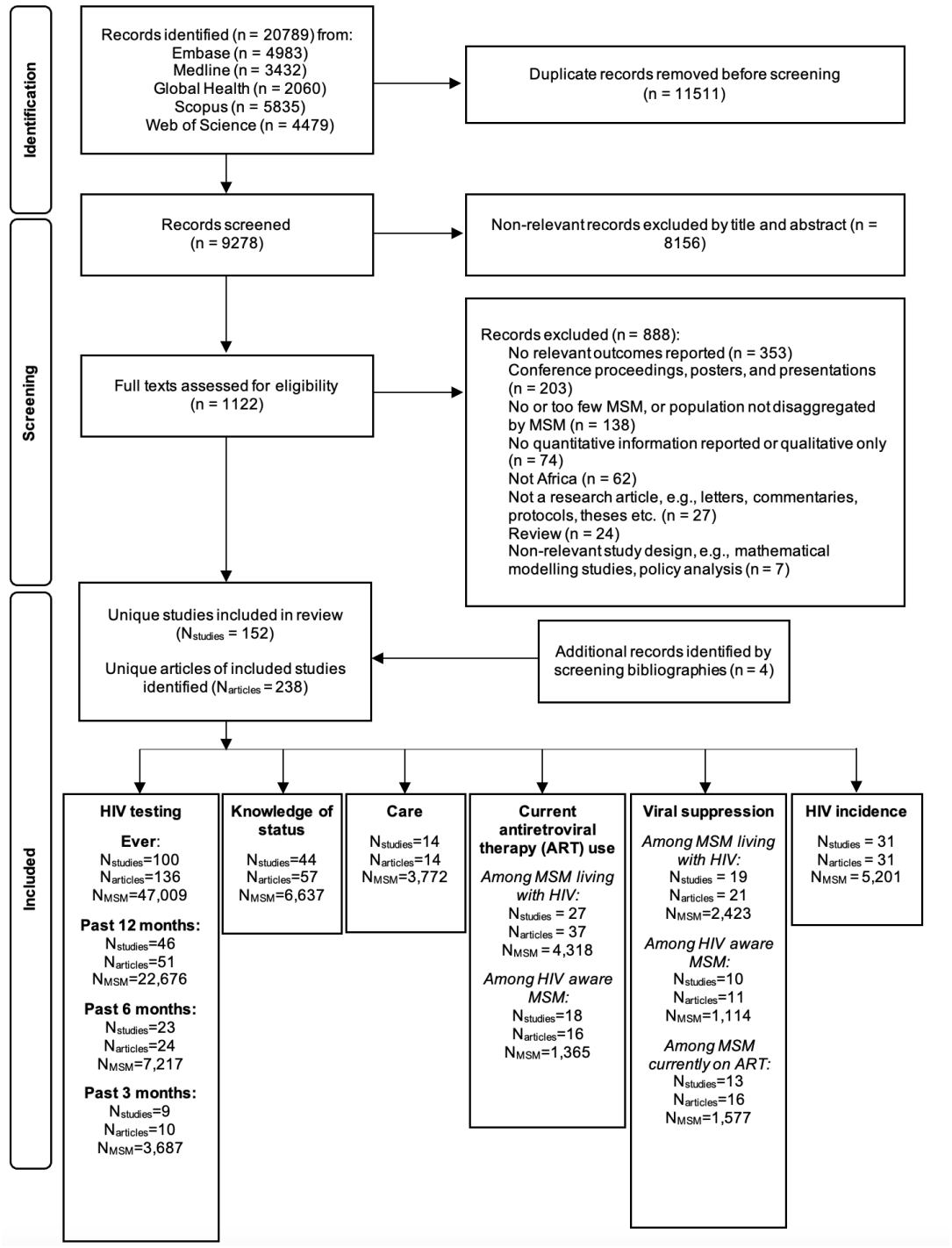

Figure 5.2.1. PRISMA flowchart. Screening identified 152 unique studies, reported in 238 unique articles, that were included in our analyses of HIV incidence, testing, and treatment cascade outcomes among men who have sex with men (MSM) in Africa.

Included studies predominantly reported ever HIV testing (number of studies [N_s]=100, number of independent observations [N_o]=100, number of MSM [N_{MSM}]=47,009), testing in the

past 12 months (N_s=46, N_o=46, N_{MSM}=22,676), and knowledge of status (N_s=44, N_o=44, N_{MSM}=6,637; Table 5.4.2, 44). Fewer studies reported testing over shorter recall periods such as 3 and 6 months (N_s=27, N_o=32, N_{MSM}=9,298), MSM currently on ART (N_s=29, N_o=45, N_{MSM}=4,437), MSM virally suppressed (defined based on viral loads ranging from ≤20 to <1000 copies per mL; N_s=23, N_o=42, N_{MSM}=3,127), or HIV incidence (N_s=31, N_o=39, N_{MSM}=5,201). Few observations of engagement in care other than current ART use were available.

Most studies were conducted between 2011-2020 (N_s=108) and in Western (N_s=52), Eastern (N_s=50), and Southern (N_s=40) Africa (Table 5.4.2-3). Few studies were from Central (N_s=9) or Northern (N_s=2) Africa. Observations were available from 31 countries, including 27 countries with HIV testing data, 25 countries with HIV treatment cascade data, and 12 countries with HIV incidence data. In 100 studies, conducted in 23 countries, sexual partnerships between men were criminalised at the time the study was conducted.

HIV testing and treatment cascade outcomes were primarily available from cross-sectional studies (N_s=113), and incidence estimates from prospective cohort studies (N_s=29). Most studies used convenience sampling (N_s=61) or respondent-driven sampling (RDS, N_s=52; Table 5.4.2-3). When recruiting participants, most studies defined MSM using eligibility criteria based on self-reported sexual behaviours (e.g., anal, anal/oral, and anal/oral/masturbatory sex) with men in the past 12 months (N_s=42), and participants were mainly recruited from the general population of MSM (N_s=96). However, in over 90% of studies, MSM definitions either included transgender women, or it was unclear whether they did. Overall, study sample sizes ranged from 23 to 5,796 MSM. Enrolled MSM were largely young, with mean or median age ranging between 25-34 years in most studies (N_s=107; Table 5.4.2-3). Face-to-face interviews were primarily used to collect self-reported information (N_s=114).

HIV testing, the treatment cascade, and HIV incidence among MSM in Africa: estimates for 2020 and time trends

In 2020, we estimated from self-reports that 73% (95%CrI 62-87%) of MSM had ever tested for HIV (Table 5.2.1). We estimated that ever HIV testing increased from 61% (53-69%) in 2010 to 94% (85-97%) in 2020 in Eastern Africa (Odds Ratio per year [OR_{year}]=1.23, 1.07-1.39, N_o=35), increasing particularly in Kenya and Tanzania (Figure 5.2.2, Table 5.2.1, Figure 5.4.2). Most observations were available from South Africa and Kenya.

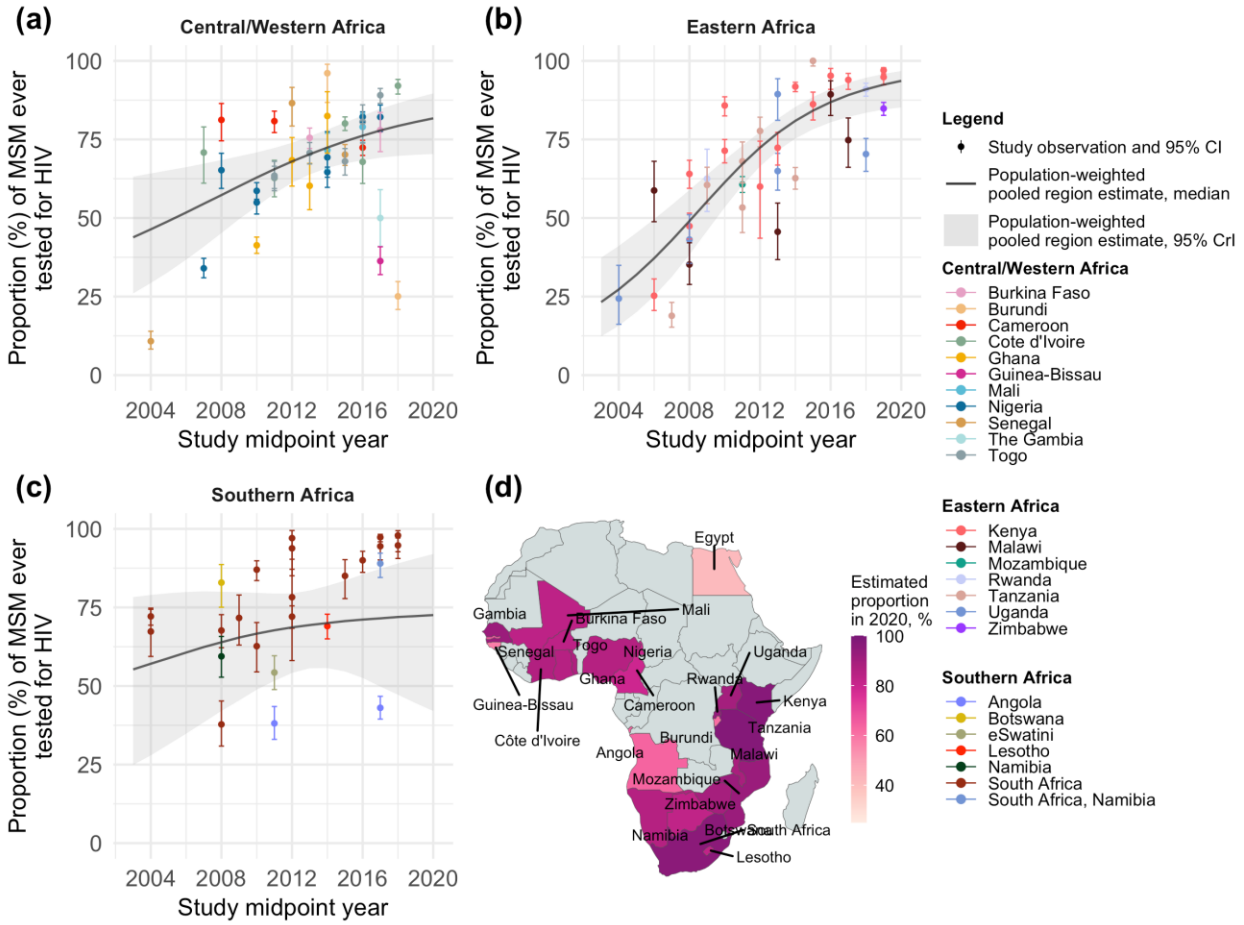

Figure 5.2.2. Estimated ever HIV testing among men who have sex with men (MSM) over time, by region and country of Africa. Ever HIV testing among MSM in (a) Central/Western Africa, (b) Eastern Africa, and (c) Southern Africa, and (d) the estimated proportion of MSM ever tested for HIV in 2020, by country, estimated using a Bayesian logistic generalized linear mixed-effects model, with study-, country-, and region-level random effects. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The solid lines and shaded areas represent the estimated population-weighted region-level proportions and 95% credible intervals (CrI), respectively, which were estimated using only countries with available data (see Figure 5.4.3 for individual country trends and 95% CrI).

Table 5.2.1. Estimated time trends in HIV testing, treatment cascade, and HIV incidence among men who have sex with men (MSM) in Africa and estimated outcomes in 2010 and 2020, overall and by region of Africa. See Table 5.4.4 for unweighted pooled estimates.

Outcome	Region of Africa	N_o	Estimate of time trend (per year)	95% CrI	Population weighted estimate in 2010	95% CrI	Population weighted estimate in 2020	95% CrI
Ever HIV testing (%)		100*						
Among all MSM†	Overall	96	OR=1.09	0.77-1.42	64%	52–73%	73%	62–87%
	Central/Western Africa	37	OR=1.10	0.97–1.22	63%	54–71%	82%	70–90%
	Eastern Africa	35	OR=1.23	1.07–1.39	61%	53–69%	94%	85–97%
	Southern Africa	24	OR=1.10	0.93–1.26	67%	49–80%	73%	42–92%
Past 12 months HIV testing (%)		46						
Among all MSM‡	Overall	46	OR=1.23	1.01–1.51	50%	41–60%	82%	70–91%
	Central/Western Africa	18	OR=1.23	1.07–1.43	51%	39–63%	82%	65–92%
	Eastern Africa	15	OR=1.26	1.09–1.48	45%	31–59%	87%	74–94%
	Southern Africa	12	OR=1.20	1.00–1.42	48%	32–65%	87%	56–96%
Knowledge of status (%)		44						
Among MSM living with HIV	Overall	44	OR=1.18	0.82–1.65	19%	10–39%	51%	30–72%
	Central/Western Africa	12	OR=1.10	0.79–1.43	19%	6–54%	44%	9–79%
	Eastern Africa	17	OR=1.27	1.04–1.58	14%	7–26%	59%	37–78%
	Southern Africa	15	OR=1.16	0.89–1.44	24%	11–49%	56%	26–86%
Currently on ART (%)		43*						
Among MSM living with HIV	Overall	26	OR=1.37	0.79–2.26	14%	6–41%	73%	47–88%
	Central/Western Africa	9	OR=1.41	1.08–1.93	12%	2–53%	78%	39–95%
	Eastern/Southern Africa	17	OR=1.37	1.04–1.84	14%	4–43%	67%	43–86%
Among HIV aware MSM	Overall	17	OR=1.47	0.77–2.79	22%	7–63%	89%	47–97%
	Central/Western Africa	5	OR=1.54	0.90–2.75	16%	1–79%	91%	26–99%
	Eastern/Southern Africa	12	OR=1.48	0.99–2.33	30%	9–63%	87%	69–97%
Viral suppression (%)		40*						
Among MSM living with HIV	Overall	18	OR=1.23	0.66–2.16	27%	7–61%	69%	38–89%
	Central/Western Africa	6	OR=1.19	0.78–1.89	29%	5–77%	68%	22–94%
	Eastern/Southern Africa	12	OR=1.31	0.90–1.91	19%	3–59%	73%	47–90%
Among HIV aware MSM	Overall	10	OR=1.06	0.49–2.26	64%	13–95%	75%	20–96%
	Central/Western Africa	3	OR=1.03	0.41–2.40	67%	4–100%	77%	7–99%
	Eastern/Southern Africa	7	OR=1.10	0.64–1.93	60%	9–94%	73%	28–95%

Among MSM currently on ART	Overall	12	OR=1.23	0.49–3.13	37%	8–96%	91%	47–99%
	Central/Western Africa	5	OR=1.21	0.42–3.47	26%	7–100%	91%	28–100%
	Eastern/Southern Africa	7	OR=1.28	0.59–2.85	46%	4–95%	92%	60–99%
HIV incidence rate (py-100)		39						
Among MSM not living with HIV	Overall	39	IRR=0.96	0.63–1.50	$8.8py^{-100}$	4.1–28.9	$6.9py^{-100}$	3.1–27.6
	Central/Western Africa	17	IRR=0.96	0.80–1.17	$9.5py^{-100}$	3.1–38.5	$7.8py^{-100}$	2.8–36.4
	Eastern/Southern Africa	22	IRR=0.96	0.79–1.15	$6.7py^{-100}$	4.3–11.4	$4.7py^{-100}$	2.3–11.9

ART, antiretroviral therapy; CrI, credible interval; IRR, incidence rate ratio (per year); MSM, men who have sex with men; No, number of observations; OR, odds ratio (per year); py-100, per 100 person-years.

* Study years of 4 observations of ever tested, 1 observation of current ART use among MSM living with HIV, 1 observation of current ART use among HIV aware MSM, 1 observation of viral suppression among MSM living with HIV, and 1 observation of current ART use among MSM currently on ART were not available, therefore these observations were excluded from our analyses of time trends.
† 1 observation from Northern Africa included in analysis but not shown in the table.
‡ 1 observation from Northern Africa included in analysis but not shown in the table.

In 2020 we estimated that 82% (70-91%) of MSM in Africa had been tested for HIV in the past 12 months (Table 5.2.1). Testing in the past 12 months increased overall (OR_{year}=1.23, 1.01-1.51, N_o=46) and from 51% (39-63%) in 2010 to 82% (65-92%) in 2020 in Central/Western Africa (OR_{year}=1.23, 1.07-1.43, N_o=18), from 45% (31-59%) in 2010 to 87% (74-94%) in 2020 in Eastern Africa (OR_{year}=1.26, 1.09-1.48, N_o=15), and from 48% (32-65%) in 2010 to 87% (56-96%) in Southern Africa (OR_{year}=1.20, 1.00-1.42, N_o=12), although only one observation was available for most countries (Figure 5.2.3, Table 5.2.1, Figure 5.4.4-5). Ever testing seemed to increase overall and in the Central/Western and Southern Africa regions, but trends were inconclusive, although clear increases occurred in South Africa (Figure 5.2.2c, 5.2.3c, Table 5.2.1, Figure 5.4.3). There were not enough observations from Northern Africa, and for HIV testing in the past 3 months, to assess time trends (Figure 5.4.6). Time trends in past 6 months HIV testing were inconclusive (Figure 5.4.7, Table 5.4.5).

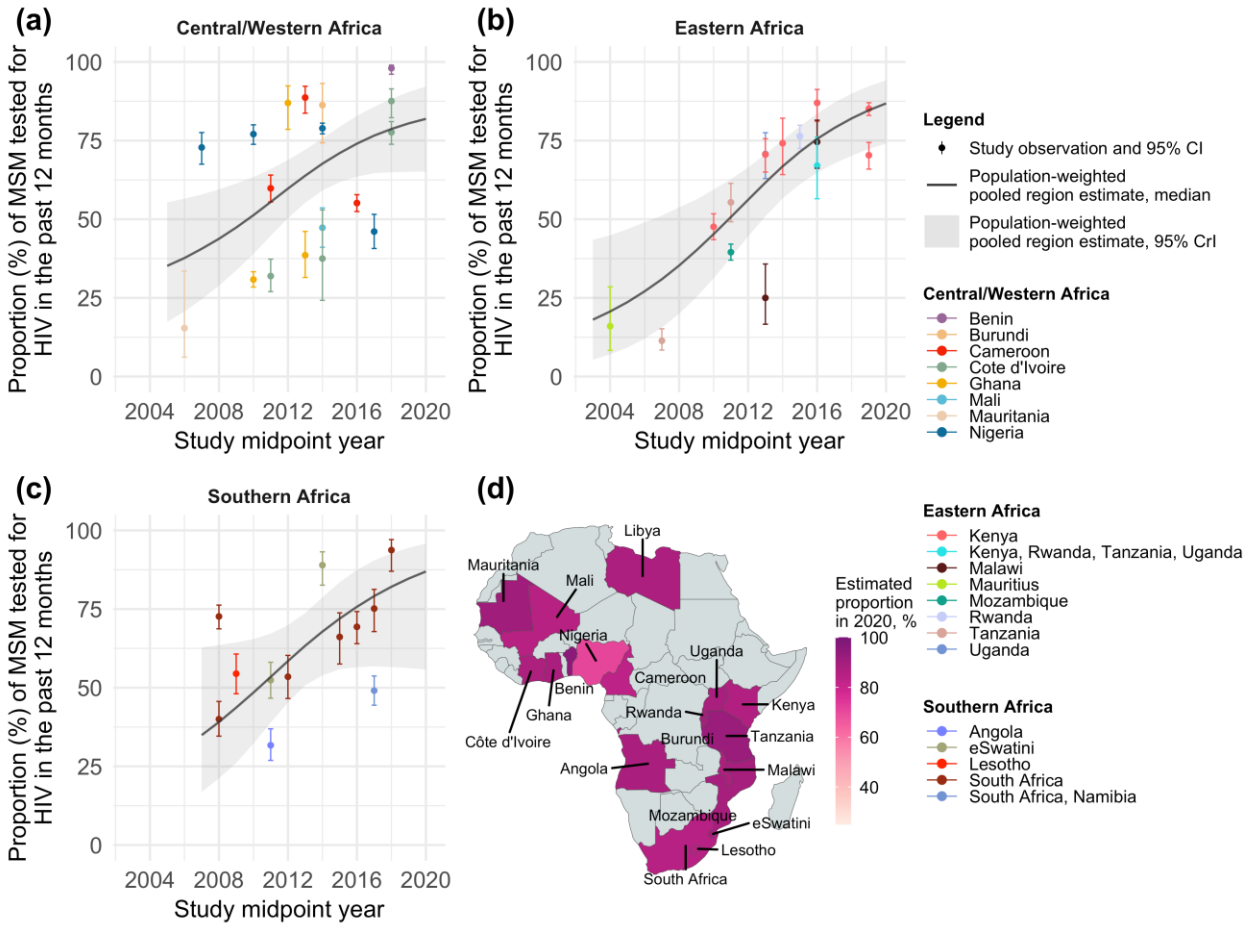

Figure 5.2.3. Estimated HIV testing in the past 12 months among men who have sex with men (MSM) over time, by region and country of Africa. Past 12 months HIV testing in (a) Central/Western Africa, (b) Eastern Africa, (c) Southern Africa, and (d) the estimated proportion of MSM tested for HIV in the past 12 months in 2020, by country. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The solid lines and shaded areas represent the estimated population-weighted region-level proportions and 95% credible intervals (CrI), respectively, estimated using only countries with available data (see Figure 5.4.7 for individual country-level time trends and 95% credible intervals). N=1 observation from Mauritius not shown on the map.

Among MSM living with HIV, we estimated that knowledge of status in 2020 was 51% (30-72%). Knowledge of status increased substantially over time from 14% (7-26%) in 2010 to 59% (37-78%) in 2020 in Eastern Africa (OR_{year}=1.27, 1.04-1.58, N_o=17) (Figure 5.2.4, Table 5.2.1, Figure 5.4.8-9). Time trends in other regions were inconclusive (Figure 5.2.4c, Table 5.2.1). In all regions, observations of knowledge of status were heterogenous, and overall, only six countries had multiple observations.

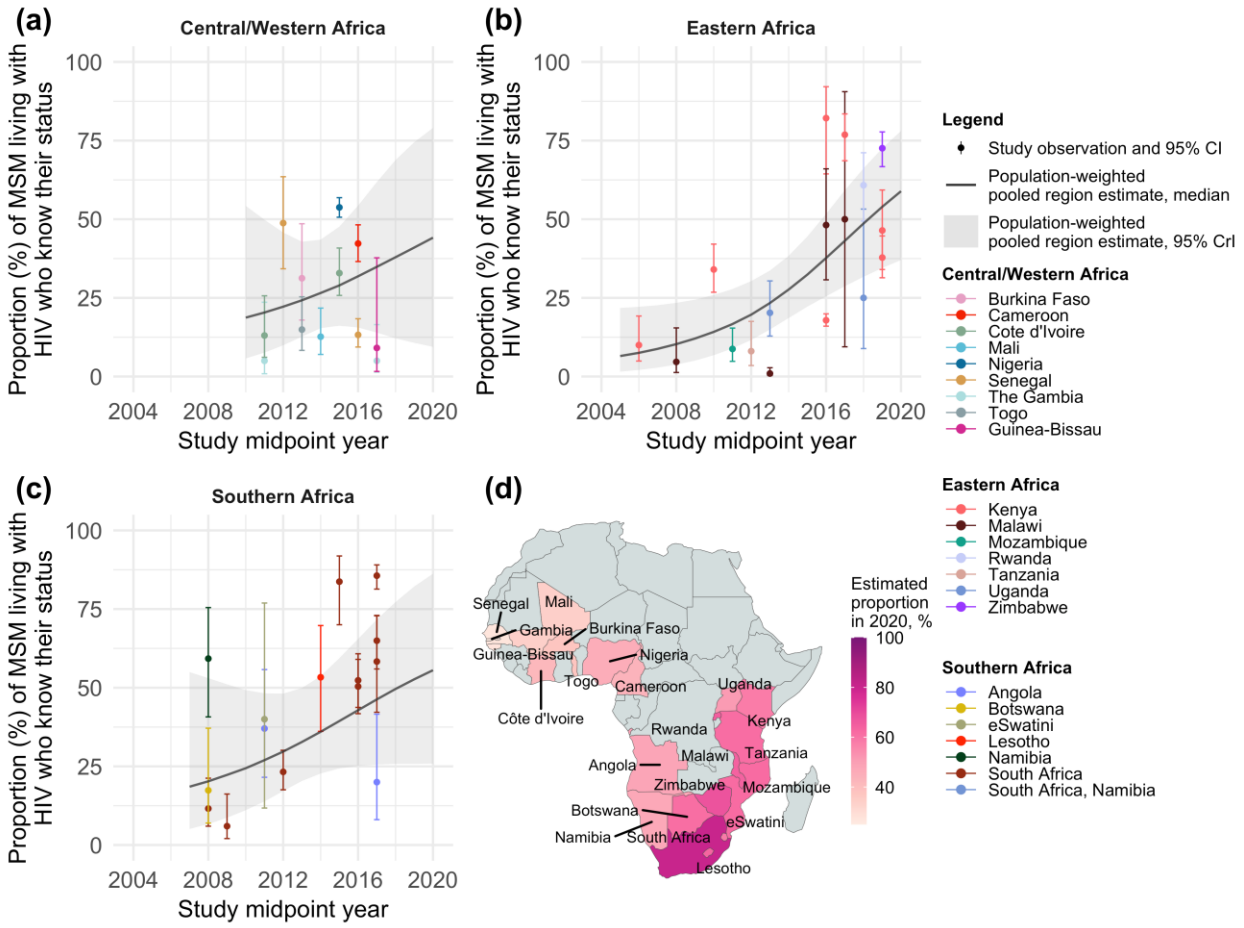

Figure 5.2.4. Estimated knowledge of status among men who have sex with men (MSM) living with HIV over time, by region and country of Africa. Knowledge of status in (a) Central/Western Africa, (b) Eastern Africa, (c) Southern Africa, and (d) the estimated proportion of MSM living with HIV who know their status in 2020, by country. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The solid lines and shaded areas represent the estimated population-weighted region-level proportions and 95% credible intervals (CrI), respectively, estimated using only countries with available data (see Figure 5.4.9 for individual country-level time trends and 95% CrI).

Except for current ART use, there were too few observations of the remaining engagement in care outcomes (e.g., ever or currently receiving non-ART care, retention in care in the past 12 months, ever ART use) to investigate time trends (Text 5.4.6, Figure 5.4.10-11).

Among MSM living with HIV, we estimated that 73% (47-88%) were on ART in 2020. Current ART use among MSM living with HIV increased from 12% (2-53%) in 2010 to 78% (39-95%) in 2020 in Central/Western Africa (OR_{year}=1.41, 1.08-1.93, N_o=9), and from 14% (4-43%) in 2010 to 67% (43-86%) in 2020 in Eastern/Southern Africa (OR_{year}=1.37, 1.04-1.84, N_o=17) (Figure 5.2.5, Table 5.2.1, Figure 5.4.12-13). Time trends in current ART use among those aware were similar, albeit inconclusive, and in 2020 current ART use among HIV aware MSM was 89% (47-97%; Table 5.2.1, Figure 5.4.14-16).

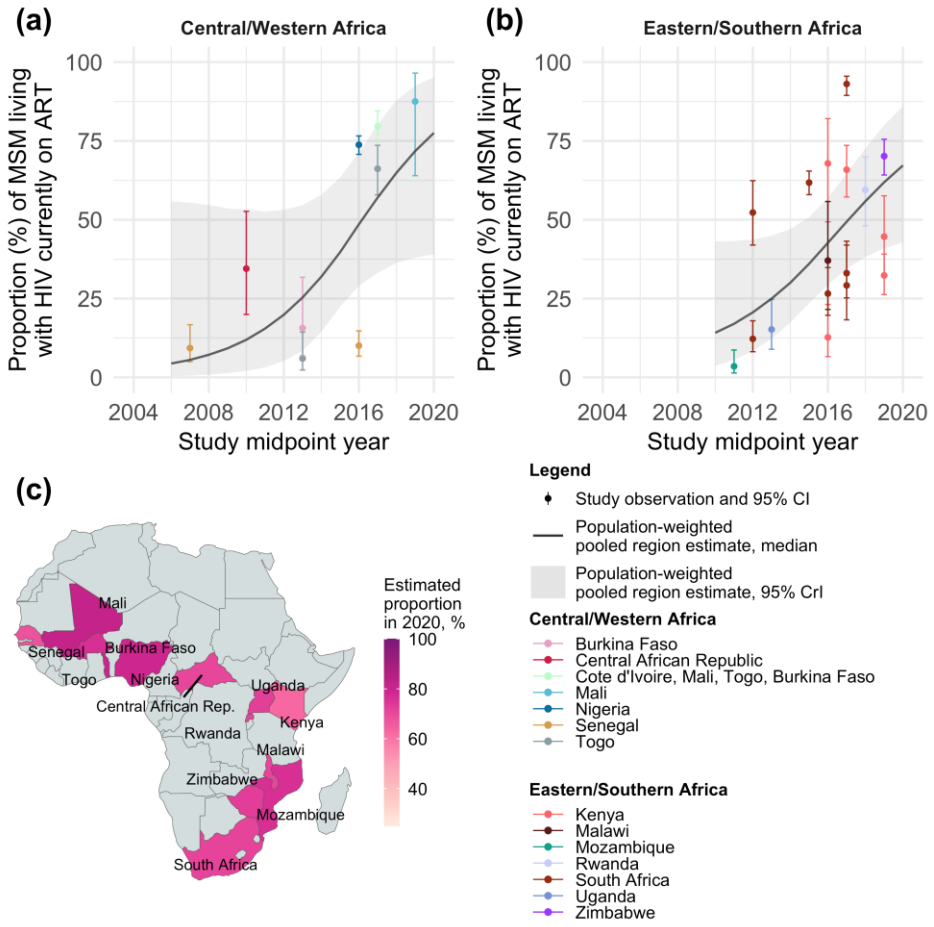

Figure 5.2.5. Estimated current antiretroviral therapy (ART) use among men who have sex with men (MSM) living with HIV over time, by region and country of Africa. Current ART use among MSM living with HIV in (a) Central/Western Africa, (b) Eastern/Southern Africa, and (c) the estimated proportion of MSM living with HIV currently on ART in 2020, by country. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The solid lines and shaded areas represent the estimated population-weighted region-level proportions and 95% credible intervals (CrI), respectively, estimated using only countries with available data (see Figure 5.4.13 for individual country-level time trends and 95% CrI).

In 2020, we found that viral suppression was achieved among 69% (95%CrI 38-89%) of MSM living with HIV (Table 5.2.1). Time trends in viral suppression among MSM living with HIV suggested potential increases over time overall and within regions, although all credible intervals crossed the null (Figure 5.2.6, Table 5.2.1, Figure 5.4.17-18). Our 2020 viral suppression estimates were 75% (20-96%) among HIV aware MSM and 91% (47-99%) among MSM currently on ART (Table 5.2.1, Figure 5.4.19-23).

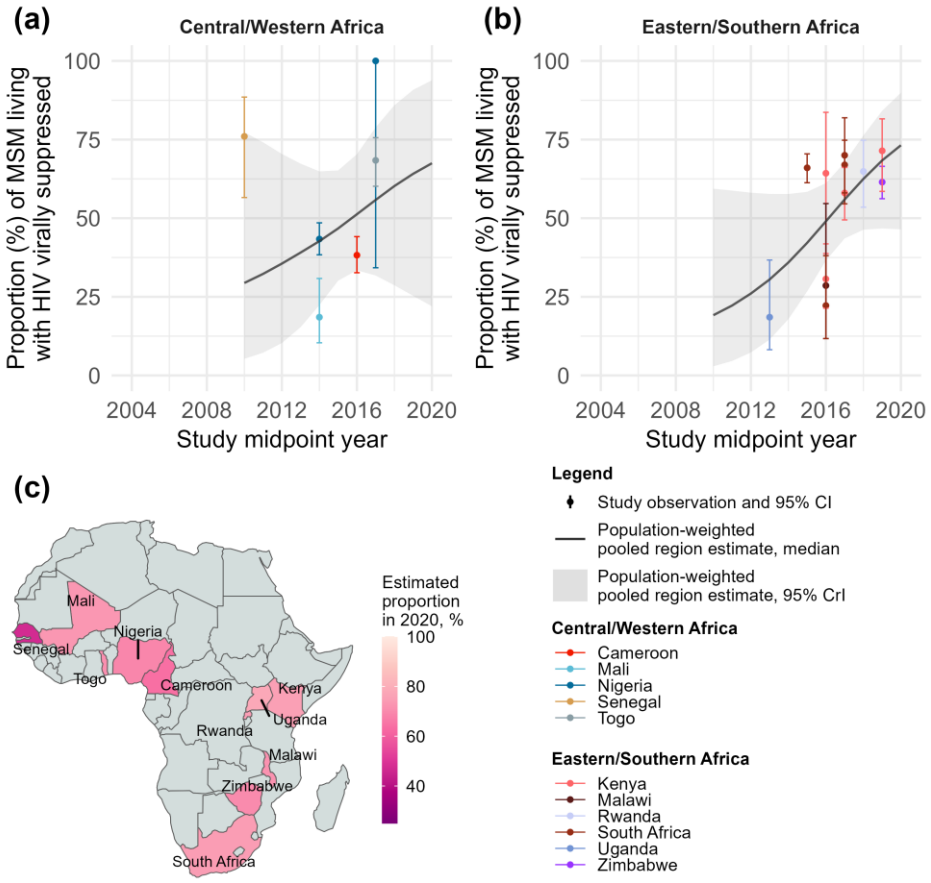

Figure 5.2.6. Estimated viral suppression among men who have sex with men (MSM) living with HIV over time, by region and country of Africa. Viral suppression among MSM living with HIV in (a) Central/Western Africa, (b) Eastern/Southern Africa, and (c) the estimated proportion of MSM living with HIV virally suppressed in 2020, by country. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The solid lines and shaded areas represent the estimated population-weighted region-level proportions and 95% credible intervals (CrI), respectively, estimated using only countries with available data (see Figure 5.4.18 for individual country-level time trends and 95% CrI).

In 2020, we estimated that HIV incidence among African MSM was 6.9 per 100 person years (95%CrI 3.1-27.6) and there was no conclusive evidence of a decline in HIV incidence among MSM in Africa over time since 2010 (IRR_{year}=0.96, 0.63-1.50, N_o=39), or in any region (Central/Western Africa: IRR_{year}=0.96, 0.80-1.17, N_o=17; Eastern/Southern Africa: IRR_{year}=0.96, 0.79-1.15, N_o=22; Figure 5.2.7, Table 5.2.1, Figure 5.4.24-25).

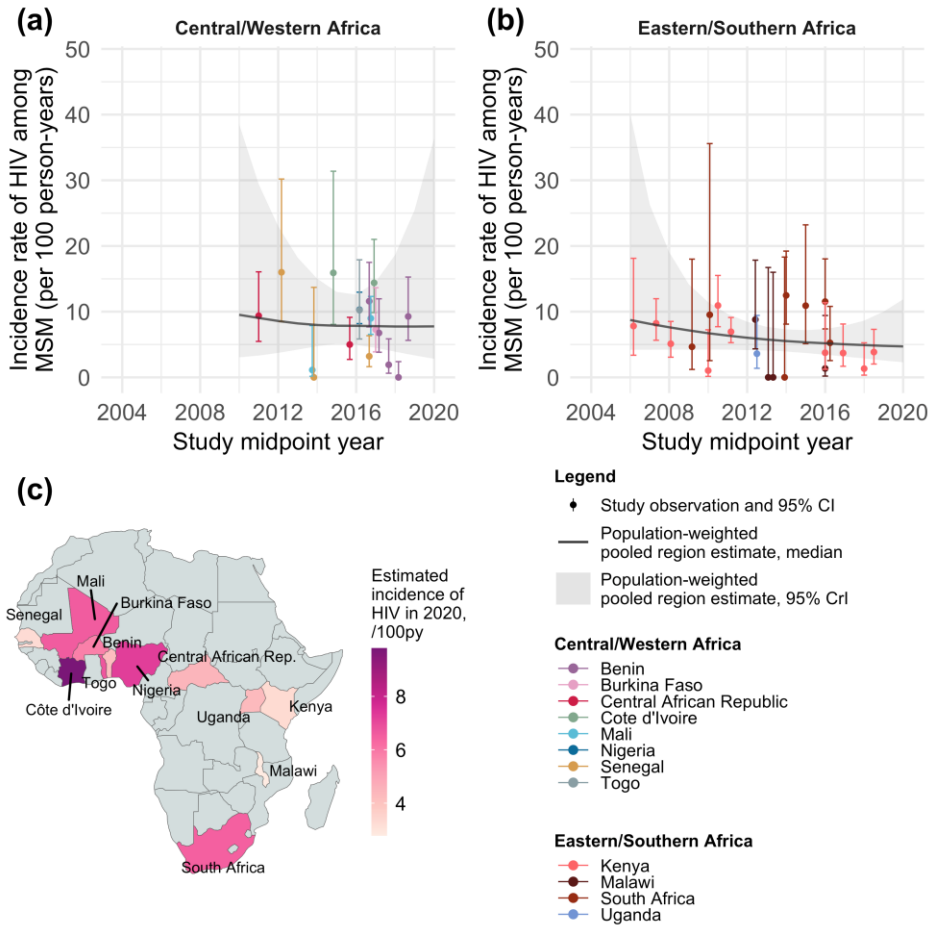

Figure 5.2.7. Estimated HIV incidence among men who have sex with men (MSM) over time, by region and country of Africa. (a) HIV incidence over time among MSM in Central/Western Africa, (b) Eastern/Southern Africa, and (c) the estimated incidence of HIV among MSM in 2020, by country, estimated using a Bayesian Poisson generalized linear mixed-effects model, with study-, country-, and region-level random effects. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The solid lines and shaded areas represent the estimated population-weighted region-level HIV incidence and 95% credible intervals (CrI), respectively, estimated using only countries with available data (see Figure 5.4.25 for individual country-level time trends and 95% CrI).

Ever HIV testing, knowledge of status and current ART use among MSM living with HIV, and HIV incidence seemed to be lower where partnerships between men were criminalized compared to not criminalized, but estimates were highly uncertain. For HIV testing in the past 12 months and viral suppression among MSM living with HIV, estimates were similar between

criminalizing and non-criminalizing settings. All credible intervals were wide and included the null (Table 5.4.6).

The HIV treatment cascade and HIV incidence among MSM compared with all men

Knowledge of status among MSM living with HIV between 2015 and 2020 was consistently lower than year-matched UNAIDS estimates among all men living with HIV aged 15+ in Eastern/Southern Africa, yielding a prevalence ratio (PR) of 0.68 (0.48-0.88) in 2020, and in Central/Western Africa, but credible intervals there crossed the null (Figure 5.4.26). Point estimates of the PR for current ART use and viral suppression varied in direction across regions, but the credible intervals were mostly wide and crossed the null (Figure 5.4.26).

Our estimates of HIV incidence among MSM were substantially higher than corresponding UNAIDS estimates among all men aged 15-49 (Figure 5.4.27). In 2020, UNAIDS reported an HIV incidence among men of 0.04% in Eastern/Southern Africa and 0.20% in Central/Western Africa. This entails that HIV incidence among MSM could be 27 times higher (95%CrI 13-67 times) than among all men in Eastern/Southern Africa, and 199 times higher (95%CrI 73-932) in Central/Western Africa.

Study quality and risk of bias

Across all studies, risk of bias in reported outcomes was mostly moderate ($N_{outcomes}$=185; Table 5.4.7). Study outcomes with a higher risk of bias ($N_{outcomes}$=129) were largely limited by non-representative sampling designs, selected study populations of MSM, and non-confidential interview methods. Funnel plots did not provide strong evidence of publication bias in study observations of HIV incidence, testing, and treatment cascade outcomes, and there was little difference between directly reported study observations and those calculated from available data (Figure 5.4.28).

Discussion

In this comprehensive systematic review and meta-regression study, we highlighted improvements in HIV testing and ART coverage over time among MSM in Africa. Nevertheless, 1 in 5 MSM living with HIV do not have a suppressed viral load. Estimated HIV incidence among MSM in Africa was close to 7 per 100 person-years in 2020, and there was weak indication of a temporal decline in new HIV acquisitions between 2006 and 2020. Such HIV

incidence rates among MSM are 27-199 times larger, depending on region, than corresponding rates among all men. This highlights the extreme disparities and exacerbated vulnerabilities to HIV acquisition and transmission among MSM in Africa.

HIV incidence among the overall population has steadily declined over the past decade, by 44% in Eastern/Southern Africa, and 43% in Central/Western Africa.[1,17] This decline has mainly been attributed to ART scale-up and the resulting population-level viral suppression.[1,17] As this study suggests, HIV incidence declines among the overall population may not reflect HIV incidence trends among MSM. If fewer resources are allocated to prevention in response to decreasing incidence trends in the overall population, progress among key populations could be compromised.[18] This is especially salient in Central/Western Africa where our 2020 HIV incidence estimate among MSM was 199 times higher than among all men. Even in a hyperendemic context in Eastern/Southern Africa where MSM are estimated to have accounted for only 6% of new HIV acquisitions in 2020, incidence was 27 times higher.[1] In all regions, these disparities are worsening over time as incidence decreases among the general population, despite recent advances in biomedical prevention, including oral and injectable pre-exposure prophylaxis (PrEP), for which access currently remains very limited.[1,19,20]

Studies suggest high willingness to use HIV prevention, including PrEP, among MSM in Africa and potential population-level benefits, through network effects of preventing onward transmissions.[21-25] Yet, comprehensive HIV prevention services, including PrEP provision, are not available in many countries, or are too far away, too inconvenient, or not adapted to the needs of MSM.[26] These are compounded by economic barriers such as poverty that further limit access.[26,27] Resources to provide services are often limited and efficacious interventions may not be scalable.[26] This study highlights the need for combination HIV prevention, with elements of structural, behavioural, and biomedical interventions. Such an approach is considered the most desirable strategy for attracting and retaining MSM in care and prevention services to achieve reductions in HIV incidence.[26,28] Tailored services could be provided in supportive spaces that promote queer identities, give access to appropriate health care and social support, and mediate the threat of stigma and discrimination.[29] However, services dedicated to MSM may not be appealing if men fear being identified as MSM.[28] Integrating services for MSM within those for other populations, combined with sensitivity training for health care workers, could enable the

provision of culturally competent care within non-discriminatory environments, and promote entry and retention in HIV treatment.[30]

Understanding where losses to follow-up occur along the HIV treatment cascade is critical to developing appropriate interventions to reduce HIV transmission and incidence among MSM. We estimated that, in 2020, most MSM had tested for HIV in the past year (82%), and that testing has increased over time in Central/Western, Eastern, and Southern Africa, mirroring population-level increases in HIV testing.[31] Nevertheless, only 51% of MSM living with HIV in 2020 were aware of their status. Knowledge of status also remains lower among MSM than among all men living with HIV in Africa. However, knowledge of status may be underestimated since the majority of studies relied on self-reports, which are susceptible to underreporting.[32,33] This is particularly apparent when comparing our knowledge of status estimates with those from current ART coverage, which are roughly 20%-point higher. Going forward, biomarkers could be used to adjust self-reports, but this is only useful in settings where ART coverage is high. More generally, enabling environments are needed that encourage uptake of HIV testing, linkage to care, and disclosure of HIV status. Expanding community-led services, including involving peer-navigators to support MSM to access and remain in care, and increasing the use of alternative, decentralized HIV testing modalities such as HIV self-tests and virtual services could improve knowledge of status and linkage into care for MSM in Africa.[34]

Current ART use has increased over time to reach 78% and 67% of all MSM living with HIV in 2020 in Central/Western Africa and Eastern/Southern Africa, respectively. These coverage estimates are on par with those reported for all men, and similar in Eastern/Southern Africa to those from a recent synthesis of MSM surveys that reported 69% ART coverage there in 2021.[12] Their estimate in Central/Western Africa (52%) was lower than ours, but the uncertainty intervals in both studies overlap. Nonetheless, viral suppression among all MSM living with HIV in Africa was lower, at 69%. Our estimates of ART use and viral suppression are lower than what is needed to achieve the 95-95-95 targets, which require that at least 90% of all MSM living with HIV are on ART, and 86% are virally suppressed. Criminalization of partnerships between men could hinder progress towards these targets, but our estimates of the impacts of criminalization were inconclusive. Failure to close these gaps leaves MSM vulnerable to ongoing transmission and continued HIV-related morbidity and mortality, undermining the strategy the end HIV. Innovative drug delivery models, including peer-navigation and provision

of ART outside of clinics, could help increase equitable access to first-line ART regimens and increase viral suppression among MSM.[35] Long-acting ART formulations, once availability increases, could also be important for overcoming some barriers to ART adherence.

Our results should be interpreted considering several limitations. First, although we did not exclude studies based on language, we used English and French search terms, which may have missed studies published in other languages. Second, most included studies used non-representative sampling designs, largely convenience sampling, particularly in cohort studies that measured incidence, whilst RDS was common in cross-sectional studies. RDS can theoretically yield more representative estimates when adjusted for sampling design, but could oversample young, urban, socially connected MSM. As such, MSM in small cities and rural locations, and older, non-gay identifying MSM could have been under-represented. [36] However, few of the included studies that used complex sampling designs (including RDS, cluster, and time-location sampling) provided adjusted estimates. Third, we included several large research cohorts (e.g., *CohMSM* in Western Africa and *Anza Mapema* in Kenya) that may have led to improvements among their own participants that are not generalizable to wider MSM. Nevertheless, such large cohort studies are important vehicles for improvements in care among MSM and data-driven recognition of knowledge gaps and targets for intervention. Fourth, variable MSM definitions were applied to recruit participants, and most studies included some transgender women. Fifth, self-reported outcomes were often assessed in face-to-face interviews, which may be impacted by social desirability and recall biases. Increased use of confidential interview methods including audio computer-assisted self-interviews (ACASI) could improve accuracy.[37] Sixth, we assumed the same proportion of MSM in each country when weighting pooled estimates, given the lack of reliable population sizes for MSM.[10-12] Finally, the heterogeneity in observations and limited number of surveys entailed that we had to rely on assumptions of linear temporal trends. There were particularly few observations of engagement in care, ART use, and viral suppression among MSM, with minimal increases since previous reviews and few observations of any outcome from Central or Northern Africa.[6]

Strengths of this study include the substantial increase in the number of included studies compared to previous reviews,[6,38,39] using data from 152 studies in 31 countries encompassing over 40,000 MSM, conducted from 2003-2020. Importantly, we provide novel analyses and results of pooled HIV incidence estimates among MSM over time in Africa. We pooled

observations using mixed-effects meta-regression models within a Bayesian framework, which allowed us to borrow information across observations to produce estimates in settings with sparse data. We also calculated additional study estimates, minimizing publication bias.

Conclusions

Despite continued increases in HIV testing and engagement in the HIV treatment cascade among MSM in Africa across settings, HIV incidence remains high among this group and may not be decreasing. Better combination interventions tailored to the primary HIV prevention needs of MSM that address the social, structural, and behavioural factors that exacerbate their vulnerabilities to HIV will likely be important to increase access to ART and viral suppression and, ultimately, reduce disparities in HIV incidence.

Data sharing statement

Data used in our analyses is provided in the Table 5.4.2.

Contributions

JS, MC-B, MM-G, and JL conceptualized this review and planned the analysis. JS, NS, and LJ did the search and independently did all stages of screening. JS, NS, and LJ independently extracted data, and JS conducted all analyses. NS and KG double checked the data extraction. MM-G and MC-B checked the data analysis. JS, MM-G, and MC-B interpreted the results and conceptualized the first draft of the review. KM, NK, RM, MNN, and GMK made substantial contributions to the interpretation of the results and edited the manuscript. All authors had full access to all data in the study and had final responsibility to submit for publication. All authors read and approved the final version of the manuscript.

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programme supported by the European Union, for partial funding of this work. For the purpose of open access, the authors have applied a Creative Commons Attribution (CC BY) license to any Author Accepted Manuscript version arising.

