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An HIV-1 risk assessment tool for men aged 15–59 years in 13 African countries: A pooled analysis of nationally representative surveys

Nora E. Rosenberg, PhD[1,§], **Amber M. Young, BS**[2], **Yating Zou, BS**[2], **Jessica Justman, MD**[3], **Manhattan E. Charurat, PhD**[4], **Sizulu Moyo, PhD**[5,6], **Khangelani Zuma**[5], **Linda-Gail Bekker, MD, PhD**[7], **Lynda Stranix-Chibanda, MMed**[8,9], **Sam J. Phiri, PhD**[10,11], **Nadia A. Sam-Agudu, MD**[12,13,14], **Marcel Yotebieng, PhD**[15], **Michael G. Hudgens, PhD**[2], **Benjamin H. Chi, MD**[16], **Bonnie E. Shook-Sa, DrPH**[2]

[1]Department of Health Behavior, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

[2]Department of Biostatistics, University of North Carolina at Chapel Hill, Chapel Hill, NC, USA

[3]ICAP at Columbia, Mailman School of Public Health, Columbia University, New York, NY USA

[4]Institute of Human Virology, University of Maryland School of Medicine, Baltimore, MD, USA

[5]Human Sciences Research Council, Pretoria, South Africa

[6]School of Public Health and Family Medicine, University of Cape Town, Cape Town, South Africa

[7]The Desmond Tutu HIV Centre, University of Cape Town, Cape Town, South Africa

[8]Child and Adolescent Health Unit, Faculty of Medicine and Health Sciences, University of Zimbabwe, Harare, Zimbabwe

[9]University of Zimbabwe Clinical Trials Research Centre, Harare, Zimbabwe

[10]Partners in Hope, Lilongwe, Malawi

[11]School of Global and Public Health, Kamuzu University of Health Sciences, Lilongwe, Malawi

[12]Global Pediatrics Program and Division of Infectious Diseases, Department of Pediatrics, University of Minnesota Medical School, Minneapolis, MN, USA

[13]Department of Paediatrics and Child Health, University of Cape Coast School of Medical Sciences, Cape Coast, Ghana

[14]International Research Center of Excellence, Institute of Human Virology Nigeria, Abuja, Nigeria

[§]**Corresponding author:** Nora E. Rosenberg, PhD, Department of Health Behavior | Gillings School of Global Public Health | UNC Chapel Hill, Campus Box 7440; Chapel Hill, NC 27599, United States, Nora_Rosenberg@unc.edu.

Author Contributions:

NER, BES, MGH, and BHC conceptualized the overall study and were responsible for the funding acquisition. The parent studies were conceptualized with data collection overseen by MC (NAIIS and ZAMPHIA-2021), SM and KZ (SABSSM) and JJ (all other PHIAs). BES, AY, and YZ analyzed the data, oversaw the development of tables and figures, and accessed and verified the underlying data. All authors reviewed and edited the manuscript and approved the final submission. NER and BES were responsible for the decision to submit for publication.

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The authors report no conflict of interest.

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[15]Division of General Internal Medicine, Department of Medicine, Albert Einstein College of Medicine, Bronx, NY, USA

[16]Department of Obstetrics and Gynecology, University of North Carolina at Chapel Hill, Chapel Hill NC, USA

Abstract

Background: Globally, approximately half of new HIV acquisitions occur among African adults. This analysis examines which African men are at highest risk of acquiring HIV-1 and in greatest need of HIV pre-exposure prophylaxis (PrEP).

Setting: National population-based surveys from Eswatini, Ivory Coast, Kenya, Lesotho, Malawi, Namibia, Nigeria, Rwanda, South Africa, Tanzania, Uganda, Zambia, Zimbabwe.