Declarations of interests statement

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5.4 Manuscript 2: Supplementary materials

Table 5.4.1: Search terms for HIV testing, treatment cascade, and incidence studies, by database and search domain

a) Embase search strategy Search conducted March 24th 2022 – 4622 articles retrieved
HIV domain (exp Human immunodeficiency virus/ OR exp acquired immune deficiency syndrome/ OR exp Human immunodeficiency virus infection/ OR exp Human immunodeficiency virus antibody/ OR exp Human immunodeficiency virus prevalence/ OR exp HIV test/ OR "hiv*".ab,kw,ti. OR human immun#deficiency virus.ab,kw,ti. OR human immun# deficiency virus.ab,kw,ti. OR acquired immun#deficiency syndrome.ab,kw,ti. OR acquired immun# deficiency syndrome.ab,kw,ti. OR "AIDS*".ab,kw,ti. OR SIDA.ab,kw,ti. OR syndrome d'immunodeficience acquise.ab,kw,ti. OR VIH.ab,kw,ti. OR virus de l'immunodeficience humaine.ab,kw,ti.)
AND MSM domain (exp male homosexuality/ OR exp bisexuality/ OR gay.ab,kw,ti. OR MSM.ab,kw,ti. OR men who have sex with men.ab,kw,ti. OR men that have sex with men.ab,kw,ti. OR HRSH.ab,kw,ti. OR hommes qui ont des relations sexuelles avec des hommes.ab,kw,ti. OR same-sex.ab,kw,ti. OR same sex.ab,kw,ti. OR queer.ab,kw,ti. OR "bisex*".ab,kw,ti. OR "homosex*".ab,kw,ti. OR same-gender.ab,kw,ti. OR same gender.ab,kw,ti. OR "meme sex*".ab,kw,ti. OR "meme genre*".ab,kw,ti. OR (male adj2 sex worker*).ab,kw,ti. OR "male sex work*".ab,kw,ti. OR exp men who have sex with men/ OR exp "sexual and gender minority"/ OR exp "men who have sex with men and women"/ OR sexual minority men.ab,kw,ti. OR (sexual and gender minority men).ab,kw,ti.)
AND Africa domain (exp africa/ OR exp "africa south of the sahara"/ OR exp north africa/ OR exp South Africa/ OR exp North Africa/ OR exp Central Africa/ OR exp African/ OR "Africa*".ab,kw,ti. OR "Afriq*".ab,kw,ti. OR "Algeri*".ab,kw,ti. OR "Angola*".ab,kw,ti. OR "Benin*".ab,kw,ti. OR (Botswana* OR Matswana* OR Batswana*).ab,kw,ti. OR (Burkina* OR Burundi*).ab,kw,ti. OR (Cabo Verde* OR Cape Verde* OR Cap#Vert).ab,kw,ti. OR (Camero* OR Central African Republic* OR republique centrafricaine OR Chad* OR Tchad* OR Comor* OR Cote d'Ivoire OR Ivory Coast OR Ivorian*).ab,kw,ti. OR (Djibouti OR Democratic Republic of the Congo OR Democratic Republic of the Congo OR Congo*).ab,kw,ti. OR (Egypt* OR Equatorial Guinea* OR Guinee Equatoriale OR Equatoguinean* OR Eritrea* OR Erythree* OR eSwatini* OR Ethiop*).ab,kw,ti. OR (Gabon* OR Gambi* OR Ghana* OR Guine*).ab,kw,ti. OR "Kenya*".ab,kw,ti. OR (Lesotho* OR Bathoso* OR Liberia* OR Liby*).ab,kw,ti. OR (Madagas* OR Malawi* OR Mali* OR Maurit* OR Moroc* OR Maroc* OR Mozambi*).ab,kw,ti. OR (Namibi* OR Niger*).ab,kw,ti. OR (Rwanda* OR Rouanda* OR Ruanda*).ab,kw,ti. OR (Sao* OR Senegal* OR Seychel* OR Sierra Leon* OR Somali* OR South Africa* OR Afrique du Sud OR South Sudan* OR Soudan du sud OR Sudan* OR Swazi*).ab,kw,ti. OR (Tanzani* OR Togo* OR Republique togolaise or tunisi*).ab,kw,ti. OR (Uganda* OR Ouganda*).ab,kw,ti. OR (Zambi* OR Zimbabwe*).ab,kw,ti. OR exp Algeria/ OR exp Angola/ OR exp Benin/ OR exp Botswana/ OR exp Burkina Faso/ OR exp Burundi/ OR exp Cape Verde/ OR exp Cameroon/ OR exp Central African Republic/ OR exp Chad/ OR exp Comoros/ OR exp Cote d'Ivoire/ OR exp Djibouti/ OR exp Congo/ OR exp Democratic Republic Congo/ OR exp Egypt/ OR exp Guinea-Bissau/ OR exp Guinea/ OR exp Equatorial Guinea/ OR exp Eritrea/ OR exp Ethiopia/ OR exp Gabon/ OR exp Gambia/ OR exp Ghana/ OR exp Kenya/ OR exp Lesotho/ OR exp Liberia/ OR exp Libyan Arab Jamahiriya/ OR exp Madagascar/ OR exp Malawi/ OR exp Mali/ OR exp Mauritania/ OR exp Mauritius/ OR exp Morocco/ OR exp Mozambique/ OR exp Namibia/ OR exp Niger/ OR exp Nigeria/ OR exp Rwanda/ OR exp "Sao Tome and Principe"/ OR exp Senegal/ OR exp Seychelles/ OR exp Sierra Leone/ OR exp Somalia/ OR exp South Africa/ OR exp South Sudan/ OR exp Sudan/ OR exp Eswatini/ OR exp Tanzania/ OR exp Togo/ OR exp Tunisia/ OR exp Uganda/ OR exp Zambia/ OR exp Zambia/ OR exp Zimbabwe/)
AND limit to yr="1980-Current"
b) Medline search strategy Search conducted March 24th 2022 – 3163 articles retrieved
HIV domain (exp HIV/ OR exp hiv infections/ OR exp acquired immunodeficiency syndrome/ OR exp HIV testing/ OR exp HIV seropositivity/ OR (HIV* OR human immun#deficiency virus OR human immun# deficiency virus OR acquired immun#deficiency syndrome OR acquired immun# deficiency syndrome OR AIDS* OR SIDA OR syndrome d'immunodeficience acquise OR VIH OR virus de l'immunodeficience humaine).ab,kw,ti.)
AND MSM domain (exp Homosexuality, Male/ OR exp Bisexuality/ OR exp "Sexual and Gender Minorities"/ OR "homosex*".ab,kw,ti. OR sexual minority men.ab,kw,ti. OR (sexual and gender minority men).ab,kw,ti. OR (gay OR MSM OR men who have sex with men OR men that have sex with men).ab,kw,ti. OR (HRSH OR hommes qui ont des relations sexuelles avec des hommes).ab,kw,ti. OR (same-sex OR same sex OR same-gender OR same gender OR queer OR bisex*).ab,kw,ti. OR (male adj2 sex worker*).ab,kw,ti. OR "male sex work*".ab,kw,ti. OR (meme sex* OR meme genre*).ab,kw,ti.)
AND Africa domain (exp Africa, Central/ OR exp "Africa South of the Sahara"/ OR exp Africa, Southern/ OR exp Africa, Northern/ OR exp Africa, Western/ OR exp Africa, Eastern/ OR exp Africa/ OR exp South Africa/ OR (Africa* OR Afriq*).ab,kw,ti. OR exp Algeria/ OR exp Angola/ OR exp Benin/ OR exp Botswana/ OR exp Burkina Faso/ OR exp Burundi/ OR exp Cabo Verde/ OR exp Cameroon/ OR exp Central African Republic/ OR exp Chad/ OR exp Comoros/ OR exp Cote d'Ivoire/ OR exp Djibouti/ OR exp "Democratic Republic of the Congo"/ OR exp Congo/ OR exp Egypt/ OR exp Guinea/ OR

exp Equatorial Guinea/ OR exp Guinea-Bissau/ OR exp Eritrea/ OR exp Ethiopia/ OR exp Gabon/ OR exp Gambia/ OR exp Ghana/ OR exp Kenya/ OR exp Lesotho/ OR exp Liberia/ OR exp Libya/ OR exp Madagascar/ OR exp Malawi/ OR exp Mali/ OR exp Mauritania/ OR exp Mauritius/ OR exp Morocco/ OR exp Mozambique/ OR exp Namibia/ OR exp Niger/ OR exp Nigeria/ OR exp Rwanda/ OR exp "Sao Tome and Principe"/ OR exp Senegal/ OR exp Seychelles/ OR exp Sierra Leone/ OR exp Somalia/ OR exp Sudan/ OR exp South Sudan/ OR exp Eswatini/ OR exp Tanzania/ OR exp Togo/ OR exp Tunisia/ OR exp Uganda/ OR exp Zambia/ OR exp Zimbabwe/ OR (Algeri* OR Angola*).ab,kw,ti. OR (Benin* OR Botswana* OR Motswana* OR Batswana* OR Burkina* OR Burundi*).ab,kw,ti. OR (Cabo Verde* OR Cape Verde* OR Cap-Vert).ab,kw,ti. OR (Camero* OR Central African Republic* OR republique centrafricaine OR Chad* OR Tchad* OR Comor* OR Cote d'Ivoire OR Ivory Coast OR Ivorian*).ab,kw,ti. OR (Djibouti OR Democratic Republic of the Congo OR Democratic Republic of the Congo OR Congo*).ab,kw,ti. OR (Egypt* OR Equatorial Guinea* OR Guinee Equatoriale OR Equatoguinean* OR Eritrea* OR Erythree* OR eSwatini* OR Ethiop*).ab,kw,ti. OR (Gabon* OR Gambi* OR Ghana* OR Guine*).ab,kw,ti. OR "Kenya*".ab,kw,ti. OR (Lesotho* OR Bathoso* OR Liberia* OR Liby*).ab,kw,ti. OR (Madagas* OR Malawi* OR Mali* OR Maurit* OR Moroc* OR Maroc* OR Mozambi*).ab,kw,ti. OR (Namibi* OR Niger*).ab,kw,ti. OR (Rwanda* OR Rouanda* OR Ruanda*).ab,kw,ti. OR (Sao* OR Senegal* OR Seychel* OR Sierra Leon* OR Somali* OR South Africa* OR Afrique du Sud OR South Sudan* OR Soudan du sud OR Sudan* OR Swazi*).ab,kw,ti. OR (Tanzani* OR Togo* OR Republique togolaise OR tunisi*).ab,kw,ti. OR (Uganda* OR Ouganda*).ab,kw,ti. OR (Zambi* OR Zimbabwe*).ab,kw,ti.)

AND limit to yr="1980-Current"

c) Global Health search strategy
Search conducted March 24th 2022 – 1951 articles retrieved

HIV domain (exp human immunodeficiency viruses/ OR exp human immunodeficiency virus 1/ OR exp human immunodeficiency virus 2/ OR exp acquired immune deficiency syndrome/ OR exp aids related complex/ OR exp hiv infections/ OR exp hiv-1 infections/ OR exp hiv-2 infections/ OR (HIV* OR human immun#deficiency virus OR human immun# deficiency virus OR acquired immun#deficiency syndrome OR acquired immun# deficiency syndrome OR AIDS* OR SIDA OR syndrome d'immunodeficience acquise OR VIH OR virus de l'immunodeficience humaine).ab,ti.)

AND MSM domain (exp homosexuality/ OR exp homosexual transmission/ OR exp men who have sex with men/ OR exp bisexuality/ OR exp homosexual men/ OR (gay OR MSM OR men who have sex with men OR men that have sex with men).ab,ti. OR (HRSH OR hommes qui ont des relations sexuelles avec des hommes).ab,ti. OR (same-sex OR same sex OR same-gender OR same gender OR queer OR bisex*).ab,ti. OR "male sex work*".ab,ti. OR (male adj2 sex work*).ab,ti. OR (meme sex* OR meme genre*).ab,ti. OR "homosex*".ab,ti. OR sexual minority men.ab,ti. OR (sexual and gender minority men).ab,ti.)

AND Africa domain (exp "Africa South of Sahara"/ OR exp East Africa/ OR exp Africa/ OR exp Central Africa/ OR exp North Africa/ OR exp Southern Africa/ OR exp West Africa/ OR exp Algeria/ OR exp Angola/ OR exp Benin/ OR exp Botswana/ OR exp Burkina Faso/ OR exp Burundi/ OR exp Cape Verde/ OR exp Cameroon/ OR exp Central African Republic/ OR exp Chad/ OR exp Comoros/ OR exp Cote d'Ivoire/ OR exp Djibouti/ OR exp Congo/ OR exp Congo Democratic Republic/ OR exp Egypt/ OR exp Equatorial Guinea/ OR exp Guinea-Bissau/ OR exp Guinea/ OR exp Eritrea/ OR exp Ethiopia/ OR exp Gabon/ OR exp Gambia/ OR exp Ghana/ OR exp Kenya/ OR exp Lesotho/ OR exp Liberia/ OR exp Libya/ OR exp Madagascar/ OR exp Malawi/ OR exp Mali/ OR exp Mauritania/ OR exp Mauritius/ OR exp Morocco/ OR exp Mozambique/ OR exp Namibia/ OR exp Niger/ OR exp Nigeria/ OR exp Rwanda/ OR exp "sao tome and principe"/ OR exp Senegal/ OR exp Seychelles/ OR exp Sierra Leone/ OR exp Somalia/ OR exp South Africa/ OR exp South Sudan/ OR exp Sudan/ OR exp swaziland/ OR exp Tanzania/ OR exp Togo/ OR exp Tunisia/ OR exp Uganda/ OR exp Zambia/ OR exp Zimbabwe/ OR (Africa* OR Afriq*).ab,ti. OR (Algeri* OR Angola*).ab,ti. OR (Benin* OR Botswana* OR Motswana* OR Batswana* OR Burkina* OR Burundi*).ab,ti. OR (Cabo Verde* OR Cape Verde* OR Cap-Vert).ab,ti. OR (Camero* OR Central African Republic* OR republique centrafricaine OR Chad* OR Tchad* OR Comor* OR Cote d'Ivoire OR Ivory Coast or Ivorian*).ab,ti. OR (Djibouti OR Democratic Republic of the Congo OR Democratic Republic of the Congo OR Congo*).ab,ti. OR (Egypt* OR Equatorial Guinea* OR Guinee Equatoriale OR Equatoguinean* OR Eritrea* OR Erythree* OR eSwatini* OR Ethiop*).ab,ti. OR (Gabon* OR Gambi* OR Ghana* OR Guine*).ab,ti. OR "Kenya*".ab,ti. OR (Lesotho* OR Bathoso* OR Liberia* OR Liby*).ab,ti. OR (Madagas* OR Malawi* OR Mali* OR Maurit* OR Moroc* OR Maroc* OR Mozambi*).ab,ti. OR (Namibi* OR Niger*).ab,ti. OR (Rwanda* OR Rouanda* OR Ruanda*).ab,ti. OR (Sao* OR Senegal* OR Seychel* OR Sierra Leon* OR Somali* OR South Africa* OR Afrique du Sud OR South Sudan* OR Soudan du sud OR Sudan* OR Swazi*).ab,ti. OR (Tanzani* OR Togo* OR Republique togolaise or tunisi*).ab,ti. OR (Uganda* OR Ouganda*).ab,ti. OR (Zambi* OR Zimbabwe*).ab,ti.)

AND limit to yr="1980-Current"

d) Scopus search strategy
Search conducted March 24th 2022 – 5451 articles retrieved

HIV domain (TITLE-ABS-KEY(aids*) OR TITLE-ABS-KEY("acquired immune deficiency syndrome") OR TITLE-ABS-KEY("acquired immun?deficiency syndrome") OR TITLE-ABS-KEY("acquired immun? deficiency syndrome") OR TITLE-ABS-KEY(HIV*) OR TITLE-ABS-KEY("human immun?deficiency virus") OR TITLE-ABS-KEY("human immun? deficiency virus") OR TITLE-ABS-KEY(SIDA) OR TITLE-ABS-KEY("syndrome d'immunodeficience acquise") OR TITLE-ABS-KEY(VIH) OR TITLE-ABS-KEY("virus de l'immunodeficience humaines"))

AND MSM domain (TITLE-ABS-KEY(homosex*) OR TITLE-ABS-KEY(bisex*) OR TITLE-ABS-KEY("men who have sex with men") OR TITLE-ABS-KEY("men that have sex with men") OR TITLE-ABS-KEY("same sex") OR TITLE-ABS-KEY("same-sex") OR TITLE-ABS-KEY(gay) OR TITLE-ABS-KEY(MSM) OR TITLE-ABS-KEY(queer) OR TITLE-ABS-

KEY("male sex work*") OR TITLE-ABS-KEY("male W/2 sex work*") OR TITLE-ABS-KEY("same gender") OR TITLE-ABS-KEY("same-gender") OR TITLE-ABS-KEY("meme sex*") OR TITLE-ABS-KEY("meme genre*") OR TITLE-ABS-KEY(HRSH) OR TITLE-ABS-KEY("hommes qui ont des relations sexuelles avec des hommes") OR TITLE-ABS-KEY("sexual minority men") OR TITLE-ABS-KEY("sexual and gender minority men"))
AND Africa domain (TITLE-ABS-KEY(africa*) OR TITLE-ABS-KEY(afriq*) OR TITLE-ABS-KEY(algeri*) OR TITLE-ABS-KEY(angola*) OR TITLE-ABS-KEY(benin*) OR TITLE-ABS-KEY(botswana*) OR TITLE-ABS-KEY(motswana*) OR TITLE-ABS-KEY(batswana*) OR TITLE-ABS-KEY(burkina*) OR TITLE-ABS-KEY(burundi*) OR TITLE-ABS-KEY("Cabo Verde*") OR TITLE-ABS-KEY("Cape Verde*") OR TITLE-ABS-KEY("Cap-Vert") OR TITLE-ABS-KEY(Camero*) OR TITLE-ABS-KEY("Central African Republic*") OR TITLE-ABS-KEY("republique centrafricaine") OR TITLE-ABS-KEY(chad*) OR TITLE-ABS-KEY(tchad*) OR TITLE-ABS-KEY(comor*) OR TITLE-ABS-KEY("cote d'ivoire") OR TITLE-ABS-KEY("ivory coast") OR TITLE-ABS-KEY(ivorian*) OR TITLE-ABS-KEY(djibouti*) OR TITLE-ABS-KEY("democratic republic of the congo") OR TITLE-ABS-KEY(congo*) OR TITLE-ABS-KEY(egypt*) OR TITLE-ABS-KEY("equatorial guinea*") OR TITLE-ABS-KEY("guinee equatoriale") OR TITLE-ABS-KEY(equatoguinean*) OR TITLE-ABS-KEY(eritrea*) OR TITLE-ABS-KEY(erythree*) OR TITLE-ABS-KEY(ethiop*) OR TITLE-ABS-KEY(gabon*) OR TITLE-ABS-KEY(gambi*) OR TITLE-ABS-KEY(ghana*) OR TITLE-ABS-KEY(guine*) OR TITLE-ABS-KEY(kenya*) OR TITLE-ABS-KEY(lesotho*) OR TITLE-ABS-KEY(bathoso*) OR TITLE-ABS-KEY(liberia*) OR TITLE-ABS-KEY(liby*) OR TITLE-ABS-KEY(madagas*) OR TITLE-ABS-KEY(malawi*) OR TITLE-ABS-KEY(mali*) OR TITLE-ABS-KEY(maurit*) OR TITLE-ABS-KEY(moroc*) OR TITLE-ABS-KEY(maroc*) OR TITLE-ABS-KEY(mozambi*) OR TITLE-ABS-KEY(namibi*) OR TITLE-ABS-KEY(niger*) OR TITLE-ABS-KEY(rwanda*) OR TITLE-ABS-KEY(rouanda*) OR TITLE-ABS-KEY(ruanda*) OR TITLE-ABS-KEY(sao*) OR TITLE-ABS-KEY(senegal*) OR TITLE-ABS-KEY(seychel*) OR TITLE-ABS-KEY("sierra leone*") OR TITLE-ABS-KEY(somali*) OR TITLE-ABS-KEY("south africa*") OR TITLE-ABS-KEY("afrique du sud") OR TITLE-ABS-KEY("south sudan*") OR TITLE-ABS-KEY("soudan du sud") OR TITLE-ABS-KEY(sudan*) OR TITLE-ABS-KEY(soudan*) OR TITLE-ABS-KEY(swazi*) OR TITLE-ABS-KEY(eswatini) OR TITLE-ABS-KEY(tanzani*) OR TITLE-ABS-KEY(togo*) OR TITLE-ABS-KEY(tunisi*) OR TITLE-ABS-KEY("republique togolaise") OR TITLE-ABS-KEY(uganda*) OR TITLE-ABS-KEY(ouganda*) OR TITLE-ABS-KEY(zambi*) OR TITLE-ABS-KEY(zimbabwe*))
AND PUBYEAR > 1979
e) Web of Science search strategy Search conducted March 24th 2022 – 4232 articles retrieved
HIV domain (TS = (AIDS* or "acquired immune deficiency syndrome" or "acquired immun?deficiency syndrome" or "acquired immun? deficiency syndrome" or HIV* or "human immun?deficiency virus" or "human immun? deficiency virus" or SIDA or "syndrome d'immunodeficience acquise" or VIH or "virus de l'immunodeficience humaine"))
AND MSM domain (TS = (homosex* or bisex* or "men who have sex with men" or "men that have sex with men" or "same sex" or "same-sex" or "same gender" or "same-gender" or gay or MSM or queer or "male sex work*" or male near/2 "sex work*" or "meme sex*" or "meme genre*" or "harsh" or "hommes qui ont des relations sexuelles avec des hommes" or "sexual minority men" or "sexual and gender minority men"))
AND Africa domain (TS = (Africa* or afriq* or algeri* or angola* or benin* or botswana* or motswana* or batswana* or burkina* or burundi* or "cabo verde*" or "cap-vert*" or "cape verde*" or camero* or "central african republic*" or "republique centrafricaine" or chad* or tchad* or comor* or "cote d'ivoire" or "ivory coast" or ivorian* or djibouti* or "democratic republic of the congo" or congo* or egypt* or "equatorial guinea*" or "guinee equatoriale" or equatoguinean* or eritrea* or erythree* or ethiop* or gabon* or gambi* or ghana* or guine* or kenya* or lesotho* or bathoso* or liberia* or liby* or madagas* or malai* or mali* or maurit* or moroc* or maroc* or mozambi* or namibi* or niger* or rwanda* or rouanda* or ruanda* or sao* or senegal* or seychel* or "sierra leone*" or somali* or "south africa*" or "afrique du sud" or "south sudan*" or "soudan du sud" or sudan* or soudan* or swazi* or eswatini* or tanzani* or togo* or tunisi* or uganda* or ouganda* or zambi* or zimbabwe*))
AND Timespan=1980-2022

Text 5.4.1. Including respondent driven sampling-adjusted HIV testing and treatment cascade proportions which accounted for sampling design

To derive the estimated proportion of HIV testing and treatment cascade outcomes in R requires specifying the numerator (n) and denominator (N) of observations before pooling. As pooling does not account for design effect, we conducted extra steps to be able to include observations from respondent-driven sampling (RDS) and time-location or cluster sampling studies that reported weighted proportions adjusted for sampling design, which typically have a

wider confidence interval than the corresponding crude proportion (n/N), due to the design effect). In practice, this only applied to RDS studies.

To include RDS-adjusted observations that accounted for sampling design in our meta-regression analyses, we extracted the RDS-adjusted proportion (p_{rds}) and the RDS-adjusted 95% confidence interval ($95\%CI_{rds}$) from studies that reported them. We then used these to obtain an estimate of the design effect (DE_{rds}), which we calculated from the ratio of variances of the RDS-adjusted proportion and the simple random sample (SRS) proportion for each adjusted observation reported. We then used the design effect to derive the effective sample size, including estimates of the numerator (n_{rds}) and denominator (N_{rds}), which were included in our meta-regression analyses.

To estimate the effective numerator and denominator of adjusted observations and their 95%CI reported in RDS studies, we used the information on n, N, p_{rds}, and $95\%CI_{rds}$ and performed the following steps:

1) Derive the variance of the RDS-adjusted proportion from the $95\%CI_{rds}$:

$$\mathrm{var}_{\mathrm{rds}} = \left(\frac{p_{\mathrm{rds\_uci}} - p_{\mathrm{rds\_lci}}}{3.92}\right)^2$$

where var_{rds} is the variance of the RDS-adjusted proportion accounting for sampling design and p_{rds_uci} and p_{rds_lci} are the upper and lower confidence limits of the $95\%CI_{rds}$.

2) Derive the variance of the SRS proportion, using the RDS-adjusted proportion and the crude sample size, N:

$$\mathrm{var}_{\mathrm{srs}} = \frac{p_{\mathrm{rds}} \times (1 - p_{\mathrm{rds}})}{N}$$

where var_{srs} is the variance of the RDS proportion not accounting for sampling design (as in a simple random sample).

3) Derive the design effect (the ratio of the variances of the RDS-adjusted and SRS proportions):

$$\mathrm{DE}_{\mathrm{rds}} = \frac{\mathrm{var}_{\mathrm{rds}}}{\mathrm{var}_{\mathrm{srs}}}$$

where DE_{rds} is the design effect.

4) Derive the effective sample size from the crude sample size and the design effect:

$$N_{\mathrm{rds}} = \frac{N}{\mathrm{DE}_{\mathrm{rds}}}$$

where N_{rds} is the effective sample size/denominator.

5) Finally, derive the effective numerator for the RDS-adjusted observations:

$$n_{\mathrm{rds}} = N_{\mathrm{rds}} \times p_{\mathrm{rds}}$$

6) Use n_{rds} and N_{rds} in the meta-regression analyses

Text 5.4.2. Calculations to standardize proportions of viral suppression to a viral threshold of <1000 copies per mL

We standardized proportions of viral suppression to a threshold of below 1000 copies per mL, which is the viral threshold specified in the 2016 World Health Organization Consolidated guidelines on the use of antiretroviral drugs for treating and preventing HIV infection. [1]

For study observations of viral suppression that used different viral thresholds, we estimated the proportion at a threshold of <1000 copies per mL using the following formula based on the reverse Weibull distribution, used as the default for standardizing viral load measurements by the UNAIDS Reference Group on Estimates, Modelling and Projections: [2]

$$p_1 = p_0^{\left(\frac{6-\log_{10} 1000}{6-\log_{10} t_0}\right)^{\phi}}$$

Where p_1 is the proportion of viral suppression at the WHO threshold of <1000 copies per mL, p_0 is the proportion originally reported by the study when the threshold used differed from 1000, t_0 is the viral threshold originally used by the study (e.g., if the threshold used was <200 copies per mL, t_0=200), and ϕ is the region-specific shape parameter for the reverse Weibull distribution, extracted from Johnson et al., 2021. [2]

Text 5.4.3. Details of model specifications of generalized linear mixed effects models for meta-regression by study year

Depending on the outcomes, either Bayesian logistic or Poisson generalized mixed effects model (GLMM) are used. These are detailed below.

Binomial regression model for proportions

For HIV testing, knowledge of status, current ART use, and viral suppression outcomes among men who have sex with men (MSM) in Africa, we used a binomial regression model. It takes the following form:

$$y_i \sim \text{Binomial}(n_i, \theta_i)$$

$$\text{logit}(\theta_i) = a_i + b_i$$

Where y_i is the number of MSM with the outcome (e.g., ever or recently testing for HIV, who know their status, currently on ART, or virally suppressed) in study i. These are assumed to follow a binomial distribution with sample size n_i and proportion θ_i, in study i. The logit-transformed proportion θ_i is modeled as the sum of study-specific intercepts a_i, and the time trend b_i.

$$a_i = \alpha_g + \alpha_{r[i]} + \alpha_{c[i]} + \alpha_{s[i]}$$

The random intercept a_i for study *i,* corresponds to the sum of the global intercept α_g, the region-level intercept $\alpha_{r[i]}$ for region *r,* the country-level intercept $\alpha_{c[i]}$ for country *c,* and the survey-specific intercept $\alpha_{s[i]}$ for survey *s*.

$$b_i = (\beta_g + \beta_{r[i]} + \beta_{c[i]})X_i$$

The time trend b_i for study *i* is modeled as a random slope. It corresponds to the sum of the global time trend β_g, the region-level time trend $\beta_{r[i]}$, and the country-level time trend $\beta_{c[i]}$. These coefficients are then multiplied by the mean-centered calendar year of the study's midpoint X_i.

The model's specification is complemented with the following prior distributions. We assumed that the global intercept parameter, α_g, and global slope parameter, β_g, follow normal distributions. We used weakly informative prior distributions for the country-level and region-level variance parameters of the random intercepts and random slopes, assuming half-normal distributions, and selected the hyperparameters such that the variance was higher across regions than countries, as we expect outcomes to be more similar with countries than within regions. We allowed for correlations between random intercepts and slopes using multivariate normal distributions, and used weakly informative Lewandowski-Kurowicka-Joe (LKJ) priors for the Cholesky factors, R_c and R_r of the correlation matrices that specify the country-level and region-level variance-covariance matrices Σ_c, and Σ_r.[3] The LKJ-prior has a scale parameter, ζ, that modifies the strength of the correlations. If ζ = 1, the density is uniform over correlation matrices. If ζ > 1, there is a sharper peak in the density for larger values of ζ. If 0 < ζ < 1, the distribution is U-shaped, giving higher probabilities for non-zero correlations.

$$\alpha_s \sim \text{Normal}(0, \sigma_s)$$

$$\begin{bmatrix}\alpha_c \\ \beta_c\end{bmatrix} \sim \text{MVNormal}(\begin{bmatrix}0 \\ 0\end{bmatrix}, \Sigma_c)$$

$$\begin{bmatrix}\alpha_r \\ \beta_r\end{bmatrix} \sim \text{MVNormal}(\begin{bmatrix}0 \\ 0\end{bmatrix}, \Sigma_r)$$

$$\alpha_g \sim \text{Normal}(0, 2)$$

$$\beta_g \sim \text{Normal}(0, 1)$$

$$\sigma_s \sim \text{HalfNormal}(0, 1)$$

$$\sigma_{\alpha_c}, \sigma_{\beta_c} \sim \text{HalfNormal}(0, 1)$$

$$\sigma_{\alpha_r}, \sigma_{\beta_r} \sim \text{HalfNormal}(0, 0.5)$$

$$R_c, R_r \sim \text{LKJ}(1)$$

$$\Sigma_c = \begin{bmatrix}\sigma_{\alpha_c} & 0 \\ 0 & \sigma_{\beta_c}\end{bmatrix} * R_c * \begin{bmatrix}\sigma_{\alpha_c} & 0 \\ 0 & \sigma_{\beta_c}\end{bmatrix}$$

$$\Sigma_r = \begin{bmatrix} \sigma_{\alpha_r} & 0 \\ 0 & \sigma_{\beta_r} \end{bmatrix} * R_r * \begin{bmatrix} \sigma_{\alpha_r} & 0 \\ 0 & \sigma_{\beta_r} \end{bmatrix}$$

Poisson regression model for counts

For the meta-regression models of HIV incidence rates among MSM in Africa, the model takes the following form:

$$y_i \sim \text{Poisson}(\lambda_i)$$

$$\log(\lambda_i) = a_i + b_i + \log(\delta_i)$$

Where y_i is the number of HIV acquisitions occurring over follow-up in study i, that are Poisson distributed. The log-transformed incidence rate λ_i is modeled as the sum of study-specific intercepts a_i, the time trend b_i, and the offset $\log(\delta_i)$ which corresponds to the log-transformed person-years for study i. The remainder of the model follows the same specification as above. The model's specification is complemented with the following prior distributions.

$$\alpha_s \sim \text{Normal}(0, \sigma_s)$$

$$\begin{bmatrix} \alpha_c \\ \beta_c \end{bmatrix} \sim \text{MVNormal}(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \Sigma_c)$$

$$\begin{bmatrix} \alpha_r \\ \beta_r \end{bmatrix} \sim \text{MVNormal}(\begin{bmatrix} 0 \\ 0 \end{bmatrix}, \Sigma_r)$$

$$\alpha_g \sim \text{Normal}(0, 10)$$

$$\beta_g \sim \text{Normal}(0, 1)$$

$$\sigma_s \sim \text{HalfNormal}(0, 1)$$

$$\sigma_{\alpha_c}, \sigma_{\beta_c} \sim \text{HalfNormal}(0, 1)$$

$$\sigma_{\alpha_r}, \sigma_{\beta_r} \sim \text{HalfNormal}(0, 0.5)$$

$$R_c, R_r \sim \text{LKJ}(1)$$

$$\Sigma_c = \begin{bmatrix} \sigma_{\alpha_c} & 0 \\ 0 & \sigma_{\beta_c} \end{bmatrix} * R_c * \begin{bmatrix} \sigma_{\alpha_c} & 0 \\ 0 & \sigma_{\beta_c} \end{bmatrix}$$

$$\Sigma_r = \begin{bmatrix} \sigma_{\alpha_r} & 0 \\ 0 & \sigma_{\beta_r} \end{bmatrix} * R_r * \begin{bmatrix} \sigma_{\alpha_r} & 0 \\ 0 & \sigma_{\beta_r} \end{bmatrix}$$

Text 5.4.4. Calculations to population-weight pooled estimates based on the population size of MSM in each country

For these calculations, we assumed that MSM comprise the same proportion of all adult men in each country.

We calculated population-weighted pooled estimates, by region of Africa, for each outcome as follows:

1) For each iteration of the model, we predicted the estimated outcome of e.g., the proportion of MSM ever tested for HIV in each country, in each year
2) We then multiplied the proportion for each iteration by the population size of MSM in the relevant country and year, to give the estimated number of MSM ever tested for HIV in each iteration, for each country and year
3) We then summed the numbers of MSM ever tested across all countries, by iteration and year, to give the numerator of the population-weighted estimate in each iteration and year
4) We then summed the total number of MSM across countries, by iteration and year, to give the denominator of the population-weighted estimate in each iteration and year
5) We then divided the numerator by the denominator, by iteration and year, to calculate the population-weighted pooled estimate for the region for each iteration and year

Finally, we summarized the median and 95% credible interval of the population-weighted proportions across all iterations, by year, to give the population-weighted pooled regional estimates in each year.

Text 5.4.5. Study quality assessment tool

Criteria used to assess the quality and risk of bias of included studies
1) **Appropriateness of the sampling method to recruit a representative sample of MSM participants (maximum 1 points)**
a) RDS/cluster/time-location sampling with or without statistical adjustment for study design, or snowball/chain-referral sampling (1 point)
b) Convenience or purposive sampling (0 points)
c) Sampling strategy not described (0 points)
2) **Statistical adjustment of outcomes for complex survey design (maximum 1 point)**
a) Observations of outcome adjusted for complex sampling design (e.g., RDS-adjusted observations; 1 point)
b) Crude observations available only (0 points)
3) **Representativeness of MSM participants based on eligibility criteria used to recruit MSM into the study (maximum 1 point)**
a) Eligibility criteria designed to recruit a representative sample of MSM participants from the 'general' population of MSM (e.g., not only MSM who are behaviourally vulnerable to HIV (e.g., male sex workers, PWID), or definition of MSM based on sexual behaviour with another man over recall periods >3 months; 1 point)
b) Study recruited a selected sample of MSM participants or eligibility criteria led to more selected sample of MSM (e.g., MSM who are behaviourally vulnerable to HIV

(e.g., male sex workers, PWID), definitions of MSM based on anal sex over recall periods <3 months; 0 points)
c) Eligibility criteria not described (0 points)
4) **Inclusion of transgender women in the study definition of MSM (maximum 1 point)**
a) Study did not define transgender women as MSM, or outcome(s) were disaggregated and available among only MSM (1 point)
b) Transgender women were defined as MSM, or outcomes were not disaggregated (0 points)
c) Unclear whether transgender women were included as MSM (0 points)
5) **Risk of misclassification in ascertainment of the relevant outcome(s) reported (maximum 1 point)**
a) Confirmed using biomarkers (for incidence and viral suppression outcomes; 1 point)
b) Self-report in confidential interview (for all other outcomes; e.g., ACASI, CAPI, SAQ, PBS; 1 point)
c) Self-report in face-to-face interview (0 points)
d) Ascertainment method not described (0 points)

ACASI, audio computer-assisted self-interview; CAPI, computer-assisted personal interview; MSM, gay, bisexual, and other men who have sex with men; PBS, pooling booth survey; PWID, people who inject drugs; RCT, randomized controlled trial; RDS, respondent driven sampling; SAQ, self-administered questionnaire.

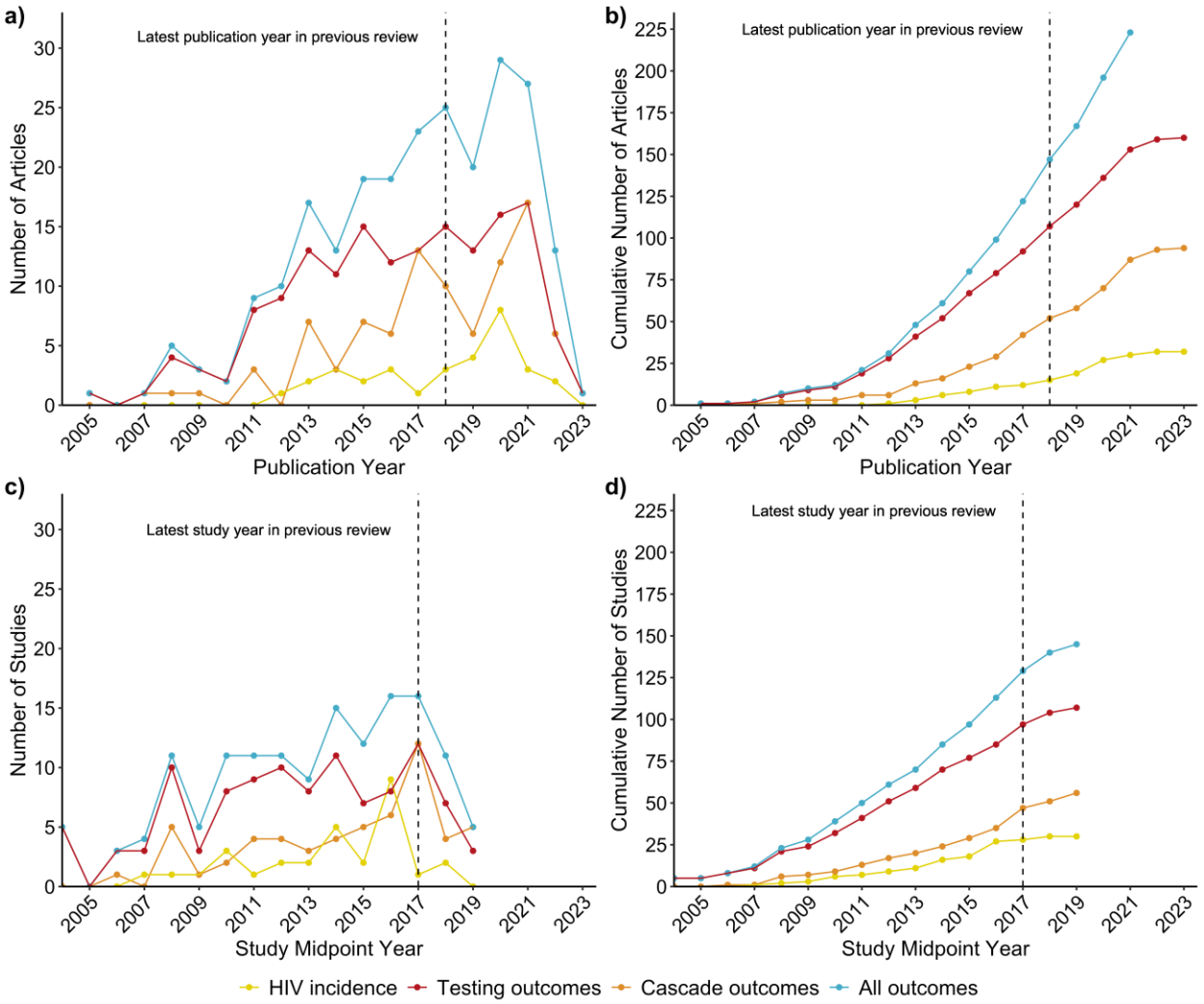


Figure 5.4.1. Number of articles and studies over time. (a) The number of unique research articles published over time (by publication year), (b) the cumulative number of unique research articles published over time (by publication year), (c) the number of unique studies conducted over time (by study midpoint year), and (d) the cumulative number of studies conducted over time (by study midpoint year) included in our review reporting HIV incidence rates (yellow lines), HIV testing outcomes (red lines), and HIV treatment cascade outcomes (orange lines). In 5 studies, the study year was not reported. The dashed lines represent our previous systematic review.

Table 5.4.2. Characteristics of unique studies included in our analyses and outcomes reported.

Reference	PARTICIPANT CHARACTERISTICS							STUDY CHARACTERISTICS				HIV TESTING, TREATMENT CASCADE, AND HIV INCIDENCE OUTCOMES									
	Study population of MSM*	**MSM eligibility criteria**	**TGW included**	**N_{MSM}**	**Country**	**Median age**	**Mean age**	**Study midpoint year**	**Study design**	**Sampling method**	**Interview method**	**Ever test** (self-reported)	**Recent test** (self-reported)	**Period of recent test** (months)	**Knowledge of HIV status** (confirmed with biological test and answered "yes" to question "are you living with HIV?")	**Engagement in care** (self-reported)	**ART use (denominator)** (self-reported)	**Period of ART use** (ever or current)	**Viral suppression (denominator)** (confirmed with biological test)	**Viral threshold** (selected by study authors, copies per mL)	**HIV incidence rate**
Central Africa																					
Lillie 2021[4]	general	sex with men in the past 12 months	N	363	Burundi	NR	30	2018	CS	convenience	FTFI	25.1%	12.4%	6	NR	NR	NR	NR	NR	NR	NR
Coulaud 2016[5]	selected population - lower vulnerability	MSM engaged in prevention activities	N	51	Burundi	23	25	2014	CS	convenience	SAQ	96·1%	86·3%	12	NR	NR	NR	NR	NR	NR	NR
													86·3%	6							
													68·6%	3							
Lyons 2023[6], Bowring 2019[7], Rao 2017[8]	general	anal sex with men in the past 12 months	Y	1323	Cameroon	23	28	2016	CS	RDS	FTFI	72.4%	55.1%	12	42.3%	NR	66.1% (HIV aware MSM)	Ever	38.2% (MSM living with HIV)	1000	NR
																			90.4% (HIV aware MSM)	1000	NR
Rao 2017[8]	general	anal sex with men in the past 12 months	Y	259	Cameroon	NR	31	2013	CS	snowball	FTFI	NR	88.7%	12	NR	NR	NR	NR	NR	NR	NR
Holland 2015[9], Park 2014[10]	general	anal or oral sex with men in the past 12 months	Y	511	Cameroon	24	26	2011	CS	RDS	FTFI	80.8%	59.8%	12	NR	NR	NR	NR	NR	NR	NR
Lorente 2012[11]	general	ever sex with men	Y	174	Cameroon	25	NR	2008	CS	snowball	FTFI	81.2%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Mbeko Simaleko 2020[12]	NR	NR	NR	202	Central African Republic	NR	NR	2015	prospective cohort	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	$5.0^{py\text{-}100}$
Mbeko Simaleko 2018[13]	selected population - higher vulnerability	identified as MSM by peers	NR	99	Central African Republic	NR	24	2011	prospective cohort	purposive	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	$9.4^{py\text{-}100}$
Gresenguet 2017[14], Longo 2018[15], Boussa 2018[16]	selected population - higher vulnerability	identified as MSM by peers	Y	396	Central African Republic	23	23	2010	CS	purposive	FTFI	9.1%	NR	NR	NR	NR	34.5% (MSM living with HIV)	Current	NR	NR	NR
Eastern Africa																					

Bhattacharjee 2020[17]	general	anal or oral sex with men in the past 12 months	Y	1200	Kenya	23	28	2019	CS	cluster	FTFI	97.0%	85.1%	12	37.8%	32.8% (registered in HIV treatment and care centre)	32.3% (MSM living with HIV); 85.5% (HIV aware MSM)	Current	NR	NR	NR
													71.8%	6			32.8% (MSM living with HIV); 86.8% (HIV aware MSM)	Ever			
													60.3%	3							
Dijkstra 2021[18]	general	anal or oral sex in with men the past 6 months or sex with partner living with HIV	Y	452	Kenya	26	NR	2019	CS	convenience	FTFI	94.8%	70.3%	12	46.4%	NR	44.6% (MSM living with HIV); 96.2% (HIV aware MSM)	Current	37.5% (MSM living with HIV); 87.5% (MSM currently on ART)	50	NR
													7.0%	3							
Graham 2022[19]	selected population - higher vulnerability	three or more male partners, condomless anal sex with partner living with HIV, transactional sex, PWID	NR	157	Kenya	27	NR	2018	prospective cohort (*Anza Mapema* Mbili)	purposive	ACASI	NR	NR	NR	NR	NR	NR	NR	NR	NR	$1.3^{py\text{-}100}$
Wahome 2020[20], Wahome 2020[21], Sanders 2013[22]	selected population - higher vulnerability	anal sex with men in the past 3 months	NR	170	Kenya	25	29	2018	prospective cohort	purposive/ snowball	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	$3.9^{py\text{-}100}$
Smith 2021[23], Smith 2021[24], Fearon 2020[25]	general	anal or oral sex with men in the past 12 months	Y	761	Kenya	24	28	2017	CS	RDS	SAQ	93.9%	59.2%	6	73.7%	73.4% (currently engaged in care)	65.3% (MSM living with HIV); 86.9% (HIV aware MSM)	Current	60.2% (MSM living with HIV); 68.8% (HIV aware MSM); 79.2% (MSM currently on ART)	1000 or NR	NR
Kunzweiler 2019[26], Kunzweiler 2018[27], Korhonen 2018[28], Kunzweiler 2017[29]	general	anal or oral sex with men in the past 6 months	Y	1476 (knowledge of status), 711 (ART use and viral suppression)	Kenya	24-27	26-32	2016	prospective cohort baseline	snowball	ACASI	NR	NR	NR	17.9%	NR	2.7% (MSM living with HIV); 9.5% (HIV aware MSM)	Ever	31.1% (MSM living with HIV); 33.3% (HIV aware MSM); 30.6% (MSM currently on ART)	1000	NR
																	12.7% (MSM living with HIV); 44.4% (HIV aware MSM)	Current			
Palumbo 2021[30], Sandfort 2021[31], Sivay 2021[32], Sandfort 2019[33], Zhang 2018[34], Fogel 2018[35]	selected population - higher vulnerability	ever sex with men	Y	85	Kenya	NR	28	2016	prospective cohort (*HPTN 075*)	snowball/ convenience	FTFI/CASI	95.3%	87.0%	12	82.1%	NR	67.9% (MSM living with HIV); 82.6% (HIV aware MSM)	Current	50% (MSM living with HIV)	400	$3.7^{py\text{-}100}$
													75.7%	6							

Kimani 2019[36]	general	NR	Y	168	Kenya	NR	26	2016	prospective cohort	purposive	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	3.7[py-100]
Graham 2020[37]	selected population - higher vulnerability	sex with men in the past 12 months	Y	60	Kenya	NR	31	2015	RCT baseline	purposive	FTFI	NR	NR	NR	NR	NR	55% (HIV aware MSM)	Ever	54.7% (HIV aware MSM)	40	NR
Nyblade 2017[38]	selected population - higher vulnerability	male sex workers	NR	232	Kenya	NR	26	2015	CS	RDS	FTFI	86.2%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Shangani 2017[39]	general	anal or oral sex in with men the past 6 months	Y	89	Kenya	NR	29	2014	CS	snowball	FTFI	NR	74.2%	12	NR	NR	NR	NR	NR	NR	NR
Musyoki 2018[40], Bhattacharjee 2015[41]	general	NR	Y	1308	Kenya	NR	26	2014	CS	cluster	PBS	91.8%	73.7%	3	NR	NR	NR	NR	NR	NR	NR
Wahome 2020[20], Wahome 2020[21], Wahome 2018[42], Moller 2015[43], Kamali 2015[44], Sanders 2013[22], Price 2012[45]	selected population - higher vulnerability	anal sex with men in the past 3 months	Y	561 (ever test), 726 (incidence)	Kenya	25	26	2008	prospective cohort	convenience	FTFI	47.4%	NR	NR	NR	NR	NR	NR	NR	NR	8.2[py-100] (2005-2008); 6.9[py-100] (2009-2012)
Muraguri 2022[46]	selected population - higher vulnerability	male sex workers	NR	282	Kenya	26	NR	2013	CS	RDS	FTFI	72.3%	70.6%	12	NR	NR	NR	NR	NR	NR	NR
Githuka 2014[47]	general	ever sex with men	NR	25	Kenya	NR	NR	2012	CS	cluster	FTFI	61.3%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Mdodo 2016[48]	selected population - higher vulnerability	sex with men and either STI, anal sex with more than 2 partners in the past 12 months or HIV+ partner	NR	97	Kenya	NR	NR	2010	prospective cohort	snowball	ACASI/ CAPI	NR	NR	NR	NR	NR	NR	NR	NR	NR	1.0[py-100]
Muraguri 2015[49]	general	anal or oral sex with men in the past 6 months	Y	563	Kenya	NR	30	2010	CS	RDS	FTFI	71.4%	47.6%	12	34.0%	NR	NR	NR	NR	NR	NR
McKinnon 2013[50]	selected population - higher vulnerability	male sex workers	NR	507	Kenya	27	NR	2010	prospective cohort	snowball/ convenience	FTFI	85.8%	NR	NR	NR	NR	NR	NR	NR	NR	10.9[py-100]
Luchters 2011[51]	selected population - higher vulnerability	male sex workers	Y	442	Kenya	NR	25	2008	CS	time-venue	FTFI	64.0%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Graham 2013[52]	selected population - higher vulnerability	ever sex with men or sex during follow-up	Y	108	Kenya	NR	30	2008	prospective cohort baseline	snowball	FTFI/ ACASI	NR	NR	NR	NR	15.2% (currently in care)	6.8% (MSM living with HIV)	Ever	NR	NR	NR

Kamali 2015[44], Price 2012[45]	selected population - higher vulnerability	NR	NR	303	Kenya	NR	NR	2007	prospective cohort	snowball/ convenience	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	7.8[py-100] (2006); 5.1[py-100] (2006-2009)
Sanders 2007[53]	selected population - higher vulnerability	anal sex with men in the past 3 months	Y	285	Kenya	27	29	2006	prospective cohort baseline	convenience	FTFI	25.3%	NR	NR	10.0%	NR	NR	NR	NR	NR	NR
Gebrebrhan 2021[54]	selected population - higher vulnerability	ever sex with men	Y	70	Kenya	28	NR	NR	CS	convenience	NR	NR	NR	NR	NR	NR	67.7% (MSM living with HIV)	Current	41.9% (MSM living with HIV); 72.2% (MSM currently on ART)	40	NR
Rucinski 2022[55]	general	NR	NR	303	Malawi	27	NR	2018	retrospective cohort baseline	convenience	NR	NR	NR	NR	NR	55.4% (ART initiation within 30 days of diagnosis)	NR	NR	NR	NR	NR
Herce 2018[56]	general	self-identified as gay or bisexual or ever anal sex with men	N	119	Malawi	NR	NR	2017	CS	time-venue	FTFI	74.8%	NR	NR	50.0%	NR	NR	NR	NR	NR	NR
Palumbo 2021[30], Sandfort 2021[31], Sivay 2021[32], Sandfort 2019[33], Zhang 2018[34], Fogel 2018[35]	selected population - higher vulnerability	ever sex with men	Y	83	Malawi	NR	28	2016	prospective cohort (*HPTN 075*)	snowball/ convenience	FTFI/ CASI	89.3%	74.6% 60.7%	12 6	48.1%	NR	37.0% (MSM living with HIV); 76.9% (HIV aware MSM)	Current	14.3% (MSM living with HIV)	400	1.3[py-100]
Wirtz 2017[57], Poteat 2017[58], Stahlman 2016[59], Wirtz 2015[60], Wirtz 2013[61]	general	anal or oral sex with men in the past 12 months	Y	422 (CS); 103 (cohort)	Malawi	24-25	27	2013	CS and prospective cohort	RDS	FTFI	45.9%	24.9%	12	9.0%	NR	0.8% (MSM living with HIV); 19.1% (HIV aware MSM)	Ever	NR	NR	8.8[py-100] (2012); 0[py-100] (2012-2013); 0[py-100] (2013)
Fay 2011[62], Beyrer 2010[63], Baral 2009[64]	general	ever anal sex with men	Y	202	Malawi	25	26	2008	CS	snowball	FTFI	35.2%	NR	NR	4.7%	NR	NR	NR	NR	NR	NR
Ntata 2008[65]	general	NR	NR	97	Malawi	NR	27	2006	CS	snowball	FTFI	58.8%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Adam 2009[66]	NR	NR	NR	50	Mauritius	NR	NR	2004	NR	NR	NR	NR	16.0%	12	NR	NR	NR	NR	NR	NR	NR
Boothe 2021[67], Boothe 2021[68], Sathane 2016[69], Horth 2015[70]	general	anal or oral sex with men in the past 12 months	Y	1412	Mozambique	NR	22	2011	CS	RDS	FTFI	60.7%	38.0%	12	8.8%	6.1% (ever linked to care)	3.5% (MSM living with HIV) 3.5% (MSM living with HIV)	Ever Current	NR	NR	NR
Lyons 2023[6]; Twahirwa Rwema 2020[71]	general	anal sex with men in the past 12 months	Y	736	Rwanda	NR	27	2018	CS	RDS	FTFI	91.0%	NR	NR	60.8%	NR	59.6% (MSM living with HIV); 97.8% (HIV aware MSM)	Current	44.6% (MSM living with HIV); 73.3% (HIV aware MSM); 75% (MSM	200	NR

																			currently on ART)		
Ntale 2019[72]	general	anal or oral sex with men in the past 12 months	NR	504	Rwanda	23	NR	2015	CS	snowball	FTFI	NR	76.4%	12	NR	NR	NR	NR	NR	NR	NR
Chapman 2011[73]	general	anal or oral sex with men in the past 12 months	Y	99	Rwanda	26	24	2009	CS	snowball	FTFI	62.5%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Ross 2018 [74]	general	ever sex with men	NR	231	Tanzania	26	26	2015	CS	convenience	FTFI	100.0%	78.8%	6	NR	NR	NR	NR	NR	NR	NR
Mmbaga 2018[75]	general	has sex with men	Y	753	Tanzania	NR	27	2014	CS	RDS	FTFI	62.7%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Ahaneku 2016[76], Romijnders 2016[77], Anderson 2015[78], Ross 2014[79]	general	sex with another man in the past 6 months	Y	300	Tanzania	23	24	2012	CS	RDS	SAQ	77.7%	NR	NR	8.1%	NR	NR	NR	NR	NR	NR
Mmbaga 2012[80]	general	occasionally or regularly has sex with men	NR	150	Tanzania	NR	21	2011	CS	RDS	FTFI	53.3%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Khatib 2017[81]	selected population - higher vulnerability	anal sex with men in the past 3 months	Y	344	Tanzania	32	36	2011	CS	RDS	FTFI	68.2%	55.3%	12	NR	NR	NR	NR	NR	NR	NR
Nyoni 2013[82], Nyoni 2012[83]	general	ever sex with men	Y	271	Tanzania	24	26	2009	CS	RDS	FTFI	60.5%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Khatib 2017[81], Dahoma 2011[84], Johnston 2010[85]	selected population - higher vulnerability	anal sex with another man in the past 3 months	Y	509	Tanzania	31	32	2007	CS	RDS	FTFI	18.8%	11.3%	12	NR	NR	NR	NR	NR	NR	NR
Magesa 2014[86]	general	ever anal sex with men plus "feminine-like characteristics"	Y	50	Tanzania	NR	26	NR	CS	snowball	FTFI	84.0%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Okoboi 2021[87], Okoboi 2020[88]	general	NR	NR	297	Uganda	28	NR	2018	CS	snowball/ convenience	FTFI	70.3%	NR	NR	25.0%	NR	NR	NR	NR	NR	NR
Wanyenze 2016[89]	general	self-identified MSM	Y	85	Uganda	NR	24	2013	CS	snowball	FTFI	89.4%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Hladik 2017[90]	general	anal sex with men in the past 6 months	Y	607	Uganda	23	25	2013	CS	RDS	ACASI	65.1%	70.9%	12	20.2%	NR	15.2% (MSM living with HIV); 75% (HIV aware MSM)	Current	21.5% (MSM living with HIV); 50% (HIV aware MSM); 58.3% (MSM currently on ART)	1000	NR

Robb 2016[91]	selected population - higher vulnerability	sex with 3 or more partners, or HIV+ partner, in the past 3 months	NR	187	Uganda	NR	NR	2012	prospective cohort	convenience	ACASI	NR	NR	NR	NR	NR	NR	NR	NR	NR	3.6[py-100]
Hladik 2012[92]	selected population - higher vulnerability	anal sex with men in the past 3 months	Y	295	Uganda	25	NR	2008	CS	RDS	ACASI	43.4%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Raymond 2009[93], Kajubi 2008[94]	general	self-identifying as gay or bisexual	Y	224	Uganda	NA	24	2004	CS	RDS	FTFI	24.0%	23.7%	6	NR	NR	NR	NR	NR	NR	NR
Parmley 2022[95], Parmley 2022[96], Harris 2022[97]	general	anal or oral sex with men in the past 12 months	Y/N	1194	Zimbabwe	25	26	2019	CS	RDS	FTFI	84.8%	NR	NR	72.6%	NR	70.2% (MSM living with HIV); 96.7% (HIV aware MSM)	Current	61.5% (MSM living with HIV); 74.8% (HIV aware MSM); 86.8% (MSM currently on ART)	1000	NR
Virkud 2020[98]	general	sex with men in the past 12 months	NR	183	Kenya, Rwanda, Tanzania, Uganda	NR	NR	2016	CS	convenience	FTFI	NR	67.3%	122	NR	NR	NR	NR	NR	NR	NR
Northern Africa																					
Elmahy 2018[99]	general	self-identifying as gay or bisexual	Y	461	Egypt	NR	27	2016	CS	online	SAQ	34·5%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Valadez 2013[100]	general	anal sex with another man in the past 6 months	Y	227	Libya	NR	24	2010	CS	RDS	FTFI	NR	45.8%	12	NR	NR	NR	NR	NR	NR	NR
Southern Africa																					
Herce 2018[56]	general	anal sex with men in the past 6 months	N	713	Angola	NR	NR	2017	CS	time-venue	FTFI	47.5%	NR	NR	18.2%	NR	NR	NR	NR	NR	NR
Kendall 2014[101]	general	anal sex with men in the past 6 months	Y	351	Angola	NR	NR	2011	CS	RDS	FTFI	38.1%	31.7% 15.9%	12 3	37.0%	NR	NR	NR	NR	NR	NR
Fay 2011[62], Beyrer 2010[63], Baral 2009[64]	general	ever anal sex with men	Y	117	Botswana	24	25	2008	CS	snowball	FTFI	82.9%	NR	NR	17.4%	NR	NR	NR	NR	NR	NR
Rao 2017[8]	general	anal sex with men in the past 12 months	Y	173	eSwatini	NR	29	2014	CS	snowball	FTFI	NR	89%%	12	NR	NR	NR	NR	NR	NR	NR
Lyons 2023[6], Rao 2017[8], Poteat 2017[58], Grover 2016[102], Stahlman 2016[59], Brown 2016[103], Stahlman 2015[104], Risher 2013[105], Baral 2013[106]	general	anal sex with men in the past 12 months	Y	326	eSwatini	22	23	2011	CS	RDS	FTFI	54.3%	52.4%	12	30.4%	NR	NR	NR	NR	NR	NR

Poteat 2017[58], Stahlman 2016[59], Wendi 2016[107], Stahlman 2015[104], Stahlman 2015[108]	general	anal sex with men in the past 12 months	Y	530	Lesotho	22-23	NR	2014	CS	RDS	FTFI	69.1%	NR	NR	44.0%	NR	NR	NR	NR	NR	NR
Baral 2011[109]	general	ever anal sex with men	N	249	Lesotho	NR	26	2009	CS	snowball	FTFI	NR	54.5%	12	NR	NR	NR	NR	NR	NR	NR
Russell 2019[110]	selected population - higher vulnerability	NR	N	94	Namibia	NR	27	2016	CS	convenience	FTFI	NR	45.7%	6	NR	NR	NR	NR	NR	NR	NR
Fay 2011[62], Beyrer 2010[63], Baral 2009[64]	general	ever anal sex with men	Y	218	Namibia	23	24	2008	CS	snowball	FTFI	59.4%	NR	NR	59.3%	NR	8.3% (MSM living with HIV)	Current	NR	NR	NR
Montgomery 2021[111], Minnis 2020[112]	young MSM	NR	NR	190	South Africa	20	NR	2019	CS	RDS/ convenience	SAQ/ FTFI	94.7%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Pillay 2020[113]	selected population - lower vulnerability	self-identified MSM recruited from MSMO	Y	96	South Africa	NR	33	2018	CS	purposive	FTFI	97.9%	93.8% 85.4% 42.7%	12 6 3	NR	NR	NR	NR	NR	NR	NR
Scheibe 2020[114]0	general	ever sex with men	Y	746	South Africa	29	34	2017	CS	convenience	FTFI	97.3%	NR	NR	85.6%	NR	93.1% (MSM living with HIV)	Current	NR	NR	NR
Fearon 2020[115]	mix	sex with men in the past 12 months	Y	182	South Africa	NR	24-28	2017	CS	RDS	SAQ	94.5%	73.0%	12	64.4%	NR	30.0% (MSM living with HIV); 53.2% (HIV aware MSM)	Current	46.9% (MSM living with HIV); 77.3% (MSM currently on ART)	50	NR
Fearon 2020[25]	general	sex with men in the past 12 months	Y	301	South Africa	NR	29	2017	CS	RDS	SAQ	NR	65.7%	6	65.0%	NR	33.1% (MSM living with HIV)	Current	54.2% (MSM living with HIV)	200	NR
Chen 2020[116], Radebe 2020[117], Lippman 2018[118], Lippman 2018[119]	general	sex with men in the past 6 months	Y	127	South Africa	NR	25	2016	CS and prospective cohort	RDS	FTFI	85.0%	66.1% 37.8%	12 6	NR	NR	NR	NR	NR	NR	$10.9^{py\text{-}100}$
Sullivan 2020[120]	general	anal sex with men in the past 12 months	Y	167	South Africa	NR	31	2016	prospective cohort (Sibanye Health Project)	convenience	SAQ	NR	NR	NR	50.4%	NR	NR	NR	NR	NR	$5.3^{py\text{-}100}$
Palumbo 2021[30], Sandfort 2021[31], Sivay 2021[32], Sandfort 2019[33], Zhang 2018[34], Fogel 2018[35]	general	ever sex with men	Y	161	South Africa	NR	25-28	2016	prospective cohort (*HPTN 075*)	snowball/ convenience	FTFI/ CASI	90%%	69.4% 46.1%	12 6	52.3%	NR	26.6% (MSM living with HIV); 50.7% (HIV aware MSM)	Current	13.9% (MSM living with HIV)	400	$11.5^{py\text{-}100}$
Kufa 2017[121]	general	anal or oral sex with men in the past 6 months	Y	2503	South Africa	25	NR	2015	CS	RDS	FTFI	NR	NR	NR	NR	NR	NR	NR	35.0% (MSM living with HIV)	20	NR
Rees 2017[122], van Liere 2019[123]	selected population - higher vulnerability	self-identified gay or bisexual, recruited at clinic	NR	5796	South Africa	28-30	NR	2015	CS	convenience	FTFI	NR	NR	NR	83.7%	NR	61.8% (MSM living with HIV)	NR	NR	NR	NR

Lane 2016[124], Lane 2014[125]	general	anal or oral sex with men in the past 6 months	Y	605	South Africa	NR	27	2012-2014	serial CS	RDS	FTFI/ ACASI	72.1%	NR	NR	28.2%	15.7% (linked to care within 30 days of diagnosis)	12.2% (MSM living with HIV); 52.5% (HIV aware MSM)	Current	NR	NR	12.5[py-100]
Batist 2013[126]	general	reported to have sex with men	Y	98	South Africa	24	NR	2012	CS	convenience	SAQ	93.8%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Rebe 2015[127]	selected population - higher vulnerability	sex with men in the past 12 months	Y	200	South Africa	32	NR	2012	CS	convenience	FTFI	NR	53.5%	12	NR	NR	52.3% (MSM living with HIV)	Current	NR	NR	NR
Siegler 2015[128]	general	anal sex with men in the past 6 months	Y	34	South Africa	25	NR	2012	CS	snowball	FTFI	97.1%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Knox 2019[129]	general	sex with men in the past 12 months	NR	480	South Africa	NR	30	2012	CS	RDS	FTFI	NR	34.6%	6	NR	NR	NR	NR	NR	NR	NR
Maleke 2017[130]	general	self-identified gay or has sex with men	NR	23	South Africa	NR	25	2012	CS	snowball	FTFI	78.3%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Maenetje 2019[131]	selected population - higher vulnerability	self-identified gay or bisexual and anal sex with men in the past 3 months	NR	27	South Africa	NR	22	2012	prospective cohort	snowball/ convenience	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	0[py-100]
Stephenson 2012[132], Wagenaar 2012[133]	general	sex with men in the past 12 months	Y	449	South Africa	30	31	2010	CS	online	SAQ	87.0%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Eaton 2013[134]	selected population - higher vulnerability	drinking venues	Y	143	South Africa	NA	29	2010	CS	convenience	SAQ	62.7%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Kamali 2015[44], Price 2012[45]	selected population - higher vulnerability	NR	NR	29	South Africa	NR	NR	2010	prospective cohort	convenience	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	9.5[py-100]
Baral 2011[135]	general	ever anal sex with men	N	200	South Africa	24	26	2009	CS	convenience	FTFI	NR	NR	NR	6.0%	NR	NR	NR	NR	NR	NR
Tun 2012[136]	general	NR	Y	NR	South Africa	NR	NR	2009	CS	RDS	FTFI	71.1%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Buchbinder 2014[137], Buchbinder 2014[138]	selected population - higher vulnerability	anal sex with at least 4 male partners in the past 6 months	Y	43	South Africa	NR	NR	2009	RCT	convenience	CASI/ FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	4.7[py-100]
Knox 2013[139], Knox 2011[140]	general	sex with men in the past 12 months	Y	300	South Africa	NR	26	2008	CS	convenience	ACASI	67.7%	40.0%	12	NR	NR	NR	NR	NR	NR	NR
Arnold 2013[141], Lane 2011[142]	general	anal or oral sex with men in the past 6 months	Y	377	South Africa	NR	24	2008	CS	RDS	FTFI	43.5%	NR	NR	11.6%	NR	NR	NR	NR	NR	NR
Burrel 2010[143]	general	self-identified MSM	Y	542	South Africa	27	NR	2008	CS	convenience	SAQ	NR	72.7%	12	NR	NR	NR	NR	NR	NR	NR
Lane 2008[144]	general	ever sex with men	Y	147	South Africa	NR	28	2004	CS	snowball/ convenience	FTFI	67.3%	31.3%	6	NR	NR	NR	NR	NR	NR	NR
Nel 2013[145], Sandfort 2008[146]	general	same-sex attraction	Y	1045	South Africa	NR	26-29	2004	CS	convenience	SAQ	72.2%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Jobson 2018[147]	general	self-identified MSM	Y	316	South Africa	26	31	NR	CS	snowball	SAQ	86.1%	NR	NR	NR	NR	NR	NR	NR	NR	NR

Cloete 2008[148]	general	NR	NR	92	South Africa	NR	28	NR	CS	convenience	SAQ	NR	NR	NR	NR	NR	27.1% (HIV aware MSM)	Current	NR	NR	NR
Metheny 2022[149], Stephenson 2022[150], Stephenson 2021[151]	partnered MSM	self-identified gay or bisexual and anal or oral sex with men in the past 3 months	NR	440	South Africa, Namibia	NR	28	2017	CS	snowball/ convenience	FTFI	89.0%	49.1% 83.5%	12 6	NR	NR	NR	NR	NR	NR	NR
Western Africa																					
Ahouada 2020[152]	general	self reported not living with HIV or unaware and anal sex with men in the past 12 months	N	400	Benin	NR	26	2018	CS	RDS	FTFI	NR	98.0%	12	NR	NR	NR	NR	NR	NR	NR
Hessou 2020[153]	general	anal or oral sex with men in the past 12 months	Y	358	Benin	NR	24	2017	prospective cohort	RDS	FTFI	NR	NR	NR	NR	NR	NR	NR	NR	NR	11.6py-100 (2016); 6.8py-100 (2016-2017); 1.9py-100 (2017); 0py-100 (2017-2018); 9.3py-100 (2018)
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	selected population - higher vulnerability	anal sex with men in the past 3 months, clinic-recruited	Y	168	Burkina Faso	23	NR	2017	prospective cohort (*CohMSM*)	purposive	FTFI	78.0%	NR	NR	NR	NR	NR	NR	NR	NR	7.3^{py-100}
Lyons 2023[6], Grosso 2019[160], Kim 2018[161], Poteat 2017[58], Holland 2016[162], Goodman 2016[163], Stahlman 2016[164]	general	anal sex with men in the past 12 months	Y	672	Burkina Faso	21-22	25	2013	CS	RDS	FTFI	75.5%	NR	NR	31.3%	NR	15.6% (MSM living with HIV); 41.7% (HIV aware MSM)	Current	NR	NR	NR
Diabate 2021[165]	general	anal sex with men in the past 12 months	NR	201	Cote d'Ivoire	NR	27	2018	CS	RDS	FTFI	NR	87.6%	12	NR	NR	NR	NR	NR	NR	NR
Inghels 2022[166], Inghels 2021[167]	general	ever sex with men	NR	518	Cote d'Ivoire	NR	26	2018	CS	RDS	phone	88.9%	77.6%	12	NR	NR	NR	NR	NR	NR	NR
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	selected population - higher vulnerability	anal sex with men in the past 3 months, clinic-recruited	Y	193	Cote d'Ivoire	24	NR	2016	prospective cohort (*CohMSM*)	purposive	FTFI	67.9%	NR	NR	NR	NR	NR	NR	NR	NR	14.4^{py-100}
Lyons 2023[6], Moran 2020[168], Ulanja 2019[169]	general	anal or oral sex with men in the past 12 months	Y	1301	Cote d'Ivoire	23	24	2015	CS	RDS	FTFI	70.9%	38.3%	6	32.9%	NR	NR	NR	NR	NR	NR

Bouscaillou 2016[170]	selected population - higher vulnerability	men PWID who ever had sex with men	Y	41	Cote d'Ivoire	29	33	2014	CS	RDS	FTFI	NR	37.5%	12	NR	NR	NR	NR	NR	NR	NR
Couderc 2017[171]	selected population - higher vulnerability	anal sex with men in the past 3 months	NR	73	Cote d'Ivoire	25	NR	2014	prospective cohort	convenience	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	15.9[py-100]
Hakim 2015[172], Aho 2014[173]	general	anal or oral sex with men in the past 12 months	Y	601	Cote d'Ivoire	23	25	2011	CS	RDS	FTFI	62.6%	32.1%	12	13.6%	NR	NR	NR	NR	NR	NR
Vuylsteke 2012[174]	selected population - higher vulnerability	male sex workers	NR	96	Cote d'Ivoire	27	NR	2007	CS	convenience	FTFI	70.8%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Gu 2021[175]	selected population - higher vulnerability	MSM living with HIV, ever had sex with men	N	225	Ghana	25	27	2017	CS	snowball/ convenience	SAQ	NR	NR	NR	NR	53.6% (linked to care within 3 months of diagnosis plus at least 1 follow-up visit) 93.6% (retained in care within the past 6 months)	NR	NR	NR	NR	NR
Ogunbajo 2018[176]	general	ever anal or oral sex with another man	Y	30	Ghana	NR	29	2015	CS	convenience	FTFI	NR	NR	NR	NR	70.0% (currently engaged in care)	NR	NR	NR	NR	NR
Abubakari 2021[177]	general	self-identified MSM	N	56	Ghana	NR	27	2014	CS	snowball	SAQ/ FTFI	82.5%	24.6% 26.3%	6 3	NR	NR	NR	NR	NR	NR	NR
Girault 2015[178]	selected population - lower vulnerability	self-reported HIV negative and anal or oral sex with men in the past 12 months	Y	191	Ghana	NR	25	2013	CS	RDS	FTFI	60.2%	59.6%	12	NR	NR	NR	NR	NR	NR	NR
Kushwaha 2017[179], Nelson 2015[180]	general	sex with men in the past 6 months	N/NR	137	Ghana	NR	25	2012	CS	snowball	FTFI/ SAQ	68.4%	87.0% 64.1% 25.0%	12 6 3	NR	NR	NR	NR	NR	NR	NR
Gyamerah 2020[181]	general	anal or oral sex with men in the past 12 months	Y	1382	Ghana	NR	NR	2010	CS	RDS	FTFI	41.3%	30.8%	12	NR	NR	NR	NR	NR	NR	NR
Lyons 2023[6]	NR	NR	NR	451	Guinea-Bissau	NR	NR	2017	CS	RDS	NR	36.3%	NR	NR	9.1%	NR	NR	NR	NR	NR	NR
Lieber 2018[182]	general	ever sex with men	Y	107	Liberia	NR	27	NR	CS	purposive	FTFI	77.6%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Koyalta 2021[183]	general	identified as MSM by peers	NR	50	Mali	NR	24	2019	CS	purposive	FTFI	NR	NR	NR	NR	NR	87.5% (MSM living with HIV)	Current	NR	NR	NR
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	selected population - higher vulnerability	anal sex with men in the past 3 months, clinic-recruited	Y	295	Mali	23	NR	2016	prospective cohort (*CohMSM*)	purposive	FTFI	79.0%	NR	NR	NR	NR	NR	NR	NR	NR	9.0[py-100]

Knox 2021[184], Lahuerta 2018[185], Hakim 2018[186], Hakim 2017[187]	general	ever anal or oral sex with another man	Y	552	Mali	NR	24-28	2014	CS	RDS	FTFI	71.6%	50.2%	12	16.5%	NR	61.2% (HIV aware MSM)	Current	29.1% (MSM living with HIV); 85.2% (HIV aware MSM); 100.0% (MSM currently on ART)	1000	NR
Couderc 2017[171]	selected population - higher vulnerability	anal sex with men in the past 3 months	NR	168	Mali	22	NR	2013	prospective cohort	convenience	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	11.2[py-100]
Adam 2009[66]	NR	NR	NR	26	Mauritania	NR	NR	2006	NR	NR	NR	NR	15.4%	12	NR	NR	NR	NR	NR	NR	NR
Afolaranmi 2021[188]	selected population - higher vulnerability	MSM affiliated with MSM support group	NR	114	Nigeria	NR	26	2019	CS	RDS	FTFI	NR	NR	NR	NR	37.7% (retained in care in the past 6 months)	NR	NR	NR	NR	NR
Ibiloye 2021[189]	selected population - higher vulnerability	MSM living with HIV and on ART	NR	129	Nigeria	NR	25	2018	retrospective cohort baseline	NR	NR	NR	NR	NR	NR	25.8% (currently engaged in care)	NR	NR	NR	NR	NR
Tun 2018[190]	general	anal sex with men in the past 6 months	Y	319	Nigeria	25	NR	2017	prospective cohort baseline	snowball	FTFI	82.1%	46.1% 17.6%	12 6	NR	NR	NR	NR	NR	NR	NR
Lyons 2023[6], LeeVan 2022[191], Olawore 2021[192], Li 2020[193], Nowak 2020[194], Ramadhani 2020[195], Tiamiyu 2020[196], Robbins 2020[197], Kayode 2020[198], Nowak 2019[199], Nowak 2019[200], Billings 2019[201], Crowell 2019[202], Ramadhani 2018[203], Rodriguez-Hart 2018[204], Stahlman 2017[205], Nowak 2017[206], Ramadhani 2017[207], Crowell 2017[208], Nowak 2016[209], Rodriguez-Hart 2016[210], Baral 2015[211], Schwartz 2015[212], Charurat 2015[213]	general	anal sex with men in the past 12 months	Y	2737	Nigeria	23-25	25-28	2017	prospective cohort	RDS	FTFI	82.2%	NR	NR	53.8%	NR	73.8% (MSM living with HIV); 45.8 (HIV aware MSM) 10.1% (MSM living with HIV)	Current Ever	43.4% (MSM living with HIV); 40.6% (HIV aware MSM); 77.3% (MSM currently on ART)	1000 (MSM living with HIV and HIV aware MSM) and 50 (MSM on ART)	10.3[py-100]
Ibiloye 2021[214]	selected population - higher vulnerability	MSM living with HIV on ART	N	1040	Nigeria	NR	NR	2017	retrospective cohort baseline (KP-CBART)	convenience	NR	NR	NR	NR	NR	50.2% (currently engaged in care)	NR	NR	98.3% (MSM currently on ART)	1000	NR

Ibiloye 2018[215]	selected population - higher vulnerability	NR	NR	32	Nigeria	NR	30	2017	prospective cohort baseline	convenience	NR	NR	NR	NR	NR	NR	NR	NR	100.0% (MSM living with HIV)	1000	NR
Offie 2021[216]	selected population - higher vulnerability	self-identified MSM, living with HIV enrolled in care	NR	181	Nigeria	24	30	2016	CS	convenience	phone	NR	NR	NR	NR	92.3% (retained in care within the past 12 months)	NR	NR	NR	NR	NR
Tobin-West 2017[217]	general	anal or oral sex with men in the past 12 months	Y	101	Nigeria	NR	25	2014	CS	purposive	SAQ	69.3%	44.6%	6	NR	NR	NR	NR	NR	NR	NR
Eluwa 2019[218]	general	anal sex with men in the past 6 months	NR	3611	Nigeria	22	26	2014	CS	RDS	FTFI	64.6%	78.9%	12	NR	NR	NR	NR	NR	NR	NR
Eluwa 2019[218], Eluwa 2015[219]	general	anal sex with men in the past 6 months	Y	1545	Nigeria	24	29	2010	CS	RDS	FTFI	50.3%	77.1%	12	NR	NR	NR	NR	NR	NR	NR
Adebajo 2014[220], Sheehy 2014[221], Vu 2013[222], Vu 2013[223]	general	anal or oral sex with men in the past 12 months	Y	712	Nigeria	23	25	2010	CS	RDS	FTFI/ ACASI	54.9%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Stromdahl 2019[224], Stromdahl 2012[225]	general	ever anal sex with men	Y	297	Nigeria	26	26	2008	CS	convenience	FTFI	65.2%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Eluwa 2019[218], Merrigan 2011[226], Adam 2009[66]	general	anal or oral sex with men in the past 6 months	Y	879	Nigeria	22	26	2007	CS	RDS	FTFI	34.0%	72.9%	12	NR	NR	NR	NR	NR	NR	NR
Lyons 2023[6], Lyons 2020[227], Lyons 2017[228]	general	anal sex with men in the past 12 months	Y	724	Senegal	NR	23	2016	CS and prospective cohort	RDS/ purposive	FTFI	70.2%	NR	NR	13.2%	7.8% (ever engaged in care)	10.0% (MSM living with HIV); 75.9% (HIV aware MSM)	Current	63.6% (MSM currently on ART)	1000	3.2[py-100]
																	11.0% (MSM living with HIV); 82.8% (HIV aware MSM)	Ever			
Couderc 2017[171]	selected population - higher vulnerability	anal sex with men in the past 3 months	NR	54	Senegal	26	NR	2013	prospective cohort	convenience	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	0[py-100]
Drame 2013[229]	selected population - lower vulnerability	anal sex with men in the past 12 months	Y	119	Senegal	NR	28	2012	prospective cohort	NR	NR	88.0%	NR	NR	48.8%	NR	NR	NR	NR	NR	16.0[py-100]
Dieye 2022[230]	NR	NR	NR	49	Senegal	30	NR	2010	Retrospective CS	purposive	NR	NR	NR	NR	NR	NR	NR	NR	52.0% (MSM living with HIV)	50	NR
Ndiaye 2013[231], Wade 2005[232]	general	ever sex with men	Y	463	Senegal	24-26	NR	2004-2007	CS	snowball	FTFI	10.8%	NR	NR	NR	NR	9.3% (MSM living with HIV)	Current	NR	NR	NR
Lyons 2023[6]	NR	NR	NR	114	The Gambia	NR	NR	2017	CS	RDS	NR	50.0%	NR	NR	5.0%	NR	NR	NR	NR	NR	NR
Poteat 2017[58], Stahlman 2016[164], Mason 2013[233]	general	anal sex with men in the past 12 months	Y	207	The Gambia	20	22	2011	CS	snowball	FTFI	NR	NR	NR	5.0%	NR	NR	NR	NR	NR	NR

Ferré 2022[234], Sadio 2019[235]	general	anal or oral sex with men in the past 12 months	NR	678	Togo	23	27	2017	CS	RDS	FTFI	89.1%	NR	NR	NR	NR	66.2% (MSM living with HIV)	Current	52.9% (MSM living with HIV); 80.0% (MSM currently on ART)	200	NR
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	selected population - higher vulnerability	anal sex with men in the past 3 months, clinic-recruited	Y	160	Togo	23	NR	2016	prospective cohort (*CohMSM*)	purposive	FTFI	80.6%	NR	NR	NR	NR	NR	NR	NR	NR	$10.2^{py\text{-}100}$
Teclessou 2017[236]	general	ever sex with men	N	491	Togo	23	26	2015	CS	RDS	FTFI	68.0%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Lyons 2023[6], Ruisenor-Escudero 2019[237], Ruisenor-Escudero 2019[238], Grosso 2019[160], Poteat 2017[58], Ruisenor-Escudero 2017[239], Holland 2016[162], Stahlman 2016[164]	general	anal sex with men in the past 12 months	Y	683	Togo	22-24	NR	2013	CS	RDS	FTFI	70.7%	NR	NR	14.9%	NR	6.0% (MSM living with HIV); 4.0% (HIV aware MSM)	Current	NR	NR	NR
Bakai 2016[240]	general	NR	Y	724	Togo	25	NR	2011	CS	snowball	FTFI	63.0%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Ekouevi 2014[241]	general	ever sex with men	NR	758	Togo	24	29	2011	CS	snowball	FTFI	63.4%	NR	NR	NR	NR	NR	NR	NR	NR	NR
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	selected population - higher vulnerability	anal sex with men in the past 3 months, clinic-recruited	Y	335	Burkina Faso, Cote d'Ivoire, Mali, Togo	24	NR	2017	prospective cohort baseline (*CohMSM*)	purposive	FTFI	NR	NR	NR	NR	89.0% (ART initiation within 30 days of diagnosis)	79.6% (MSM living with HIV)	Current	NR	NR	NR
Multiple Regions																					
Herce 2018[56]	general	anal sex with another man in the past 6 months	Y	832	Angola, Malawi	NR	NR	2017	CS	time-venue	FTFI	NR	19·8%	6	NR	NR	NR	NR	NR	NR	NR
Sandfort 2019[33]	general	ever anal sex with another man	Y	601	Kenya, Malawi, South Africa	23	27	2016	prospective cohort baseline (*HPTN 075*)	snowball/ convenience	FTFI/ CASI	NR	NR	NR	NR	38.8% (currently engaged in care)	NR	NR	50.5% (MSM living with HIV); 82.5% (MSM currently on ART)	400	NR

ACASI, audio computer-assisted self-interview; ART, anti-retroviral therapy; CASI, computer-assisted self-interview; CS, cross-sectional; FTFI, face-to-face interview; MSM, men-who-have-sex-with-men; NR, not reported; PBS, polling booth survey; PWID, people who inject drugs; RCT, randomized controlled trial; RDS, respondent driven sampling; SAQ, self-administered questionnaire; TGW, transgender women.
References of all include studies are provided in table 5.4.2..
* selected - higher vulnerability includes male sex workers, study MSM definitions based on anal sex only in the past 3 months, sex with multiple partners, MSM with sexually transmitted infections, sex with partners living with HIV, or that recruited MSM living with HIV only. Selected - lower vulnerability includes MSM involved in MSM organisations or prevention activities.
† midpoint between study start and finish

Table 5.4.3. Number and characteristics of unique studies included in our review. This includes (a) HIV incidence, testing, and treatment cascade outcomes among men who have sex with men (MSM) in Africa reported by studies, and a summary of (b) study characteristics, (c) participant characteristics, and (d) study quality, of included studies that provided observations that were included in our analyses.

	Total unique studies* (N_s=152)
HIV incidence, testing, and treatment cascade outcomes	
HIV incidence rate (among MSM not living with HIV)	31
HIV testing (among all MSM)	123
Ever	100
Past 12 months	46
Past 6 months	23
Past 3 months	9
Knowledge of status (among MSM living with HIV)	44
Engagement in Care (among MSM living with HIV)	16
Ever in care (non-ART)	3
Ever on ART	7
Currently in care (non-ART)	6
Linked to care within 3 months	1
Linked to care within 30 days	3
Retained in care in the past 12 months	1
Retained in care in the past 6 months	2
Currently on ART	31
Among MSM living with HIV	27
Among HIV aware MSM	18
Viral suppression	23
Among MSM living with HIV	19
Among HIV aware MSM	10
Among MSM currently on ART	13
Study characteristics	
Study midpoint year†	
2011-2020	108
2010 and earlier	41
NR	5
Region†	
Central Africa	9
Western Africa	52
Eastern Africa	50
Southern Africa	40
Northern Africa	2
Multiple regions	2
Study design†	
Cross-sectional	113
Serial cross-sectional surveys	1
Prospective cohort – follow-up	29
Prospective cohort – baseline	7
Retrospective cohort – baseline	3
RCT – follow-up	1
RCT – baseline	1

NR	2
Sampling method[†]	
RDS	52
Cluster/time-location sampling	6
Snowball	37
Convenience	61
Online	2
NR	5
Interview method[†]	
FTFI[‡]	114
Confidential[§]	34
NR	15
Participant characteristics	
MSM eligibility criteria[†]	
Ever sex with men	24
Sex with men in the past 12 months	42
Sex with men in the past 6 months	20
Sex with men in the past 3 months	16
Sex with men occasionally/regularly	2
Male sex workers	5
Self-identified MSM or gay/bisexual	11
Peer-identified as MSM	3
Involvement with MSM organizations/HIV prevention	2
NR	18
Study population of MSM[†]	
General population of MSM	96
Selected population of MSM	50
Selected population – higher vulnerability to HIV[¶]	47
Selected population – lower vulnerability to HIV[‖]	4
NR	6
TGW included[†]	
Yes	95
No	14
Unclear	46
Mean or median age[†]	
15-24	49
25-34	107
NR	17
Study quality	
Risk of bias	
Lower (4-5)	16
Moderate (2-3)	185
Higher (0-1)	129

Table 5.4.4: Unweighted estimates of HIV testing, treatment cascade, and HIV incidence outcomes among men who have sex with men (MSM) in Africa in 2010 and 2020, overall and by region of Africa.

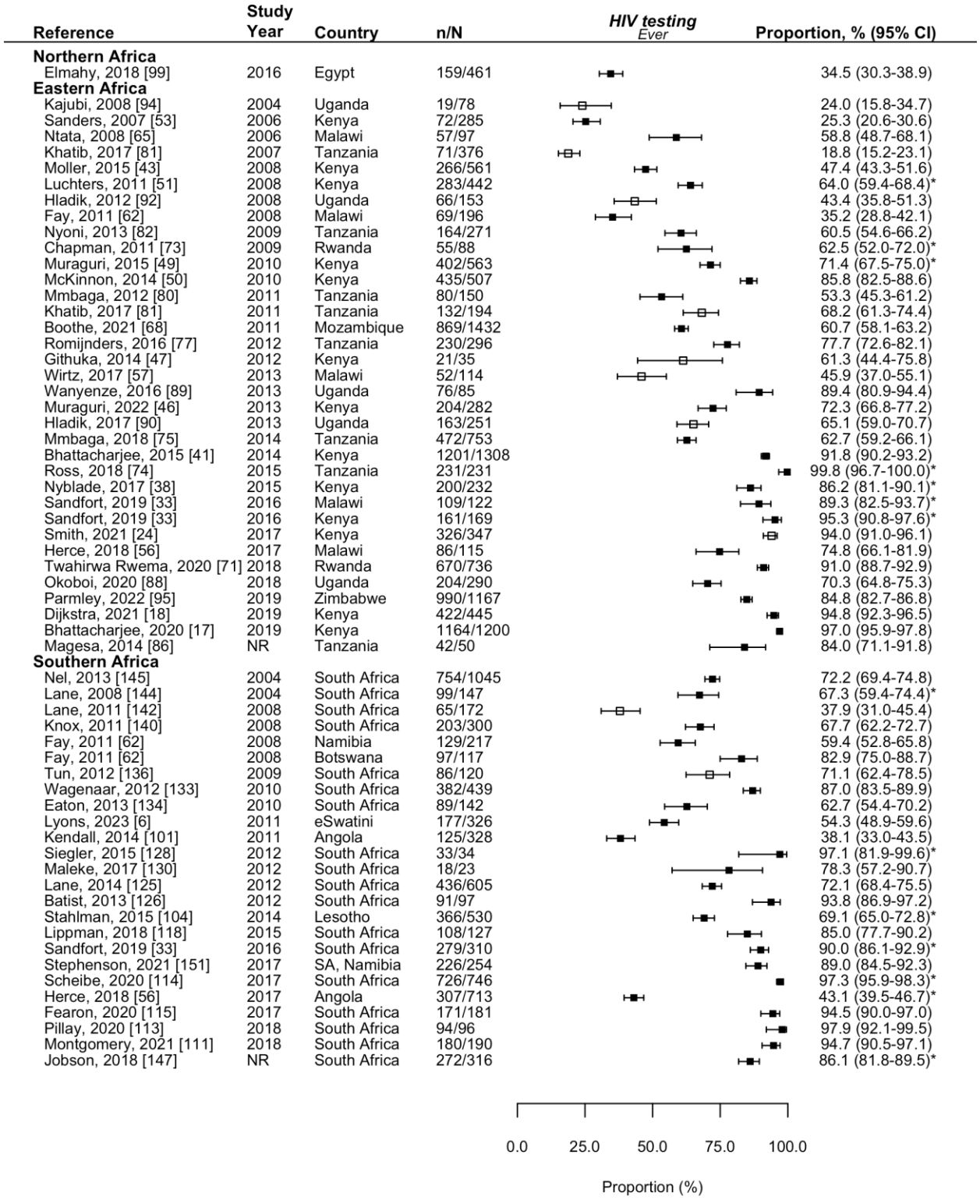
Outcome	Region of Africa	N_o*	Unweighted estimate in 2010	95% CrI	Unweighted estimate in 2020	95% CrI
Ever HIV testing (%)		95				
Among all MSM†	Overall	95	65%	45–85%	83%	26–97%
	Central/Western Africa	37	64%	52–75%	82%	64–92%
	Eastern Africa	34	60%	49–71%	92%	79–97%
	Southern Africa	23	68%	54–79%	85%	57–95%
Past 12 months HIV testing (%)		46				
Among all MSM‡	Overall	46	48%	30–66%	88%	62–97%
	Central/Western Africa	18	49%	34-63%	88%	72–96%
	Eastern Africa	15	45%	30–60%	89%	73–96%
	Southern Africa	12	50%	35–67%	87%	63–96%
Knowledge of status (%)		44				
Among MSM living with HIV	Overall	44	18%	5–50%	53%	10–90%
	Central/Western Africa	12	17%	6–48%	38%	7–75%
	Eastern Africa	17	13%	5–27%	59%	28–85%
	Southern Africa	15	23%	10–47%	58%	17–88%
Currently on ART (%)		43				
Among MSM living with HIV	Overall	26	11%	1–70%	74%	17–97%
	Central/Western Africa	9	10%	2–35%	77%	43–95%
	Eastern/Southern Africa	17	11%	2–40%	72%	41–92%
Among HIV aware MSM	Overall	17	20%	1–91%	93%	37–100%
	Central/Western Africa	5	16%	1–77%	93%	46–100%
	Eastern/Southern Africa	12	22%	2–74%	93%	65–99%
Viral suppression (%)		40				
Among MSM living with HIV	Overall	18	22%	1–92%	70%	13–96%
	Central/Western Africa	6	27%	2–80%	67%	22–94%
	Eastern/Southern Africa	12	16%	2–68%	74%	38–93%
Among HIV aware MSM	Overall	10	64%	2–99%	78%	10–99%
	Central/Western Africa	3	72%	2–100%	79%	5–100%
	Eastern/Southern Africa	7	57%	4–98%	79%	25–98%
Among MSM currently on ART	Overall	12	63%	0–100%	93%	32–100%
	Central/Western Africa	5	66%	0–100%	93%	24–100%
	Eastern/Southern Africa	7	55%	1–100%	94%	50–100%
HIV incidence rate (py^{-100})		39				
Among MSM not living with HIV	Overall	39	$7.6py^{-100}$	1.1–53.3	$4.9py^{-100}$	0.3–71.2
	Central/Western Africa	17	$8.7py^{-100}$	2.9–24.2	$5.6py^{-100}$	2.0–15.8
	Eastern/Southern Africa	22	$8.0py^{-100}$	1.7–39.0	$4.2py^{-100}$	1.3–13.8

ART, antiretroviral therapy; CrI, credible interval; IRR, incidence rate ratio (per year); MSM, men who have sex with men; N_o, number of observations; OR, odds ratio (per year); py^{-100}, per 100 person-years.

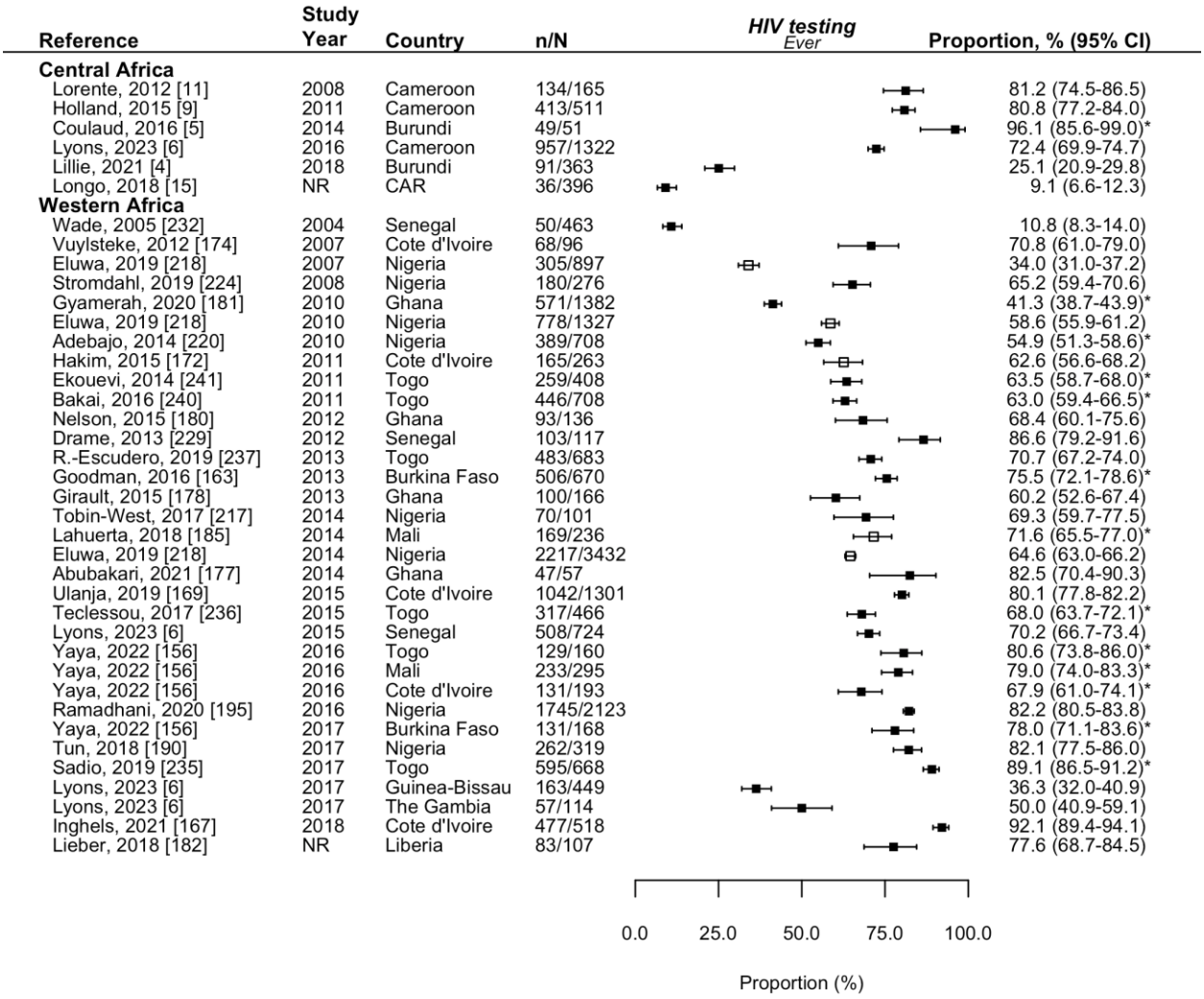
* Study years of 4 observations of ever tested, 1 observation of current ART use among MSM living with HIV, 1 observation of current ART use among HIV aware MSM, 1 observation of viral suppression among MSM living with HIV, and 1 observation of current ART use among MSM currently on ART were not available, therefore these observations were excluded from our analyses of time trends

† 1 observation from Northern Africa included in analysis but not shown

‡ 1 observation from Northern Africa included in analysis but not shown


Reference
Study Year
Country
n/N
HIV testing
Ever
Proportion, % (95% CI)
Northern Africa
Elmahy, 2018 [99] 2016 Egypt 159/461 34.5 (30.3-38.9)
Eastern Africa
Kajubi, 2008 [94] 2004 Uganda 19/78 24.0 (15.8-34.7)
Sanders, 2007 [53] 2006 Kenya 72/285 25.3 (20.6-30.6)
Ntata, 2008 [65] 2006 Malawi 57/97 58.8 (48.7-68.1)
Khatib, 2017 [81] 2007 Tanzania 71/376 18.8 (15.2-23.1)
Moller, 2015 [43] 2008 Kenya 266/561 47.4 (43.3-51.6)
Luchters, 2011 [51] 2008 Kenya 283/442 64.0 (59.4-68.4)*
Hladik, 2012 [92] 2008 Uganda 66/153 43.4 (35.8-51.3)
Fay, 2011 [62] 2008 Malawi 69/196 35.2 (28.8-42.1)
Nyoni, 2013 [82] 2009 Tanzania 164/271 60.5 (54.6-66.2)
Chapman, 2011 [73] 2009 Rwanda 55/88 62.5 (52.0-72.0)*
Muraguri, 2015 [49] 2010 Kenya 402/563 71.4 (67.5-75.0)*
McKinnon, 2014 [50] 2010 Kenya 435/507 85.8 (82.5-88.6)
Mmbaga, 2012 [80] 2011 Tanzania 80/150 53.3 (45.3-61.2)
Khatib, 2017 [81] 2011 Tanzania 132/194 68.2 (61.3-74.4)
Boothe, 2021 [68] 2011 Mozambique 869/1432 60.7 (58.1-63.2)
Romijnders, 2016 [77] 2012 Tanzania 230/296 77.7 (72.6-82.1)
Githuka, 2014 [47] 2012 Kenya 21/35 61.3 (44.4-75.8)
Wirtz, 2017 [57] 2013 Malawi 52/114 45.9 (37.0-55.1)
Wanyenze, 2016 [89] 2013 Uganda 76/85 89.4 (80.9-94.4)
Muraguri, 2022 [46] 2013 Kenya 204/282 72.3 (66.8-77.2)
Hladik, 2017 [90] 2013 Uganda 163/251 65.1 (59.0-70.7)
Mmbaga, 2018 [75] 2014 Tanzania 472/753 62.7 (59.2-66.1)
Bhattacharjee, 2015 [41] 2014 Kenya 1201/1308 91.8 (90.2-93.2)
Ross, 2018 [74] 2015 Tanzania 231/231 99.8 (96.7-100.0)*
Nyblade, 2017 [38] 2015 Kenya 200/232 86.2 (81.1-90.1)*
Sandfort, 2019 [33] 2016 Malawi 109/122 89.3 (82.5-93.7)*
Sandfort, 2019 [33] 2016 Kenya 161/169 95.3 (90.8-97.6)*
Smith, 2021 [24] 2017 Kenya 326/347 94.0 (91.0-96.1)
Herce, 2018 [56] 2017 Malawi 86/115 74.8 (66.1-81.9)
Twahirwa Rwema, 2020 [71] 2018 Rwanda 670/736 91.0 (88.7-92.9)
Okoboi, 2020 [88] 2018 Uganda 204/290 70.3 (64.8-75.3)
Parmley, 2022 [95] 2019 Zimbabwe 990/1167 84.8 (82.7-86.8)
Dijkstra, 2021 [18] 2019 Kenya 422/445 94.8 (92.3-96.5)
Bhattacharjee, 2020 [17] 2019 Kenya 1164/1200 97.0 (95.9-97.8)
Magesa, 2014 [86] NR Tanzania 42/50 84.0 (71.1-91.8)
Southern Africa
Nel, 2013 [145] 2004 South Africa 754/1045 72.2 (69.4-74.8)
Lane, 2008 [144] 2004 South Africa 99/147 67.3 (59.4-74.4)*
Lane, 2011 [142] 2008 South Africa 65/172 37.9 (31.0-45.4)
Knox, 2011 [140] 2008 South Africa 203/300 67.7 (62.2-72.7)
Fay, 2011 [62] 2008 Namibia 129/217 59.4 (52.8-65.8)
Fay, 2011 [62] 2008 Botswana 97/117 82.9 (75.0-88.7)
Tun, 2012 [136] 2009 South Africa 86/120 71.1 (62.4-78.5)
Wagenaar, 2012 [133] 2010 South Africa 382/439 87.0 (83.5-89.9)
Eaton, 2013 [134] 2010 South Africa 89/142 62.7 (54.4-70.2)
Lyons, 2023 [6] 2011 eSwatini 177/326 54.3 (48.9-59.6)
Kendall, 2014 [101] 2011 Angola 125/328 38.1 (33.0-43.5)
Siegler, 2015 [128] 2012 South Africa 33/34 97.1 (81.9-99.6)*
Maleke, 2017 [130] 2012 South Africa 18/23 78.3 (57.2-90.7)
Lane, 2014 [125] 2012 South Africa 436/605 72.1 (68.4-75.5)
Batist, 2013 [126] 2012 South Africa 91/97 93.8 (86.9-97.2)
Stahlman, 2015 [104] 2014 Lesotho 366/530 69.1 (65.0-72.8)*
Lippman, 2018 [118] 2015 South Africa 108/127 85.0 (77.7-90.2)
Sandfort, 2019 [33] 2016 South Africa 279/310 90.0 (86.1-92.9)*
Stephenson, 2021 [151] 2017 SA, Namibia 226/254 89.0 (84.5-92.3)
Scheibe, 2020 [114] 2017 South Africa 726/746 97.3 (95.9-98.3)*
Herce, 2018 [56] 2017 Angola 307/713 43.1 (39.5-46.7)*
Fearon, 2020 [115] 2017 South Africa 171/181 94.5 (90.0-97.0)
Pillay, 2020 [113] 2018 South Africa 94/96 97.9 (92.1-99.5)
Montgomery, 2021 [111] 2018 South Africa 180/190 94.7 (90.5-97.1)
Jobson, 2018 [147] NR South Africa 272/316 86.1 (81.8-89.5)*
0.0
25.0
50.0
75.0
100.0
Proportion (%)