Methods: The thirteen surveys were pooled and sampling weights were applied to represent all susceptible men aged 15–59 years-old. HIV-1 incidence was calculated based on a recent HIV-1 testing algorithm. A least absolute shrinkage and selection operator (Lasso) regression model was fit with 28 variables to predict recent HIV-1. Models were trained and internally cross-validated to estimate area under the receiver-operating characteristic (ROC) curve (AUC). Along the ROC curve, at sensitivity levels from 10%-90%, performance tradeoffs were evaluated.

Results: Of 167,121 participants, 112 had recent HIV-1, representing 256,000 new annual infections among 122 million men. Only two variables were retained—reporting a male sexual partner and living in a subnational area where a high proportion of adults have detectable HIV-1 viremia. Overall AUC was 0.80 (95% Confidence Interval (CI): 0.71–0.89); cross-validated AUC was 0.76 (95% CI: 0.64–0.87). At 10% sensitivity, 25,000 cases could be averted if 357,000 men adhered to PrEP (Number Needed to Treat [NNT]=14). At 90% sensitivity, 229,000 cases could be averted if 50 million men adhered to PrEP (NNT=219).

Conclusion: This predictive, parsimonious, generalizable risk assessment tool could help policymakers weigh tradeoffs between PrEP reach and efficiency.

Keywords

HIV; prevention; Africa; risk score; viral suppression; pre-exposure prophylaxis

Introduction

Each year, Southern, Eastern, and West/Central Africa have accounted for a majority of the new annual HIV infections globally. (1–3) Adult cisgender men (hereafter referred to as men) account for approximately 40% of these African cases. (1, 4) Prevention is critical as men living with HIV-1 are less likely than cisgender women to engage in HIV care and achieve viral suppression (5) resulting in higher mortality, (6) and onward HIV transmission. (7) However, men have not been the primary focus of prevention efforts, especially pre-exposure prophylaxis (PrEP). (1)

Tenofovir-based daily oral PrEP is safe and effective, (8–11) but reach has been low. (1) Long-acting injectable PrEP (cabotegravir and lenacapavir) is even more effective

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than daily oral PrEP, but availability is limited. Determining who is in greatest need of PrEP—especially long-acting formulations—is an important public health question. Global guidance around this question has differed between institutions and evolved over time, underscoring the challenge. (12) The World Health Organization (WHO) guidance has shifted from narrow population groups (e.g. men who have sex with men, prisoners) to HIV incidence thresholds (e.g. 3 per 100 person years), to client-centered approaches. (13–15) UNAIDS emphasizes the importance of individual, partner, and population characteristics and recognizes regional variability. (16)

Risk assessment tools, (17, 18) models for predicting which individuals are at elevated risk of an outcome, are promising for identifying men at highest risk of HIV acquisition and in greatest need for PrEP. (19) Three tools have been developed for African men in the general population, (20–22) but these have important limitations regarding internal validity, implementation characteristics, and external validity. With respect to internal validity, area under the receiver-operating characteristic (ROC) curve (AUC), has been moderate (0.69–0.73). Two lacked community- and population-level variables, particularly a population-level HIV-1 viral non-suppression variable, a primary determinant of HIV acquisition, and instead used multiple individual-level items that can be difficult to operationalize at scale. External validity has also been limited, with tools developed in parts of one or two countries without external validation. (20) An implementable risk assessment tool with strong internal and external validity is needed to optimize PrEP access.

To address this gap, we sought to develop an HIV-1 risk assessment tool for men aged 15–59 from 13 African countries using machine learning. We then applied the model separately to Southern, Eastern, and West Africa and evaluated model performance.

Methods

Data Sources

Data sources were all available PEPFAR-supported African-based HIV-focused household surveys designed to estimate national HIV-1 incidence and other key HIV-related measures, specifically the 95–95-95 targets. We pooled data from 15 surveys collected from 2015–2019: the fifth South African National HIV Prevalence, Incidence, Behaviour, and Communication Survey (SABSSM-V), (23) the Nigeria HIV/AIDS Indicator and Impact Survey (NAIIS), (24) and 13 Population-based HIV Impact Assessment surveys (PHIAs). (25) Surveys came from Southern Africa (Eswatini, Lesotho, Malawi, Namibia, South Africa, Zambia, and Zimbabwe), Eastern Africa (urban Ethiopia, Kenya, Rwanda, Tanzania, and Uganda), and West Africa (Cameroon, Côte d'Ivoire and Nigeria). Surveys from Cameroon and urban regions of Ethiopia were excluded from most analyses because they lacked a question about sexual activity with male partners, a key variable of interest.

All protocols were approved by each in-country local ethics committees and other relevant institutional review boards. Adults 18 years and older provided informed consent. Adolescents 15–17 years-old provided assent after a parent or guardian granted permission. (26) For this analysis, we accessed publicly available de-identified data.

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Participants in all surveys completed an individual interview. Participants in 12 surveys provided venous blood for rapid HIV testing and measurement of HIV-1 biomarkers. (27) Participants in SABSSM-V provided dried blood spots for HIV-1 biomarkers. (23) Data were restricted to men aged 15–59 years-old who tested HIV-1 sero-negative in the survey or had recent HIV-1 infection (described below).

Outcome of interest

Recent HIV-1 infection was our primary outcome of interest. Except South Africa, which used laboratory testing only, all samples were tested for HIV-1 using each country's HIV rapid testing algorithm and confirmed with laboratory testing. (27) Among those with confirmed HIV, further assessments for recent HIV-1 infection were based on a cross sectional recent HIV-1 infection testing algorithm: laboratory-based limiting antigen-avidity EIA (LAg) normalized optical density values ≤ 1.5, HIV RNA ("viral load") of ≥1,000 copies/mL, and no qualitative detection of commonly prescribed antiretroviral agents. (28) HIV-1 seropositive individuals without recent HIV-1 infection were excluded.

Predictor variables

Twenty-eight individual, partnership, household, and epidemiologic characteristics were harmonized across surveys (Figure 1a–1d). Individual characteristics included age, educational level, marital status, number of wives, occurrence and age of sexual debut, prior HIV-1 testing, and circumcision. Sexual partnership characteristics included number of partners in the last year and whether any of the last three partners was non-steady, transactional, or male; had an unknown HIV status; lived outside the participant's home; and used a condom at the last encounter. Household variables included urbanicity, number of household members and bedrooms, wall material, water source, toilet type, and item ownership. Three epidemiologic variables were calculated based on survey data from all men and women aged 15–59 years in 208 subnational areas and then applied to each observation (Supplement 1). HIV-1 prevalence was defined as the proportion of adults living with HIV-1 (range=0%-31%). HIV-1 viremia among adults living with HIV (ALHIV HIV-1 viremia) was the proportion of ALHIV with HIV RNA >1000 copies/mL (range=0%-100%). Population HIV-1 viremia was the proportion of the full adult population with HIV-1 RNA >1000 copies/mL (range=0–11%). A map of population HIV-1 viremia has been published. (29) Variables were standardized to have a mean of zero and a standard deviation of one prior to model fitting.

Statistical analysis for model development and internal validation

Methods closely follow those used to develop a similar risk assessment tool for women. (29) Supplement 2 provides details on statistical analyses, with a summary provided here. Surveys used a two-stage stratified cluster sample design, which was accounted for in all analyses through incorporation of sampling weights, strata, and clusters. For the data from each national survey, sampling weights were constructed to draw inference to all men aged 15–59 susceptible to HIV-1. Survey data were pooled so that sampling weights summed to population totals by country and age group. Thus, the weighted results represent all men aged 15–59 years who were susceptible to HIV-1 in these 13 countries. Analyses were

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conducted using SAS version 9.4 (SAS Institute, Cary, NC) and R version 4.2.0 (Vienna, Austria).