Ever HIV testing continued…



* observation calculated using available data reported within article

Figure 5.4.2. Forest plot of study proportions of men who have sex with men (MSM) ever tested for HIV, by region of Africa. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

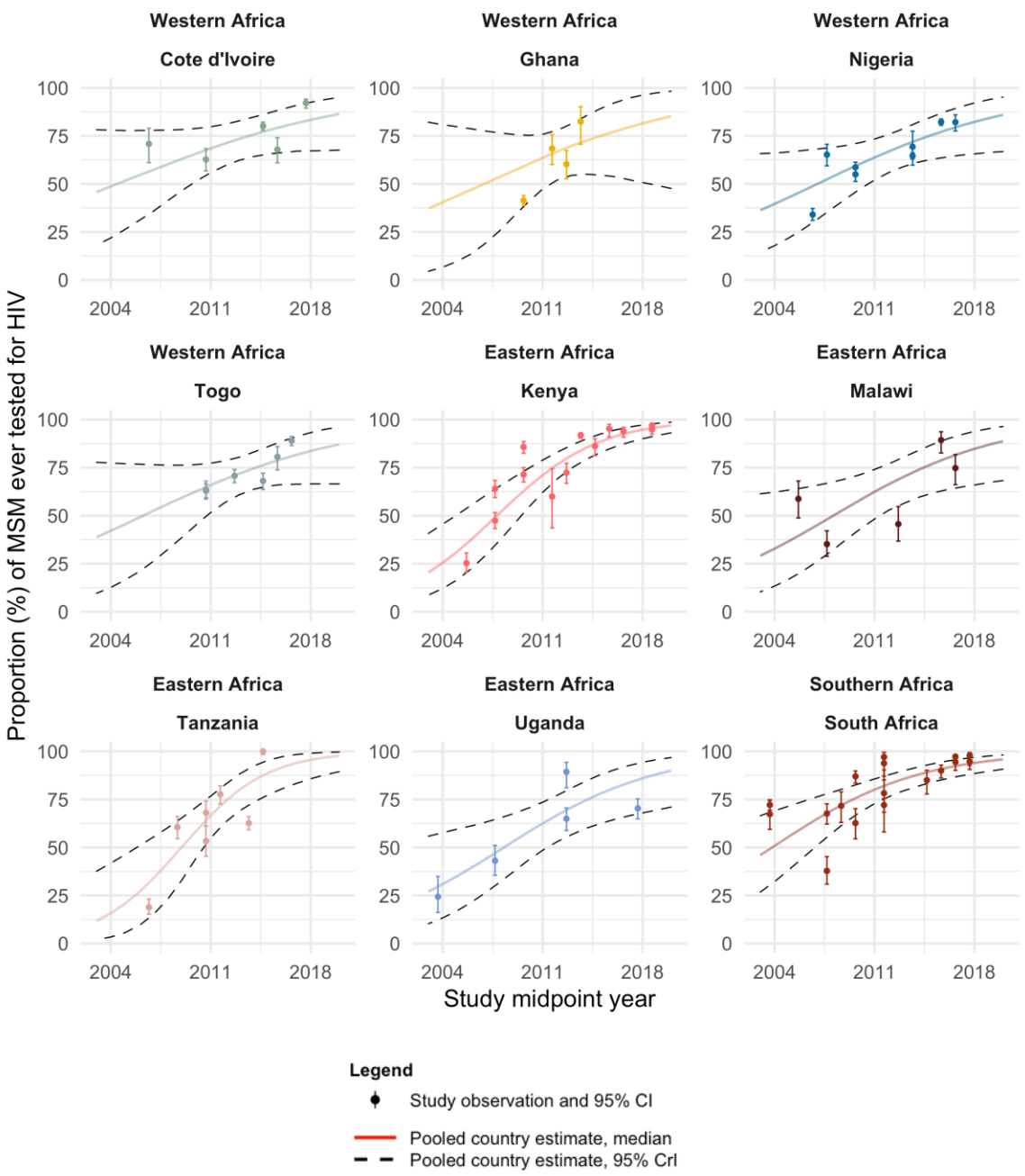
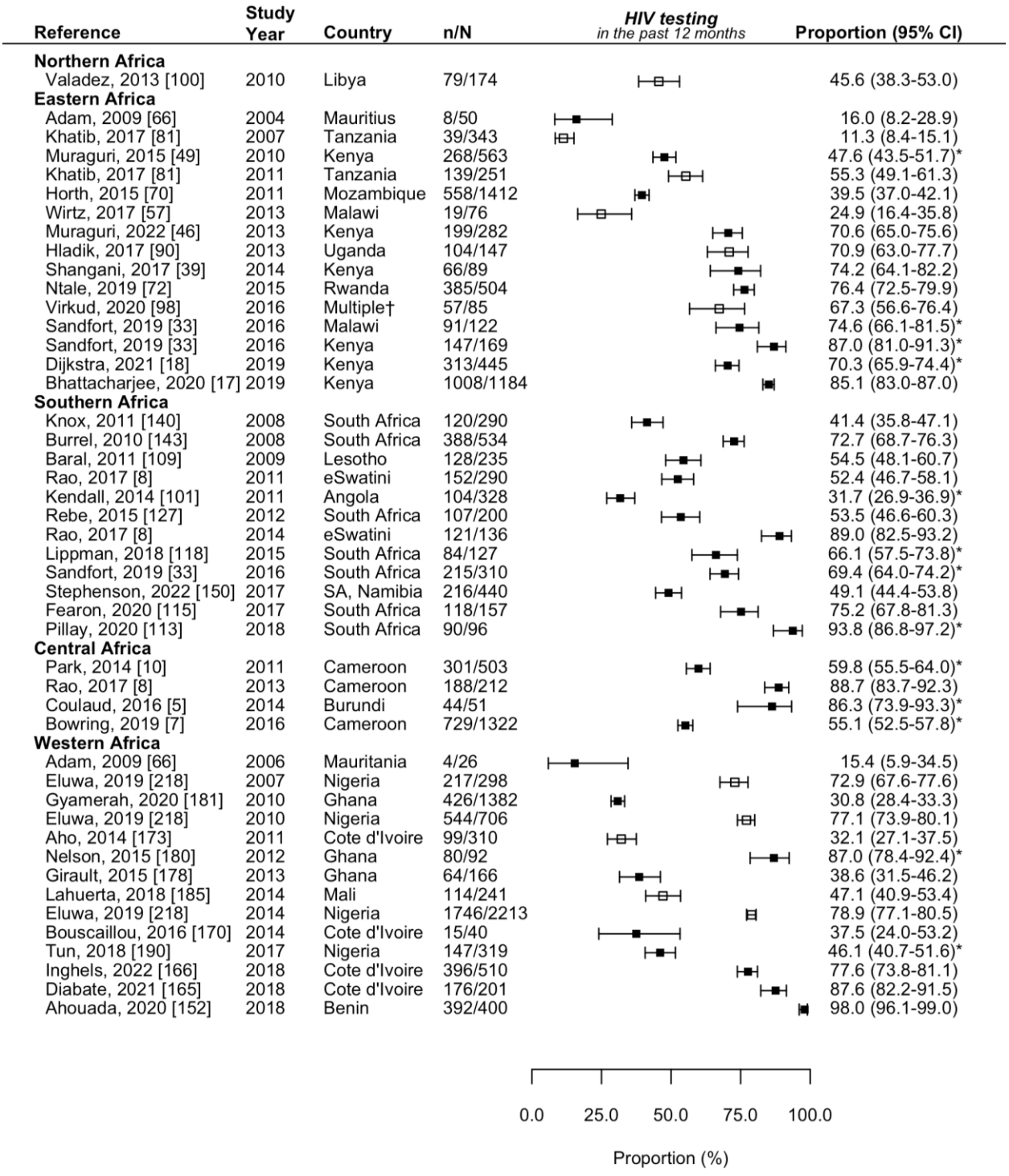


Figure 5.4.3. Ever HIV testing among men who have sex with men (MSM) over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.



***** observation calculated using available data reported within article

† includes Kenya, Rwanda, Tanzania, and Uganda.

Figure 5.4.4. Forest plot of study proportions of men who have sex with men (MSM) tested for HIV in the past 12 months, by region of Africa. Studies reported crude proportions (filled

squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

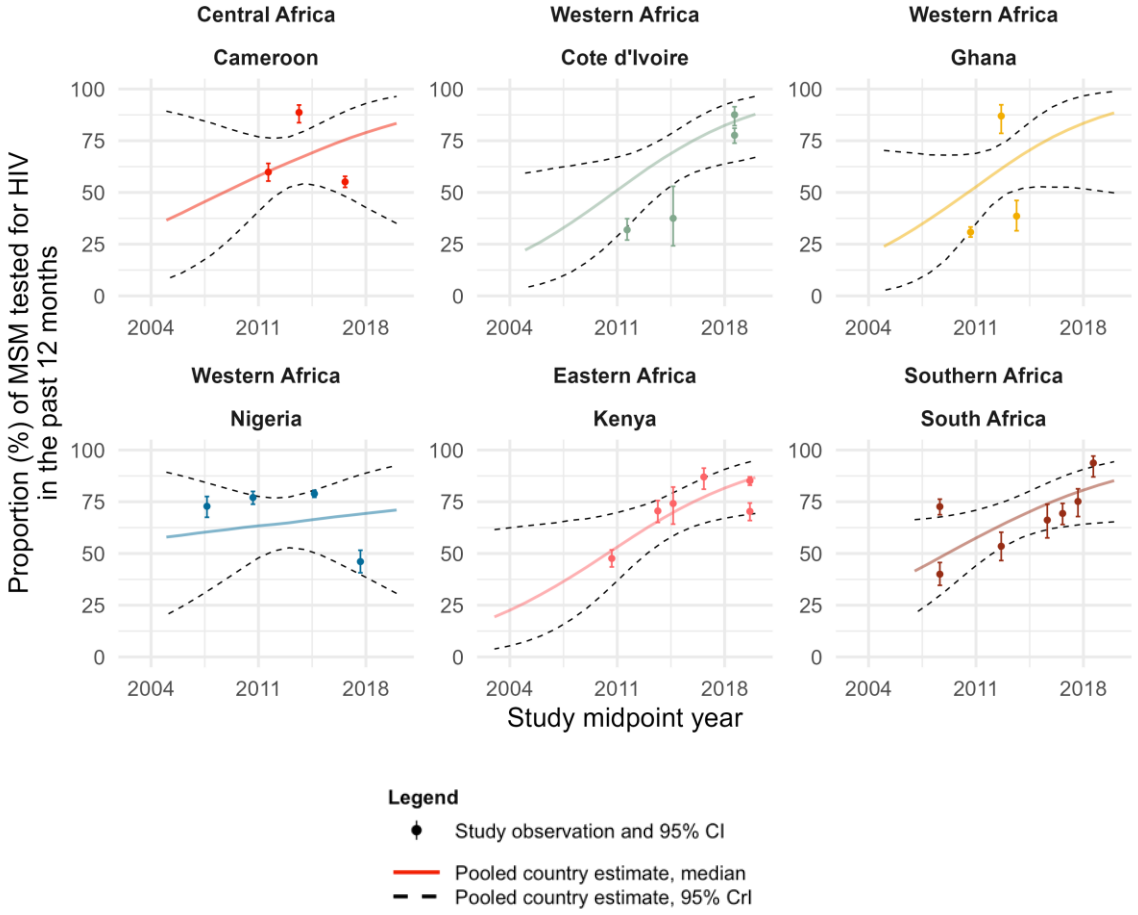
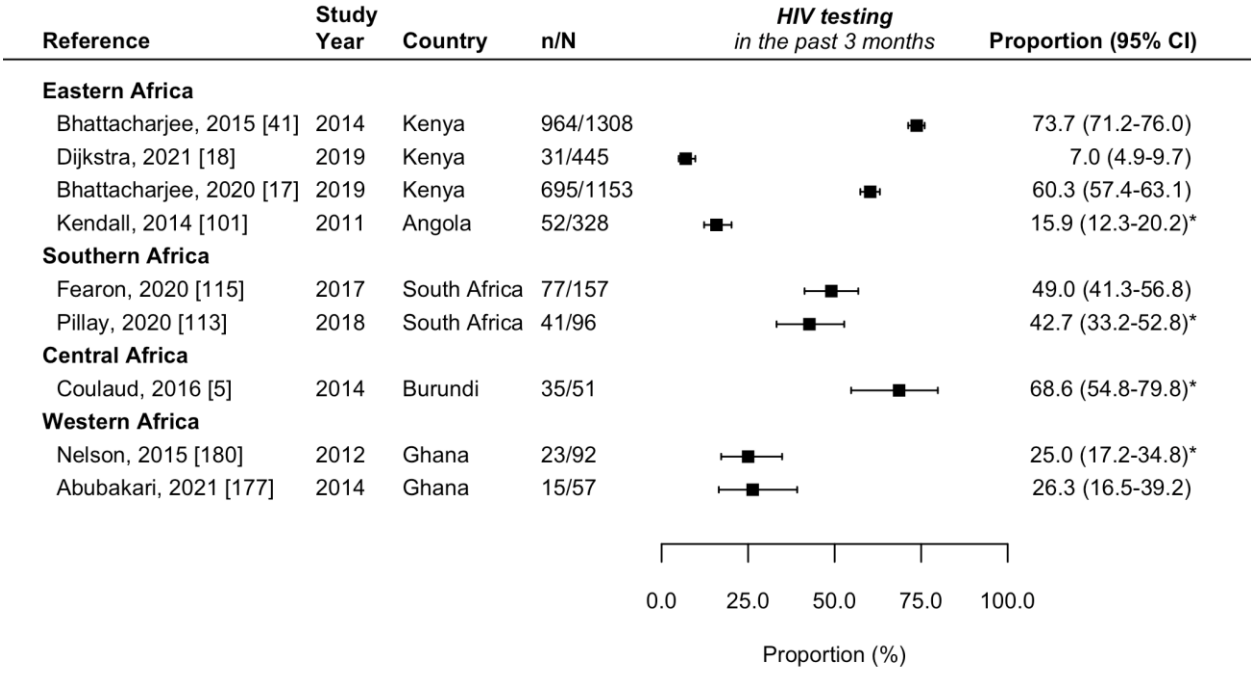
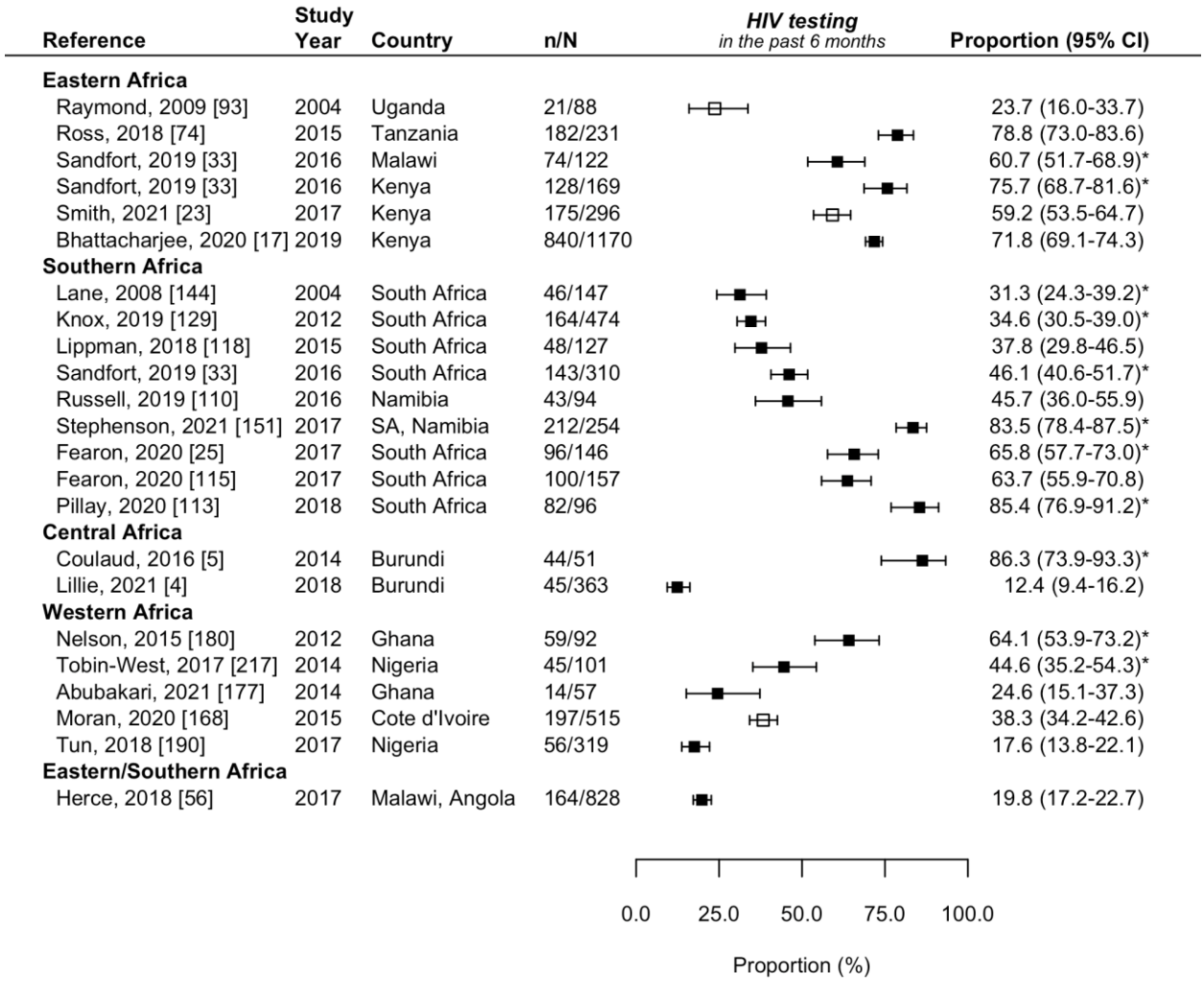


Figure 5.4.5. HIV testing in the past 12 months among men who have sex with men (MSM) over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.



* observation calculated using available data reported within article

Figure 5.4.6. Forest plot of study proportions of men who have sex with men (MSM) tested for HIV in the past 3 months, by region of Africa. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).



* observation calculated using available data reported within article

Figure 5.4.7. Forest plot of study proportions of men who have sex with men (MSM) tested for HIV in the past 6 months, by region of Africa. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

Table 5.4.5a. Estimated time trends in HIV testing in the past 6 months among men who have sex with men (MSM) in Africa and population weighted estimated outcomes in 2010 and 2020, overall and by region of Africa.

Outcome	Region of Africa	N_o	Estimate of time trend (per year)	95% CrI	Population weighted estimate in 2010	95% CrI	Population weighted estimate in 2020	95% CrI
Past 6 months HIV testing (%)								
Among all MSM*	Overall	23	OR=0.85	0.40-1.74	69%	43-82%	31%	23-52%
	Central/Western Africa	7	OR=0.64	0.41-1.08	86%	46-97%	7%	1-43%
	Eastern/Southern Africa	16	OR=1.08	0.76-1.36	44%	23-68%	70%	50-83%

ART, antiretroviral therapy; CrI, credible interval; IRR, incidence rate ratio; MSM, men who have sex with men; OR, odds ratio.

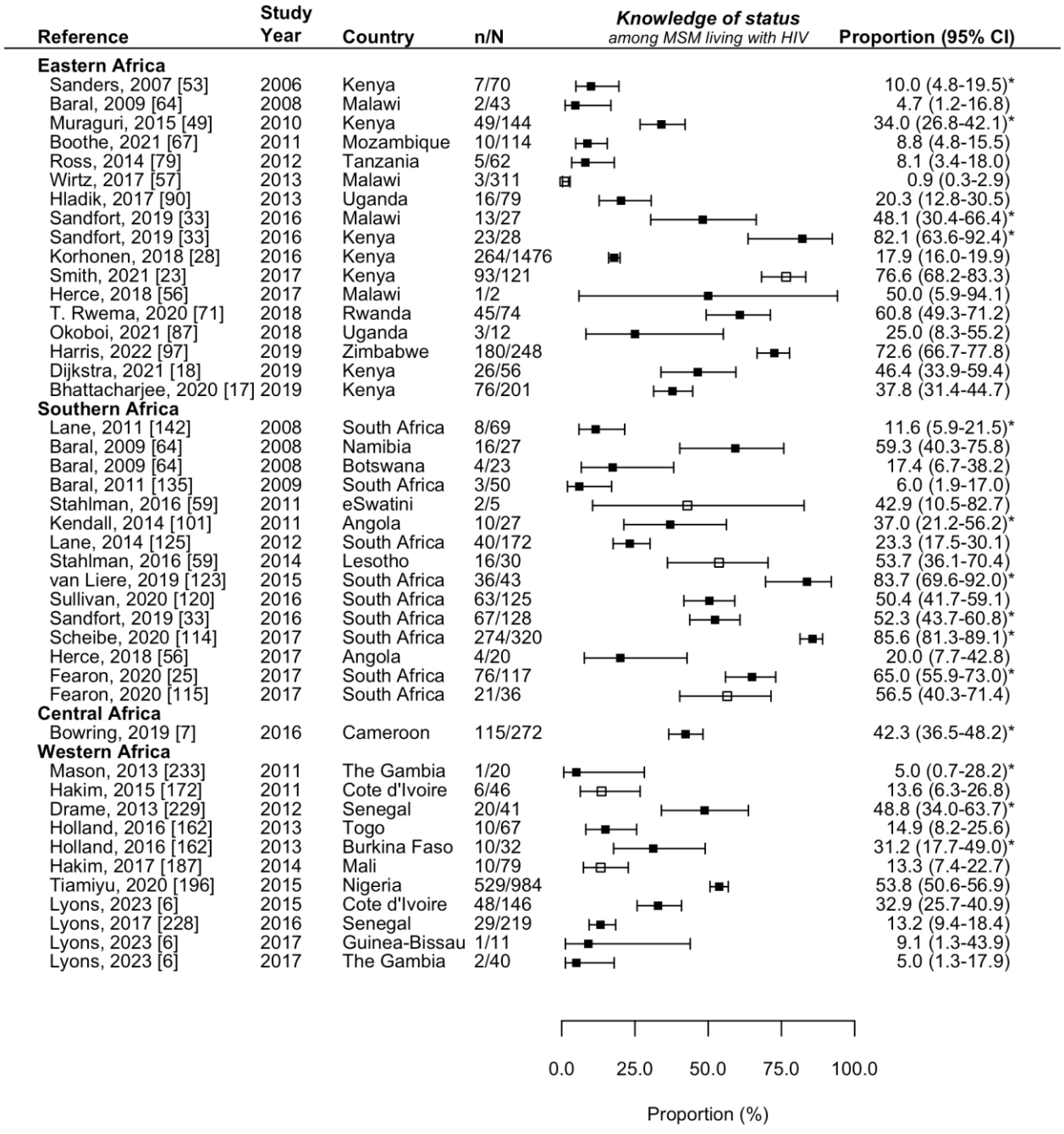
* n = 1 observation from Central/Eastern Africa not included

Table 5.4.5b. Unweighted estimate of HIV testing in the past 6 months in 2010 and 2020, overall and by region of Africa.

Outcome	Region of Africa	N_o	Unweighted estimate in 2010	95% CrI	Unweighted estimate in 2020	95% CrI
Past 6 months HIV testing (%)						
Among all MSM*	Overall	23	68%	7-99%	31%	1-96%
	Central/Western Africa	7	88%	37-99%	7%	1-60%
	Eastern/Southern Africa	16	43%	18-86%	65%	25-86%

ART, antiretroviral therapy; CrI, credible interval; IRR, incidence rate ratio; MSM, men who have sex with men; OR, odds ratio.

* n = 1 observation from Central/Eastern Africa not shown



***** observation calculated using available data reported within article

Figure 5.4.8. Forest plot of study proportions of men who have sex with men (MSM) living with HIV who know their status (HIV aware MSM), by region of Africa. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

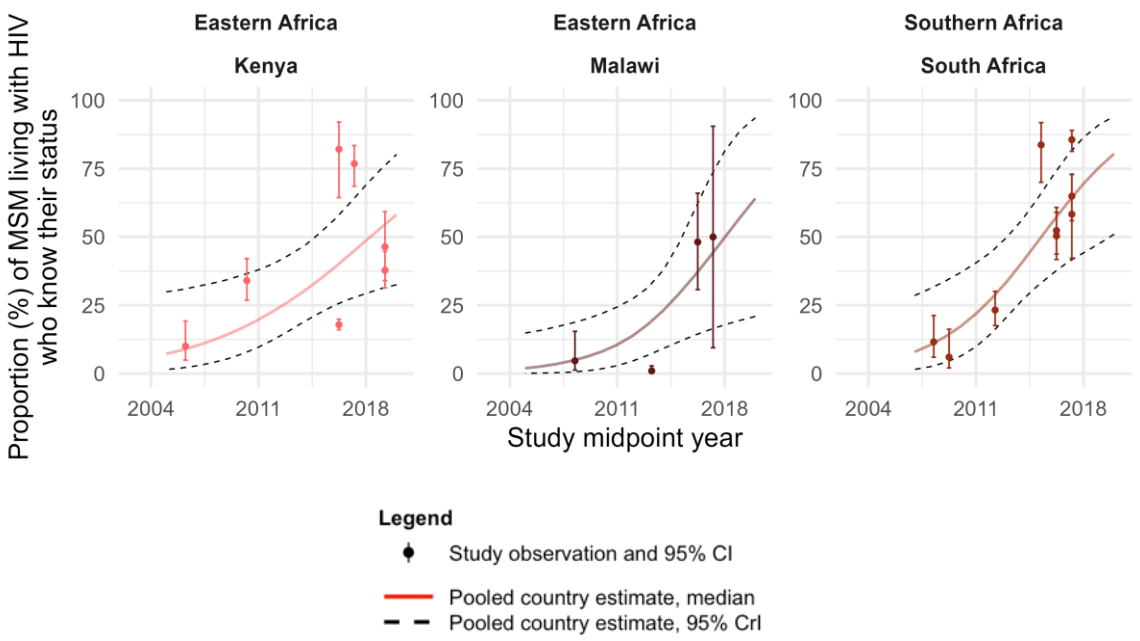
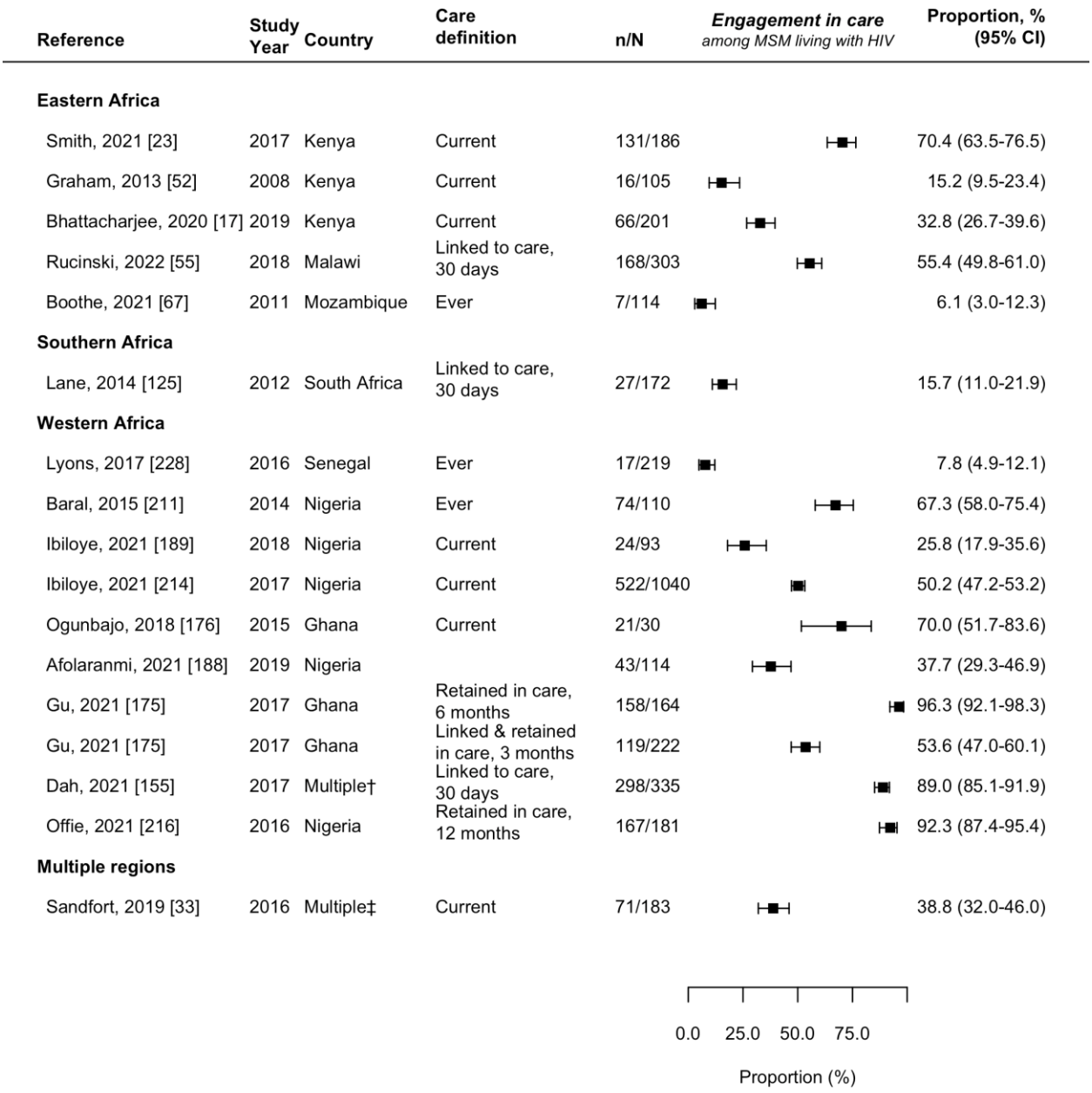


Figure 5.4.9. Knowledge of status (self-reported) among men who have sex with men (MSM) living with HIV over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.

Text 5.4.6. Additional results pertaining to engagement in care outcomes

Observations of engagement in care (other than current ART use) among MSM living with HIV included reports of ever receiving care (N_o=3), ever receiving ART (N_o=7), currently receiving care (N_o=7), being linked to care within 30 days of diagnosis (N_o=2), being linked and retained in care within 3 months of diagnosis (N_o=1), and being retained in care in the past 12 (N_o=1) or 6 months (N_o=1). In 6 studies, ever ART use among HIV aware MSM was reported (N_o=6).



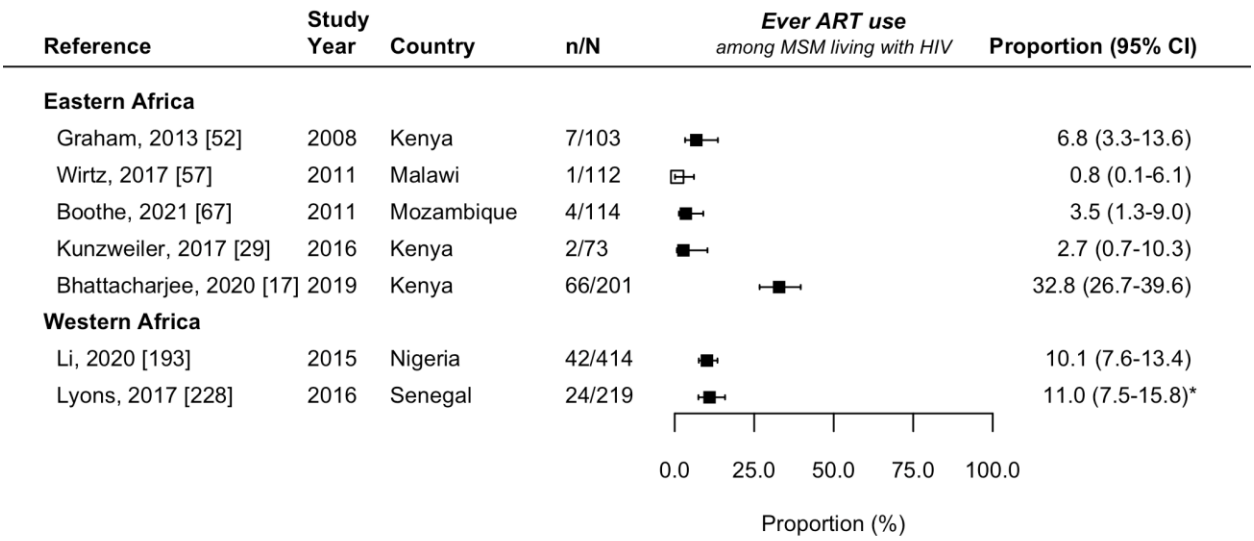
***** observation calculated using available data reported within article

† includes Burkina Faso, Cote d'Ivoire, Mali, Togo

‡ includes Kenya, Malawi, South Africa

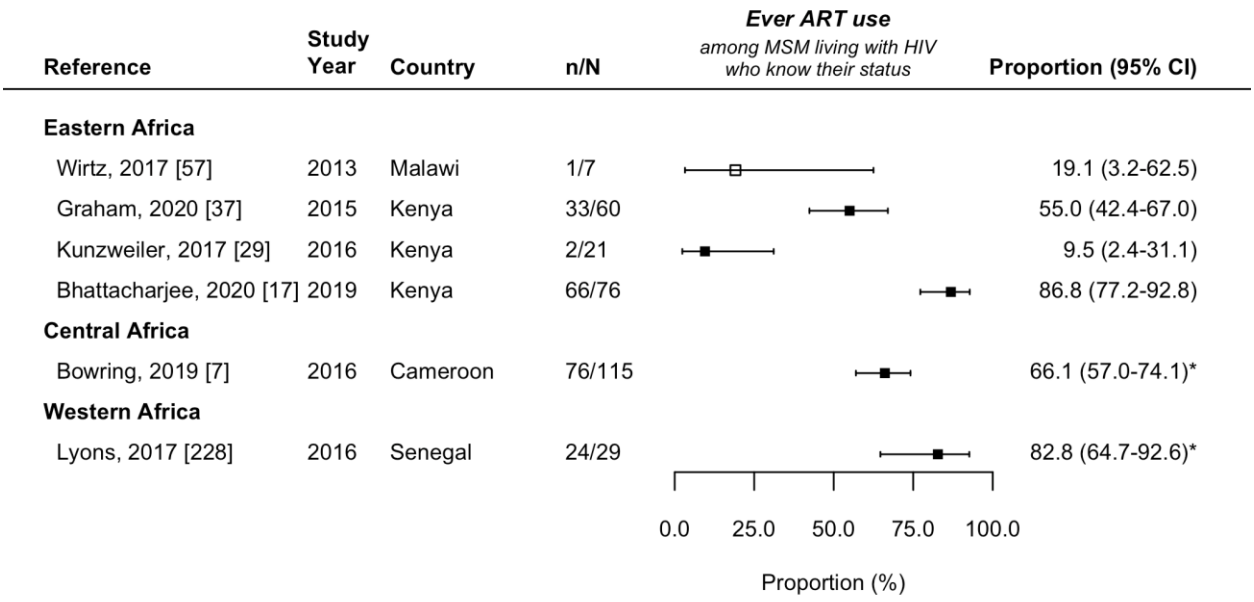
Figure 5.4.10. Forest plot of study proportions of men who have sex with men (MSM) living with HIV engaged in care other than current ART use, by region of Africa.

(a)



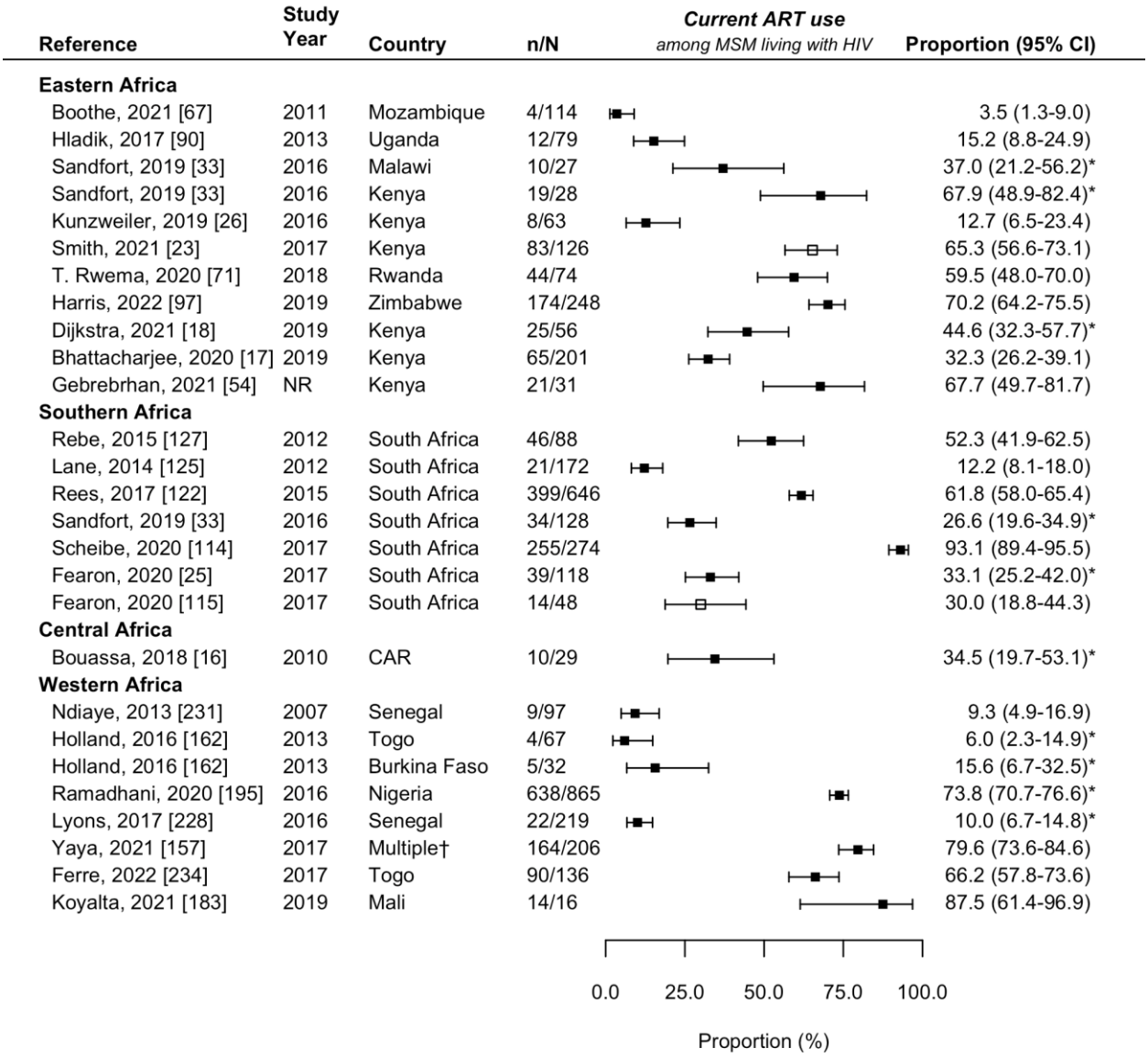
* observation calculated using available data reported within article

(b)



* observation calculated using available data reported within article

Figure 5.4.11. Forest plot of study proportions of men who have sex with men (MSM) ever on ART, by region of Africa. Ever ART use among (a) MSM living with HIV, and (b) HIV aware MSM. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).



***** observation calculated using available data reported within article

† includes Burkina Faso, Cote d'Ivoire, Mali, and Togo.

Figure 5.4.12. Forest plot of study proportions of men who have sex with men (MSM) living with HIV currently on antiretroviral therapy (ART), by region of Africa. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

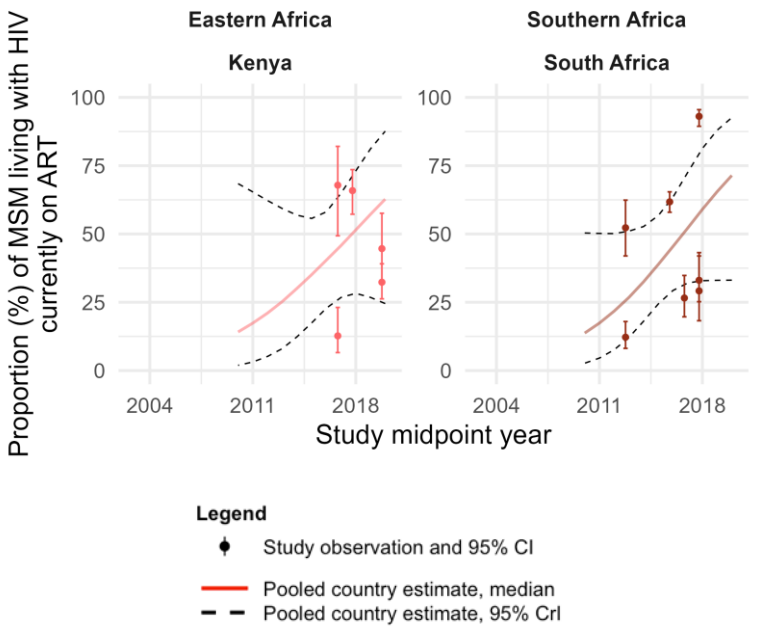
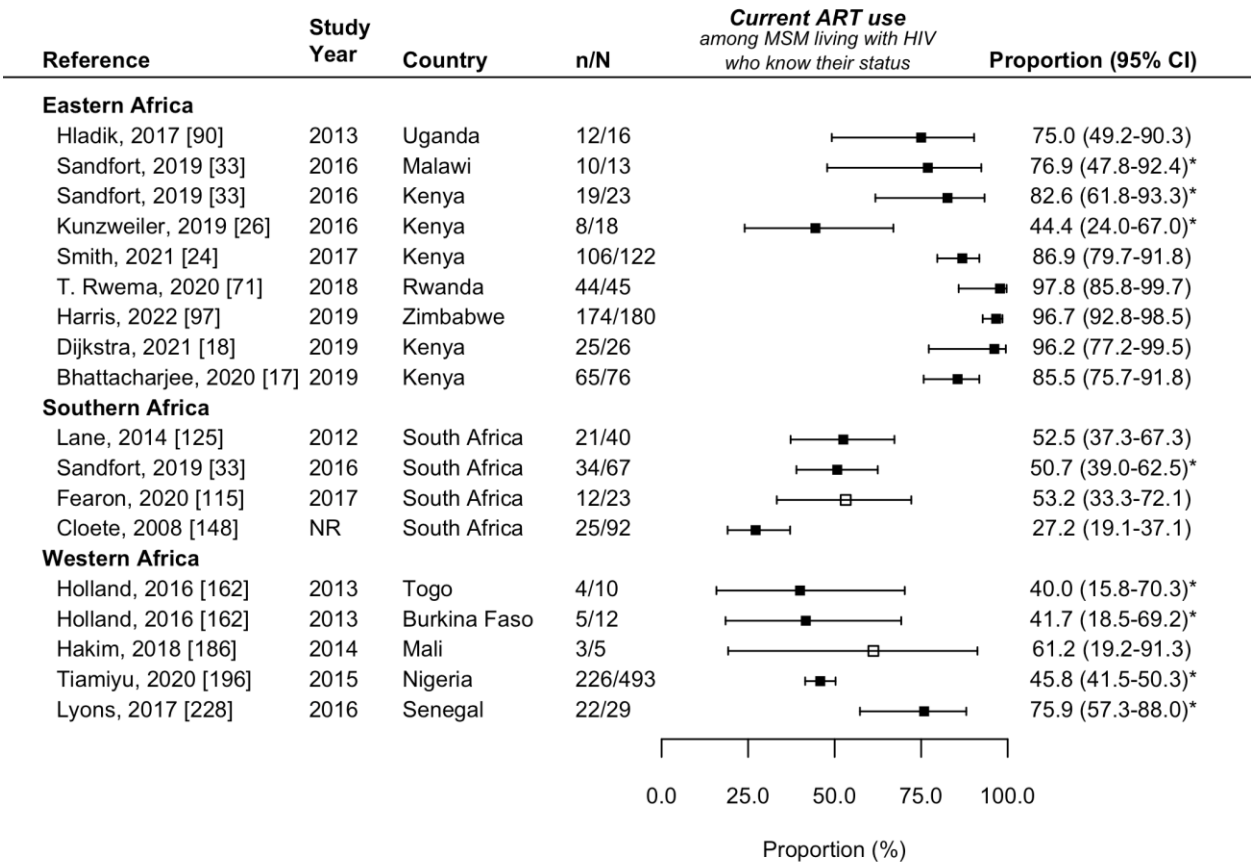


Figure 5.4.13. Current antiretroviral therapy (ART) use among men who have sex with men (MSM) living with HIV over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.



* observation calculated using available data reported within article

Figure 5.4.14. Forest plot of study proportions of HIV aware men who have sex with men (MSM) currently on antiretroviral therapy (ART), by region of Africa. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

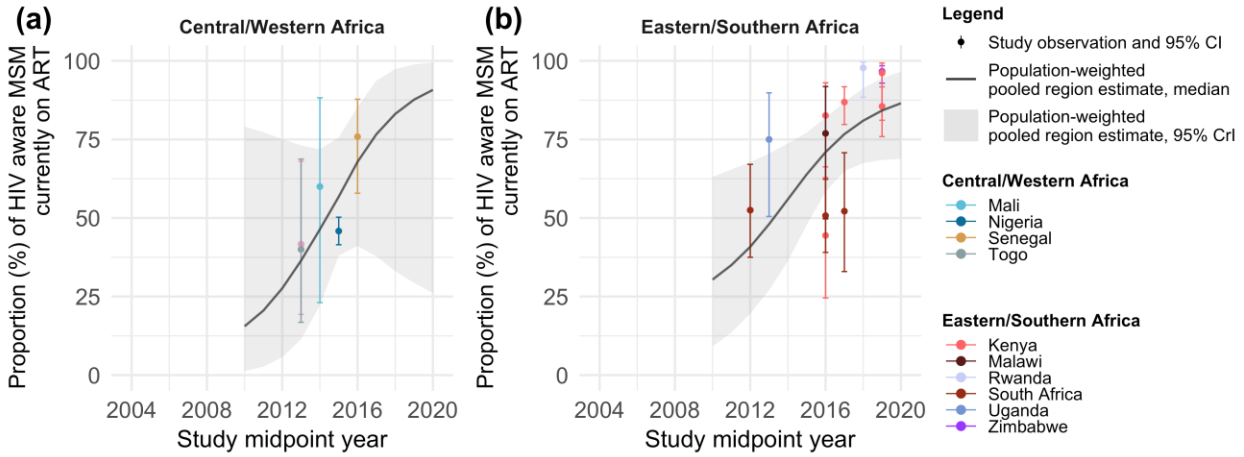


Figure 5.4.15. Current antiretroviral therapy (ART) use among HIV aware men who have sex with men (MSM) over time, by region and country of Africa. Current ART use among HIV aware MSM in (a) Central/Western Africa, and (b) Eastern/Southern Africa. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The black solid and dotted lines represent the estimated region-level proportions and 95% credible intervals (CrI), respectively. Coloured solid lines represent estimated country-level proportions for countries with at least 3 estimates from 3 different time points (see Figure S20 for individual country-level time trends and 95% CrI).