Incidence rates were estimated using a cross-sectional recent HIV infection testing algorithm (Supplement 2). The algorithm includes the number of recent HIV-1 infections, number of HIV-1 sero-negative individuals, mean duration of recent infection, assay cutoff time, and proportion of false positive recent cases. (4) Incidence rate estimates were computed using the *inctools* package in R. For incidence rates and bivariate analyses, variances were estimated using Taylor Series Linearization and used for the construction of 95% confidence intervals (CIs). Missing data for each variable was sparse (0%-5.2%), though 17.8% of observations had ≥1 missing value. Missing values were imputed using multiple imputation by chained equations. (30) The outcome, predictors, and sample design features were included in multiple imputation models. (31) From the weighted imputed datasets, we estimated the proportion of men within each level of each predictor, the percentage of men with recent HIV-1 infection, and odds ratios (approximating incidence rate ratios) with corresponding 95% CIs.

To develop a risk assessment tool, weighted logistic Least Absolute Shrinkage and Selection Operator (Lasso) regression models were applied to the pooled dataset. To avoid over-fitting, five-fold cross validation was used to identify the tuning parameter that maximized the AUC within a 2% tolerance. (32) From the final Lasso model, an overall AUC was estimated by applying the model to the full dataset. The relative importance of the final predictors was estimated by the absolute value of the Lasso model's coefficients. An additional five-fold cross validation was used to internally validate the model's AUC. Predictive performance was gauged by the AUC.

Based on the Lasso model, at four sensitivity thresholds (10%, 30%, 70% and 90%) the following quantities were estimated: specificity, number of men prioritized for PrEP, HIV-1 incidence rate among men prioritized for PrEP, and number of men needed to treat (NNT) with PrEP to avert one infection. Annual infections averted were estimated, assuming perfect one-year PrEP effectiveness, which was an upper bound. For all performance metrics, corresponding 95% CIs were constructed based on the Rao-Wu rescaling bootstrap. (33) We also did not account for additional infections averted due to onward transmissions.

Sensitivity analyses

Two sensitivity analyses were conducted. First, logistic regression using a backward elimination approach was applied. Based on the estimated bivariate associations between each variable and recent HIV-1 infection, variables with Wald-test p-values <0.05 were included in the initial backward regression model, and then removed individually based on Wald tests, conditional on inclusion of other predictors, until all remaining predictors had p-values ≤0.05. Second, a weighted random forest model was fit to the data. Parameters were tuned to maximize the out of bag five-fold cross validated weighted AUC. For both methods, overall and cross-validated AUCs were estimated.

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Results

Study sample

The unweighted 13-country analytic sample comprised 167,121 men aged 15–59 and represented a target population of all 122 million susceptible men in this age range across these 13 countries between 2015 and 2019. Approximately 22% of the target population came from Southern Africa, 31% from Eastern Africa, and 47% from West Africa (Table 1). In the sample, 112 (0.1%) had recent HIV-1, representing an estimated 256,000 (CI: 160,000–353,000) new annual infections in the target population. The HIV-1 incidence rate was 0.21 per 100 PYs (95% CI: 0.13–0.30) overall: 0.57 per 100 PYs in Southern Africa (95% CI: 0.24–0.91), 0.21 per 100 PYs in Eastern Africa (95% CIs: 0.12–0.30), and 0.05 per 100 PYs in West Africa (95% CI: 0.02–0.08).

Bivariate analysis

In bivariate analysis, at an alpha level of 0.05, two individual characteristics were associated with recent HIV-1 infection: occurrence of sexual debut and prior HIV testing (Figure 1). Partner characteristics associated with recent HIV-1 were number of sexual partners, having a partner living outside the home, condom use, and reporting a male sexual partner. Four household characteristics were associated with recent HIV-1: wall material, number of household members, water source, and vehicle ownership. All three HIV-1 epidemiologic variables were associated with recent HIV-1. HIV-1 prevalence and population HIV-1 viremia were highly correlated and associated with recent HIV-1 in a dose-response relationship.

Lasso results

Only two of 28 variables were retained in the Lasso model: living in an area with high subnational prevalence of HIV-1 viremia and having a male sexual partner. Of the two variables, reporting a male sexual partner had slightly greater importance. AUC was 0.80 (0.71–0.89) (Figure 2) and cross-validated AUC was 0.76 (0.64–0.87). When applied to each subregion, overall AUC was 0.64 in Southern Africa, 0.76 in Eastern Africa, and 0.63 in West Africa.

Based on the full-population Lasso model, we examined tradeoffs between reach (cases averted) and efficiency (NNT) at four sensitivity levels along the ROC curve from 10% to 90% (Table 2). Preventing more infections required more men on PrEP and worse efficiency. At a sensitivity of 10%, 357,000 men would be prioritized for PrEP with an HIV-1 incidence of 7.0 per 100 PYs (95% CI: 0.0–15.7). If these men were perfectly adherent, up to 25,000 cases could be averted each year, and NNT would be 14. At the other extreme, a sensitivity of 90%, 50.2 million men (41% of all susceptible adult men) would be prioritized for PrEP; if these men were perfectly adherent, most new HIV-1 infections (N=229,000 cases) could be averted, but NNT would be 219.

We mapped which men would be prioritized for PrEP at each sensitivity threshold (Figure 3). At a sensitivity of 10%, PrEP would be prioritized exclusively for men who have sex with men (MSM): nearly all MSM in Southern Africa, many MSM in Eastern Africa, and

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few MSM in West Africa. To prevent 90% of new infections, PrEP would be offered to nearly all men aged 15–59 years in Southern Africa, a subset of MSM and other men in Eastern Africa, and all MSM in Western Africa.

15-country model

The surveys in Cameroon and Ethiopia were excluded from the main analyses because they did not include a question about having a male sexual partner. In a 15-country Lasso model that included 27 of the 28 variables, only population HIV-1 viremia was retained. Both the overall AUC and cross-validated AUC were 0.78, similar to the main model. However, the prioritization map was different. (Supplement 3).

Sensitivity Analyses

Predictive performance of both backwards regression and the random forest approaches was similar to the Lasso models, but less parsimonious. With backwards regression, six variables were retained, including living in an area with high HIV-1 prevalence and reporting a male sexual partner. Overall AUC was 0.83; cross-validated AUC was 0.74 (Supplement 4). The random forest model retained 26 of 28 candidate predictors and achieved an overall AUC of 0.87 and a cross-validated AUC of 0.77 (Supplement 5). In both models, higher overall AUC relative to cross-validated AUC may be due to overfitting.

Discussion

We applied a machine learning model to nationally representative survey data from 13 African countries to identify men at highest risk of HIV-1 acquisition who would benefit most from PrEP. In the resulting risk assessment tool, only two variables were needed to identify which men were most likely to acquire HIV-1: having a recent male sexual partner and living in an area with a high prevalence of HIV-1 viremia. This risk assessment tool was more generalizable than prior work, had stronger predictive performance, and was parsimonious. Nonetheless, there were tradeoffs between reach and efficiency.

Due to the representative survey designs, our analyses had strong external validity, generalizing to an extremely broad population: 122 million men aged 15–59 years across Southern, Eastern, and West Africa. In contrast, prior tools were derived from narrow subregions in one or two countries (20–22) and only included populations with very high HIV-1 incidence (≥1 per 100 PYs). Our tool was developed in a population with an HIV-1 incidence several times lower: 0.2 per 100 PYs, where risk targeting is more important. (4) Our findings generalize to a broad range of African epidemiologic contexts.

This risk assessment tool does not include characteristics that were unmeasured or localized, an important set of limitations. For example, having other sexually transmitted infections is a known risk factor for HIV acquisition, but these biomarkers were not collected across the PHIA surveys. Similarly, certain characteristics, such as driving a truck, working in the fishing industry, or being a migrant, are known risk factors in certain regions, but do not generalize across the continent. Our analysis did not capture these local factors. Incorporating facts and local knowledge atop these findings is important.