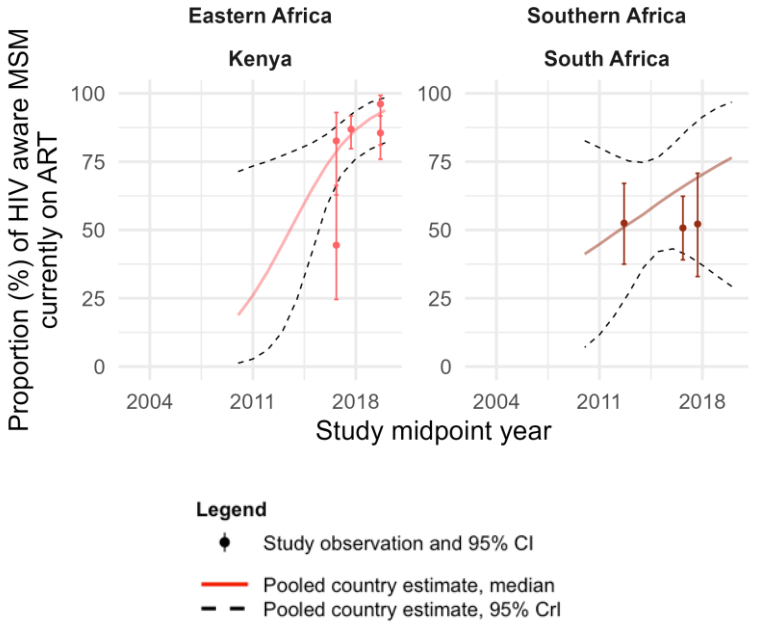
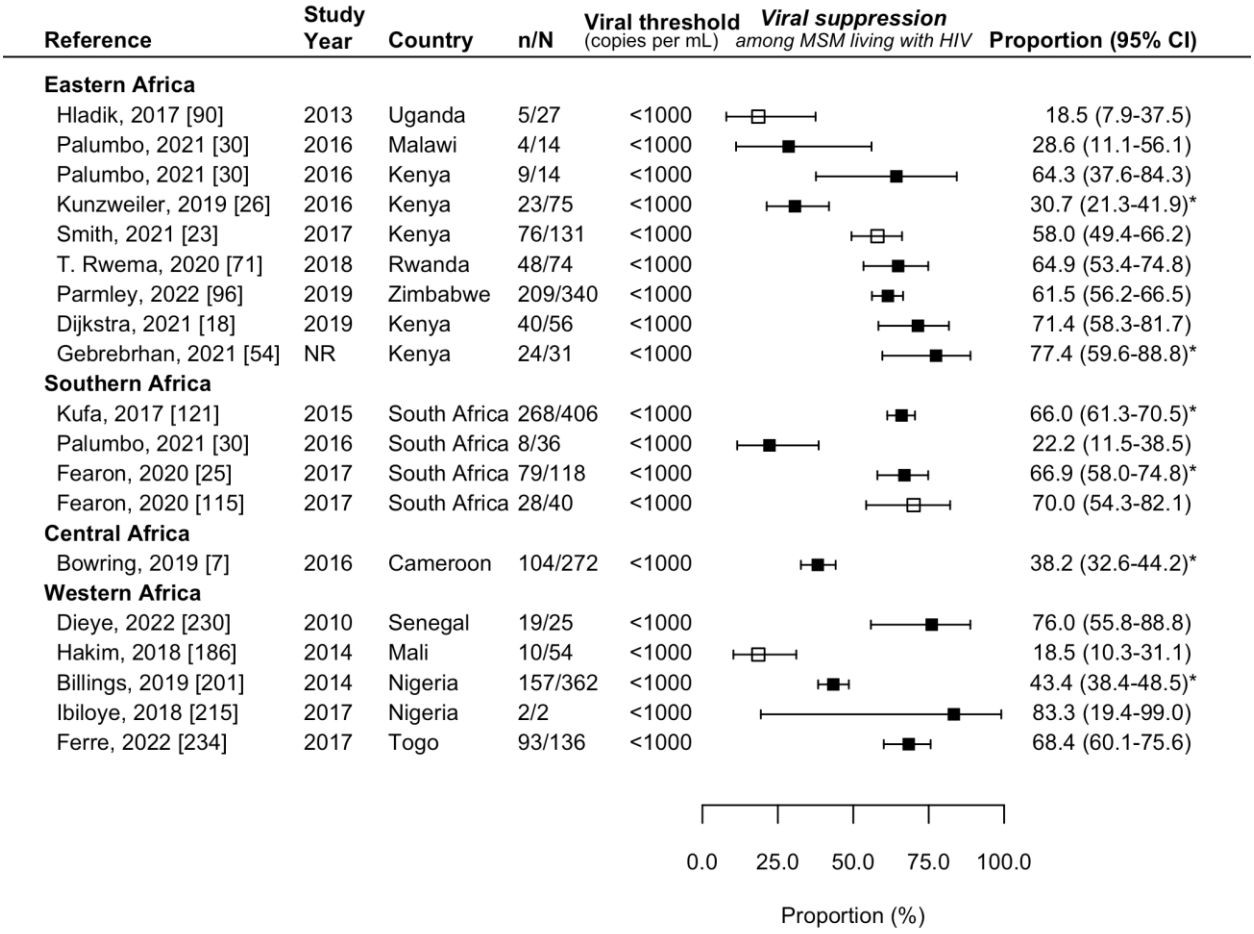


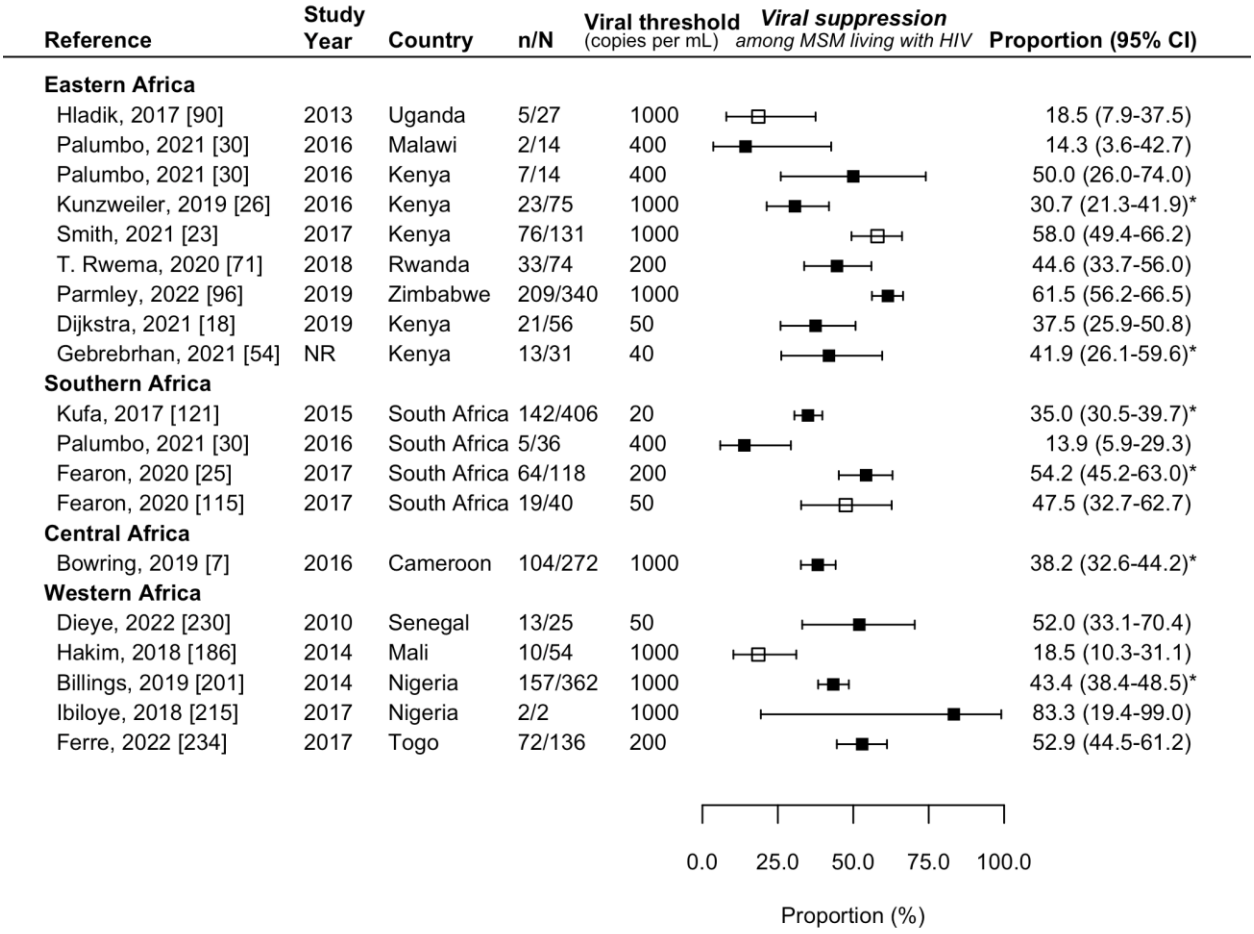
Figure 5.4.16. Current antiretroviral therapy (ART) use among HIV aware men who have sex with men (MSM) over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals.

The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.



***** observation calculated using available data reported within article

Figure 5.4.17a. Forest plot of study proportions of men who have sex with men (MSM) living with HIV virally suppressed, by region of Africa, standardised to a viral threshold of <1000 copies per mL. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).



* observation calculated using available data reported within article

Figure 5.4.17b. Forest plot of study proportions of men who have sex with men (MSM) living with HIV virally suppressed, by region of Africa, based on viral threshold defined by the authors of each included study. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

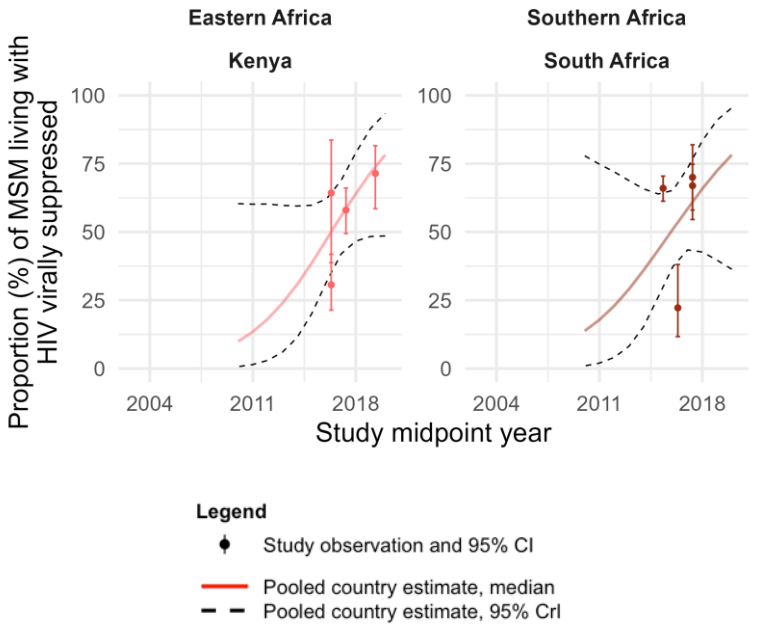
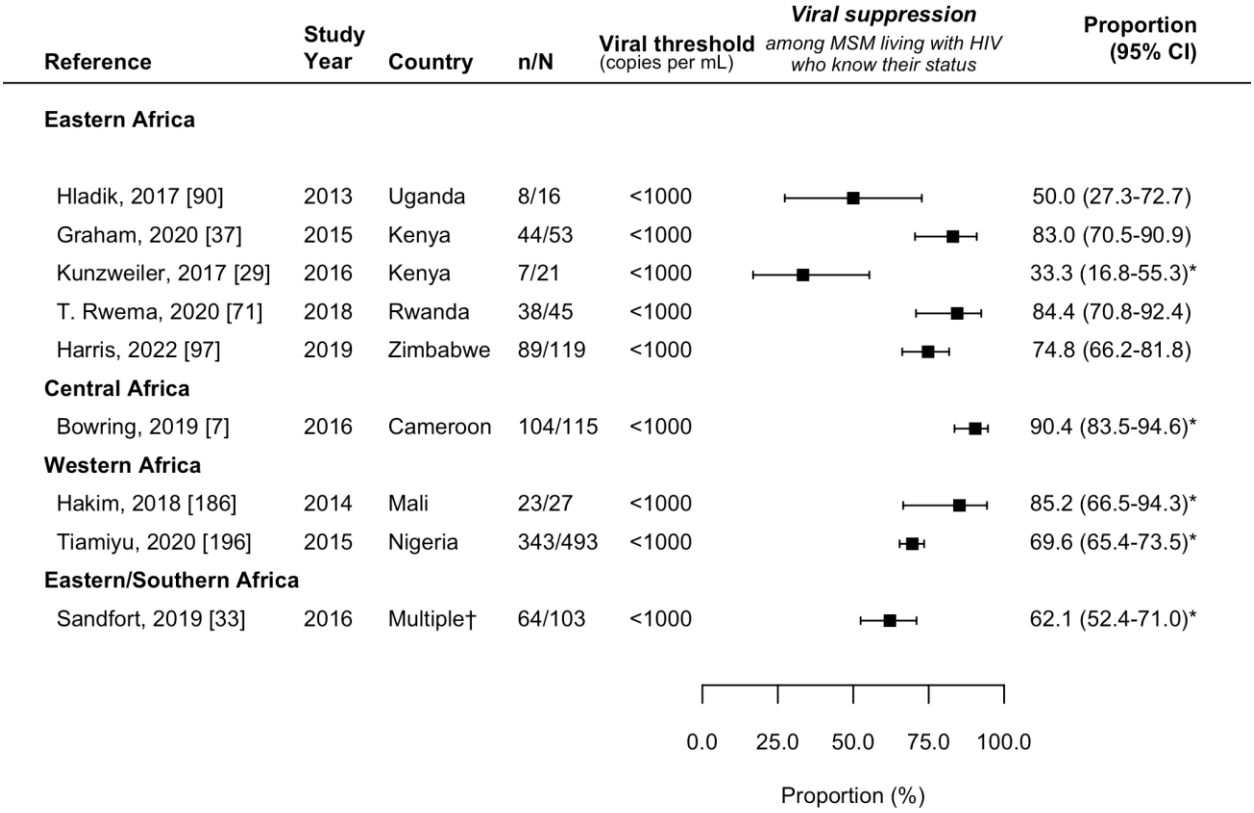


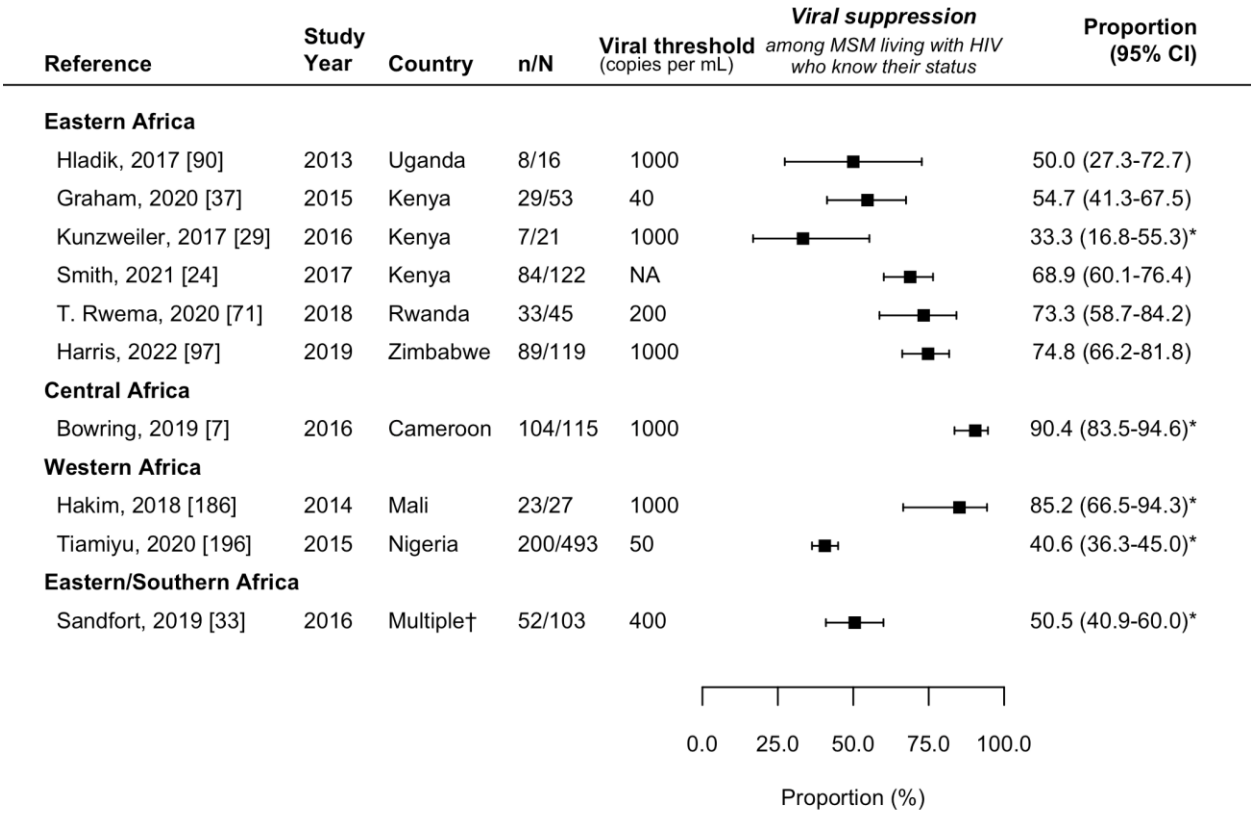
Figure 5.4.18. Viral suppression among men who have sex with men (MSM) living with HIV over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.



***** observation calculated using available data reported within article

† includes Kenya, Malawi, and South Africa.

Figure 5.4.19a. Forest plot of study proportions of HIV aware men who have sex with men (MSM) virally suppressed, by region of Africa, standardized to a viral threshold of <1000 copies per mL. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).



***** observation calculated using available data reported within article

† includes Kenya, Malawi, and South Africa.

Figure 5.4.19b. Forest plot of study proportions of HIV aware men who have sex with men (MSM) virally suppressed, by region of Africa, based on viral thresholds defined by the authors of each included study. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

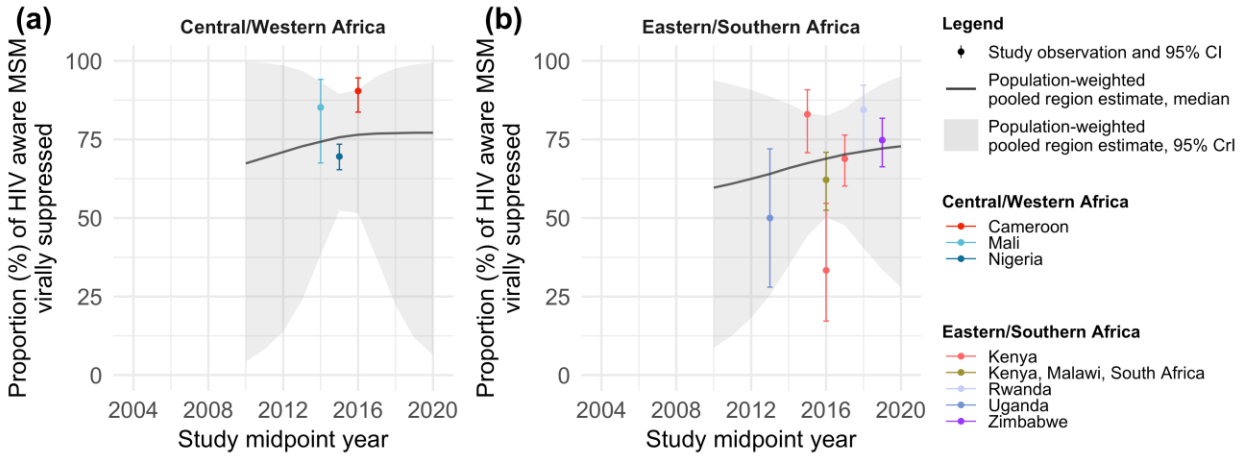


Figure 5.4.20. Viral suppression among HIV aware men who have sex with men (MSM) over time, by region and country of Africa. Viral suppression among HIV aware MSM in (a) Central/Western Africa, and (b) Eastern/Southern Africa. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The black solid and dotted lines represent the estimated region-level proportions and 95% credible intervals (CrI), respectively. Coloured solid lines represent estimated country-level proportions for countries with at least 3 estimates from 3 different time points (see Figure S22 for individual country-level time trends and 95% CrI).

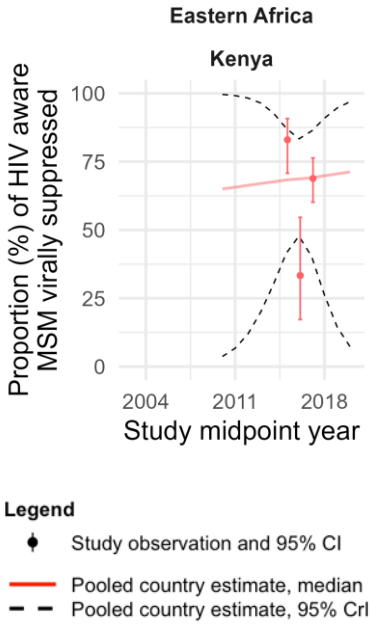
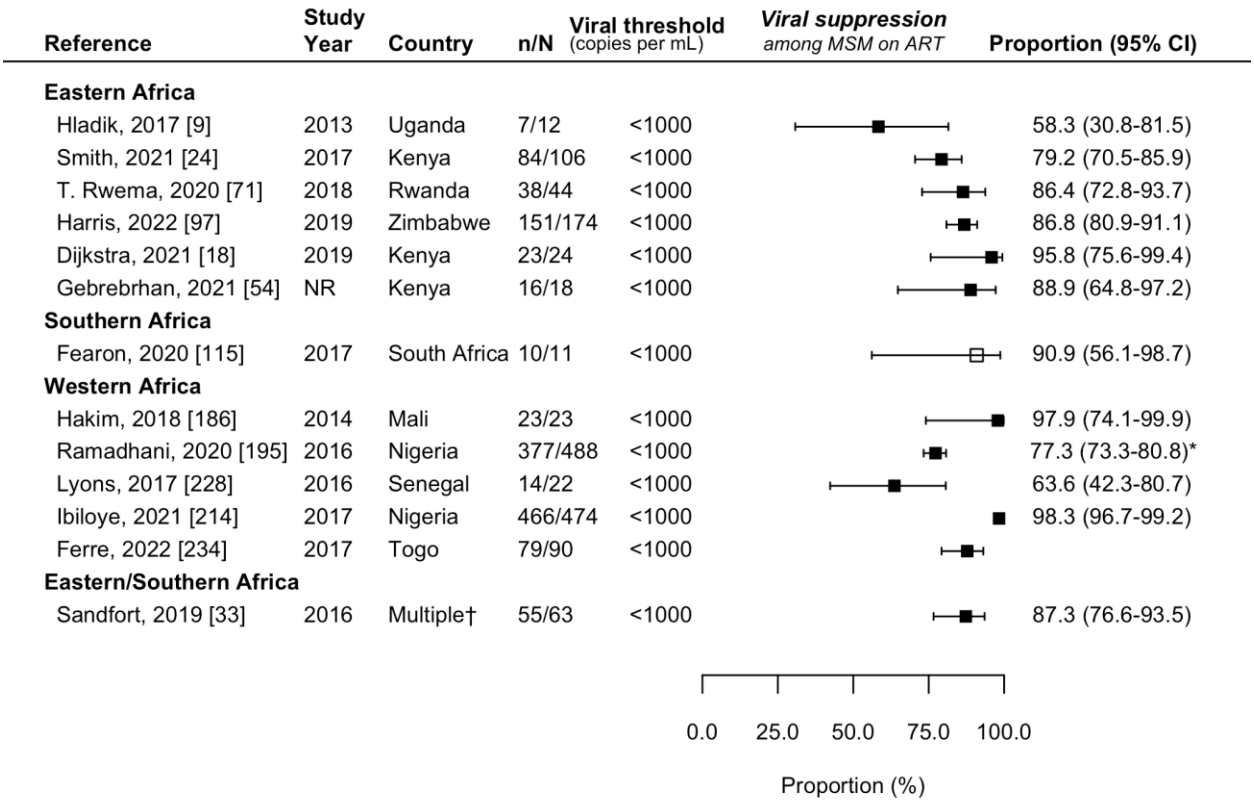


Figure 5.4.21. Viral suppression among HIV aware men who have sex with men (MSM) over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted

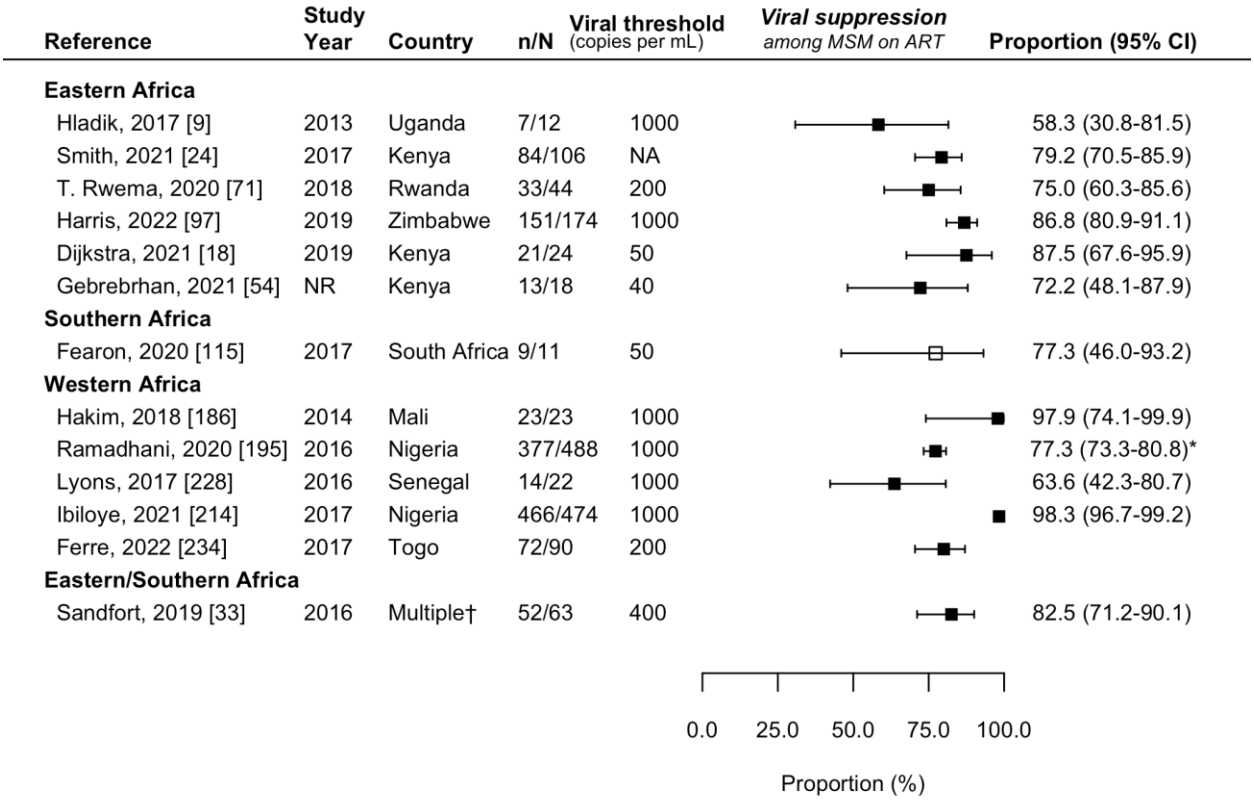
lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.



* observation calculated using available data reported within article

† includes Kenya, Malawi, and South Africa.

Figure 5.4.22a. Forest plot of study proportions of men who have sex with men (MSM) currently on antiretroviral therapy (ART) virally suppressed, by region of Africa, standardized to a viral threshold of <1000 copies per ml. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).



***** observation calculated using available data reported within article

† includes Kenya, Malawi, and South Africa.

Figure 5.4.22b. Forest plot of study proportions of men who have sex with men (MSM) currently on antiretroviral therapy (ART) virally suppressed, by region of Africa, based on viral thresholds defined by the authors of each included study. Studies reported crude proportions (filled squares) or proportions adjusted for sampling design (e.g., respondent driven sampling, cluster, time-location sampling; unfilled squares).

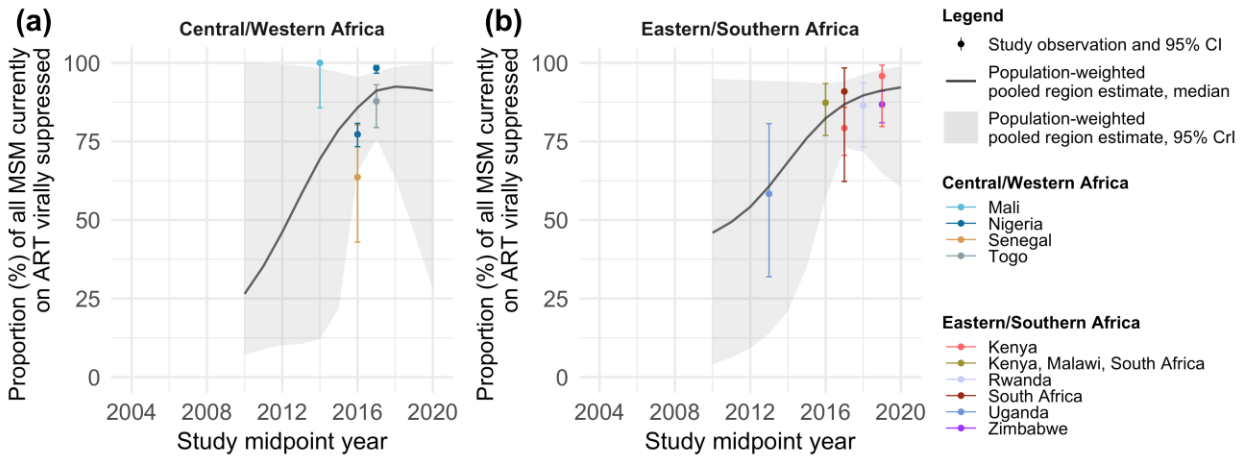
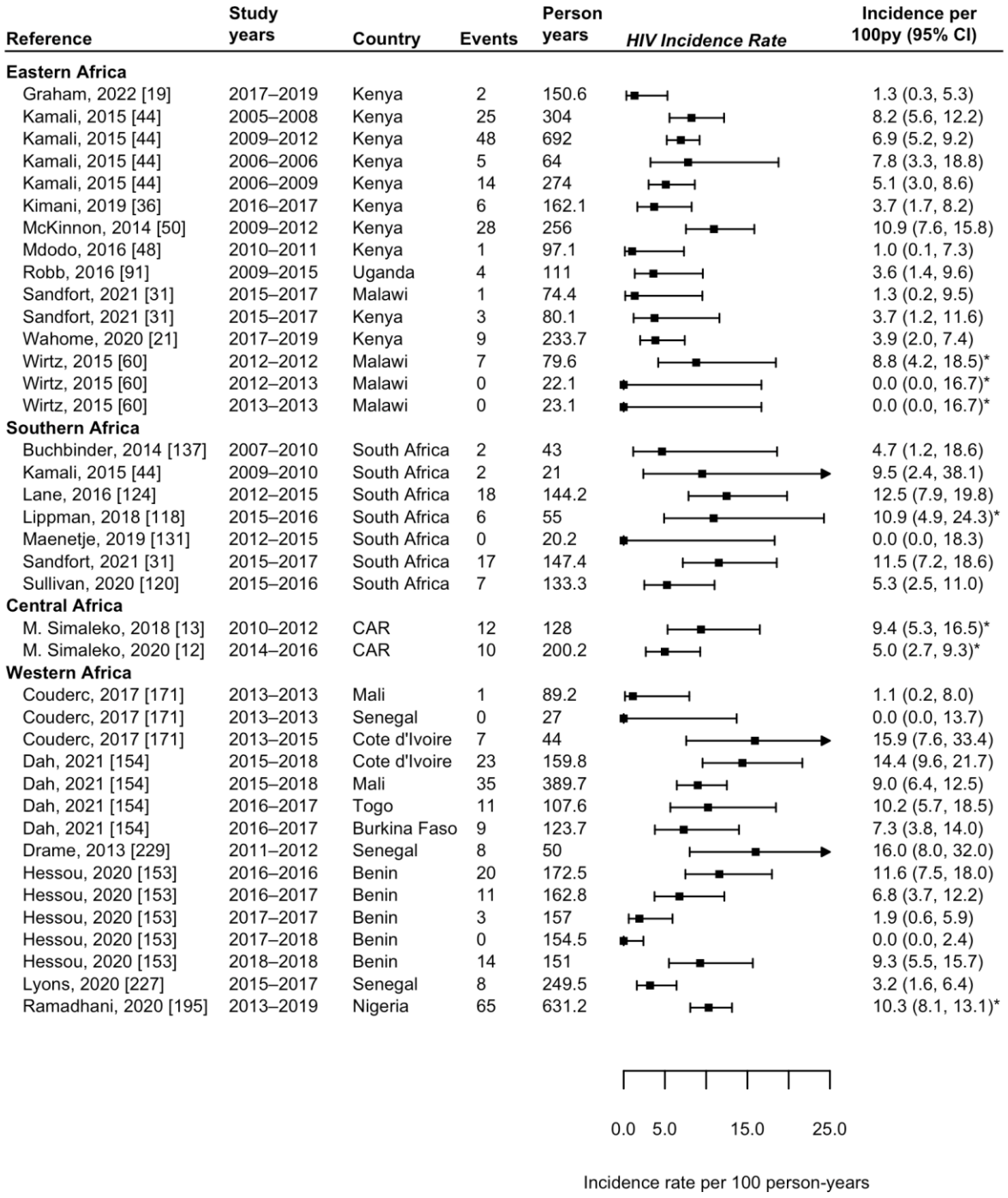


Figure 5.4.23. Viral suppression among men who have sex with men (MSM) currently on antiretroviral therapy (ART) over time, by region and country of Africa. Viral suppression among MSM currently on ART over time in (a) Central/Western Africa and (b) Eastern/Southern Africa. Points represent available study observations and their 95% confidence intervals, coloured by country in which the study was conducted. The black solid and dotted lines represent the estimated region-level proportions and 95% credible intervals (CrI), respectively. Coloured solid lines represent estimated country-level proportions for countries with at least 3 estimates from 3 different time points (see Figure S22 for individual country-level time trends and 95% CrI).



***** observation calculated using available data reported within article

Figure 5.4.24. Forest plot of study observations of HIV incidence among men who have sex with men (MSM), by region of Africa.

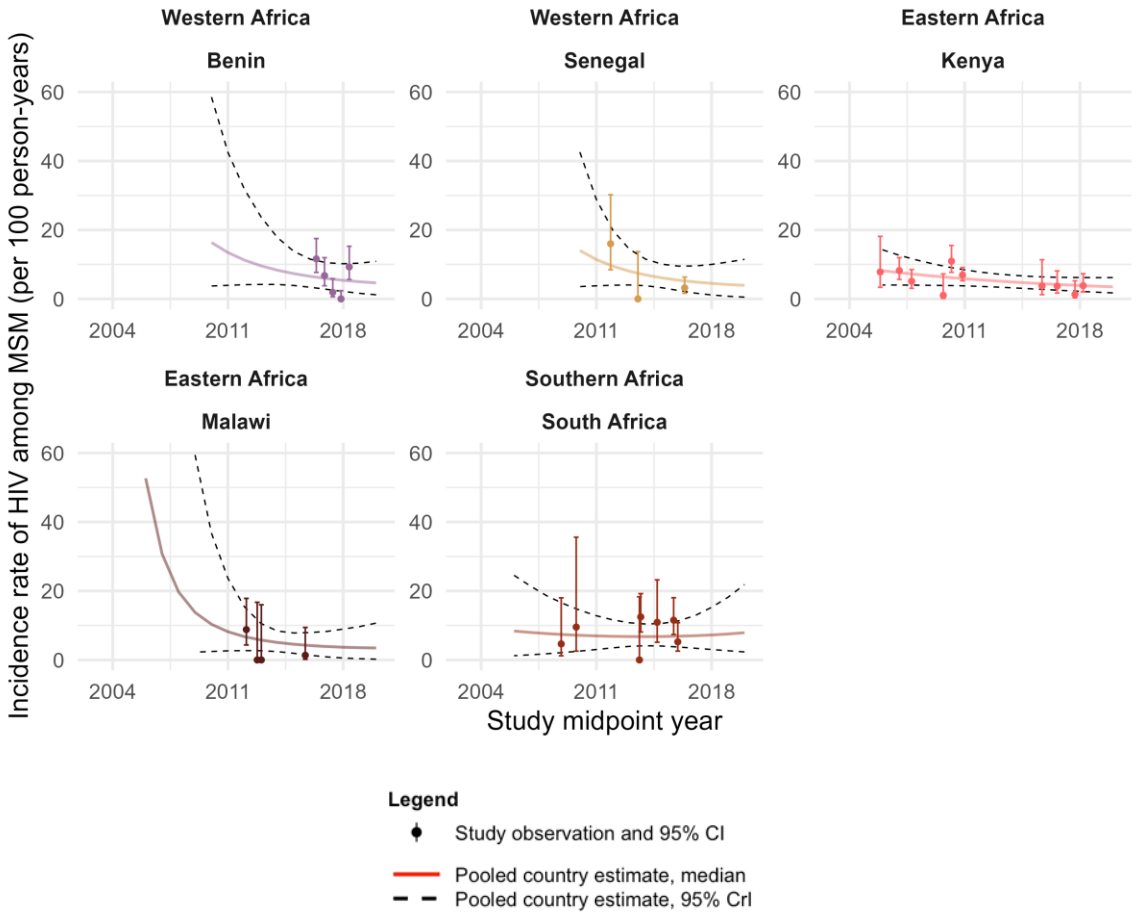


Figure 5.4.25. HIV incidence among men who have sex with men (MSM) over time, by country of Africa. Estimates are shown over the range of available years in each region of Africa for countries with at least 3 observations from different time points. Points represent available study observations and their 95% confidence intervals. The solid and dotted lines represent the estimated country-level proportions and 95% credible intervals (CrI) over time, respectively.

Table 5.4.6. Estimated associations between HIV testing, treatment cascade (among those living with HIV), and HIV incidence among MSM, with the criminalization of partnerships between men, compared to no criminalisation, adjusted for the midpoint of the study year.

Outcome	Number of studies conducted where partnerships between men were not legal	Number of studies conducted where partnerships between men were legal	Estimate of association with criminalization (adjusted for midpoint of study year)	95% CrI	Unweighted overall pooled estimate in 2010 in presence of criminalization (95% CrI)	Unweighted overall pooled estimate in 2020 in presence of criminalization (95% CrI)	Unweighted overall pooled estimate in 2010 in absence of criminalization (95% CrI)	Unweighted overall pooled estimate in 2020 in absence of criminalization (95% CrI)
Ever HIV testing (%)	68	31	OR_{crim}=0.64	0.37-1.16	63% (44-82%)	80% (25-96%)	73% (51-88%)	86% (32-98%)
Past 12 months HIV testing (%)	30	14	OR_{crim}=1.14	0.53-2.32	47% (28-68%)	91% (62-99%)	44% (21-69%)	90% (61-98%)
Knowledge of status (%)	28	16	OR_{crim}=0.78	0.33-1.95	17% (5-51%)	49% (8-88%)	20% (5-58%)	55% (9-91%)
MSM living with HIV currently on ART (%)	15	11	OR_{crim}=0.57	0.21-1.58	9% (1-69%)	66% (10-96%)	15% (1-80%)	77% (17-98%)
MSM living with HIV virally suppressed (%)	13	6	OR_{crim}=0.97	0.36-2.83	20% (1-92%)	70% (13-96%)	21% (1-93%)	71% (12-97%)
HIV incidence (py^{-100})	16	15	IRR_{crim}=0.69	0.38-1.25	6.3py^{-100} (0.8-49.8)	4.1py^{-100} (0.3-59.5)	9.1py^{-100} (1.1-76.8)	5.9py^{-100} (0.4-88.5)

CrI, credible interval; IRR_{crim}, incidence rate ratio for criminalization vs no criminalization; MSM, men who have sex with men; OR_{crim}, odds ratio for criminalization vs no criminalization, py^{-100}, per 100 person-years

* 1 observation of ever HIV testing and 2 observations of past 12 months HIV testing were excluded from analyses of criminalization, as they were from studies conducted in both criminalizing and non-criminalizing settings (e.g., studies conducted in multiple countries), or criminalization data was not available

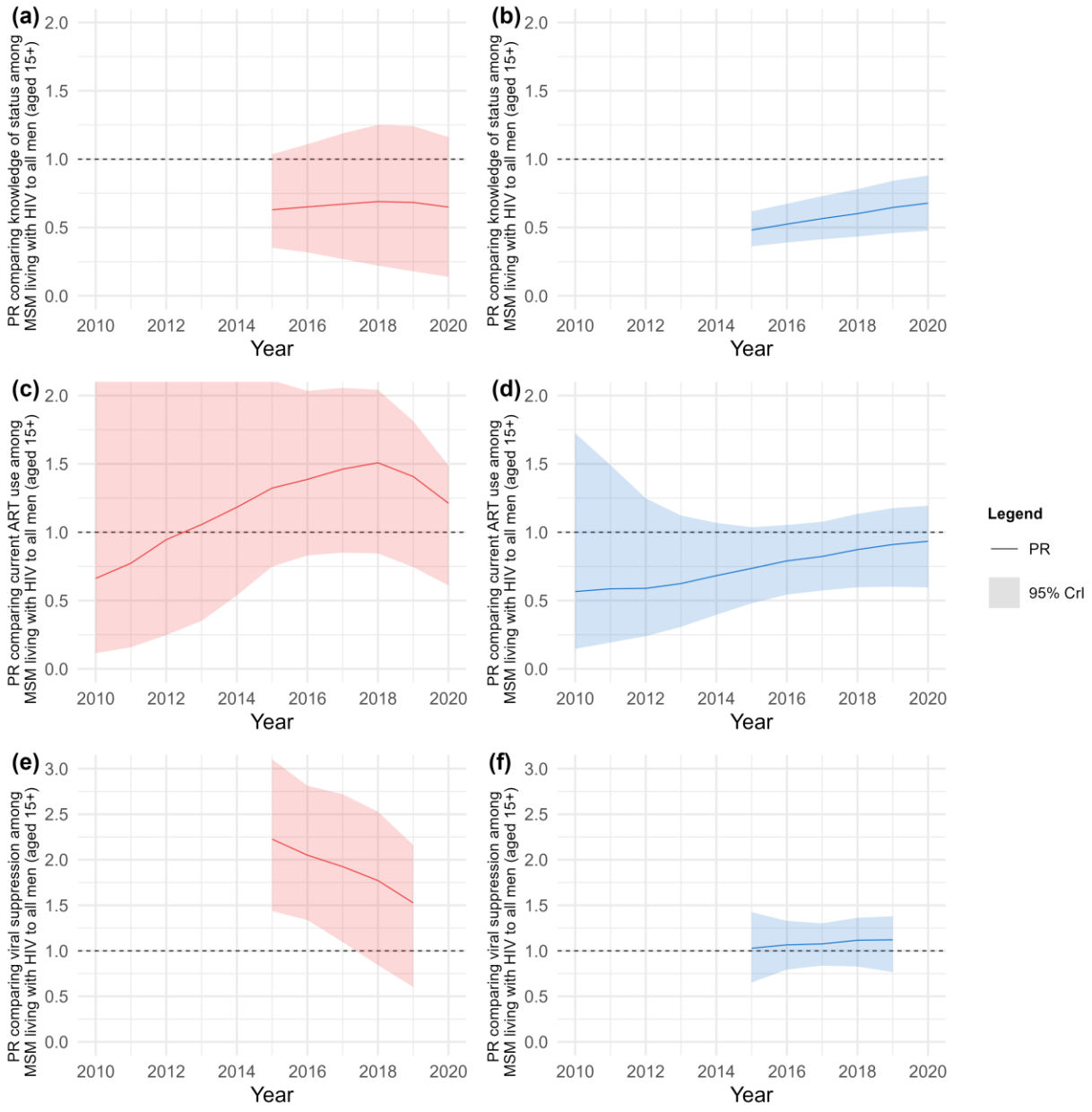


Figure 5.4.26. Prevalence ratios (PR) and 95% credible intervals (CrI) comparing population-weighted estimates of HIV treatment cascade outcomes among men who have sex with men (MSM) living with HIV with UNAIDS estimates among all men living with HIV (aged 15+), by region of Africa. PRs comparing estimates of (a) knowledge of status in Central/Western Africa, and (b) knowledge of status in Eastern/Southern Africa, (c) current antiretroviral therapy (ART) use in Central/Western Africa, and (d) current ART use in Eastern/Southern Africa, and (e) viral suppression in Central/Western Africa, and (f) viral suppression in Eastern/Southern Africa among MSM living with HIV with UNAIDS estimates among all men living with HIV (aged 15+). PRs were estimated over the range of years of estimates available for all men.

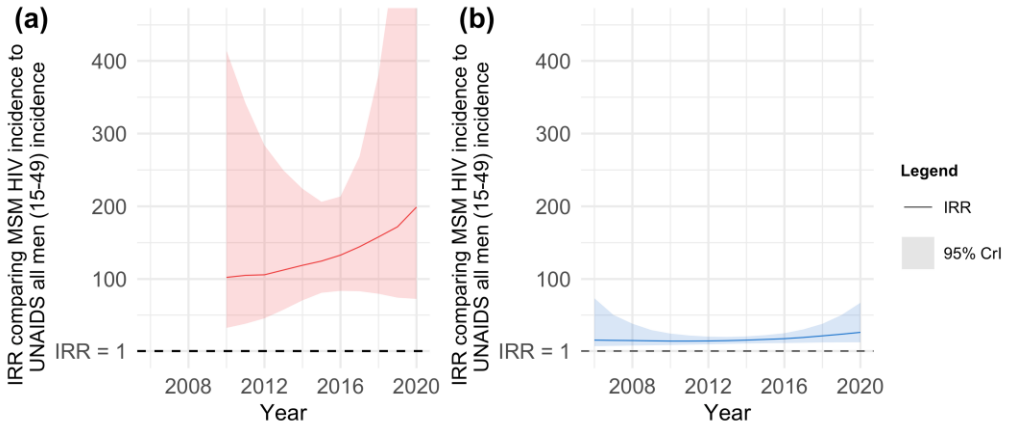


Figure 5.4.27. Incidence rate ratios (IRR) over time comparing population-weighted HIV incidence estimates among men who have sex with men (MSM) with UNAIDS estimates among all men (15-49), by region of Africa. (a) Central/Western Africa, and (b) Eastern/Southern Africa. The solid lines and shaded areas represent the estimated region-level IRR and 95% credible intervals (CrI), respectively.

Table 5.4.7. Study quality assessment of studies included in our review. Studies received a score ranging from 0-5 for each outcome reported in the study.

References	Country	Midpoint Year	Outcomes reported	Criterion 1: Appropriateness of the sampling method to recruit a representative sample of MSM participants (maximum 1 point)	Criterion 2: Statistical adjustment of outcomes for complex survey design (maximum 1 point)	Criterion 3: Representativeness of MSM participants based on eligibility criteria used to recruit MSM into the study (maximum 1 point)	Criterion 4: Inclusion of transgender women in the study definition of MSM (maximum 1 point)	Criterion 5: Risk of misclassification in ascertainment of the relevant outcome(s) (maximum 1 point)	Study quality score /5
Northern Africa									
Valadez 2013[100]	Libya	2010	HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Elmahy 2018[99]	Egypt	2016	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
Central Africa									
Coulaud 2016[5]	Burundi	2014	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
			HIV testing in the past 12 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
			HIV testing in the past 6 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
			HIV testing in the past 3 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
Lillie 2021[4]	Burundi	2018	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	a = 1 point	c = 0 points	2
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	a = 1 point	c = 0 points	2
Lorente 2012[11]	Cameroon	2008	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Holland 2015[9], Park 2014[10]	Cameroon	2011	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Rao 2017[8]	Cameroon	2013	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Lyons 2023[6], Bowring 2019[7], Rao 2017[8]	Cameroon	2015/ 2016	HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Ever ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2

			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Gresenguet 2017[14], Longo 2018[15], Boussa 2018[16]	Central African Republic	2010	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Current antiretroviral therapy (ART) use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
Mbeko Simaleko 2018[13]	Central African Republic	2011	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Mbeko Simaleko 2020[12]	Central African Republic	2015	HIV incidence	c = 0 points	b = 0 points	c = 0 points	c = 0 points	a = 1 point	1
Western Africa									
Hessou 2020[153]	Benin	2017	HIV incidence	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Ahouada 2020[152]	Benin	2018	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	a = 1 point	c = 0 points	3
Lyons 2023[6], Grosso 2019[160], Kim 2018[161], Poteat 2017[58], Holland 2016[162], Goodman 2016[163], Stahlman 2016[164]	Burkina Faso	2013	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	Burkina Faso	2017	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Engagement in care	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV incidence	b = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Vuylsteke 2012[174]	Côte d'Ivoire	2007	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
Hakim 2015[172], Aho 2014[173]	Côte d'Ivoire	2011	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Couderc 2017[171]	Côte d'Ivoire	2014	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Bouscaillou 2016[170]	Côte d'Ivoire	2014	HIV testing in the past 12 months	a = 1 point	b = 0 points	b = 0 points	b = 0 points	c = 0 points	1
Lyons 2023[6], Moran 2020[168], Ulanja 2019[169]	Côte d'Ivoire	2015	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV testing in the past 6 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
	Côte d'Ivoire	2016	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0

Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]			Engagement in care	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Current ART use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV incidence	b = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Diabate 2021[165]	Côte d'Ivoire	2018	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Inghels 2022[166], Inghels 2021[167]	Côte d'Ivoire	2018	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	c = 0 points	c = 0 points	3
Gyamerah 2020[181]	Ghana	2010	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Kushwaha 2017[179], Nelson 2015[180]	Ghana	2012	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			HIV testing in the past 3 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
Girault 2015[178]	Ghana	2013	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Abubakari 2021[177]	Ghana	2014	HIV testing ever	a = 1 point	b = 0 points	b = 0 points	a = 1 point	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	b = 0 points	b = 0 points	a = 1 point	c = 0 points	2
			HIV testing in the past 6 months	a = 1 point	b = 0 points	b = 0 points	a = 1 point	c = 0 points	2
Ogunbajo 2018[176]	Ghana	2015	Engagement in care	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
Gu 2021[175]	Ghana	2017	Engagement in care	b = 0 points	b = 0 points	a = 1 point	a = 1 point	b = 1 point	3
Lyons 2023[6]	Guinea-Bissau	2017	HIV testing ever, knowledge of status	a = 1 point	b = 0 points	c = 0 points	c = 0 points	d = 0 points	1
Lieber 2018[182]	Liberia	NR	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
Couderc 2017[171]	Mali	2013	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
	Mali	2014	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3

Knox 2021[184], Lahuerta 2018[185], Hakim 2018[186], Hakim 2017[187]			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Current ART use	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Viral suppression	a = 1 point	a = 1 point	a = 1 point	b = 0 points	a = 1 point	4
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	Mali	2016	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Engagement in care	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Current ART use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV incidence	b = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Koyalta 2021[183]	Mali	2019	Current ART use	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
Adam 2009[66]	Mauritania	2006	HIV testing in the past 12 months	c = 0 points	b = 0 points	c = 0 points	c = 0 points	d = 0 points	0
Eluwa 2019[218], Merrigan 2011[226], Adam 2009[66]	Nigeria	2007	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Stromdahl 2019[224], Stromdahl 2012[225]	Nigeria	2008	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
Eluwa 2019[218], Eluwa 2015[219]	Nigeria	2010	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Adebajo 2014[220], Sheehy 2014[221], Vu 2013[222], Vu 2013[223]	Nigeria	2010	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Lyons 2023[6], LeeVan 2022[191], Olawore 2021[192], Li 2020[193], Nowak 2020[194], Ramadhani 2020[195], Tiamiyu 2020[196], Robbins 2020[197], Kayode 2020[198], Nowak 2019[199], Nowak 2019[200], Billings 2019[201], Crowell 2019[202], Ramadhani 2018[203], Rodriguez-Hart 2018[204], Stahlman 2017[205], Nowak 2017[206], Ramadhani 2017[207],	Nigeria	2013	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Engagement in care	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Ever ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
			HIV incidence	a = 1 point	b = 0 points	a = 1 point	a = 1 point	a = 1 point	4

Crowell 2017[208], Nowak 2016[209], Rodriguez-Hart 2016[210], Baral 2015[211], Schwartz 2015[212], Charurat 2015[213]									
Tobin-West 2017[217]	Nigeria	2014	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
Eluwa 2019[218]	Nigeria	2014	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	c = 0 points	c = 0 points	3
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	c = 0 points	c = 0 points	3
Offie 2021[216]	Nigeria	2016	Engagement in care	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
Tun 2018[190]	Nigeria	2017	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Ibiloye 2018[215]	Nigeria	2017	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	c = 0 points	d = 0 points	0
Ibiloye 2021[214]	Nigeria	2017	Engagement in care	b = 0 points	b = 0 points	c = 0 points	a = 1 point	d = 0 points	1
			Viral suppression	b = 0 points	b = 0 points	c = 0 points	a = 1 point	a = 1 point	2
Ibiloye 2021[189]	Nigeria	2018	Engagement in care	c = 0 points	b = 0 points	c = 0 points	c = 0 points	d = 0 points	0
Afolaranmi 2021[188]	Nigeria	2019	Engagement in care	a = 1 point	b = 0 points	b = 0 points	c = 0 points	c = 0 points	1
Ndiaye 2013[231], Wade 2005[232]	Senegal	2004/ 2005	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Dieye 2022[230]	Senegal	2010	Viral suppression	b = 0 points	b = 0 points	c = 0 points	c – 0 points	d = 0 points	0
Drame 2013[229]	Senegal	2012	HIV testing ever	c = 0 points	b = 0 points	b = 0 points	b = 0 points	d = 0 points	0
			Knowledge of status	c = 0 points	b = 0 points	b = 0 points	b = 0 points	d = 0 points	0
			HIV incidence	c = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Couderc 2017[171]	Senegal	2013	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Lyons 2023[6], Lyons 2020[227], Lyons 2017[228]	Senegal	2015	Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Engagement in care	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Ever ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Current ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Viral suppression	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
			HIV incidence	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2

Poteat 2017[58], Stahlman 2016[164], Mason 2013[233]	The Gambia	2011	Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Lyons 2023[6]	The Gambia	2017	HIV testing ever, knowledge of status	a = 1 point	b = 0 points	c = 0 points	c = 0 points	d = 0 points	1
Ekouevi 2014[241]	Togo	2011	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Bakai 2016[240]	Togo	2011	HIV testing ever	a = 1 point	b = 0 points	c = 0 points	b = 0 points	c = 0 points	1
Lyons 2023[6], Ruisenor-Escudero 2019[237], Ruisenor-Escudero 2019[238], Grosso 2019[160], Poteat 2017[58], Ruisenor-Escudero 2017[239], Holland 2016[162], Stahlman 2016[164]	Togo	2013	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Teclessou 2017[236]	Togo	2015	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	a = 1 point	c = 0 points	3
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	Togo	2016	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Engagement in care	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Current ART use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV incidence	b = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Ferré 2022[234], Sadio 2019[235]	Togo	2017	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Dah 2021[154], Dah 2021[155], Yaya 2022[156], Yaya 2021[157], Laurent 2021[158], Coulaud 2020[159]	Burkina Faso, Cote d'Ivoire, Mali, Togo	2017	Engagement in care	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Current ART use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
Eastern Africa									
Gebrebrhan 2021[54]	Kenya	NR	Current ART use	b = 0 points	b = 0 points	b = 0 point	b = 0 points	d = 0 points	0
			Viral suppression	b = 0 points	b = 0 points	b = 0 point	b = 0 points	a = 1 point	1
Sanders 2007[53]	Kenya	2006	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Knowledge of status	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
Kamali 2015[44], Price 2012[45]	Kenya	2007	HIV incidence	b = 0 points	b = 0 points	c = 0 points	c = 0 points	a = 1 point	1
Luchters 2011[51]	Kenya	2008	HIV testing ever	a = 1 point	b = 0 points	b = 0 points	b = 0 points	c = 0 points	1
Graham 2013[52]	Kenya	2008	Engagement in care	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Graham 2020[37]	Kenya	2015	Ever ART use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Viral suppression	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
Graham 2022[19]	Kenya	2018	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Mdodo 2016[48]	Kenya	2010	HIV incidence	a = 1 point	b = 0 points	b = 0 points	c = 0 points	a = 1 point	2

Muraguri 2015[49]	Kenya	2010	HIV testing ever	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
Muraguri 2022[46]	Kenya	2013	HIV testing ever and in the past 12 months	a = 1 point	b = 0 points	b = 0 points	c = 0 points	c = 0 points	1
McKinnon 2013[50]	Kenya	2010	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
			HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Wahome 2020[20], Wahome 2020[21], Wahome 2018[42], Moller 2015[43], Kamali 2015[44], Sanders 2013[22], Price 2012[45]	Kenya	2008	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Githuka 2014[47]	Kenya	2012	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	c = 0 points	c = 0 points	3
Shangani 2017[39]	Kenya	2014	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Musyoki 2018[40], Bhattacharjee 2015[41]	Kenya	2014	HIV testing ever	a = 1 point	b = 0 points	c = 0 points	b = 0 points	b = 1 point	2
			HIV testing in the past 3 months	a = 1 point	b = 0 points	c = 0 points	b = 0 points	b = 1 point	2
			Viral suppression	b = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Nyblade 2017[38]	Kenya	2015	HIV testing ever	a = 1 point	b = 0 points	b = 0 points	c = 0 points	c = 0 points	1
Kimani 2019[36]	Kenya	2016	HIV incidence	b = 0 points	b = 0 points	c = 0 points	a = 1 point	a = 1 point	2
Kunzweiler 2019[26], Kunzweiler 2018[27], Korhonen 2018[28], Kunzweiler 2017[29]	Kenya	2016	Knowledge of status	a = 1 point	b = 0 points	a = 1 point	c = 0 points	b = 1 point	3
			Ever ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Current ART use	a = 1 point	b = 0 points	[35]a = 1 point	c = 0 points	b = 1 point	3
			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Palumbo 2021[30], Sandfort 2021[31], Sivay 2021[32], Sandfort 2019[33], Zhang 2018[34], Fogel 2018[35]	Kenya	2016	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 12 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Engagement in care	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Current ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1

			Viral suppression	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
			HIV incidence	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
Smith 2021[23], Smith 2021[24], Fearon 2020[25]	Kenya	2017	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	a = 1 point	b = 1 point	4
			HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Engagement in care	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Wahome 2020[20], Wahome 2020[21], Sanders 2013[22]	Kenya	2018	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Bhattacharjee 2020[17]	Kenya	2019	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 3 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Engagement in care	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Dijkstra 2021[18]	Kenya	2019	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 12 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 3 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Current ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Viral suppression	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
Virkud 2020[98]	Kenya, Rwanda, Tanzania, Uganda (cross-border areas)	2016	HIV testing in the past 12 months	b = 0 points	b = 0 points	a = 1 point	c = 0 points	c = 0 points	1

Ntata 2008[65]	Malawi	2006	HIV testing ever	a = 1 point	b = 0 points	c = 0 points	c = 0 points	c = 0 points	1
Fay 2011[62], Beyrer 2010[63], Baral 2009[64]	Malawi	2008	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Wirtz 2017[57], Poteat 2017[58], Stahlman 2016[59], Wirtz 2015[60], Wirtz 2013[61]	Malawi	2013	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Ever ART use	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			HIV incidence	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Palumbo 2021[30], Sandfort 2021[31], Sivay 2021[32], Sandfort 2019[33], Zhang 2018[34], Fogel 2018[35]	Malawi	2016	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 12 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Engagement in care	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Current ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Viral suppression	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
			HIV incidence	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
Herce 2018[56]	Malawi	2017	HIV testing ever	a = 1 point	a = 1 point	b = 0 points	a = 1 point	c = 0 points	3
			HIV testing in the past 6 months	a = 1 point	a = 1 point	b = 0 points	a = 1 point	c = 0 points	3
Rucinski 2022[55]	Malawi	2018	Engagement in care	b = 0 points	b = 0 points	c = 0 points	c = 0 points	d = 0 points	0
Adam 2009[66]	Mauritius	2004	HIV testing in the past 12 months	c = 0 points	b = 0 points	c = 0 points	c = 0 points	d = 0 points	0
Boothe 2021[67], Boothe 2021[68], Sathane 2016[69], Horth 2015[70]	Mozambique	2011	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Engagement in care	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Ever ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Chapman 2011[73]	Rwanda	2009	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2

Ntale 2019[72]	Rwanda	2015	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Lyons 2023[6]; Twahirwa Rwema 2020[71]	Rwanda	2018	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Magesa 2014[86]	Tanzania	NR	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Khatib 2017[81], Dahoma 2011[84], Johnston 2010[85]	Tanzania	2007	HIV testing ever	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
Nyoni 2013[82], Nyoni 2012[83]	Tanzania	2009	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Khatib 2017[81]	Tanzania	2011	HIV testing ever	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
Mmbaga 2012[80]	Tanzania	2011	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Ahaneku 2016[76], Romijnders 2016[77], Anderson 2015[78], Ross 2014[79]	Tanzania	2012	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
Mmbaga 2018[75]	Tanzania	2014	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Ross 2018 [74]	Tanzania	2015	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	c = 0 points	c = 0 points	1
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	c = 0 points	c = 0 points	1
Raymond 2009[93], Kajubi 2008[94]	Uganda	2004	HIV testing ever	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
			HIV testing in the past 6 months	a = 1 point	a = 1 point	b = 0 points	b = 0 points	c = 0 points	2
Hladik 2012[92]	Uganda	2008	HIV testing ever	a = 1 point	a = 1 point	b = 0 points	b = 0 points	b = 1 point	3
Robb 2016[91]	Uganda	2012	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1
Wanyenze 2016[89]	Uganda	2013	HIV testing ever	a = 1 point	b = 0 points	b = 0 points	b = 0 points	c = 0 points	1
Hladik 2017[90]	Uganda	2013	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Viral suppression	a = 1 point	a = 1 point	a = 1 point	b = 0 points	a = 1 point	4
Okoboi 2021[87], Okoboi 2020[88]	Uganda	2018	HIV testing ever	a = 1 point	b = 0 points	c = 0 points	c = 0 points	c = 0 points	1
			Knowledge of status	a = 1 point	b = 0 points	c = 0 points	c = 0 points	c = 0 points	1

Parmley 2022[95], Parmley 2022[96], Harris 2022[97]	Zimbabwe	2019	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	a = 1 point	c = 0 points	3
			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Southern Africa									
Kendall 2014[101]	Angola	2011	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 3 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Herce 2018[56]	Angola	2017	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	a = 1 point	c = 0 points	4
			HIV testing in the past 6 months	a = 1 point	a = 1 point	a = 1 point	a = 1 point	c = 0 points	4
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	a = 1 point	c = 0 points	4
Fay 2011[62], Beyrer 2010[63], Baral 2009[64]	Botswana	2008	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Lyons 2023[6], Rao 2017[8], Poteat 2017[58], Grover 2016[102], Stahlman 2016[59], Brown 2016[103], Stahlman 2015[104], Risher 2013[105], Baral 2013[106]	eSwatini	2011	HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Rao 2017[8]	eSwatini	2014	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Baral 2011[109]	Lesotho	2009	HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	a = 1 point	c = 0 points	3
Poteat 2017[58], Stahlman 2016[59], Wendi 2016[107], Stahlman 2015[104], Stahlman 2015[108]	Lesotho	2014	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
Fay 2011[62], Beyrer 2010[63], Baral 2009[64]	Namibia	2008	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2

Russell 2019[110]	Namibia	2016	HIV testing in the past 6 months	b = 0 points	b = 0 points	c = 0 points	a = 1 point	c = 0 points	1
Cloete 2008[148]	South Africa	NR	Current ART use	b = 0 points	b = 0 points	c = 0 points	c = 0 points	b = 1 point	1
Jobson 2018[147]	South Africa	NR	HIV testing ever	a = 1 point	b = 0 points	b = 0 points	b = 0 points	b = 1 point	2
Lane 2008[144]	South Africa	2004	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
Nel 2013[145], Sandfort 2008[146]	South Africa	2004	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 1 point	1
Burrel 2010[143]	South Africa	2008	HIV testing in the past 12 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
Knox 2013[139], Knox 2011[140]	South Africa	2008	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	b = 1 point	2
			HIV testing in the past 12 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	b = 1 point	2
Arnold 2013[141], Lane 2011[142]	South Africa	2008	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Baral 2011[135]	South Africa	2009	Knowledge of status	b = 0 points	b = 0 points	a = 1 point	a = 1 point	c = 0 points	2
Buchbinder 2014[137], Buchbinder 2014[138]	South Africa	2009	HIV incidence	b = 0 points	b = 0 points	b = 0 points	b = 0 points	a = 1 point	1
Tun 2012[136]	South Africa	2009	HIV testing ever	a = 1 point	a = 1 point	c = 0 points	b = 0 points	c = 0 points	2
Eaton 2013[134]	South Africa	2010	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
Kamali 2015[44], Price 2012[45]	South Africa	2010	HIV incidence	b = 0 points	b = 0 points	c = 0 points	c = 0 points	a = 1 point	1
Stephenson 2012[132], Wagenaar 2012[133]	South Africa	2010	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	b = 1 point	2
Batist 2013[126]	South Africa	2012	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	b = 1 point	1
Knox 2019[129]	South Africa	2012	HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Maleke 2017[130]	South Africa	2012	HIV testing ever	a = 1 point	b = 0 points	b = 0 points	c = 0 points	c = 0 points	1
Rebe 2015[127]	South Africa	2012	HIV testing in the past 12 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			Current ART use	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
Siegler 2015[128]	South Africa	2012	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Lane 2016[124], Lane 2014[125]	South Africa	2012	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	c = 0 points	3
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Engagement in care	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
		2014	HIV incidence	a = 1 point	b = 0 points	a = 1 point	c = 0 points	a = 1 point	3
Maenetje 2019[131]	South Africa	2012	HIV incidence	b = 0 points	b = 0 points	b = 0 points	c = 0 points	a = 1 point	1

Kufa 2017[121]	South Africa	2015	Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
Rees 2017[122], van Liere 2019[123]	South Africa	2015	Knowledge of status	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
			Current ART use	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
Chen 2020[116], Radebe 2020[117], Lippman 2018[118], Lippman 2018[119]	South Africa	2016	HIV testing ever	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 12 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	c = 0 points	2
			HIV incidence	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Palumbo 2021[30], Sandfort 2021[31], Sivay 2021[32], Sandfort 2019[33], Zhang 2018[34], Fogel 2018[35]	South Africa	2016	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			HIV testing in the past 6 months	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Engagement in care	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Current ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Viral suppression	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
			HIV incidence	b = 0 points	b = 0 points	a = 1 point	b = 0 points	a = 1 point	2
Sullivan 2020[120]	South Africa	2016	Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	b = 1 point	2
			HIV incidence	b = 0 points	b = 0 points	a = 1 point	a = 1 point	a = 1 point	3
Fearon 2020[115]	South Africa	2017	HIV testing ever	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			HIV testing in the past 12 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			HIV testing in the past 6 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			HIV testing in the past 3 months	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			Knowledge of status	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			Current ART use	a = 1 point	a = 1 point	a = 1 point	b = 0 points	b = 1 point	4
			Viral suppression	a = 1 point	a = 1 point	a = 1 point	b = 0 points	a = 1 point	4
Fearon 2020[25]	South Africa	2017	HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Knowledge of status	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3
			Current ART use	a = 1 point	b = 0 points	a = 1 point	b = 0 points	b = 1 point	3

			Viral suppression	a = 1 point	b = 0 points	a = 1 point	b = 0 points	a = 1 point	3
Scheibe 2020[114]0	South Africa	2017	HIV testing ever	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Knowledge of status	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
			Current ART use	b = 0 points	b = 0 points	a = 1 point	b = 0 points	c = 0 points	1
Pillay 2020[113]	South Africa	2018	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV testing in the past 12 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV testing in the past 6 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
			HIV testing in the past 3 months	b = 0 points	b = 0 points	b = 0 points	b = 0 points	c = 0 points	0
Montgomery 2021[111], Minnis 2020[112]	South Africa	2019	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
Metheny 2022[149], Stephenson 2022[150], Stephenson 2021[151]	South Africa, Namibia	2017	HIV testing ever	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
			HIV testing in the past 6 months	b = 0 points	b = 0 points	b = 0 points	c = 0 points	c = 0 points	0
Multiple Regions									
Herce 2018[56]	Angola, Malawi	2017	HIV testing in the past 6 months	a = 1 point	b = 0 points	a = 1 point	c = 0 points	c = 0 points	2
Sandfort 2019[33]	Kenya, Malawi, South Africa	2016	Engagement in care	b = 0 points	b = 0 points	a = 1 point	c = 0 points	c = 0 points	1
			Viral suppression	b = 0 points	b = 0 points	a = 1 point	c = 0 points	c = 0 points	1

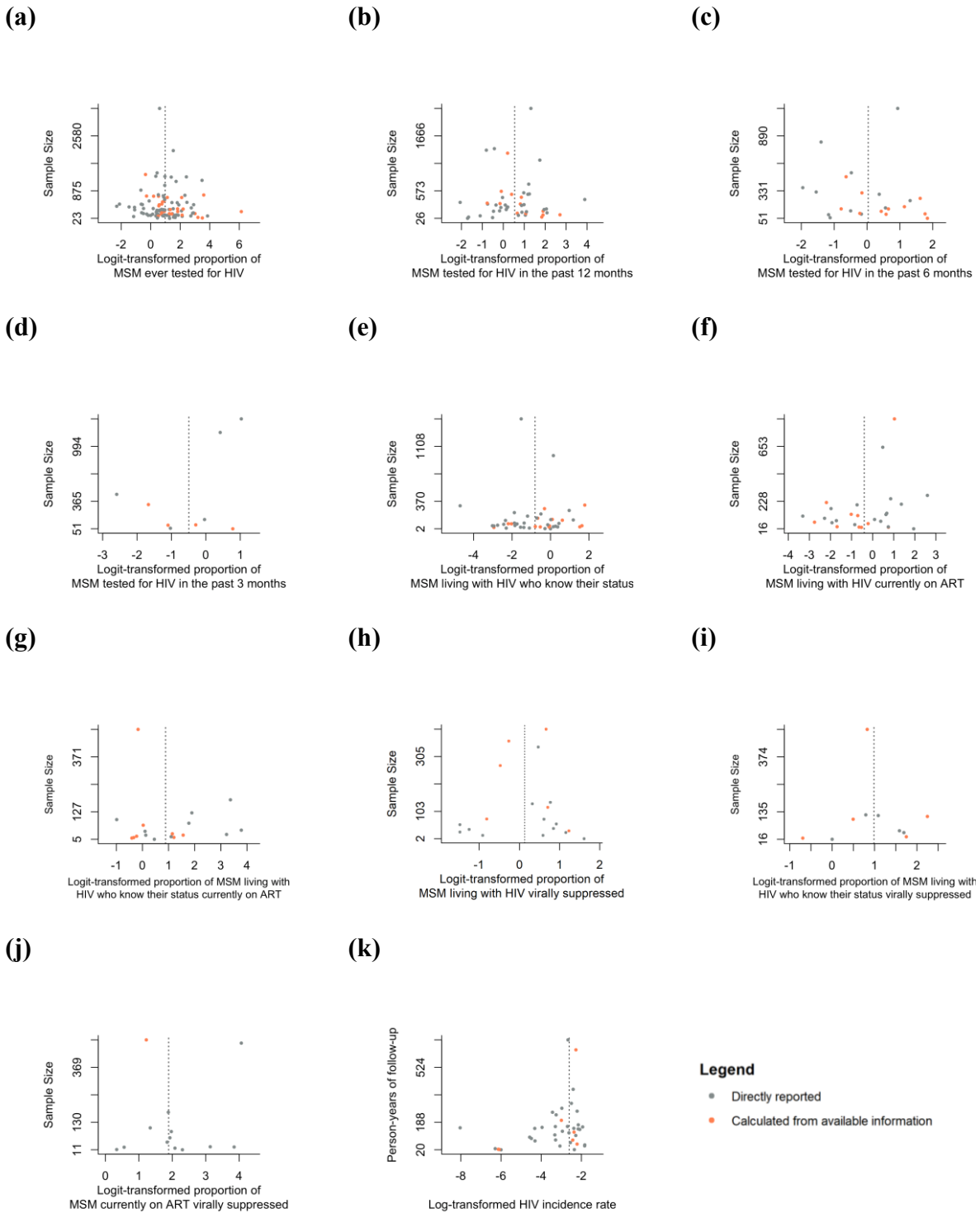


Figure 5.4.28. Funnel plots of HIV testing, treatment cascade, and HIV incidence outcomes among men who have sex with men (MSM) in Africa. Funnel plots of (a) ever HIV testing, (b) HIV testing in the past 12 months, (c) HIV testing in the past 6 months, (d) HIV testing in the past 3 months, (e) knowledge of status among MSM living with HIV, (f) current antiretroviral therapy (ART) use among MSM living with HIV, (g) current ART use among HIV aware MSM,

(h) viral suppression among MSM living with HIV, (i) viral suppression among HIV aware MSM, (j) viral suppression among MSM currently on ART, and (k) HIV incidence among MSM. Points represent study observations that were either directly reported in articles (grey points) or that we calculated from available information reported in articles (orange points). The vertical dashed line represents the overall logit or log-transformed pooled estimate.

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6. Chapter 6: The effect of sexual and gender minority violence on incident depression, condom use, and HIV acquisition among sexual and gender minorities in Africa

6.1 Preface to Manuscript 3

In my second manuscript, I found that between 2003 and 2020, HIV incidence among men who have sex with men in Africa remained high and may not have decreased. Additionally, I identified significant gaps in the HIV treatment cascade, particularly at the diagnosis and viral suppression stages, which have not increased sufficiently over time. These gaps likely contribute to the persistently high HIV incidence rates among SGM.

The underlying causes of the high HIV burden among SGM are multifactorial. Biological determinants, such as the higher risk of HIV acquisition during receptive anal intercourse and the impact of role versatility (insertive/receptive) in anal sex, significantly increase the risk of HIV acquisition and transmission among SGM.(65,66) However, structural determinants such as stigma, discrimination, and violence also drive HIV vulnerabilities and it is important to investigate the pathways through which they are influencing HIV acquisition and transmission among SGM, for example by influencing mental health, sexual behaviours, and uptake of prevention (e.g., condoms). As argued in my first paper, it is imperative to improve our quantitative understanding of causal relationships between structural determinants, mediators, and HIV, as this could provide valuable insights into the impacts of these determinants and inform structural interventions tackling them. To disentangle pathways from structural determinants to HIV among SGM, longitudinal data is recommended. Leveraging the systematic review in my second manuscript, for my third manuscript I identified cohort studies of SGM in Africa that collected data on experiences of violence among SGM due to their sexual and gender minority status (SGM violence) and HIV acquisition. Using these studies, I quantified longitudinal associations between SGM violence, potential mediating variables – depressionn, hazardous drinking, and condom use – and acquiring HIV. The resulting article is currently under review.

6.2 Manuscript 3: The effect of sexual and gender minority violence on depression, hazardous drinking, condom use, and HIV acquisition: an individual participant data meta-analysis of the *CohMSM*, *HPTN 075*, and *Anza Mapema* cohort studies in Africa

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Abstract

Introduction

Some sexual and gender minorities (SGM), including men who have sex with men and transgender women, are disproportionately vulnerable to HIV. Many SGM in Africa report verbal and physical violence due to their identities or behaviours (SGM violence). The pathways linking SGM violence to HIV acquisition are complex. We sought to describe experiences of SGM violence and explore potential pathways to HIV acquisition risk in three African cohort studies among SGM assigned male sex at birth.

Methods

We conducted an individual participant data meta-analysis of three cohorts: *CohMSM* (Burkina Faso, Côte d'Ivoire, Mali, and Togo), *HPTN 075* (Kenya, Malawi, and South Africa), and *Anza Mapema* (Kenya). SGM violence, defined as verbal and/or physical violence due to sexual identities/behaviours, was assessed at baseline and during follow-up. We fit log-linear sequential conditional mean models using generalised estimating equations to estimate risk ratios for the associations between SGM violence, moderate-to-severe depressive symptoms, hazardous drinking, condom use, and HIV acquisition, adjusted for baseline confounders and prior values of exposure and outcome. We pooled study estimates using random effects meta-analysis.

Results

At baseline, 36% (570/1590) of participants reported SGM violence in the past 6-12 months, and 20% (321/1590) reported violence during the first year of follow-up (past 3-6 months). Most violence was verbal. Violence during follow-up was more common among those reporting baseline violence. Baseline SGM violence was not associated with HIV acquisition (pooled adjusted risk ratio [aRR]=1.0, 95%CI 0.5-1.9), and during follow-up, SGM violence showed no clear relationship with HIV. However, during follow-up violence was linked to moderate-to-severe depressive symptoms at the same follow-up visit (pooled aRR=1.9, 1.5-2.4), which was in turn associated with hazardous drinking (pooled aRR=1.3, 1.1-1.5). The impacts of SGM violence, depressive symptoms, and hazardous drinking on condom use were inconclusive.

Conclusions

SGM face high rates of verbal and physical violence, which are associated with experiencing depressive symptoms and hazardous drinking –potential routes to heightened HIV vulnerability. However, our study did not conclusively demonstrate higher HIV incidence among SGM reporting violence. Standardised exposure measures and confidential interview methods may improve comparisons. Interventions to address high levels of SGM violence and support mental health are crucial.

Keywords

Structural determinants, sexual and gender minorities, homophobic violence, HIV incidence, individual participant data meta-analysis, longitudinal analysis, mental health.

Introduction

Some sexual and gender minorities (SGM) are disproportionately vulnerable to HIV acquisition globally due to intersecting biobehavioural and structural risks, including stigma, discrimination, and violence. [1,2] These structural drivers constitute human rights violations that marginalise SGM and obstruct their access to essential HIV services, hindering progress in reducing HIV incidence. [1,3] In 2022, men who have sex with men (MSM) and transgender women (TGW) were 23 and 20 times more likely to acquire HIV than the general adult population (aged 15-49 years). [3] Stigma, discrimination, and violence may exacerbate HIV acquisition risks through the way individuals cope with these negative experiences –by seeking support, engaging in risky behaviours, or avoiding situations where they may experience stigma– which impact the causal pathways to HIV. [1,4,5] The UNAIDS 10-10-10 targets aim to reduce stigma, discrimination, and violence to less than 10% among key populations by 2025 – considered essential to achieve HIV elimination by 2030. [1]

Empirical evidence from Africa suggests that these SGM frequently experience verbal, physical, and sexual violence because of their identities and/or sexual behaviours, referred to as SGM violence. [6,7] In an analysis of multiple studies, lifetime prevalence of verbal, physical, and sexual SGM violence among MSM in southern Africa in 2014 was 39%, 13%, and 7%, respectively, and in western Africa between 2013 and 2015 it was 28%, 12%, and 12%.[6] A cohort study in Kenya between 2011 and 2014 reported high incidence rates of first reported verbal (31 per 100 person-years), physical (13 per 100 person-years), and sexual violence (4 per 100 person-years) –higher than among other men. [8] Reports of SGM violence are often higher among TGW, but are less frequently documented, partly because TGW are often grouped with MSM in studies. [9,10] Perpetrators range from strangers to known individuals, including partners, friends, relatives, coworkers, and police. [8,11]

The pathways linking SGM violence to HIV acquisition are complex. Research has predominantly investigated intimate partner violence (IPV) which directly influences HIV risk (e.g., through forced sex). [12-16] However, verbal and physical SGM violence may operate differently, impacting HIV risk indirectly via mediators such as mental health and substance use. SGM violence has been associated with depression, suicidal ideation, alcohol use, and

transactional sex. [11,17-21] As depression and alcohol use have also been linked to inconsistent condom use, they may mediate the relationship between violence and HIV. [8,18,21-24] However, disentangling these pathways is difficult due to the variety of potential mediating variables (mediators) and confounders, inconsistent violence definitions, and reliance on cross-sectional studies that limit causal inference.

Longitudinal studies can provide stronger evidence by ensuring temporal relationships between violence, mediators, and HIV acquisition while controlling for potential confounders. [25] For example, a path analysis of the *TRUST/RV368* cohort study in Nigeria showed that SGM who experienced higher stigma, including physical, verbal, and sexual violence, were more likely to acquire HIV, and that suicidal ideation and condomless sex mediated the relationship. [21] Similarly, studies in other settings support the mediating role of depression and alcohol use on sexual behaviours among SGM and other populations. [26] However, few longitudinal studies have explored these pathways among SGM across Africa, and none have specifically examined verbal and physical SGM violence in isolation. Such estimates are needed to generate evidence on both the prevalence and role of SGM violence on HIV outcomes (e.g., prevention, acquisition, treatment) and to formulate more appropriate tailored interventions to tackle SGM violence.

To address these gaps, we aimed to 1) describe the prevalence and patterns of verbal and physical SGM violence over time, and 2) examine select pathways through which such violence may influence HIV acquisition in three prospective HIV cohort studies across seven African countries Africa.

Methods

Study eligibility and inclusion criteria

We conducted an individual participant data meta-analysis of longitudinal HIV cohort studies that assessed verbal and physical SGM violence in eastern, southern, central, and western Africa. We identified studies from systematic reviews of HIV testing, the treatment cascade, and HIV incidence among SGM assigned male sex at birth in Africa. [27,28] To find studies published afterwards (i.e., since March 3, 2023), we searched PubMed using terms for SGM, violence, and

HIV (Text 6.1.1). From nine identified studies, we obtained individual-level data from three eligible studies.

Cohort studies

The three cohort studies were *CohMSM* (*CohMSM* ANRS 12324–Expertise France), *HPTN 075*, and *Anza Mapema*.[29-31] Study procedures have been reported previously and are summarised in Table 6.2.1.[29-31]

Table 6.2.1. Study characteristics for the three cohorts included in the individual participant data meta-analysis of experiences of sexual and gender minority (SGM) violence on HIV acquisition.

	CohMSM	***HPTN 075***	***Anza Mapema***
Study setting (*study period*)	Abidjan, **Côte d'Ivoire** (*October 2015 – January 2018*); Bamako, **Mali** (*June 2015 – January 2018*); Ouagadougou, **Burkina Faso** (*February 2016 – November 2017*); Lomé, **Togo** (*June 2016 – November 2017*)	Cape Town and Soweto, **South Africa**; Blantyre, **Malawi**; Kisumu, **Kenya** (*June 2015 – July 2017*)	Kisumu, **Kenya** (*August 2015 – September 2016*)
Eligibility criteria	Men aged 18+, any HIV status, anal sex with another man in the previous 3 months	Male sex at birth, 18-44 years old, any HIV status, anal intercourse in the past 3 months with biological man, willing to HIV test and receive results (if not living with HIV), never in HIV cohort study before	Men aged 18+, any HIV status, self-reported anal or oral intercourse with another man in the past 6 months, not currently in another HIV study, residing in Kisumu
Recruitment method	SGM were enrolled and followed up in community-based clinics already providing SGM-specific prevention, care, and support	Site-specific, including peer outreach, snowball, informational sessions at gay-friendly places, key informant referral, indirect recruitment via announcements in real and virtual spaces	Snowball sampling
Interview method	FTFI	FTFI, with option to complete sensitive parts of the interview confidentially	ACASI
Follow-up schedule	HIV testing every 3 months, and behavioural interview every 6 months, **for 30 months total**	HIV testing every 3 months, and behavioural interview every 3 months, **for 12 months total**	HIV testing every 3 months, and behavioural interview every 3 months, **for 12 months total**
HIV prevention package provided	Clinical examination, Regular HIV testing, STI testing and treatment, PEP, individualised peer-led support, condoms and lubricants, pre- and post-HIV test counselling, HIV risk reduction counselling, ART for participants who acquired HIV	Regular HIV testing, risk reduction counselling, condoms and lubricants, PEP referrals, STI testing, and ART for participants who acquired HIV	Regular HIV testing, risk reduction counselling, condoms and lubricants, STI screening and treatment, PEP, and ART for participants who acquired HIV
Number of participants not living with HIV at baseline	625	329	636
Number of participants who acquired HIV	76 (10.3 per 100 PY, 95%CI 8.0-12.7)	21 (7.0 per 100 PY, 95%CI 4.3-10.0)	14 (2.5 per 100 PY, 95%CI 1.3-4.0)

(crude incidence rate)			
ACASI=audio computer-assisted self-interview, ART=antiretroviral therapy, CI=confidence interval, FTFI=face-to-face interview, SGM=sexual and gender minorities, PEP=post-exposure prophylaxis, PY=person-years, STI=sexually transmitted infection.			

Measures

HIV acquisition: Our analyses focused on SGM not living with HIV at baseline. In all studies, HIV testing was conducted quarterly using rapid diagnostic tests or enzyme immunoassays (Table 6.2.1, Table 6.4.1). Participants who acquired HIV during follow-up were referred to treatment and could remain enrolled in the studies.

SGM violence: Longitudinal data on violence among SGM was collected at baseline and every 6 months (6 assessments in *CohMSM* and 3 each in *HPTN 075* and *Anza Mapema*). Our primary exposure, SGM violence (binary), was defined as any reported verbal or physical violence due to identities and/or sexual behaviours at each study visit at which violence was assessed (Table 6.4.1). For *CohMSM* and *Anza Mapema*, this was based on separate questions about verbal and physical violence. For *HPTN 075*, it was based on one question about combined experiences of verbal and physical harassment, and a second on having been beaten. Sexual violence was excluded from our definition as we were interested in indirect pathways linking SGM violence to HIV acquisition. Recall periods of violence varied across studies: past six months at all visits in *CohMSM*, past 12 months at baseline in *HPTN 075* and *Anza Mapema* and past six- and three-months during follow-up, respectively (Table 6.4.1).

Potential mediators: Hypothesized mediators included moderate-to-severe depressive symptoms (binary, measured over the past two weeks using the Patient Health Questionnaire (PHQ)-9 score ≥10), [32] hazardous drinking (binary, AUDIT-C score ≥4), [33] and condom use (binary: at last sex with a man in *CohMSM* and *Anza Mapema*, consistently during anal sex with up to three recent male partners in the past three months in *HPTN 075*; Text 6.4.2; Table 6.4.1). The AUDIT-C assesses typical drinking frequency, rather than alcohol use within a specific recall period. [33] Potential mediators were assessed at variable frequencies across cohorts (Table 6.4.1).

Baseline confounders: These included age (binary: <25, ³25), gender identity (binary: man, transgender woman/non-binary), sexual identity (binary: gay, bisexual/heterosexual/other), highest level of education (binary: secondary/higher, none/primary), employment status (binary:

employed/student, unemployed), and recent transactional sex (binary: recently exchanged sex, did not).

SGM violence, potential mediators, and confounders were a priori defined, based on directed acyclic graphs (DAGs) from reviewing the literature (Figure 6.4.1). [8,11,17-25] In our analyses, we aligned the HIV data with the closest preceding exposure assessment. When analysing potential mediators as outcomes, we aligned them with exposures at 6-month intervals to estimate the effect of exposure on outcomes at the same visit or the visit 6 months later.

Statistical analyses

We described the prevalence and patterns of SGM violence, moderate-to-severe depressive symptoms, hazardous drinking, and condom use at six-monthly visit across cohorts. We categorised participants into four patterns based on SGM violence in the first 12 months of follow-up: no SGM violence at baseline or during follow-up (Pattern 1), no baseline SGM violence but violence during follow-up (Pattern 2), baseline SGM violence only (Pattern 3) and violence at both baseline and during follow-up (Pattern 4).

Next, we conducted a two-stage individual participant data meta-analysis:

Stage 1: We fit log-linear sequential conditional mean models (SCMMs) with generalised estimating equations to estimate crude and adjusted risk ratios (cRRs and aRRs, respectively) and 95% confidence intervals (CI) for: [34-36]

Violence on HIV acquisition: Baseline SGM violence on HIV acquisition at any follow-up visit (1 model), and SGM violence at follow-up visits on HIV acquisition at the same visit and six months later (2 models).

Violence on mediators: Baseline SGM violence on moderate-to-severe depressive symptoms, hazardous drinking, and condom use, at any follow-up visit (3 models), and SGM violence at follow-up visits on these variables at the same visit, and six months later (6 models).

Mediator relationships: Moderate-to-severe depressive symptoms on hazardous drinking at the same follow-up visit and six months later (2 models). Depressive symptoms and hazardous drinking on condom use at the same follow-up visit and six months later (4 models).

In all models of non-baseline exposures, we also included the exposure at the previous six-month visit and in models of non-HIV outcomes, we included the outcome at the previous

visit. For aRRs, we additionally adjusted for baseline confounders and study site (if multiple). We accounted for repeated measures using robust standard errors and used an independence correlation structure to avoid GEE bias. [37] In each cohort, we used multiple imputation to estimate missing violence, mediator, and confounder data and inverse probability of censoring weights (IPCW) to account for loss to follow-up (Text 6.4.3). [38,39]

Stage 2: We derived pooled effect estimates and 95% CI using random-effects inverse-variance meta-analysis with restricted maximum likelihood estimation. Our analyses were conducted in R version 4.3.1 using the "geepack", "mice", and "metafor" packages. [40-42]

Ethics

All analyses were performed on de-identified data. Ethics approval for secondary data analyses was obtained from McGill University's Faculty of Medicine Institutional Review Board (A02-B19-21A).

Results

Characteristics of study participants

We included a total of 1,590 SGM participants not living with HIV at baseline: 625 in *CohMSM*, 329 in *HPTN 075*, and 636 in *Anza Mapema* (Table 6.2.2). At baseline, most were aged 18-24 years (62%) and identified as cisgender men (76%). More TGW were enrolled in *CohMSM* (43%) than in *HPTN 075* (16%) or *Anza Mapema* (8%). Most participants had secondary education or higher (74%) and were employed or students (74%), with lower employment in *HPTN 075* (47%) compared to *CohMSM* (80%) and *Anza Mapema* (82%). Most participants were not currently married to a woman (86%). Just under half (42%) of participants reported exchanging sex for money, food, housing, or other in the past 3-12 months, with important variations across cohorts (32% in *CohMSM*, 19% in *HPTN 075*, and 63% in *Anza Mapema*). Moderate-to-severe depressive symptoms in the past two weeks were reported by 20% of participants, with the highest prevalence in *Anza Mapema* (28%). Hazardous drinking was reported by 34% and was highest in *HPTN 075* (48%) and lowest in *CohMSM* (16%). Condom use at last sex was reported by 61% in *CohMSM* and 73% in *Anza Mapema*. In *HPTN 075*, 54% used condoms consistently with recent male partners in the past three months. In total, 111 participants acquired HIV: 76/625 (12%) in *CohMSM*, 21/329 (6%) in *HPTN 075*, and 14/636

(2%) in *Anza Mapema*. HIV incidence rates were 10.3 per 100 person-years (/100PY) (95%CI 8.0-12.7) in *CohMSM*, 7.0 /100PY (4.3-10.0) in *HPTN 075*, and 2.5 /100PY (1.3-4.0) in *Anza Mapema*.

Table 6.2.2. Baseline characteristics and experiences of sexual and gender minority (SGM) violence among SGM not living with HIV in *Anza Mapema*, *CohMSM*, and *HPTN 075*.

	CohMSM (N=625)	*HPTN 075* (N=329)	*Anza Mapema* (N=636)	Overall (N=1590)
a) Baseline participant characteristics				
Age				
18-24 years	393 (62.9%)	219 (66.6%)	369 (58.0%)	981 (61.7%)
25 years or older	232 (37.1%)	110 (33.4%)	267 (42.0%)	609 (38.3%)
Gender identity				
Cisgender man (MSM)	356 (57.0%)	271 (82.4%)	582 (91.5%)	1209 (76.0%)
Transgender woman, non-binary, or other (TGW)	269 (43.0%)	53 (16.1%)	50 (7.9%)	372 (23.4%)
Missing	0 (0%)	5 (1.5%)	4 (0.6%)	9 (0.6%)
Sexual identity				
Gay	237 (37.9%)	199 (60.5%)	415 (65.3%)	851 (53.5%)
Heterosexual, bisexual, or other	380 (60.8%)	130 (39.5%)	221 (34.7%)	731 (46.0%)
Missing	8 (1.3%)	0 (0%)	0 (0%)	8 (0.5%)
Highest level of education				
None	20 (3.2%)	3 (0.9%)	6 (0.9%)	29 (1.8%)
Primary	66 (10.6%)	113 (34.3%)	118 (18.6%)	297 (18.7%)
Secondary	241 (38.6%)	138 (41.9%)	325 (51.1%)	704 (44.3%)
Higher	210 (33.6%)	73 (22.2%)	187 (29.4%)	470 (29.6%)
Missing	88 (14.1%)	2 (0.6%)	0 (0%)	90 (5.7%)
Current employment status				
Employed/student	502 (80.3%)	156 (47.4%)	524 (82.4%)	1182 (74.3%)
Not employed	32 (5.1%)	168 (51.1%)	112 (17.6%)	312 (19.6%)
Missing	91 (14.6%)	5 (1.5%)	0 (0%)	96 (6.0%)
Current marital status to a woman				
Yes	44 (7.0%)	12 (3.6%)	69 (10.8%)	125 (7.9%)
No	493 (78.9%)	310 (94.2%)	567 (89.2%)	1370 (86.2%)
Missing	88 (14.1%)	7 (2.1%)	0 (0%)	95 (6.0%)
Recent engagement in transactional sex				
Yes	198 (31.7%)	63 (19.1%)	401 (63.1%)	662 (41.6%)
No	427 (68.3%)	260 (79.0%)	235 (36.9%)	922 (58.0%)
Missing	0 (0%)	6 (1.8%)	0 (0%)	6 (0.4%)
Moderate to severe depressive symptoms (PHQ-9 ≥10), past 2 weeks				
Yes	89 (14.2%)	47 (14.3%)	176 (27.7%)	312 (19.6%)
No	533 (85.3%)	275 (83.6%)	460 (72.3%)	1268 (79.7%)
Missing	3 (0.5%)	7 (2.1%)	0 (0%)	10 (0.6%)
Hazardous drinking (AUDIT-C ≥4)*				
Yes	103 (16.5%)	158 (48.0%)	284 (44.7%)	545 (34.3%)
No	396 (63.4%)	148 (45.0%)	136 (21.4%)	680 (42.8%)
Missing	126 (20.2%)	23 (7.0%)	216 (34.0%)	365 (23.0%)
Condom use**				
Yes	381 (61.0%)	179 (54.4%)	464 (73.0%)	1024 (64.4%)
No	190 (30.4%)	136 (41.3%)	169 (26.6%)	495 (31.1%)
Missing	54 (8.6%)	14 (4.3%)	3 (0.5%)	71 (4.5%)
b) SGM violence at baseline and follow-up visits by study				
Reported baseline SGM violence (any type) Recall period =	Past 6 months	Past 12 months	Past 12 months	All combined
Yes	139 (22.2%)	115 (35.0%)	316 (49.7%)	570 (35.8%)
No	483 (77.3%)	212 (64.4%)	293 (46.1%)	988 (62.1%)

		CohMSM (N=625)	*HPTN 075* (N=329)	*Anza Mapema* (N=636)	Overall (N=1590)
Missing		3 (0.5%)	2 (0.6%)	27 (4.2%)	32 (2.0%)
Reported SGM violence (any type) in the first 12 months of follow-up	Recall period =	Past 6 months	Past 6 months	Past 3 months	All combined
Yes		81 (13.0%)	45 (13.7%)	195 (30.7%)	321 (20.2%)
No		435 (69.6%)	272 (82.7%)	344 (54.1%)	1051 (66.1%)
Missing		109 (17.4%)	12 (3.6%)	97 (15.3%)	218 (13.7%)
Reported baseline verbal violence	Recall period =	Past 6 months	Past 12 months	Past 12 months	All combined
Yes		134 (21.4%)	110 (33.4%)	301 (47.3%)	545 (34.3%)
No		488 (78.1%)	217 (66.0%)	303 (47.6%)	1008 (63.4%)
Missing		3 (0.5%)	2 (0.6%)	32 (5.0%)	37 (2.3%)
Reported verbal violence in the first 12 months of follow-up	Recall period =	Past 6 months	Past 6 months	Past 3 months	All combined
Yes		79 (12.6%)	44 (13.4%)	186 (29.2%)	309 (19.4%)
No		437 (69.9%)	273 (83.0%)	353 (55.5%)	1063 (66.9%)
Missing		109 (17.4%)	12 (3.6%)	97 (15.3%)	218 (13.7%)
Reported baseline physical violence	Recall period =	Past 6 months	Past 12 months	Past 12 months	All combined
Yes		33 (5.3%)	21 (6.4%)	121 (19.0%)	175 (11.0%)
No		589 (94.2%)	306 (93.0%)	475 (74.7%)	1370 (86.2%)
Missing		3 (0.5%)	2 (0.6%)	40 (6.3%)	45 (2.8%)
Reported physical violence in the first 12 months of follow-up	Recall period =	Past 6 months	Past 6 months	Past 3 months	All combined
Yes		17 (2.7%)	9 (2.7%)	88 (13.8%)	114 (7.2%)
No		499 (79.8%)	308 (93.6%)	447 (70.3%)	1254 (78.9%)
Missing		109 (17.4%)	12 (3.6%)	101 (15.9%)	222 (14.0%)
Pattern of SGM violence in the first 12 months of follow-up					
Pattern 1	No SGM violence at baseline or during follow-up	364 (58.2%)	193 (58.7%)	203 (31.9%)	760 (47.8%)
Pattern 2	No baseline SGM violence but violence during follow-up	35 (5.6%)	12 (3.6%)	42 (6.6%)	89 (5.6%)
Pattern 3	Baseline SGM violence only	68 (10.9%)	77 (23.4%)	129 (20.3%)	274 (17.2%)
Pattern 4	SGM violence at both baseline and during follow-up	46 (7.4%)	33 (10.0%)	144 (22.6%)	223 (14.0%)
Missing baseline and/or follow-up SGM violence information		112 (17.9%)	14 (4.3%)	118 (18.6%)	244 (15.3%)

MSM=men who have sex with men or those who identified with other masculine terms, SGM=sexual and gender minority, TGW=transgender women, non-binary people, or those who identified with other feminine terms. Proportions of depression, hazardous drinking, condom use, and experiences of SGM violence are presented as crude proportions (i.e., not adjusted for loss to follow-up using IPCW).

* Hazardous drinking was measured using the AUDIT-C, which assesses typical drinking frequency, rather than assessing alcohol use over a specific recall period.
** Condom use was measured at last sex with a man in *Anza Mapema* and *CohMSM*, and defined as consistent condom use during anal sex with up to three recent male partners in the past 3 months in *HPTN 075* (Text 6.4.2).

Prevalence, incidence, and patterns of SGM violence

Baseline SGM violence was reported by 22% (139/625) of *CohMSM* participants (past 6 months), 35% (115/329) in *HPTN 075* (past 12 months), and 50% (316/636) in *Anza Mapema* (past 12 months; Figure 6.2.1a). During the first 12 months of follow-up, SGM violence was reported by 13% (81/625) in *CohMSM* at any visit (past 6 months), 14% (45/329) in *HPTN 075* (past 6 months), and 31% (195/636) in *Anza Mapema* (past 3 months). The prevalence of SGM violence decreased over time in *CohMSM*, but trends were less clear in the other cohorts. In *CohMSM*, more participants in Côte d'Ivoire and Burkina Faso reported SGM violence than in Togo or Mali (Figure 6.4.2). In *HPTN 075*, baseline SGM violence was higher in Soweto (39%) than Cape Town, Kenya, and Malawi (30-35%), but more participants reported violence during follow-up in Malawi (16%) than the other sites (5-10%; Figure 6.4.3). Generally, verbal violence was more common than physical violence, with physical usually accompanying verbal violence (Figure 6.4.4). In *Anza Mapema*, more SGM violence involved both verbal and physical components compared to *CohMSM* and *HPTN 075* where violence was mostly verbal only. Perpetrator information for was available only for physical violence in *Anza Mapema*, where most physical violence was by unknown individuals (29%) or friends (19%; Table 6.4.3).

Patterns of SGM violence in the first 12 months of follow-up varied across cohorts: 48% reported no violence at baseline or any follow-up visit (Pattern 1; 760/1590; Table 6.2.1), with fewer in *Anza Mapema* than *CohMSM* or *HPTN 075* (Figure 6.2.1b). Patterns 3 (274/1590) and 4 (223/1590) accounted for 17% and 14%, respectively (Table 6.2.1), with more participants in *Anza Mapema* in Pattern 4 than 3. Overall, 6% were in Pattern 2 (89/1590). Due to loss to follow-up or non-response, this information was missing for 244 participants (15%). In all cohorts, baseline SGM violence was associated with a higher likelihood of reporting violence at follow-up visits (*CohMSM*: prevalence ratio (PR)=4.6; *HPTN 075*: PR=5.0; *Anza Mapema*: PR=3.1; Text 6.4.4). Generally, more TGW reported SGM violence than MSM at each visit, especially in *CohMSM* (Figure 6.4.5).