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The broad epidemiologic diversity permitted examination of characteristics across the region. Population HIV-1 viremia, the proportion of adults aged 15–59 years-old with detectable HIV-1 virus, was one of two variables retained in the Lasso model. The importance of this variable reinforces a well-established fact: HIV-1 transmission stems from people with circulating virus, not from people who are virally suppressed. (7, 34–36) One of the prior male risk assessment tools also found population HIV-1 viremia to be highly predictive of HIV incidence; (21) it was also the strongest predictor of HIV-1 incidence in an analogous tool for women, published by our group. (29) This finding has two implications. First, PrEP risk assessment tools may need to focus PrEP in areas with high overall population HIV-1 viremia. Second, the availability and accessibility of antiretroviral therapy remains a key priority not only for treatment but also for HIV-1 primary prevention.

Population HIV-1 viremia is not static, but rather a product of the adult HIV-1 prevalence and the proportion of adults living with HIV who are virologically unsuppressed. In seven countries with subsequent surveys conducted in 2020–2023 (Eswatini, Lesotho, Malawi, Tanzania, Uganda, Zambia, Zimbabwe), population HIV-1 viremia declined due to improved treatment coverage. Despite these declines, variation in population HIV-1 viremia persisted, and we expect our model to remain predictive to a wide range of scenarios. We plan to conduct an external temporal validation to examine this question in a future publication.

Our findings underscore the importance of prioritizing MSM for PrEP. In this representative sample, MSM had extraordinarily high HIV incidence, 25 times that of other men. These findings are comparable to a meta-analysis (37) and a systematic review which found MSM to have the highest HIV-incidence rate of any African sub-population. (38) In our main model, at the lowest sensitivity threshold, PrEP was recommended exclusively for MSM. At the next threshold (30%), PrEP was recommended for most MSM, and a small proportion of other men. Our research highlights the need to support African MSM to safely and confidentially access PrEP. Such services are needed not only for those who are openly gay, but also those with concealed sexual identities. This concealment likely occurred in these surveys where fewer than 1% of men reported sexual activity with other men. Hostile socio-legal climates and restriction to the three most recent sexual partnerships likely led to underestimation of MSM activity. (39)

Limited detail about sexual and gender identity in the surveys is a limitation. We omitted data from Cameroon and Ethiopia from the main analysis as these surveys did not include questions about male same-sex behavior. There was also an absence of gender identity questions across surveys. These omissions may reflect the stigma, discrimination, and, in some cases, criminalization around non-heteronormative sexual behaviors and non-binary gender identities.

The combination of a small fraction of men reporting MSM behaviors along with the small proportion of men with recent HIV-1 is a limitation. Although our model was trained on approximately 167,000 observations, there were only 112 men with recent HIV-1 and 882 men reporting a male sexual partner in the prior 12 months. The small number of events and sparsity of the key predictor made it challenging to examine national or even regional trends.

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Our model's overall AUC value of 0.80 was higher than the values from prior risk assessment tools, (20–22) even after internal cross-validation. In addition to the overall AUC, we examined tradeoffs along the ROC curve. The four scenarios provide information for policymakers to consider in the context of their local prevention goals and available resources. At the extreme of low sensitivity (10%), few infections would be averted, but PrEP programming would be highly efficient, with as few as 14 people on PrEP to avert one new infection. At the extreme of high sensitivity (90%), most infections could be averted, but programming would be less efficient, with more than 200 people on PrEP to avert one new infection.

There were complexities that we did not account for. On the one hand, we did not model the downstream benefits of each case averted (i.e. interrupted transmission chains). On the other hand, we did not examine tradeoffs between injectable versus oral PrEP, consider event-driven versus consistent PrEP, or account for uptake and adherence assumptions. Rather, we assumed perfect PrEP effectiveness. As such, all estimates reflect the upper bounds of cases averted. This expectation is closer to reality with long-acting injectable PrEP than oral PrEP, as uptake, adherence, and persistence have been challenges.[33] At any sensitivity threshold, if one third of the recommended men took up, adhered to, and persisted on oral PrEP, the number needed to treat to avert one new case would increase three-fold (assuming random non-adherence). Our findings must be considered in light of these simplifying assumptions.