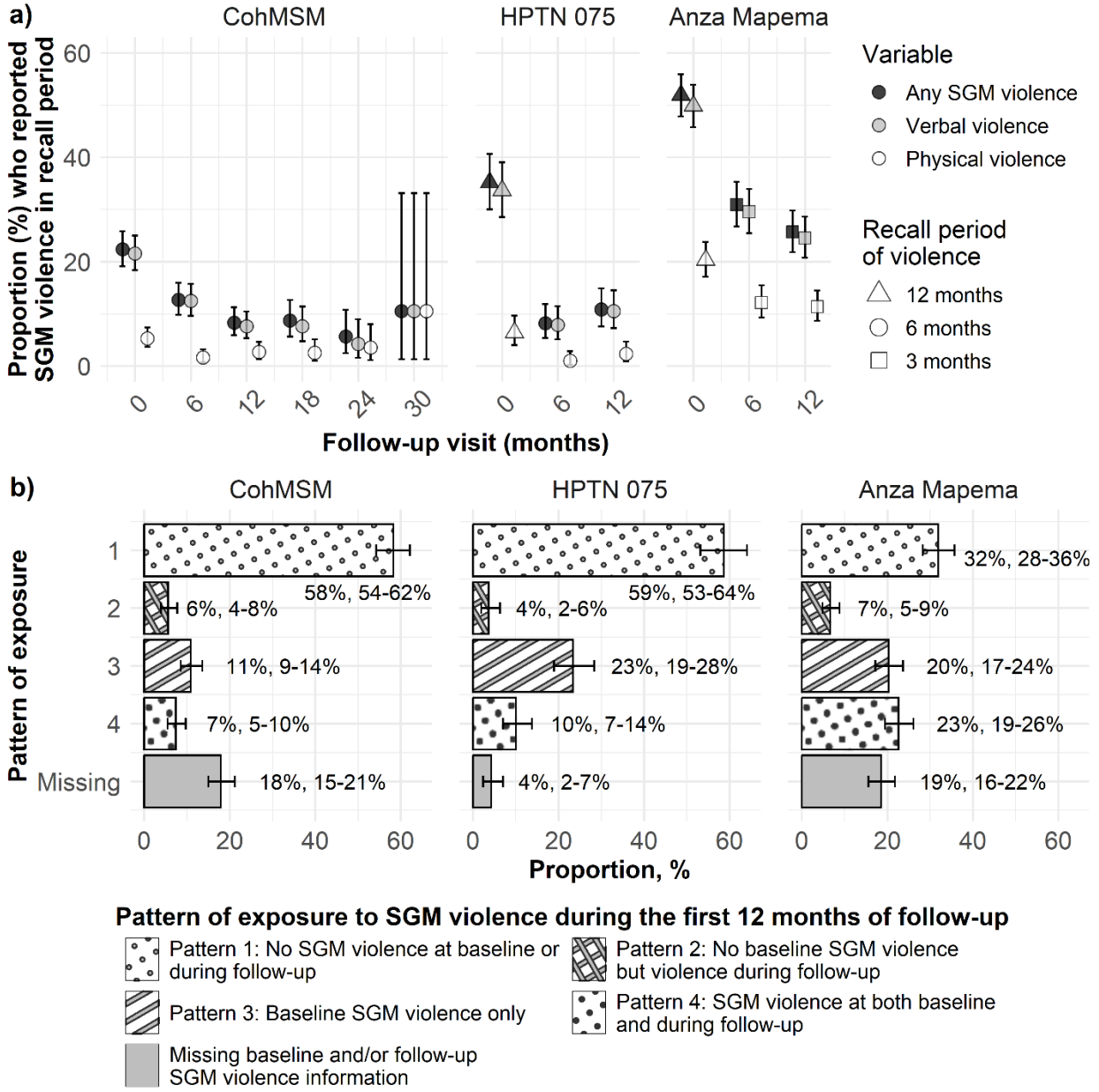

Figure 6.2.1. Reports of sexual and gender minority (SGM) violence in the *CohMSM*, *HPTN 075*, and *Anza Mapema* cohorts at baseline and at follow-up visits. a) The proportion (%) who reported SGM violence in the past 3, 6, or 12 months at each study visit, by cohort, and b) patterns of exposure to SGM violence during the first 12 months of follow-up in each cohort.

Associations among SGM violence, depressive symptoms, hazardous drinking, and HIV risk

Participants who reported SGM violence at baseline or in the first 12 months of follow-up were more likely to identify as TGW or gay, be employed, have recently engaged in transactional sex, and have more sexual partners (Figure 6.4.5; Table 6.4.2). They were also more likely to

report moderate to severe depressive symptoms and hazardous drinking, and slightly less likely to have used condoms at last sex (*CohMSM* and *Anza Mapema*) or consistently (*HPTN 075*). At all study visits, the prevalence of moderate-to-severe depressive symptoms was higher among those who reported SGM violence (Figure 6.2.2a), as was hazardous drinking in *Anza Mapema* (Figure 6.2.2b). Condom use was slightly lower among those reporting violence at most visits (Figure 6.2.2c). Participants who reported SGM violence at both baseline and follow-up visits in the first 12 months (Pattern 4) were more likely to report depressive symptoms at six-monthly follow-up visits (Figure 6.4.6).

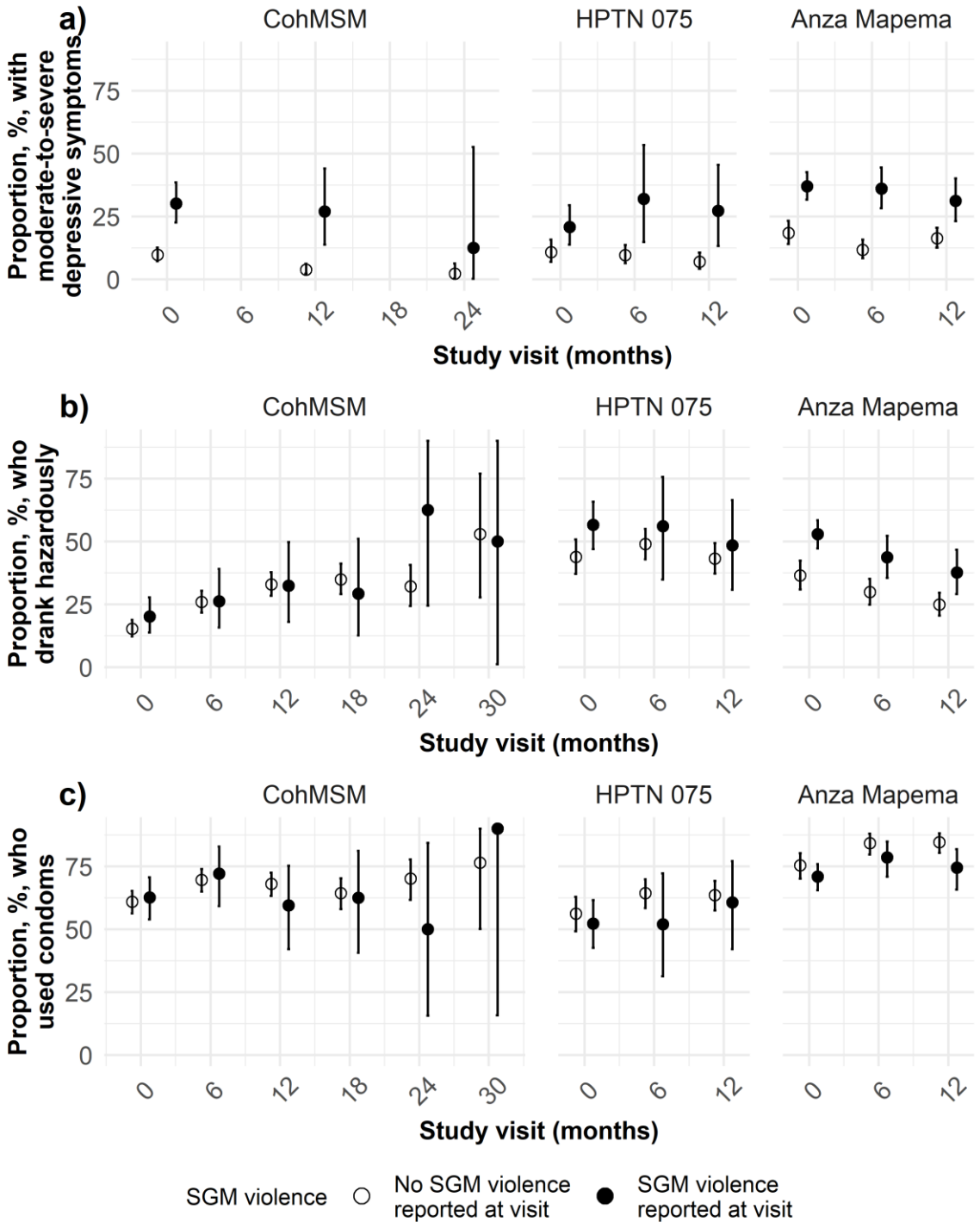

Figure 6.2.2. The proportion of participants in *CohMSM*, *HPTN 075*, and *Anza Mapema* who experienced moderate-to-severe depressive symptoms, hazardous drinking, and used condoms (as defined in each cohort) stratified by reports of sexual and gender minority (SGM) violence at the same six-monthly study visit. a) The proportion of participants who experienced moderate-to-severe depressive symptoms (PHQ-9 ≥10), b) the proportion of participants who drank hazardously (AUDIT-C ≥4), and c) the proportion who reported condom

use (at last sex in *CohMSM* and *Anza Mapema*; consistent condom use with up to three recent male partners in the past 3 months in *HPTN 075.* Text 6.4.1), by study visit. The proportions of participants with depressive symptoms and who used condoms at visits 3 and 9 in *HPTN 075* and *Anza Mapema* are not shown, as SGM violence information was not collected at these visits.

Crude HIV incidence was higher among participants who reported baseline SGM violence than those who did not in *CohMSM* (13.0 /100PY vs 9.7 /100PY) and *Anza Mapema* (3.2 /100PY vs 1.6 /100PY), but lower in *HPTN 075* (4.7 /100PY vs 8.3 /100PY). Similar patterns were seen among participants reporting SGM violence during the first 12 months of follow-up: higher in *CohMSM* (8.7 /100PY vs 7.8 /100PY) and *Anza Mapema* (2.1 /100PY vs 1.8 /100PY) but lower in *HPTN 075* (0.0 /100PY vs 4.3 /100PY).

Effect of SGM violence on HIV and potential mediators

The pooled aRR of baseline SGM violence on HIV acquisition was 1.0 (95%CI 0.5-2.0; Figure 6.2.3a). In *CohMSM* and *HPTN 075*, baseline violence was not linked to a higher probability of HIV acquisition (*CohMSM*: aRR=1.0, 0.5-2.1, *HPTN 075*: aRR=0.5, 0.2-1.4) although confidence intervals could not exclude this possibility. In *Anza Mapema*, baseline SGM violence was associated with a greater risk of HIV acquisition, although confidence intervals crossed the null (aRR=2.1, 0.6-6.9).

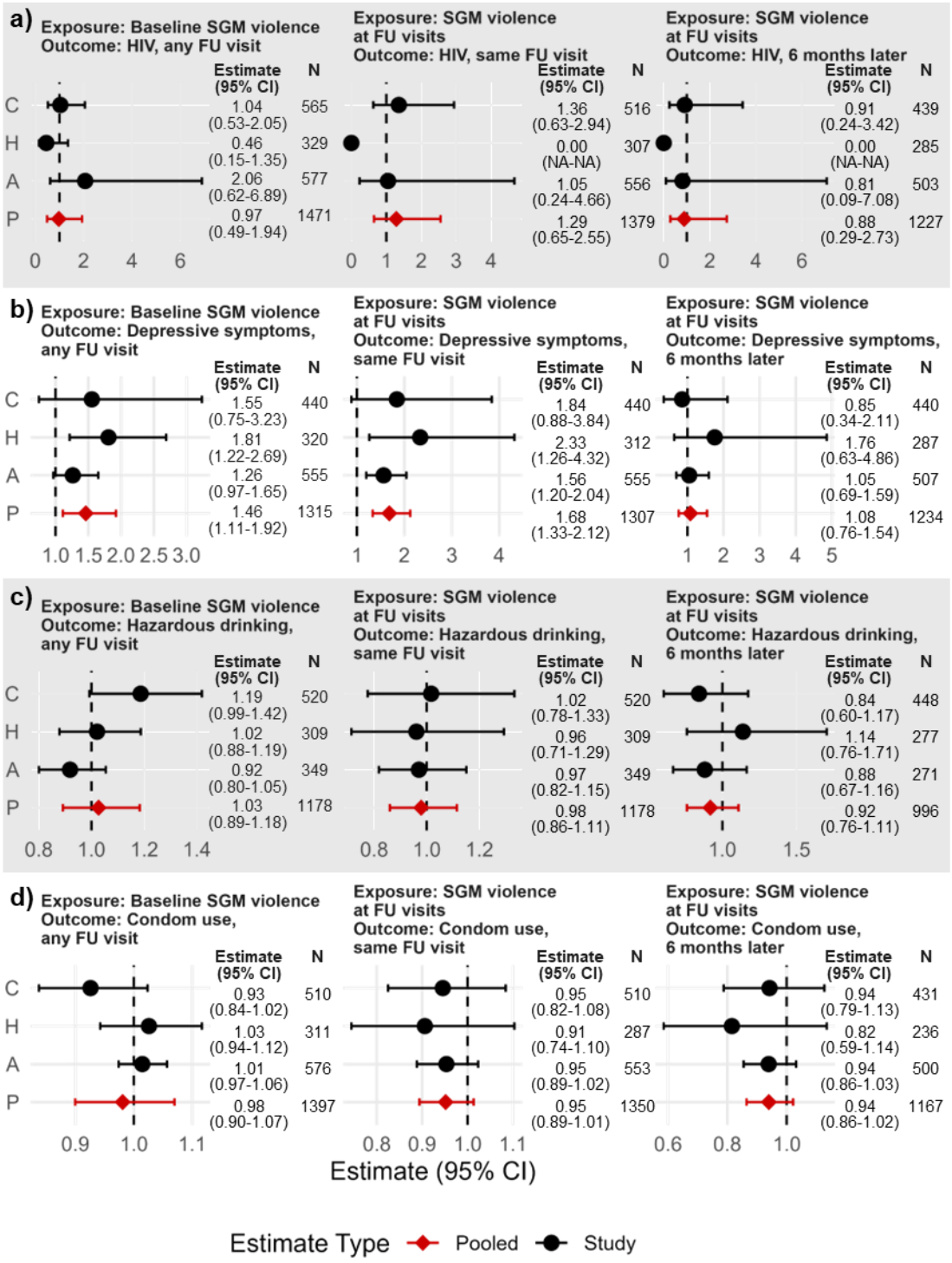

Figure 6.2.3. Forest plots of adjusted risk ratios (aRRs) of sexual and gender minority (SGM) violence on HIV acquisition, moderate-to-severe depressive symptoms, hazardous drinking, and condom use. Study and pooled estimates of aRRs and 95% confidence intervals

(95% CI) linking baseline SGM violence and violence at follow-up visits with a) HIV acquisition, b) moderate-to-severe depressive symptoms, c) hazardous drinking, and d) condom use measured at any follow-up visit, the same visit as exposure was assessed at during follow-up, and at the follow-up visit six months later, in *CohMSM*, *HPTN 075*, and *Anza Mapema*. C=*CohMSM*, H=*HPTN 075*, A=*Anza Mapema*, P=*Pooled*, FU=*follow-up*. The vertical dashed line represents a null association (aRR=1). *****The pooled aRRs for SGM violence at follow-up visits on HIV acquisition do not include *HPTN 075*, as only one person who acquired HIV reported SGM violence during follow-up, therefore we could not estimate these associations for that cohort. The pooled aRRs for condom use also do not include *HPTN 075*, in which condom use was defined differently (consistent condom use with up to three recent male partners in the past three months) from *CohMSM* and *Anza Mapema* (condom use at last sex).

The pooled aRR for SGM violence at follow-up visits on HIV acquisition at the same visit was 1.3 (95%CI 0.6-2.6) but was 0.9 (0.3-2.7) on HIV acquisition at the visit six months later, pooling only *CohMSM* and *Anza Mapema* (Figure 6.2.3a). In *HPTN 075*, only one participant who acquired HIV reported SGM violence during follow-up, at the last visit, therefore we could not estimate the effect of SGM violence at follow-up visits on HIV acquisition in that cohort. SGM violence at the same follow-up visit was associated with a higher probability of HIV acquisition in *CohMSM* (aRR=1.4, 0.6-2.9) and weakly in *Anza Mapema* (aRR=1.1, 0.2-4.7) but not six months later (aRR=0.9, 0.2-3.4 and aRR=0.8, 0.1-7.1, respectively), all with substantial uncertainty (Figure 6.2.3a).

Baseline SGM violence was associated with a significantly higher probability of moderate-to-severe depressive symptoms (pooled aRR=1.5, 95%CI 1.1-1.9; Figure 6.2.3b) and SGM violence at follow-up visits was linked to a higher probability of depressive symptoms at the same visit (pooled aRR=1.9,1.5-2.4) although not six months later (pooled aRR=1.1, 0.7-2.1). SGM violence did not exhibit an association with hazardous drinking at follow-up visits (Figure 6.2.3c), and was weakly associated with lower condom use at last sex at the same follow-up visit (pooled aRR=0.95, 0.9-1.0) and 6 months later (pooled aRR=0.9, 0.9-1.0) in *CohMSM* and *Anza Mapema* (Figure 6.2.3d). In *HPTN 075*, the aRRs for consistent condom use were 0.9 (0.7-1.1) and 0.8 (0.6-1.1), respectively. Depressive symptoms during follow-up were associated with hazardous drinking at the same visit (pooled aRR=1.4, 1.1-1.7; Figure 6.4.7a). Crude and adjusted associations were similar (Figure 6.4.8-9). Estimates for MSM and TGW were generally comparable (Table 6.4.4).

Discussion

In this individual participant data meta-analysis of three prospective cohorts of 1,590 SGM in seven African countries, we found that SGM violence was common and linked to depressive symptoms, although its association with HIV acquisition was inconclusive. Depressive symptoms were in turn linked to hazardous drinking.

SGM violence was pervasive and widespread, often exceeding the UNAIDS 10-10-10 goal of <10% experiencing violence in the past 12 months, although variations in measurement and recall periods complicate comparisons. [1] Consistent with other studies, verbal violence was more prevalent than physical violence. [8,43] In *Anza Mapema*, 50% of participants reported SGM violence in the past year at baseline, and 27% in the past three months during follow-up. This was higher than a 2008 study in Kenya among 442 MSM who sell sex, in which 14% reported past-year physical violence, [44] and similar to a study in Tanzania, the predominant perpetrators of physical SGM violence were strangers, emphasising the highly stigmatising environments in which many SGM live. [43] *HPTN 075* reported baseline prevalence of past-year violence of 31-41% across sites, with lower prevalence of past six months violence at follow-up visits (5-16%). In *CohMSM*, SGM violence was more common in Burkina Faso and Côte d'Ivoire compared to Togo or Mali. In another analysis that pooled cross-sectional data from nine countries in eastern and southern Africa, the prevalence of non-partner violence in the past year was 30% –similar to our overall baseline estimate for *HPTN 075* (35%).[7]

The baseline prevalence of SGM violence in the past year was lower in Kenya among participants of *HPTN 075* than *Anza Mapema*, despite both being conducted in the same city at overlapping time periods. In *Anza Mapema*, violence was assessed using confidential audio-computer assisted self-interviews, while face-to-face interviews were used in the other cohorts, which may be more affected by social desirability bias and underreporting. [45,46] In *HPTN 075*, multiple recruitment methods were used that may have captured a broader population of MSM, while *Anza Mapema* used only snowball sampling and recruited more SGM recently engaged in transactional sex (63%) than in *HPTN 075* (20%). This might have influenced participants' risk of SGM violence as men who sell sex may experience high levels of violence. [1,47] Additionally, other contextual factors may help explain differences in the prevalence and patterns of SGM

violence across the cohorts and countries that could not be explored in our study, such as legislation affecting SGM, social acceptance of SGM, religious beliefs, access to community-based and support services, and intersecting HIV stigma, that could exacerbate sexual identity stigma among SGM, particularly in higher HIV prevalence settings. [2,24,48,49]

Although inconclusive, our findings do not rule out an association between SGM violence and HIV acquisition, and other evidence supports such a link. [2,50] For example, in the *TRUST/RV368* cohort study in Nigeria, worse stigma – a composite measure that included verbal, physical, and sexual SGM violence – was linked to HIV acquisition. [21] Most quantitative evidence, however, focuses on intimate partner violence, and uses cross-sectional designs. [12-16] Qualitative studies and social sciences literature also support links between SGM violence and HIV risk and contextualise SGM violence within broader structural and historical forces. [15,16,24,51]

SGM who reported violence were nearly twice as likely to experience depressive symptoms, and depression was associated with hazardous drinking. These findings align with other studies demonstrating relationships between violence among SGM and mental health outcomes, including *TRUST/RV368* and a cross-sectional study among MSM in Tanzania in 2014 in which MSM who had ever experienced violence were over 10 times more likely to experience depression. [11] Integrating tailored mental health and substance use support for SGM in HIV interventions or programmes is needed to address the syndemic of HIV and poor mental health affecting SGM. [52,53] In our study, neither SGM violence or depression were conclusively linked to lower condom use, suggesting other pathways may be important. Other studies have linked SGM violence, and other stigma, to lower HIV testing, ART non-adherence, and difficulties achieving viral suppression among SGM living with HIV. [27,54]

Our study has some limitations, partly due to design variations across the included studies. First, the varied eligibility criteria may have biased estimates of SGM violence, and if SGM violence impacted eligibility, it could have affected our pooled estimates. Second, differences in the measurement of violence could also have impacted our estimates. Standardised violence questions and recall periods could be more widely used, such as the United States Agency for International Development (USAID) Health Policy Initiative (HPI) MSM Trauma Screening Tool, which includes questions on verbal, physical, sexual, and psychological SGM

violence, although the local contexts of violence should not be overlooked. [55] Standardised definitions would help countries monitor progress towards the 10-10-10 goals, especially since targets can differ in recall periods. [56] Additionally, we analysed violence as a binary variable, which limited more nuanced exposure assessments, although only *Anza Mapema* reported count data. Third, loss-to-follow-up may have influenced our estimates, especially in *CohMSM*, which had longer follow-up, although we did account for it in our analyses. Finally, the total number of participants who experienced SGM violence at follow-up visits and who acquired HIV was not high, and violence may have been underreported, which limited statistical power of our analyses and precluded more advanced approaches such as mediation analysis. [25]

Our study also had strengths. We used comprehensive, longitudinal data from three high-quality cohorts of SGM and robust longitudinal analyses with a sequential modelling approach to estimate the effects of SGM violence on HIV acquisition and potential mediators. Our approach follows recent recommendations to improve the longitudinal estimation of structural determinants parameters for mathematical modelling. [25] By using an individual participant data meta-analysis, we could harmonise variable definitions, where possible, and confounder adjustment across cohorts, to produce mostly comparable estimates for pooling.

Conclusions

Among SGM participants from three cohorts in seven African countries, we found that one in five participants reported any verbal or physical violence (SGM violence) in the first year of follow-up. Reporting SGM violence was linked to a greater probability of moderate-to-severe depressive symptoms at the same follow-up visit, which in turn was linked to hazardous drinking. Although experiencing SGM violence was not conclusively linked to a higher risk of HIV acquisition, it did not rule out a potential causal association. Reducing violence –a human rights violation– among SGM and other key populations remains a primary objective of global initiatives. Structural interventions that address SGM violence and improve the mental health of SGM are a priority and could support HIV prevention, including through pathways not examined here. Additional longitudinal studies using standardised violence definitions and recall periods will help to further explore causal pathways using alternative methods such as causal mediation analysis. Other pathways, such as those involving barriers to HIV services and delays to viral

suppression, may also be important for HIV acquisition and transmission and merit further investigation.

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6.4 Manuscript 3: Supplementary materials

Text 6.4.1. Search strategies for identifying potential studies

a) Embase (search conducted August 28, 2023)**:**

1. exp Human immunodeficiency virus/
2. exp Human immunodeficiency virus infection/
3. exp acquired immune deficiency syndrome/
4. (HIV or HIV1* or HIV2* or HIV-1* or HIV-2*).af.
5. (human immun#deficiency virus or human immun# deficiency virus).af.
6. (acquired immun#deficiency syndrome or acquired immun# deficiency syndrome).af.
7. 1 or 2 or 3 or 4 or 5 or 6
8. mathematical model/
9. theoretical model/
10. computer simulation/
11. population model/
12. biological model/
13. Monte Carlo method/
14. stochastic model/
15. ((math* or transmission or dynamic* or epidemi* or compartmental or deterministic or individual or individual#based or agent or agent#based or network or simulat*) adj3 model*).af.
16. 8 or 9 or 10 or 11 or 12 or 13 or 14 or 15
17. exp socioeconomics/
18. exp health disparity/
19. exp social aspect/
20. homelessness/
21. exp violence/
22. correctional facility/
23. poverty/
24. exp social discrimination/
25. social stigma/
26. ((structural or social) adj3 (determinant* or factor* or condition* or cause* or enabler* or driver* or exposure* or risk*)).af.
27. (criminali#ation or homeless* or unstable housing or housing instability or incarceration or prison* or stigma or discrimination or violence or poverty).af.
28. 17 or 18 or 19 or 20 or 21 or 22 or 23 or 24 or 25 or 26 or 27
29. 7 and 16 and 28

b) Medline (search conducted August 28, 2023)**:**

1. exp HIV/
2. exp HIV Infections/
3. exp Acquired Immunodeficiency Syndrome/
4. HIV.af.
5. "HIV1*".af.
6. "HIV2*".af.
7. "HIV-1*".af.
8. "HIV-2*".af.
9. human immun#deficiency virus.af.
10. human immun# deficiency virus.af.
11. acquired immun#deficiency syndrome.af.
12. acquired immun# deficiency syndrome.af.
13. 1 or 2 or 3 or 4 or 5 or 6 or 7 or 8 or 9 or 10 or 11 or 12
14. Models, Biological/ or Models, Theoretical/
15. Computer Simulation/
16. Patient-Specific Modeling/
17. Monte Carlo Method/
18. exp Stochastic Processes/
19. ((math* or transmission or dynamic* or epidemi* or compartmental or deterministic or individual or individual#based or agent or agent#based or network or simulat*) adj3 model*).af.
20. 14 or 15 or 16 or 17 or 18 or 19
21. exp Socioeconomic Factors/
22. socioeconomic disparities in health/
23. exp health status disparities/
24. Ill-Housed Persons/
25. exp Violence/
26. Prisoners/
27. social stigma/
28. exp Social Discrimination/
29. Poverty/
30. ((structural or social) adj3 (determinant* or factor* or condition* or cause* or enabler* or driver* or exposure* or risk*)).af.
31. (criminali#ation or homeless* or unstable housing or housing instability or incarceration or prison* or stigma or discrimination or violence or poverty).af.
32. housing instability/
33. 21 or 22 or 23 or 24 or 25 or 26 or 27 or 28 or 29 or 30 or 31 or 32
34. 13 and 20 and 33

Table 6.4.1. Measurement of variables in the *Anza Mapema*, *HPTN 075*, and *CohMSM* cohort studies of sexual and gender minority men.

Variable	*CohMSM**	*HPTN 075*	*Anza Mapema*
Sexual and gender minority (SGM) violence	Question 1: *In the past 6 months, have you suffered verbal attacks (insults, mockery) because of your sexual orientation?* Question 2: *In the past 6 months, have you suffered physical violence (beating, stone throwing) because of your sexual orientation?* To approximately determine whether violence was verbal or physical violence, we classified violence as verbal if yes was answered to question 1 but no to question 2, and physical violence if yes to both. SGM violence in the past 6 months was assessed at baseline, and at the 6-month, 12-month, 18-month, 24-month, and 30-month visits.	Question 1: *Have you, as a result of sexual orientation or practice, in the last 12 months (baseline) or 6 months (follow-up), been verbally or physically harassed?* Question 2: *Have you, as a result of sexual orientation or practice, in the last 12 months (baseline) or 6 months (follow-up), been beaten up?* SGM violence in the past 12 months was assessed at baseline. SGM violence in the past 6 months was assessed at the 6-month and 12-month visits.	Question 1: *In the past 12 months (baseline) or 3 months (follow-up), how many times have you had verbal insults direct at you because someone believed you had sex with other men?* Question 2: *In the past 12 months (baseline) or 3 months (follow-up), how many times have you been hit, kicked, or beaten because someone believed you have sex with other men?* SGM violence in the past 12 months was assessed at baseline. SGM violence in the past 3 months was assessed at the 6-month and 12-month visits.
Moderate to severe depressive symptoms	PHQ-9 score ≥10. PHQ-9 score for the past 2 weeks was assessed at the baseline, 12-month, 18-month, and 24-month visits.	PHQ-9 score ≥10. PHQ-9 score for the past 2 weeks was assessed every 3 months, at the baseline, 3-month, 6-month, 9-month, and 12-month visits.	PHQ-9 score ≥10. PHQ-9 score for the past 2 weeks was assessed every 6 months, at the baseline, 6-month, and 12-month visits.
Hazardous drinking	AUDIT-C score ≥4. AUDIT-C score was assessed at the 3-month, 6-month, 12-month, 18-month, 24-month and 30-month visits.	AUDIT-C score ≥4. AUDIT-C score was assessed every 6 months, at the baseline, 6-month, and 12-month visits.	AUDIT-C score ≥4. AUDIT-C score was assessed every 6 months, at the baseline, 6-month, and 12-month visits.
Condom use	Question 1: *The last time you had sex with a man, did you do [type of sex]?*	See **Text 6.4.1**. Briefly, using questions on insertive and receptive anal sex with	Question 1: *The last time you had sex with a man, did you use a condom?*

	Question 2: *Did you use a condom?* (If yes was answered to question 2 for insertive or receptive anal sex with a man, condoms were used.) Condom use was assessed every 6 months, at the baseline, 6-month, 12-month, 18-month, 24-month, and 30-month visits.	partners in the past 3 months, for each male partner (one-off encounters or continuing relationships), we estimated the number of condomless anal sex acts. If for all recent male partners, all anal sex acts involved condoms, condom use was categorised as consistent. If any anal sex acts were condomless, condom use was categorised as inconsistent. Condom use was assessed every 3 months, at the baseline, 3-month, 6-month, 9-month, and 12-month visits.	Question 2: *The last time you had sex with a man, did he use a condom?* Condom use was assessed every 3 months, at the baseline, 3-month, 6-month, 9-month, and 12-month visits.
HIV acquisition	HIV testing was offered every 3 months. HIV testing was conducted according to national algorithms. All four sites first used the Determine HIV 1/2 assay (Abbott Laboratories, Chiba, Japan). Positive results were confirmed using the Bioline HIV-1/2 3.0 assay (SD, Gyeonggi-do, Republic of Korea) in Côte d'Ivoire, Mali, and Burkina Faso, or the First Response HIV-1/2 assay (Premier Medical Corporation, Mumbai, India) in Togo. Samples with discordant results were tested a third time using the HIV 1/2 Stat-Pak assay (Chembio Diagnostics, New York, USA) in Côte d'Ivoire, the First Response HIV-1/2 assay (Premier Medical Corporation, Mumbai, India) in Mali, the Inno-Lia HIV I/II Score assay (Fujirebio, Zwijnaarde, Belgium) in Togo, or a Western Blot assay in Burkina Faso.	HIV testing was offered every 3 months. HIV serostatus was determined using a testing algorithm that included two HIV rapid tests or a rapid test and a second HIV screening test. The tests used were 4th generation Architect HIV-1 Ag/Ab test (Architect test, Abbott Laboratories, Wiesbaden, Germany); the 4th generation BioRad GS HIV Combo Ag/Ab EIA (BioRad test, Bio-Rad Laboratories, Hercules, CA); the Geenius HIV ½ Supplemental Assay (Geenius test, Bio-Rad Laboratories); and the APTIMA HIV-1 RNA Qualitative Assay (APTIMA test; Hologic Gen-Probe Inc., San Diego, CA).	HIV testing was offered every 3 months. HIV serostatus was determined through a serial testing algorithm that included two rapid tests – the Colloidal Gold rapid test kit (KHB Shanghai Kehua Bio-engineering Company, Ltd., Shanghai, China), or the Determine HIV-1/2 test (Abbott Laboratories, Chicago, IL), and the First Response Rapid HIV test kit (Premier Medical Corporation, Pty., Ltd., Kachigam, India). All indeterminate test results were confirmed with enzyme-linked immunosorbent assay.
Baseline variables			
Age	Age at baseline.	Age at baseline.	Age at baseline.

Gender identity	Participants were asked what gender identity they consider themselves, with four options. We categorised those who identified as "a man/boy" as cisgender men. Those who identified as "much more a woman" or in ways other than exclusively (i.e., cisgender) men, including "both a man and a woman" or "neither a man nor a woman", were categorised as transgender women.	It was first explained to participants that "*gender is the social part of being male or female. It relates to your self-identity. When I ask about gender, I am asking about whether you regard yourself to be male, female, transgender female, or if you identify yourself in another way*". They were then asked the question: *"How do you identify your gender?"* Those who identified as "female" or "transgender" or in ways other than exclusively (i.e., cisgender) men, were categorised as transgender women.	Question: *How do you now identify your gender?* Those who identified as female or in ways other than male were categorised as transgender women.
Sexual identity	Participants were asked how they define themselves in terms of sexual orientation. We categorised those who identified as "homosexual/gay" as gay. Those who identified as "heterosexual", "trans/ transexual/transgender", "bisexual" or "you don't want to define yourself by your sexuality" were categorised as heterosexual, bisexual, or other.	Question: *Do you identify as gay, bisexual, heterosexual, or transgender, or would you use another word to describe your sexuality?* Those who identified as "gay" were categorised as gay, and those who identified as "bisexual", "heterosexual", "transgender" or "other" were categorised as heterosexual, bisexual, or other.	Question: *How would you describe your sexual identity? Or what word would you use to describe your sexual identity?* We categorised those who responded as "gay", "homosexual", "shoga", "basha", "kucu", "hanithi", "queen", and "king" as gay, and those who responded "bisexual", "heterosexual", "transsexual", or "other" as heterosexual, bisexual, or other.
Highest level of education	Question: *What is the highest grade you have attended?* Participants responded that they had attended primary, secondary, or higher education. Never having attended school, having attended Koranic school, and responding "other" were grouped together in the category "None".	Question: *What is the highest level of education that you completed?* Primary was defined as having achieved Grade 11/Form 3 or lower. Secondary education was defined as having completed Grade 12/Form 4. Tertiary or higher education was defined as having completed college or university.	Question: *What is the highest grade that you completed in school?* Primary was defined as having completed Standard 1 to 8. Secondary was defined as Form 1 to Form 6. Higher was defined as having attended college or university.
Employment status	Question: *What is your main [work] activity?* Participants who responded they were a "uniformed body", "official", "artist",	Question: *What best describes your current employment status?* Participants who answered that they were employed part or full-time or self-	Question: *What is the main occupation or activity through which you earn income?*

	"worker", "retailer/wholesaler", "farmer, rancher, fisherman", "salaried/office worker", "small trade/resource (all jobs)", or "sex worker" were categorised as currently employed. Those who responded "unemployed" or "student" were categorised as not currently employed.	employed were categorised as currently employed. Those who answered they were unemployed or between jobs, on disability, or "other" were classified as not currently employed.	Participants who reported that answered anything other than "none" were categorised as currently employed.
Marriage status to a woman	Participants were asked to describe their marriage status. They were classified as currently married to a woman if they were legally or religiously married or in a free and consensual union with a woman. Those who responded they were single, widowed, divorced/separated or in a free and consensual union with a man or "other situation" were classified as not currently married to a woman.	Question 1: *What is your current marital status?* Question 2: *What is the gender of your partner/spouse?* Participants who responded that they were married or in a civil union/ legal partnership with a cisgender woman were classified as currently married. Participants who were single, divorced, widowed, or married/in a civil union/legal partnership with someone of a different gender were classified as not currently married.	Question: *Are you currently married to a female?* Participants who responded yes were classified as currently married.
Recently engaged in transactional sex	Question: *In the past 6 months, have you been in a situation where you exchanged sex with a man in order to receive money, accommodation or another benefit?* Participants who answered "sometimes" or "always" were classified as having recently engaged in transactional sex. Those who responded "never" were classified as not.	Question 1: *Has a man ever given you something in exchange for sex?* Question 2: *In the past year, has a man given you anything in exchange for having sex with him?* Participants who answered yes to both were classified as having recently engaged in transactional sex.	Question: *In the last 3 months, how often have you had sex with someone in order to get money, food or housing?* Those who responded "rarely", "sometimes", "often", "almost always" were categorised as having recently engaged in transactional sex. Those who responded "never" were classified as not.
* these questions were originally asked in French.			

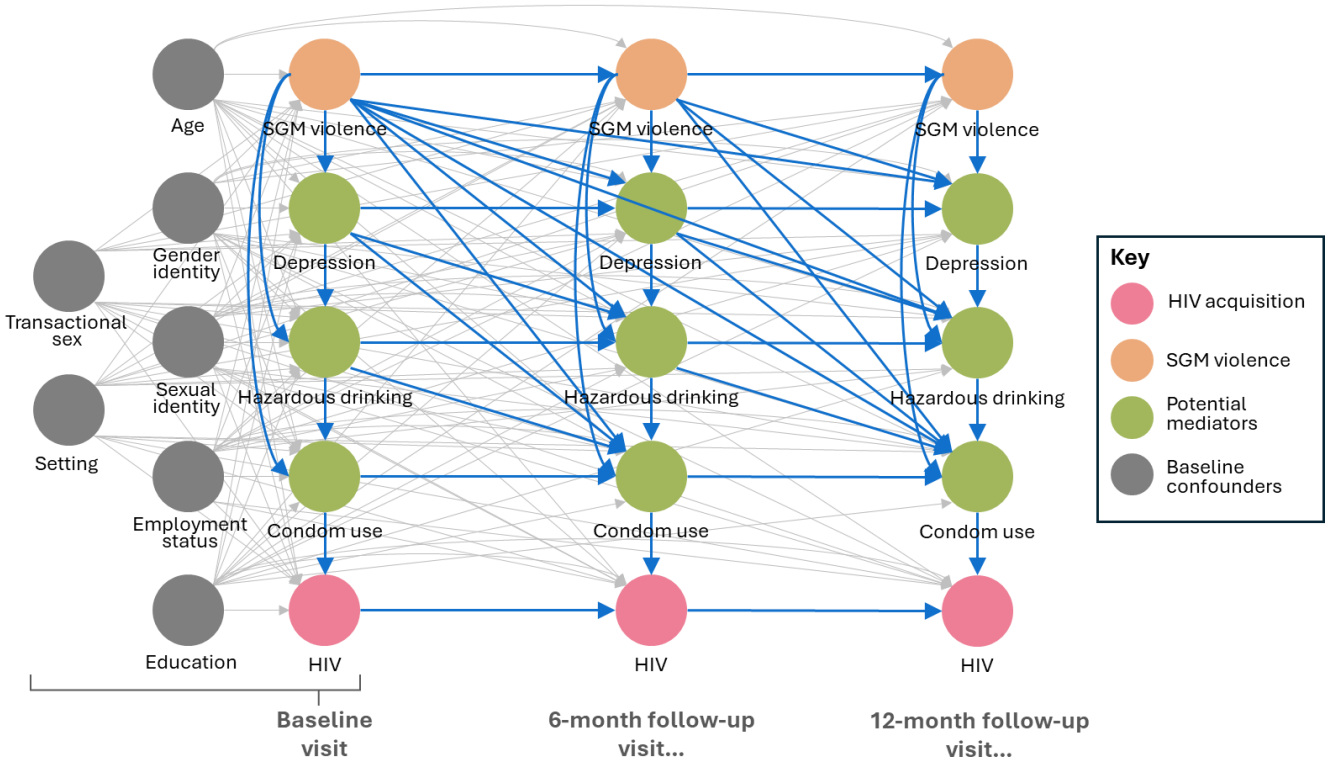

Figure 6.4.1. Directed acyclic graph (DAG) illustrating potential pathways linking SGM violence, moderate-to-severe depressive symptoms, hazardous drinking, condom use, and HIV acquisition, as well as confounders across six-monthly follow-up visits in the three analysed cohorts. Blue arrows indicate causal pathways among exposure variables, potential mediators, and outcomes. Grey arrows denote confounding pathways connecting baseline confounders (dark grey circles) to exposures, mediators, and outcomes.

Text 6.4.2. Consistent condom use variable in *HPTN 075*

In *HPTN 075*, consistent condom use (binary) was defined based on participants' responses to questions about their sexual activity with up to three recent male sexual partners over the past 3 months. For each partner, participants were asked:

- "In the past 3 months, have you had sex with [partner] once or more than once?"
- "Did you have receptive anal sex with [partner], meaning you were the "bottom", in the past 3 months?", and
- "Did you have insertive anal sex with [partner], meaning you were the "top", in the past 3 months?".

If a participant had anal sex (receptive or insertive) with a partner only once, they were asked:

- "Did [partner] use a condom when you had receptive/insertive anal sex with him?".

If they had anal sex more than once, for each of receptive and insertive anal sex, participants were asked:

- "How many times have you had anal sex with [partner] in the past 3 months?" and
- "Most men do not use condoms all the time they have anal sex. Of X times that you had anal sex with [partner], how many were unprotected, that means that no condom was used?".

If participants reported no condomless anal sex acts with any recent male partners in the past 3 months, we categorised condom use as consistent (value = 1). Otherwise, if one or more anal sex acts was condomless, we categorised condom use as inconsistent (value = 0).

Text 6.4.3. Accounting for missing data and loss to follow-up

Multiple imputation

To account for missing data, we conducted multiple imputation using multivariate imputation by chained equations (MICE) to impute missing values of SGM violence, moderate-to-severe depressive symptoms, hazardous drinking, condom use, and baseline confounders. We

did not analyse the imputed values of depressive symptoms, hazardous drinking, or condom use when these variables were analysed as outcomes. Including imputed outcomes may increase the variance of estimated risk ratios (RRs). Instead, we conducted “multiple imputation, then deletion", in which the imputed values of the outcomes were excluded from the analyses.

MICE procedure

MICE is a flexible procedure that involves fitting a series of regression models to impute missing values, conditional on other variables in the data.[1] Each variable with missing data is modelled according to its distribution meaning MICE can handle multiple variable types (e.g., continuous variables using linear regression, binary variables using logistic regression).

With MICE, missing data is imputed in several phases:[1]

- In the fill-in phase, missing values are initially imputed (filled-in) using a simple method, such as mean imputation, which provides an initial value for the iterative stages.
- In the imputation phase, the iterative stages begin, and the missing values are imputed one variable at a time, using a regression model based on the observed and filled-in values of other variables, which included all exposure, potential mediator, outcome, and confounder variables specified in the methods and additional auxiliary variables including the baseline marital status to a woman, and number of sexual partners in the past three or six months (Table S2). After each variable with missing data is imputed, the dataset is updated with these new values. The imputation phase is then repeated until the imputed values converge, and additional iterations produce minimal changes in their values.[1]

The whole process is repeated multiple times to create several imputed datasets. We imputed 40 datasets for each cohort. Analyses were then run on each of these and pooled across the imputed datasets to account for uncertainty in the imputation process. We conducted multiple imputation using the “mice” package in R.[2,3]

Inverse probability of censoring weights (IPCW)

To account for loss-to-follow-up, we included inverse probability of censoring weights (IPCW) in our analyses. At each study visit, for each participant we calculated a stabilised weight that was a ratio of the probability that the participant remained in the study up to that visit conditional on determinants of loss to follow-up, which included baseline confounders (age, gender, marital status, education, employment, sex worker status).[4] The weights were estimated using logistic regression models such that individuals who remained in the study but shared similar characteristics to those who were lost to follow-up received higher weights. By reweighting each participant this way, we constructed a "pseudo-population" that simulated what would have been observed if loss to follow-up had occurred, but randomly with respect to determinants of loss to follow-up.[4]

Text 6.4.4. Prevalence ratios of the association between reporting baseline SGM violence and violence at follow-up visits in the first 12 months

We estimated the prevalence ratios for the association between reporting baseline SGM violence and violence at any follow-up visit in the first 12 months of follow-up by estimating the proportion of participants in each cohort who reported violence at any follow-up visit who also reported baseline SGM violence, and the proportion who reported violence at any follow-up visit but did not report baseline SGM violence. The first proportion was calculated as the fraction of participants who reported baseline SGM violence (Patterns 3 and 4) who also reported violence at any follow-up visit (Pattern 4). The second proportion was calculated as the fraction who did not report baseline SGM violence (Patterns 1 and 2) who reported violence at any follow-up visit (Pattern 2).

In *CohMSM*, these proportions were 40% and 9%, respectively. In *HPTN 075*, they were 30% and 6%. In *Anza Mapema*, they were 53% and 17%.

To estimate the prevalence ratio, we divided the first proportion by the second.

Table 6.4.2. Baseline characteristics of participants in *CohMSM*, *HPTN 075*, and *Anza Mapema*, and loss to follow-up stratified by report of SGM violence at baseline or in the first 12 months of follow-up.

	CohMSM		*HPTN 075*		*Anza Mapema*		Overall	
Baseline characteristics	**Reported any SGM violence Yes (N=174)**	**No (N=451)**	**Reported any SGM violence Yes (N=127)**	**No (N=202)**	**Reported any SGM violence Yes (N=367)**	**No (N=263)**	**Reported any SGM violence Yes (N=668)**	**No (N=916)**
Age								
18-24	119 (68.4%)	274 (60.8%)	84 (66.1%)	135 (66.8%)	201 (54.8%)	164 (62.4%)	404 (60.5%)	573 (62.6%)
25 years or older	55 (31.6%)	177 (39.2%)	43 (33.9%)	67 (33.2%)	166 (45.2%)	99 (37.6%)	264 (39.5%)	343 (37.4%)
Gender identity								
Cisgender man (MSM)	60 (34.5%)	296 (65.6%)	94 (74.0%)	177 (87.6%)	333 (90.7%)	243 (92.4%)	487 (72.9%)	716 (78.2%)
Transgender woman, non-binary, or other (TGW)	114 (65.5%)	155 (34.4%)	31 (24.4%)	22 (10.9%)	31 (8.4%)	19 (7.2%)	176 (26.3%)	196 (21.4%)
Missing	0 (0%)	0 (0%)	2 (1.6%)	3 (1.5%)	3 (0.8%)	1 (0.4%)	5 (0.7%)	4 (0.4%)
Sexual identity								
Gay	91 (52.3%)	146 (32.4%)	80 (63.0%)	119 (58.9%)	238 (64.9%)	173 (65.8%)	409 (61.2%)	438 (47.8%)
Heterosexual, bisexual, or other	80 (46.0%)	300 (66.5%)	47 (37.0%)	83 (41.1%)	129 (35.1%)	90 (34.2%)	256 (38.3%)	473 (51.6%)
Missing	3 (1.7%)	5 (1.1%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)	3 (0.4%)	5 (0.5%)
Highest level of education								
None	7 (4.0%)	13 (2.9%)	3 (2.4%)	0 (0%)	4 (1.1%)	2 (0.8%)	14 (2.1%)	15 (1.6%)
Primary	16 (9.2%)	50 (11.1%)	39 (30.7%)	74 (36.6%)	77 (21.0%)	40 (15.2%)	132 (19.8%)	164 (17.9%)
Secondary	73 (42.0%)	168 (37.3%)	57 (44.9%)	81 (40.1%)	175 (47.7%)	146 (55.5%)	305 (45.7%)	395 (43.1%)
Higher	56 (32.2%)	154 (34.1%)	28 (22.0%)	45 (22.3%)	111 (30.2%)	75 (28.5%)	195 (29.2%)	274 (29.9%)
Missing	22 (12.6%)	66 (14.6%)	0 (0%)	2 (1.0%)	0 (0%)	0 (0%)	22 (3.3%)	68 (7.4%)
Current employment status								
Employed/student	140 (80.5%)	362 (80.3%)	67 (52.8%)	89 (44.1%)	316 (86.1%)	202 (76.8%)	523 (78.3%)	653 (71.3%)
Not employed	10 (5.7%)	22 (4.9%)	59 (46.5%)	109 (54.0%)	51 (13.9%)	61 (23.2%)	120 (18.0%)	192 (21.0%)
Missing	24 (13.8%)	67 (14.9%)	1 (0.8%)	4 (2.0%)	0 (0%)	0 (0%)	25 (3.7%)	71 (7.8%)
Current marital status to a woman								
Yes	10 (5.7%)	34 (7.5%)	4 (3.1%)	8 (4.0%)	42 (11.4%)	27 (10.3%)	56 (8.4%)	69 (7.5%)
No	142 (81.6%)	351 (77.8%)	123 (96.9%)	187 (92.6%)	325 (88.6%)	236 (89.7%)	590 (88.3%)	774 (84.5%)
Missing	22 (12.6%)	66 (14.6%)	0 (0%)	7 (3.5%)	0 (0%)	0 (0%)	22 (3.3%)	73 (8.0%)
Recent engagement in transactional sex								
Yes	72 (41.4%)	126 (27.9%)	37 (29.1%)	26 (12.9%)	269 (73.3%)	128 (48.7%)	378 (56.6%)	280 (30.6%)

Baseline characteristics	*CohMSM*		*HPTN 075*		*Anza Mapema*		Overall	
	Reported any SGM violence		Reported any SGM violence		Reported any SGM violence		Reported any SGM violence	
	Yes (N=174)	No (N=451)	Yes (N=127)	No (N=202)	Yes (N=367)	No (N=263)	Yes (N=668)	No (N=916)
No	102 (58.6%)	325 (72.1%)	87 (68.5%)	173 (85.6%)	98 (26.7%)	135 (51.3%)	287 (43.0%)	633 (69.1%)
Missing	0 (0%)	0 (0%)	3 (2.4%)	3 (1.5%)	0 (0%)	0 (0%)	3 (0.4%)	3 (0.3%)
Moderate-to-severe depressive symptoms (PhQ-9 ≥ 10), past 2 weeks								
Yes	50 (28.7%)	39 (8.6%)	29 (22.8%)	18 (8.9%)	128 (34.9%)	47 (17.9%)	207 (31.0%)	104 (11.4%)
No	124 (71.3%)	409 (90.7%)	97 (76.4%)	178 (88.1%)	239 (65.1%)	216 (82.1%)	460 (68.9%)	803 (87.7%)
Missing	0 (0%)	3 (0.7%)	1 (0.8%)	6 (3.0%)	0 (0%)	0 (0%)	1 (0.1%)	9 (1.0%)
Hazardous drinking (Audit-C ≥ 4)*								
Yes	32 (18.4%)	71 (15.7%)	73 (57.5%)	85 (42.1%)	192 (52.3%)	90 (34.2%)	297 (44.5%)	246 (26.9%)
No	106 (60.9%)	290 (64.3%)	43 (33.9%)	105 (52.0%)	77 (21.0%)	58 (22.1%)	226 (33.8%)	453 (49.5%)
Missing	36 (20.7%)	90 (20.0%)	11 (8.7%)	12 (5.9%)	98 (26.7%)	115 (43.7%)	145 (21.7%)	217 (23.7%)
Condom use**								
Yes	111 (63.8%)	270 (59.9%)	64 (50.4%)	115 (56.9%)	255 (69.5%)	205 (77.9%)	430 (64.4%)	590 (64.4%)
No	55 (31.6%)	135 (29.9%)	61 (48.0%)	75 (37.1%)	112 (30.5%)	55 (20.9%)	228 (34.1%)	265 (28.9%)
Missing	8 (4.6%)	46 (10.2%)	2 (1.6%)	12 (5.9%)	0 (0%)	3 (1.1%)	10 (1.5%)	61 (6.7%)
Number of sexual partners†								
0-2	62 (35.6%)	189 (41.9%)	95 (74.8%)	176 (87.1%)	196 (53.4%)	183 (69.6%)	353 (52.8%)	548 (59.8%)
3-4	43 (24.7%)	143 (31.7%)	27 (21.3%)	15 (7.4%)	93 (25.3%)	44 (16.7%)	163 (24.4%)	202 (22.1%)
5 or more	57 (32.8%)	103 (22.8%)	5 (3.9%)	7 (3.5%)	70 (19.1%)	26 (9.9%)	132 (19.8%)	136 (14.8%)
Missing	12 (6.9%)	16 (3.5%)	0 (0%)	4 (2.0%)	8 (2.2%)	10 (3.8%)	20 (3.0%)	30 (3.3%)
Lost to follow-up								
No	27 (15.5%)	64 (14.2%)	120 (94.5%)	182 (90.1%)	315 (85.8%)	204 (77.6%)	462 (69.2%)	450 (49.1%)
Yes	147 (84.5%)	387 (85.8%)	7 (5.5%)	20 (9.9%)	52 (14.2%)	59 (22.4%)	206 (30.8%)	466 (50.9%)

* Hazardous drinking was measured using the AUDIT-C, which assesses typical drinking frequency, rather than assessing alcohol use over a specific recall period.
** Condom use was measured at last sex with a man in *Anza Mapema* and *CohMSM*, and as consistent condom use with recent male partners in *HPTN 075*.
† Number of sexual partners was recorded over the past 3 months in *Anza Mapema* and *HPTN 075*, and the past 6 months in *CohMSM*, and related to male partners only in *Anza Mapema* and *CohMSM*, and male and female partners in *HPTN 075*.

Information on SGM violence at baseline or during the first 12 months of follow-up was missing for 6 participants in *Anza Mapema*.

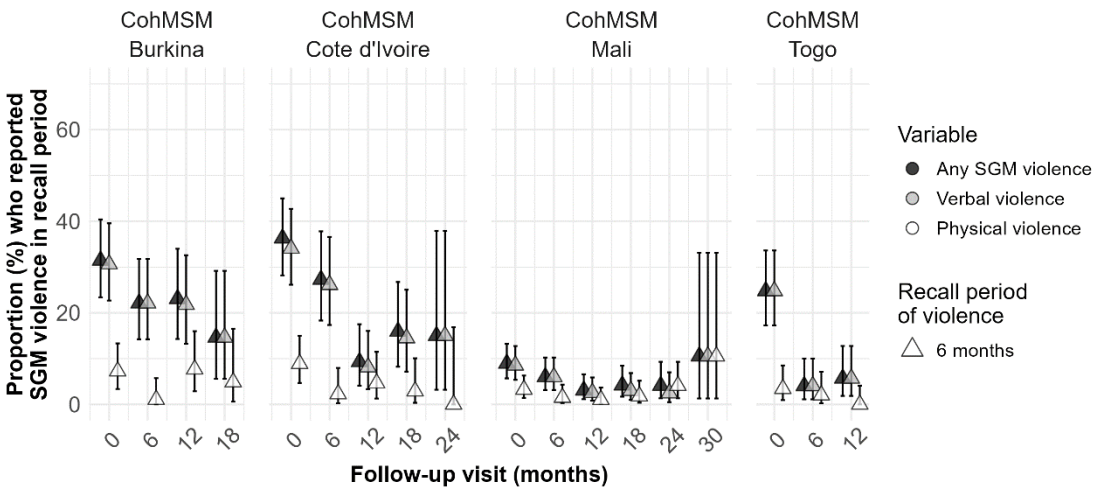

Figure 6.4.2. Prevalence of sexual and gender minority (SGM) violence in *CohMSM*, by study site.

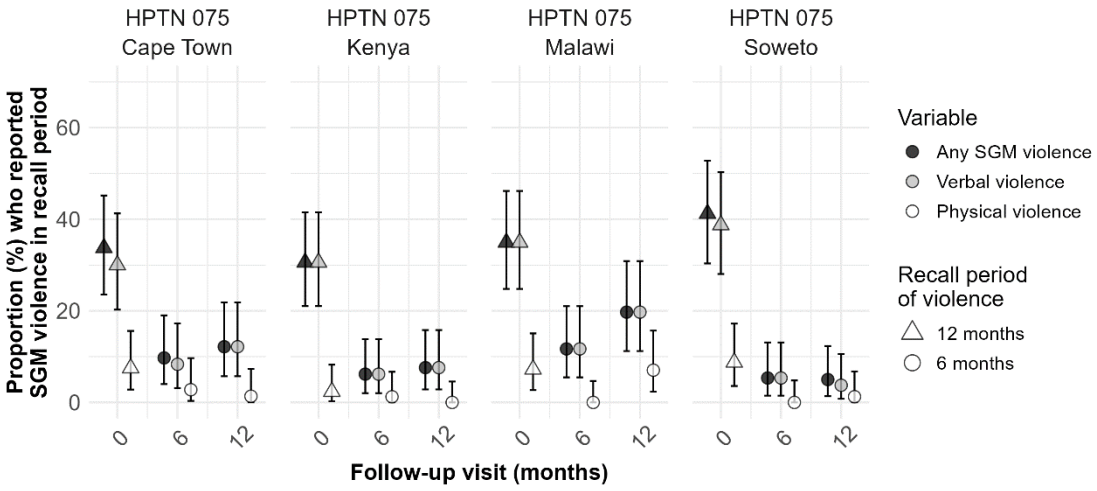

Figure 6.4.3. Prevalence of sexual and gender minority (SGM) violence in *HPTN 075*, by study site.

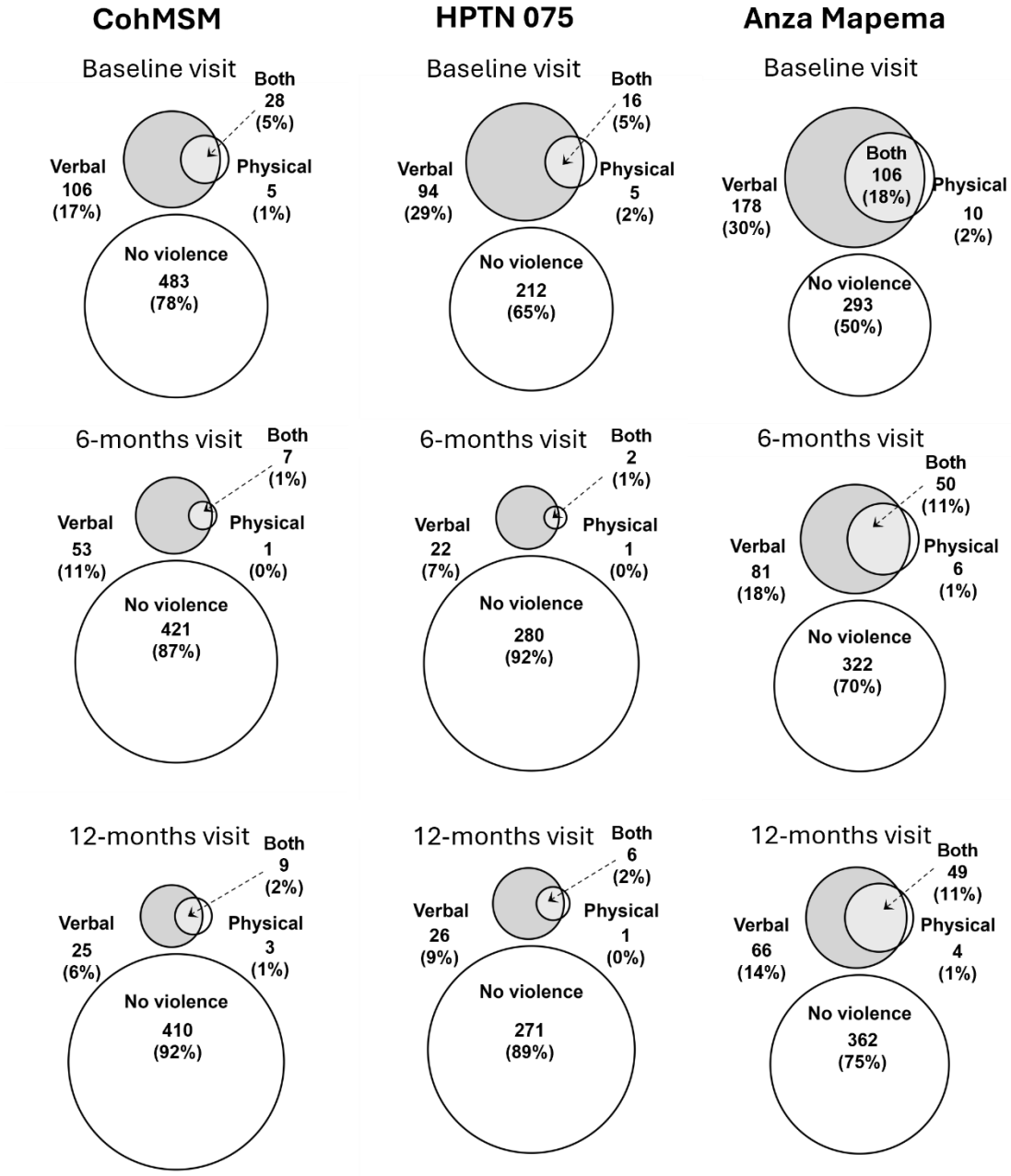

Figure 6.4.4. Venn diagrams showing the distribution of verbal and physical sexual and gender minority (SGM) violence reported at each study visit by SGM individuals at the baseline, 6-month, and 12-month visits in *CohMSM*, *HPTN 075*, and *Anza Mapema*. Values represent the number of individuals reporting verbal violence only (dark grey, left side of top circles), physical violence only (white, right side of top circles), or a combination of both (light grey, overlapping section of top circles) at each study visit, among those without missing SGM violence information.

Table 6.4.3. Perpetrators of physical SGM violence in *Anza Mapema*.

Perpetrator	n (%) of reports of physical violence N=236 reports
Unknown	68 (29%)
Friend	44 (19%)
Relative	23 (10%)
Acquaintance	32 (14%)
Client (among sex workers)	29 (12%)
Coworker (among sex workers)	27 (11%)
Other	8 (3%)
Missing perpetrator information	1 (0.4%)

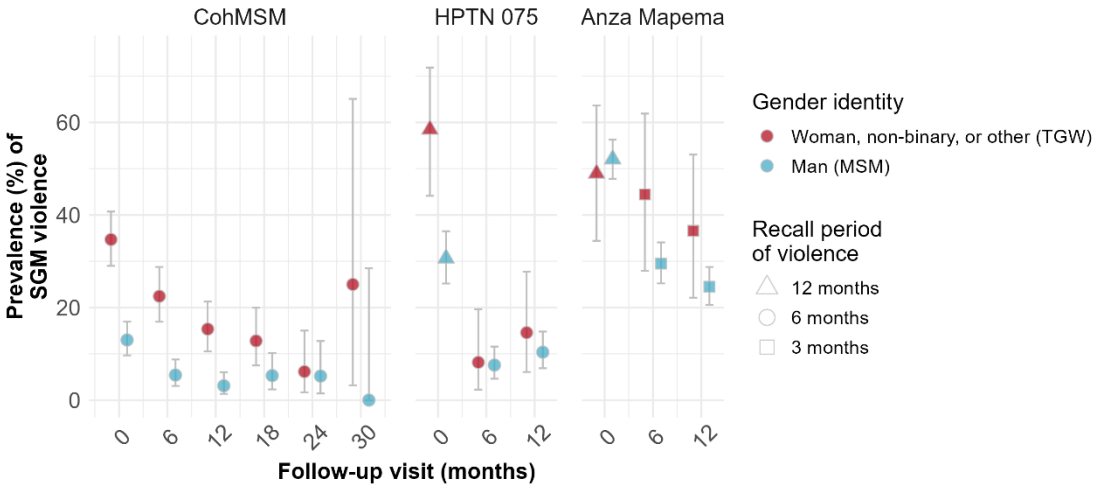

Figure 6.4.5. Prevalence of sexual and gender minority (SGM) violence in each cohort, by gender identity.

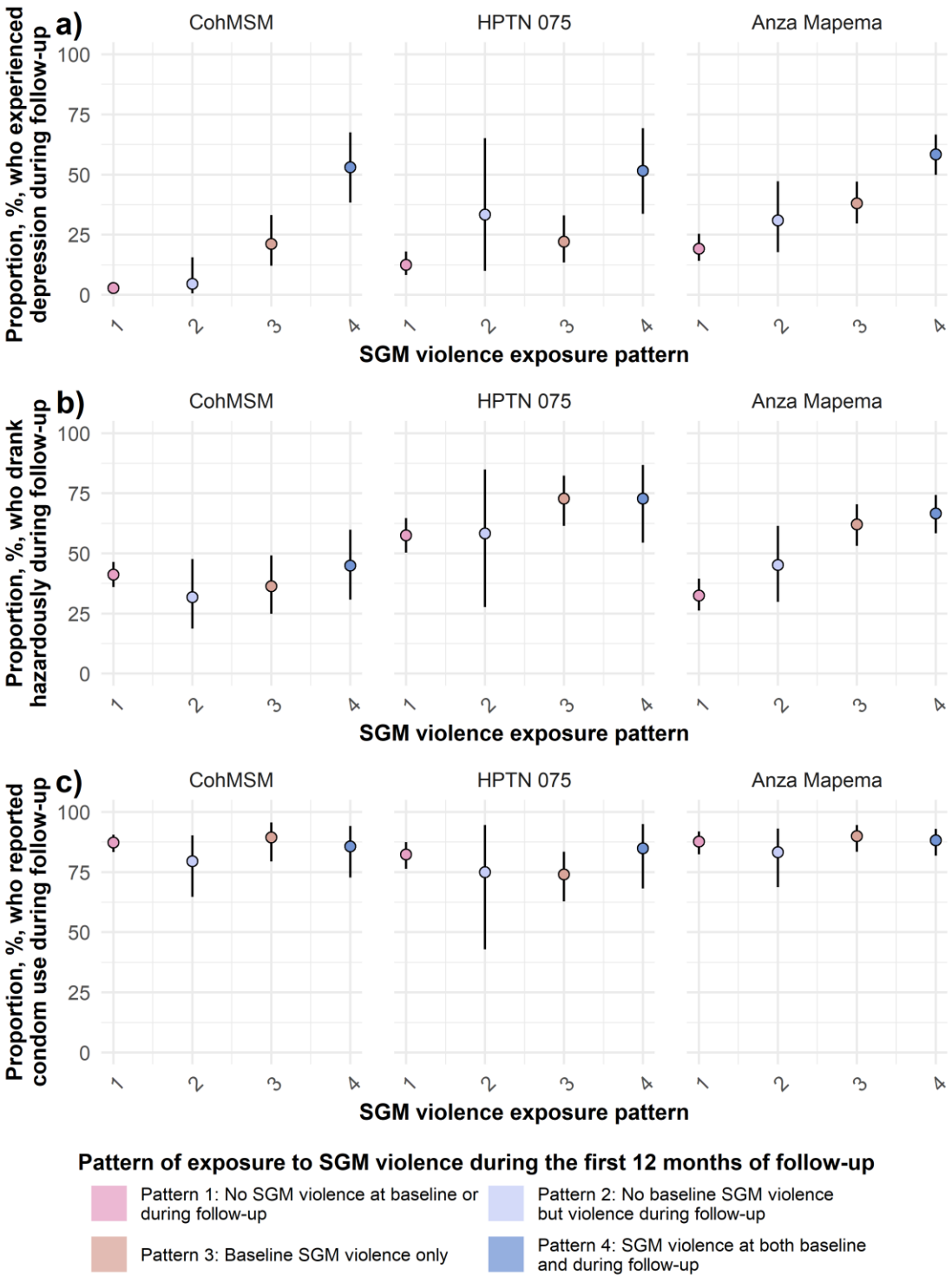

Figure 6.4.6. Proportion of participants who reported moderate-to-severe depressive symptoms, hazardous drinking, or condom use during follow-up in each cohort, by patterns of experiences of SGM violence, among participants with both baseline and follow-up SGM violence information (*CohMSM* N=508, *HPTN 075* N=301, *Anza Mapema* N=518). a) The proportion of participants who experienced moderate-to-severe depressive

symptoms (PhQ-9 ≥10) during follow-up, b) the proportion of participants who drank hazardously (Audit-C ≥4), and c) the proportion of participants who reported condom use (at last sex in *Anza Mapema* and *CohMSM*; consistently with up to three recent male sexual partners in the past three months in *HPTN 075*), by SGM violence pattern. In each plot, for those who experienced SGM violence (patterns 2, 3 and 4), proportions represent those experiencing depressive symptoms, hazardous drinking, or condom use at the same or subsequent visit to that at which SGM violence was reported (i.e., does not include those who only experienced depression before experiencing any violence).

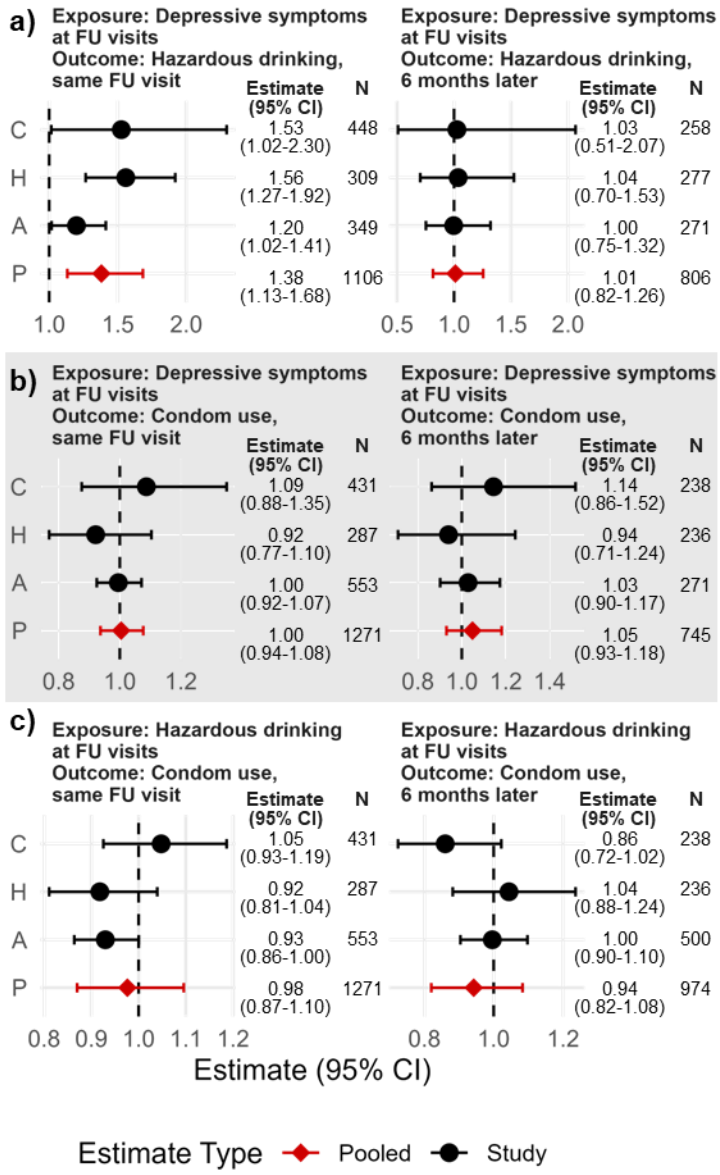

Figure 6.4.7. Forest plot of adjusted risk ratios (aRRs) linking potential mediators. Study and pooled estimates of aRRs and 95% confidence intervals (95% CI) linking a) moderate-to-severe depressive symptoms at follow-up visits with hazardous drinking, b) depressive symptoms with condom use, and c) hazardous drinking with condom use, at the same visit as exposure was assessed during follow-up, and at the follow-up visit six months later, in *CohMSM*, *HPTN 075*, and *Anza Mapema*. C=*CohMSM*, H=*HPTN 075*, A=*Anza Mapema*, P=*Pooled*, FU=*follow-up*. The vertical dashed line represents a null association (aRR=1). The pooled aRRs for condom use as the outcome do not include *HPTN 075*, in which condom use was defined differently (consistent condom use with up to three recent male partners in the past three months) from *CohMSM* and *Anza Mapema* (condom use at last sex).

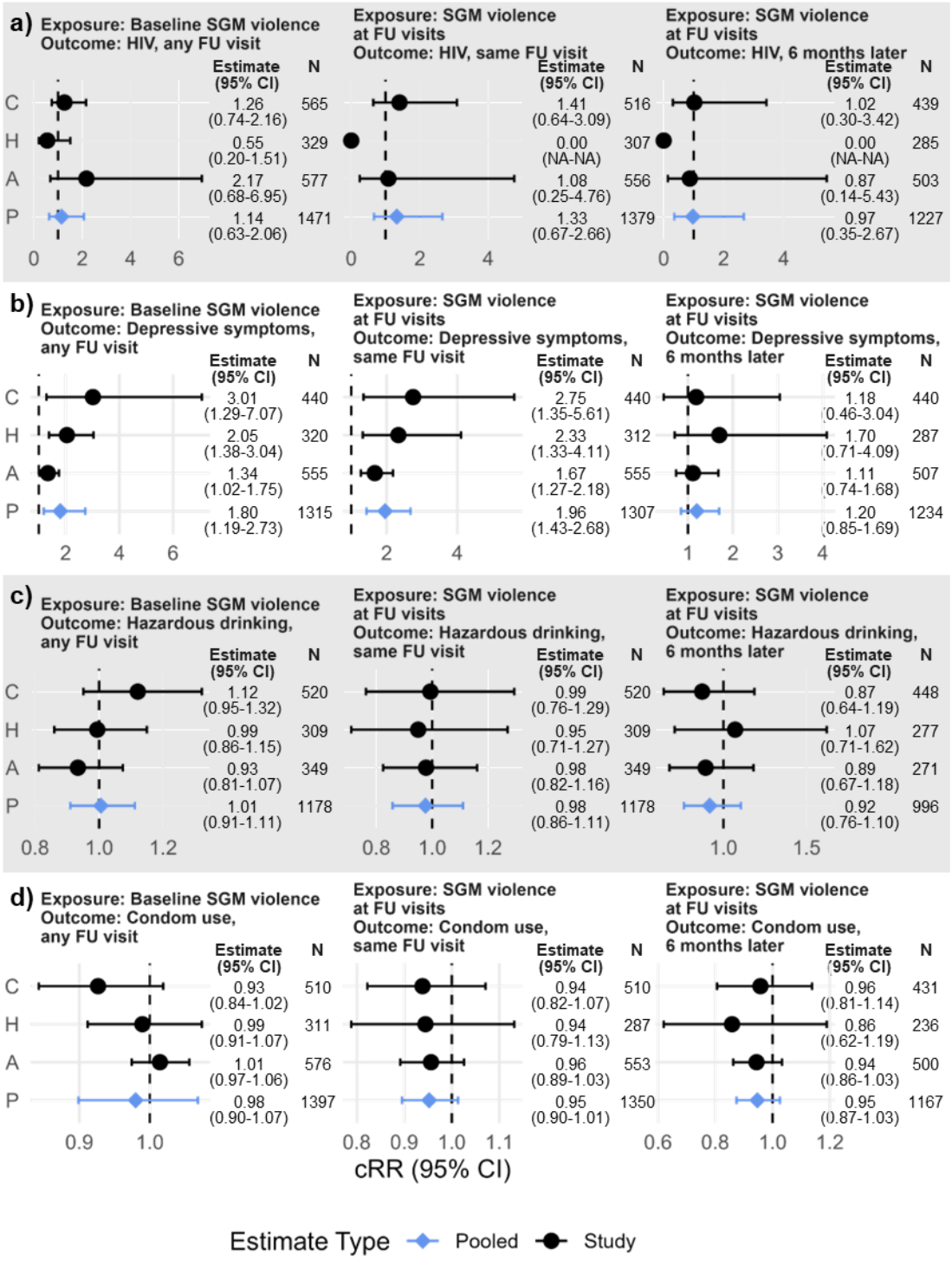

Figure 6.4.8. Forest plots of crude risk ratios (cRRs). Study and pooled estimates of cRRs and 95% confidence intervals (95% CI) linking SGM violence at baseline and at follow-up visits with a) HIV acquisition, b) moderate-to-severe depressive symptoms, c) hazardous drinking, and

d) condom use at any follow-up visit, the same visit as exposure was assessed during follow-up, and at the visit six months after exposure was assessed during follow-up, in *CohMSM*, *HPTN 075*, and *Anza Mapema*. C=*CohMSM*, H=*HPTN 075*, A=*Anza Mapema*, P=*Pooled*, FU=*follow-up*. The vertical dashed line represents a null association (cRR=1). *The pooled cRRs for SGM violence at follow-up visits on HIV acquisition do not include *HPTN 075*, as only one person who acquired HIV reported SGM violence during follow-up, therefore we could not estimate these associations for that cohort. The pooled cRRs for condom use also do not include *HPTN 075*, in which condom use was defined differently (consistent condom use with up to three recent male partners in the past three months) from *CohMSM* and *Anza Mapema* (condom use at last sex).

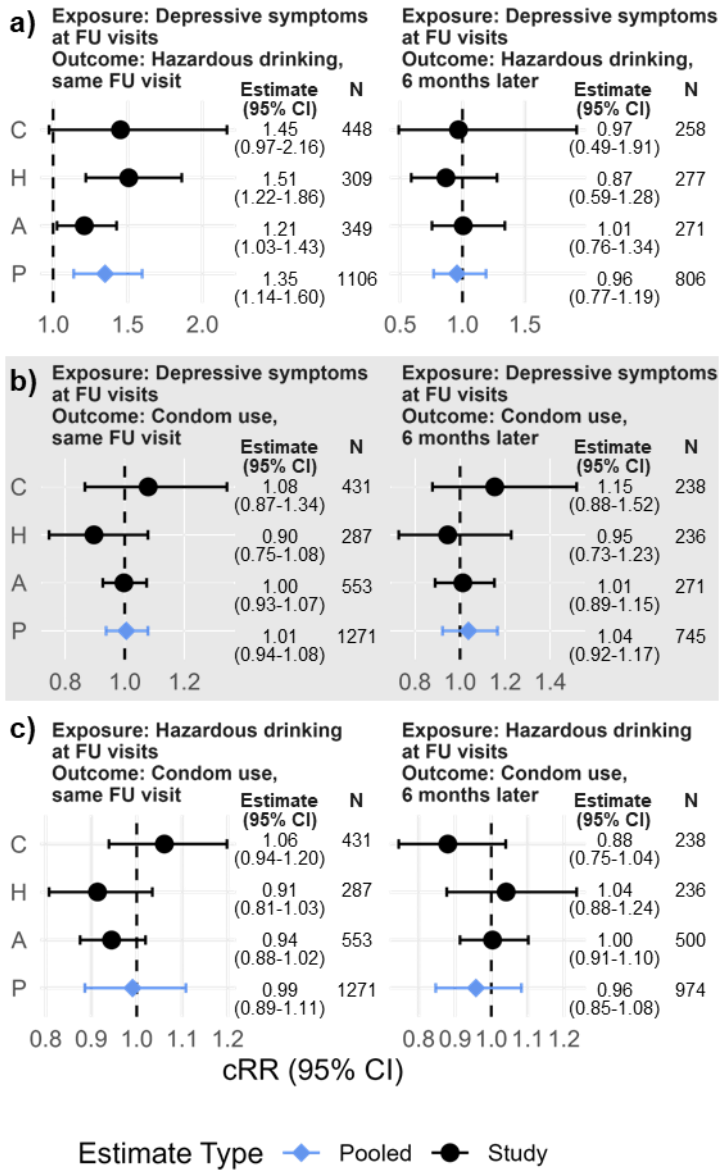

Figure 6.4.9. Forest plot of crude risk ratios (cRRs) linking potential mediators. Study and pooled estimates of cRRs and 95% confidence intervals (95% CI) linking a) moderate-to-severe depressive symptoms with hazardous drinking, b) depressive symptoms with condom use, and c) hazardous drinking with condom use, at the same follow-up visit as exposure was assessed, and six months later, in *CohMSM*, *HPTN 075*, and *Anza Mapema*. C=*CohMSM*, H=*HPTN 075*, A=*Anza Mapema*, P=*Pooled*, FU=*follow-up*. The vertical dashed line represents a null association (cRR=1). The pooled aRRs for condom use as the outcome do not include *HPTN 075*, in which condom use was defined differently (consistent condom use with up to three recent male partners in the past three months) from *CohMSM* and *Anza Mapema* (condom use at last sex).

Table 6.4.4. Study and pooled estimates of cRRs, stratified by gender identity in *CohMSM*, *HPTN 075*, and *Anza Mapema*.

Analysis	Cohort	MSM cRR (95% CI) for MSM	N of MSM	TGW cRR (95% CI) for TGW	N of TGW
Exposure: Baseline SGM violence **Outcome:** HIV, any FU visit	*CohMSM*	1.07 (0.35-3.28)	320	1.16 (0.61-2.20)	245
	HPTN 075	0.47 (0.13-1.61)	275	0.69 (0.10-4.92)	54
	Anza Mapema	2.89 (0.79-10.51)	530	0.00 (NA-NA)	47
	Pooled	**1.11 (0.41-3.00)**	**1125**	**1.10 (0.60-2.03)**	**346**
Exposure: SGM violence at FU visits **Outcome:** HIV, same FU visit	*CohMSM*	1.69 (0.50-5.68)	291	1.17 (0.44-3.14)	225
	HPTN 075	0.00 (NA-NA)	258	0.00 (NA-NA)	49
	Anza Mapema	1.21 (0.25-5.72)	511	0.00 (NA-NA)	45
	Pooled	**1.49 (0.57-3.87)**	**1060**	**1.17 (0.44-3.14)**	**319**
Exposure: SGM violence at FU visits **Outcome:** HIV, 6 months later	*CohMSM*	1.41 (0.18-10.88)	252	0.76 (0.17-3.28)	187
	HPTN 075	0.00 (NA-NA)	239	1.00 (0.37-2.68)	46
	Anza Mapema	0.92 (0.15-5.77)	462	1.00 (0.51-1.96)	41
	Pooled	**1.11 (0.28-4.36)**	**953**	**0.97 (0.57-1.63)**	**274**
Exposure: Baseline SGM violence **Outcome:** Depressive symptoms, any FU visit	*CohMSM*	1.36 (0.20-9.25)	256	3.55 (1.34-9.39)	184
	HPTN 075	2.05 (1.32-3.18)	268	1.47 (0.62-3.50)	52
	Anza Mapema	1.42 (1.06-1.90)	510	0.86 (0.48-1.55)	45
	Pooled	**1.63 (1.17-2.26)**	**1034**	**1.53 (0.69-3.43)**	**281**
Exposure: SGM violence at FU visits **Outcome:** Depressive symptoms, same FU visit	*CohMSM*	3.96 (0.88-17.95)	256	2.29 (0.97-5.37)	184
	HPTN 075	2.97 (1.49-5.92)	263	1.24 (0.52-2.94)	49
	Anza Mapema	1.63 (1.23-2.17)	510	1.77 (0.76-4.12)	45
	Pooled	**2.17 (1.28-3.69)**	**1029**	**1.72 (1.05-2.81)**	**278**
Exposure: SGM violence at FU visits **Outcome:** Depressive symptoms, 6 months later	*CohMSM*	1.33 (0.10-17.65)	256	1.08 (0.37-3.12)	184
	HPTN 075	2.08 (0.70-6.18)	241	1.27 (0.37-4.38)	46
	Anza Mapema	1.16 (0.75-1.80)	466	0.68 (0.30-1.54)	41
	Pooled	**1.26 (0.84-1.89)**	**963**	**0.89 (0.50-1.58)**	**271**
Exposure: Baseline SGM violence **Outcome:** Hazardous drinking, any FU visit	*CohMSM*	1.03 (0.78-1.36)	293	1.23 (0.98-1.54)	227
	HPTN 075	1.01 (0.87-1.18)	261	1.26 (0.70-2.26)	48
	Anza Mapema	0.91 (0.78-1.06)	318	1.12 (0.77-1.64)	31
	Pooled	**0.97 (0.88-1.07)**	**872**	**1.20 (1.00-1.45)**	**306**
Exposure: SGM violence at FU visits **Outcome:** Hazardous drinking, same FU visit	*CohMSM*	1.25 (0.83-1.87)	293	0.85 (0.61-1.17)	227
	HPTN 075	0.97 (0.73-1.30)	261	0.81 (0.27-2.44)	48
	Anza Mapema	0.97 (0.81-1.17)	318	0.98 (0.63-1.53)	31
	Pooled	**1.00 (0.87-1.16)**	**872**	**0.89 (0.68-1.14)**	**306**
Exposure: SGM violence at FU visits **Outcome:** Hazardous drinking, 6 months later	*CohMSM*	1.08 (0.69-1.70)	259	0.75 (0.51-1.10)	189
	HPTN 075	1.00 (0.64-1.57)	235	1.05 (0.27-4.08)	42
	Anza Mapema	0.87 (0.64-1.17)	247	1.01 (0.48-2.12)	24
	Pooled	**0.95 (0.76-1.18)**	**741**	**0.81 (0.58-1.13)**	**255**
Exposure: Baseline SGM violence **Outcome:** Condom use, any FU visit	*CohMSM*	0.93 (0.80-1.07)	285	0.93 (0.82-1.06)	225
	HPTN 075	1.01 (0.92-1.10)	260	0.99 (0.78-1.26)	51
	Anza Mapema	1.01 (0.97-1.05)	529	1.09 (0.95-1.26)	47
	Pooled	**1.00 (0.94-1.06)**	**1074**	**1.01 (0.86-1.18)**	**323**
Exposure: SGM violence at FU visits **Outcome:** Condom use, same FU visit	*CohMSM*	0.87 (0.69-1.10)	285	0.97 (0.82-1.14)	225
	HPTN 075	0.88 (0.71-1.09)	241	1.21 (0.94-1.56)	46
	Anza Mapema	0.95 (0.88-1.03)	508	0.95 (0.73-1.22)	45
	Pooled	**0.94 (0.88-1.01)**	**1034**	**0.96 (0.84-1.11)**	**316**
Exposure: SGM violence at FU visits	*CohMSM*	0.95 (0.71-1.28)	248	0.95 (0.76-1.19)	183
	HPTN 075	0.84 (0.58-1.22)	196	0.93 (0.49-1.77)	40

Outcome: Condom use, 6 months later	*Anza Mapema*	0.95 (0.86-1.05)	459	0.84 (0.65-1.07)	41
	Pooled	**0.95 (0.87-1.04)**	**903**	**0.90 (0.76-1.06)**	**264**
Exposure: Depressive symptoms at FU visits **Outcome:** Hazardous drinking, same FU visit	*CohMSM*	1.57 (0.69-3.57)	259	1.39 (0.88-2.21)	189
	HPTN 075	1.43 (1.14-1.79)	261	1.97 (1.14-3.42)	48
	Anza Mapema	1.19 (1.00-1.42)	318	1.59 (0.83-3.04)	31
	Pooled	**1.29 (1.10-1.53)**	**838**	**1.60 (1.18-2.18)**	**268**
Exposure: Depressive symptoms at FU visits **Outcome:** Hazardous drinking, 6 months later	*CohMSM*	0.62 (0.14-2.81)	143	1.29 (0.71-2.34)	115
	HPTN 075	0.96 (0.62-1.49)	235	0.93 (0.33-2.66)	42
	Anza Mapema	1.05 (0.78-1.42)	247	0.54 (0.24-1.25)	24
	Pooled	**1.01 (0.79-1.29)**	**625**	**0.92 (0.53-1.61)**	**181**
Exposure: Depressive symptoms at FU visits **Outcome:** Condom use, same FU visit	*CohMSM*	1.10 (0.71-1.70)	248	1.07 (0.83-1.37)	183
	HPTN 075	0.98 (0.79-1.21)	241	0.71 (0.51-1.01)	46
	Anza Mapema	0.98 (0.90-1.06)	508	1.20 (1.02-1.41)	45
	Pooled	**0.98 (0.90-1.06)**	**997**	**1.16 (1.01-1.33)**	**274**
Exposure: Depressive symptoms at FU visits **Outcome:** Condom use, 6 months later	*CohMSM*	1.05 (0.60-1.85)	129	1.17 (0.86-1.58)	109
	HPTN 075	0.86 (0.62-1.21)	296	1.28 (0.80-2.06)	40
	Anza Mapema	0.98 (0.85-1.13)	247	1.73 (0.95-3.17)	24
	Pooled	**0.99 (0.86-1.13)**	**672**	**1.30 (0.92-1.83)**	**173**
Exposure: Hazardous drinking at FU visits **Outcome:** Condom use, same FU visit	*CohMSM*	1.11 (0.95-1.31)	248	0.99 (0.82-1.20)	183
	HPTN 075	0.96 (0.84-1.10)	241	0.70 (0.49-0.99)	46
	Anza Mapema	0.94 (0.87-1.02)	508	0.99 (0.77-1.28)	45
	Pooled	**1.01 (0.86-1.19)**	**997**	**0.99 (0.85-1.15)**	**274**
Exposure: Hazardous drinking at FU visits **Outcome:** Condom use, 6 months later	*CohMSM*	0.83 (0.66-1.04)	129	0.96 (0.74-1.23)	109
	HPTN 075	1.00 (0.82-1.21)	196	1.23 (0.81-1.88)	40
	Anza Mapema	1.00 (0.91-1.11)	459	0.95 (0.74-1.23)	41
	Pooled	**0.94 (0.79-1.12)**	**784**	**0.95 (0.80-1.14)**	**190**

CI=confidence interval, cRR=crude risk ratio, FU=follow-up, MSM=men who have sex with men, N=number of participants, TGW=transgender women, non-binary people, and other

The pooled cRRs for SGM violence at FU visits on HIV acquisition do not include *HPTN 075*, as only one person who acquired HIV reported SGM violence during follow-up, therefore we could not estimate these associations for that cohort. The pooled aRRs for baseline SGM violence on HIV acquisition and for SGM violence on HIV at the same follow-up visit among TGW do not include *Anza Mapema*, as too few TGW acquired HIV and reported violence. The pooled aRRs for condom use (MSM and TGW) also do not include *HPTN 075*, in which condom use was defined differently (consistent condom use with up to three recent male partners in the past three months) from *CohMSM* and *Anza Mapema* (condom use at last sex).

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7. Chapter 7: Discussion and conclusions

7.1 Summary of findings

Structural determinants are complex social constructs and their population- and individual-level impacts on HIV transmission cannot be easily evaluated using empirical analyses of observational data. To combat inequalities and reduce the burden of HIV among key populations, the UNAIDS Global AIDS Strategy 2021-2026 committed to doubling investments in societal enablers that will "*break down barriers to achieving HIV outcomes*".(19) Despite these ambitious goals, efficient programming must understand the specific pathways through which structural determinants such as stigma and discrimination affect these HIV outcomes. As outlined in the UNAIDS Global AIDS Strategy, the new 10-10-10 targets require the "*same attention to technical details that has characterised the HIV response's programmatic efforts*" for the three 95 targets for diagnosis, treatment, and viral load suppression.(19) My thesis directly addresses this priority research area by consolidating the evidence and deepening our understanding of the impacts of structural determinants on HIV acquisition and transmission among SGM.

Mathematical models of HIV transmission have played a crucial role to guide HIV elimination efforts for a wide variety of biomedical interventions (e.g., treatment-as-prevention, prevention of vertical transmission, voluntary male medical circumcision, pre-exposure prophylaxis) and these modelling tools could be as important to assess the potential of structural interventions and guide their implementations.(22–27) In my first manuscript, I developed a novel conceptual framework and suggested ways to improve modelling efforts by explicitly considering important mediators that hinder engagement with HIV services or influence the practice of sexual risk behaviours. This conceptual framework was informed by a scoping review of mathematical modelling studies: I found 17 studies that had investigated the role of structural determinants on HIV. No model specifically examined stigma among SGM. Appraising these studies through a 'modelling lens', I developed a methodological framework to improve the representation of structural determinants in HIV transmission dynamics models. A key recommendation was that models be informed by improved data analysis of structural determinants and vulnerability to HIV. In Africa and elsewhere, however, it is challenging to

obtain representative data for SGM and other key populations and there have been no systematic attempts to collect these surveys in the region.

To overcome this constraint, in my second manuscript, I analysed observational studies to describe inequalities in HIV incidence and engagement with the HIV treatment cascade among SGM, focusing on men who have sex with men in Africa. My findings reveal a high HIV incidence rate (7 per 100 person-years), which does not appear to be decreasing (IRR per year = 1.0) despite substantial incidence reductions among non-key populations. Specifically, I found that HIV incidence could be 27 times higher in eastern and southern Africa (where epidemics have previously been categorised as generalised) and 199 times higher in central and western Africa (where epidemics have been categorised as concentrated) compared to the average national incidence among all men. A recent re-analysis of my results incorporating MSM population size estimates and HIV prevalence produced similar findings (22 and 142 times higher, respectively).(49). In addition, I showed that, despite increases in HIV testing and treatment, one in three MSM living with HIV was not able to achieve viral suppression in 2020, and gaps in all 95-95-95 targets were identified, particularly for knowledge of status (51% of MSM living with HIV being diagnosed in 2020).

In my third manuscript, I examined the impacts of sexual and gender minority violence (SGM violence) on HIV incidence, depression, hazardous drinking, and sexual risk behaviours among SGM, using data from three cohort studies found in my earlier systematic review. SGM violence was common, and across all studies, one in three SGM experienced violence in the past six or 12 months at baseline, and one in five experienced violence during the first 12 months of follow-up (recall: past three or six months). My findings revealed that verbal and/or physical violence perpetrated against SGM because of their sexual or gender identity or behaviours increased the risk of depression at subsequent follow-up visits (pooled RR = 1.5). Depression was linked to hazardous drinking at the same visit (pooled RR = 1.4). Violence was also weakly associated with reduced condom use at the same visit (violence pooled RR = 0.95). These findings strengthen previous evidence connecting violence with adverse mental health outcomes and sexual behaviours among SGM in Africa.(130) However, the total effect of SGM violence on HIV acquisition was inconclusive, primarily due to the high uncertainty stemming from the small number of new violence experiences during follow-up. Nevertheless, mine is one of the first

studies to estimate the impacts of SGM violence as a standalone exposure variable in Africa longitudinally.

7.2 Strengths and limitations

Limitations

The findings of my thesis should be interpreted considering the following limitations. Firstly, few models have explored structural determinants among SGM. In my first manuscript, SGM were included in only two models, but were not the target population for the structural determinants examined. Observational studies among SGM face challenges including that SGM can be a 'hidden' population due to high stigma, and HIV programmes may struggle to effectively engage SGM in research initiatives.(191) In my second and third manuscripts, to address challenges in accessing SGM populations, observational studies employed different eligibility criteria and recruitment methods to enroll SGM. However, this can make it difficult to precisely compare estimates across the different study populations in empirical studies and in modelling studies that rely on this data. Most studies used non-representative sampling methods, predominantly convenience sampling, including the cohort studies in my third manuscript. Consequently, sampled populations of SGM may not have fully represented their broader target populations. This could have led to over- or underestimation of my pooled estimates of HIV incidence and engagement with the treatment cascade in my second manuscript, although does not impede the internal validity of the findings of my third manuscript. Although I appraised the quality of the studies included in my second manuscript, I did not exclude the more limited studies, which may have further influenced my pooled estimates.

An important limitation of research among SGM is that many studies fail to separately examine the experiences and outcomes of TGW as distinct from MSM. Although TGW have sometimes been grouped with MSM in HIV research due to overlapping sexual behaviours, TGW experience distinct vulnerabilities related to their gender, and their sexual networks often differ from those of MSM.(189) To address the inclusion of TGW in MSM studies, I focused on including data specifically for MSM in my second manuscript, where applicable, aligning with the manuscript's emphasis on MSM. In my third manuscript, due to the limited sample sizes, I estimated my outcomes for the combined study populations of MSM and TGW, which I defined

collectively as sexual and gender minorities (SGM) assigned male sex at birth.(192,193) It has been argued that researchers should adopt more nuanced language to discuss members of sexual and gender minorities.(60) Therefore, in my third manuscript, I also conducted stratified analyses among MSM and TGW separately, where possible, although there was not sufficient information for TGW to produce all estimates for this population. More information for TGW and other sexual and gender minority groups is urgently needed.

The measurement of structural determinants poses challenges, which hinders their inclusion in mathematical modelling and observational studies, particularly when investigating their impacts on HIV outcomes.(194,195) A key concern is that observational studies may violate the consistency assumption (i.e., that the potential outcome for an individual under a specific exposure is the same as the outcome that is actually observed under that exposure), leading to biased estimates of causal effects.(196) This occurs because observational studies often fail to explicitly specify the structural interventions that are being compared, and different interventions to reduce structural determinants such as stigma among SGM – decriminalisation, changing norms, community-led services, counselling – could have different effects on HIV because the mediators involved are different for each type of intervention.(196) This complicates, but does not necessarily preclude, the interpretation of causal estimates.(197,198) In addition, the studies included in my third manuscript employed varied wording for questions on SGM violence and did not consistently use the same recall periods, which may have influenced the estimates.(199) To minimise potential bias, I harmonised measures of SGM violence across studies as much as possible.

Lastly, residual confounding of the effect of SGM violence on HIV acquisition and potential mediating variables could have influenced the findings of my third manuscript. For example, I did not account for time-varying confounders. Nevertheless. I adjusted for baseline confounders that were assumed to be largely stable over time, and my analyses focused on only one or two follow-up visits per individual, which were generally within a year of baseline. This approach therefore assumed that baseline confounders captured most of the heterogeneity in exposures and outcomes.

Strengths

Despite the above limitations, my thesis has several strengths. The conceptual framework developed in my first manuscript is among the first to clearly link structural determinants, their pathways, and mediators to HIV acquisition and transmission to inform the next generation of HIV models. I integrated this framework with mechanistic modelling of structural determinants and HIV transmission dynamics, informed by a scoping review of 17 modelling studies and diverse expertise in epidemiological methods and mathematical modelling.

In my second manuscript, I conducted one of the most exhaustive systematic reviews of SGM in Africa to date, encompassing all observational studies with data on HIV incidence, testing, and the treatment cascade. I included information from 152 studies involving over 47,000 SGM across 31 African countries and spanning nearly two decades of research. I developed robust Bayesian meta-regression models that helped uncover trends while appropriately quantifying uncertainty around pooled estimates. The studies analysed in my third manuscript were also identified through this review.

In my third manuscript, I conducted longitudinal data analysis, and conducted detailed analysis of the impacts of SGM violence experienced at baseline or during follow-up. I employed innovative statistical methods in my analyses that allowed me to consider links between baseline experiences of violence and subsequent events. These methods could be applied similarly to other structural determinants. The individual participant data meta-analysis allowed me to harmonise analyses as much as possible by using a standardised methodology for each cohort to uncover the links between SGM violence and HIV, while controlling for relevant confounders.

7.3 Implications

My thesis has important implications for HIV elimination efforts among SGM, as structural determinants can hinder progress and perpetuate inequities. UNAIDS has proposed ambitious societal enablers targets (i.e., the 10-10-10) to address these but their anticipated impacts among different key populations, including SGM, are difficult to estimate. My thesis provides a toolkit to improve mathematical modelling of structural determinants using longitudinal data. The frameworks developed in my first manuscript can guide analyses of structural determinants and their impacts on HIV among SGM and other key populations. The

framework has already been applied to a modelling study of violence among female sex workers.(200)

My findings suggest that we have a long way to go to reach the UNAIDS 95-95-95 targets for the HIV treatment and care cascade among SGM in Africa. The largest gaps exist at the knowledge of status and viral suppression stages. Structural barriers that delay HIV diagnoses and block ART adherence, including stigma, discrimination, and violence, which are common, could increase the risk of HIV acquisition among partners of SGM living with HIV.(138) These unmet prevention needs among SGM may contribute to sustaining transmission in the total population since many SGM also form sexual partnerships with women – between 23% and 58% as estimated in a recent systematic review.(56) Interventions for SGM in both concentrated and generalised epidemic settings in Africa may therefore have disproportionate benefits for the population at large, as well as protecting SGM and their sexual partners.

Many SGM in Africa report experiencing different types of SGM violence.(113) Reducing violence among SGM is an important goal in and of itself, but my findings also suggest that interventions that reduce SGM violence could protect the mental health of SGM. Interventions on violence could be integrated with HIV risk reduction counselling and health promotion, which has been shown to effectively reduce experiences of violence and the practice of sexual risk behaviours.(201) Embedding mental health services within sexual health services could also improve the uptake of services and address the syndemic of violence, mental health problems, and HIV and other STIs.(202,203) Additionally, interventions on SGM violence could also have benefits along pathways not explored in my analyses. For example, creating supportive environments for SGM and providing safe spaces to access HIV services – such as community-led initiatives and HIV self-testing – could help destigmatise the HIV care-seeking process and reduce the risk of violence, so that SGM are empowered to engage with services.(204,205) Sensitivity training for healthcare workers attending to SGM could reduce stigma (e.g., verbal SGM violence) and increase uptake of services.(206–209)

As countries strive to achieve the UNAIDS goals, it is crucial to also improve our understanding of and address the structural determinants that are upstream of SGM violence, such as legal and policy determinants of violence, for instance criminalisation, harmful social norms, and gender inequality, and building the evidence base on their impacts and interventions.

Worryingly, in some countries, such as Uganda, Nigeria, and Chad, laws and policies related to SGM are regressing(108,118,119) More punitive legislation is linked to worse HIV outcomes for SGM. For example, in an analysis of 44 sub-Saharan African countries, criminalised same-sex relationships were significantly associated with never having HIV tested (OR=0.5).(210) In my second manuscript, I estimated a similar association (OR=0.6), although with higher uncertainty. A more nuanced assessment of each country's legal landscape could provide deeper insights into the impacts of SGM-related criminalisation, beyond a simple comparison of whether laws criminalising same-sex partnerships are present or absent. Ultimately, to break the cycle of stigma, discrimination, and violence experienced by SGM, creating legal and policy environments that protect SGM are key to guarantee the success of HIV prevention and elimination up to 2030 and onward.

7.4 Conclusions

Ending HIV epidemics among key populations worldwide requires the consideration of structural determinants. In my thesis, I conceptualised, described, and analysed structural determinants of HIV among SGM. In Africa, where most countries criminalise same-sex sexual partnerships and stigma is widespread, HIV incidence among SGM remains significantly higher than among non-SGM. Many SGM living with HIV are unaware of their status, and many cannot access and adhere to HIV treatment. Pervasive stigma, discrimination, and violence faced by SGM in Africa not only exacerbates the risk of poor mental health outcomes but also poses a barrier to effective HIV prevention. Violence against SGM and other sexual and gender minorities constitutes a human rights violation. Ending violence is critical to protect SGM and safeguarding their well-being. Mathematical models that include structural determinants can contribute to this fundamental effort.

8. Chapter 8: References

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