Parsimony was a strength of this tool. With only two variables—population HIV-1 viremia and report of MSM behavior—our models had strong performance. This is a feature of Lasso models, as they tend to perform well in settings with many potential predictors and few outcomes. Indeed, many variables were associated with recent HIV-1 in bivariable analysis. (40) These observations are not contradictory, but rather address different questions. Our analysis goes beyond simple association to identify the set of variables that together best predict recent HIV-1. An additional strength of our analysis was the use of surveys with probability-based sampling. This design feature allowed for estimation of performance characteristics and downstream metrics in the *entire* population of susceptible men in these 13 countries, providing valuable information to policymakers weighing implementation decisions.

In summary, despite declines in HIV-1 incidence in Africa over the last two decades, many African countries are not on track with HIV prevention. Offering PrEP to those at highest risk for HIV-1 could advance prevention goals. Our tool—which was predictive, parsimonious, and broadly representative—could help national programs achieve HIV prevention goals and move closer to ending the HIV-1 epidemic as a public health threat by 2030.

Supplementary Material

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Data availability:

The Nigeria data are publicly available from the NAIIS Data Archive portal https://nadanaiis.nascp.gov.ng. The data for the SABSSMV were requested from the Human Sciences Research Council: https://hsrc.ac.za. The data for the PHIA surveys are publicly available and were provided upon request from the PHIA website: https://phia.icap.columbia.edu/

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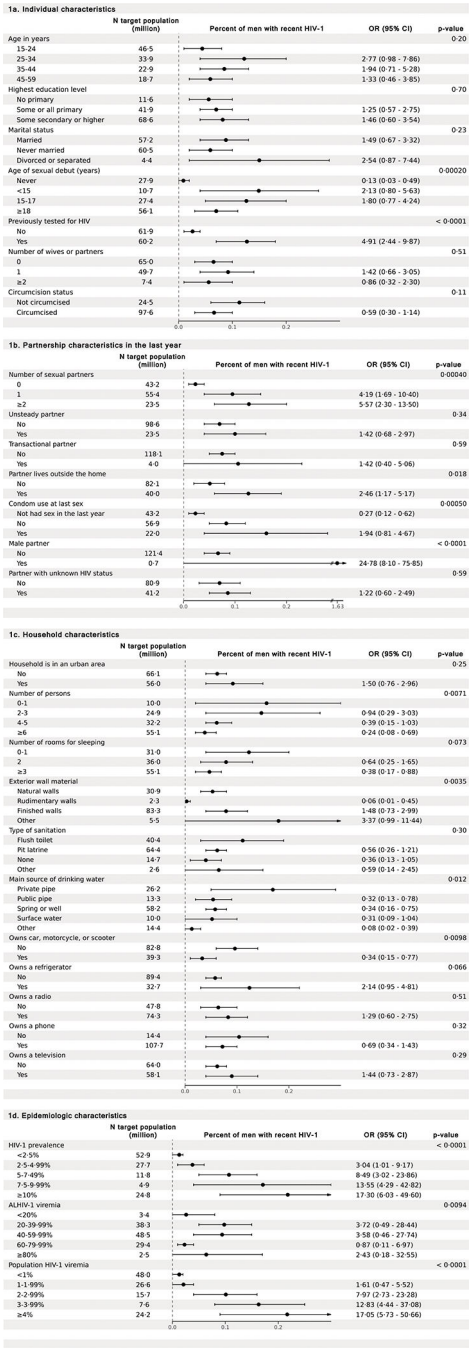


Figure 1. Characteristics associated with recent HIV-1 among men in 13 countries from 2015–2019

Figure 1 displays 1) individual, b) partnership, c) household, and d) epidemiologic characteristics of men from the 13-country target population. For each level of each characteristic the following are presented: the number of men (in millions), the proportion of men with recent HIV-1, the odds ratios and confidence intervals comparing levels, and p-value.

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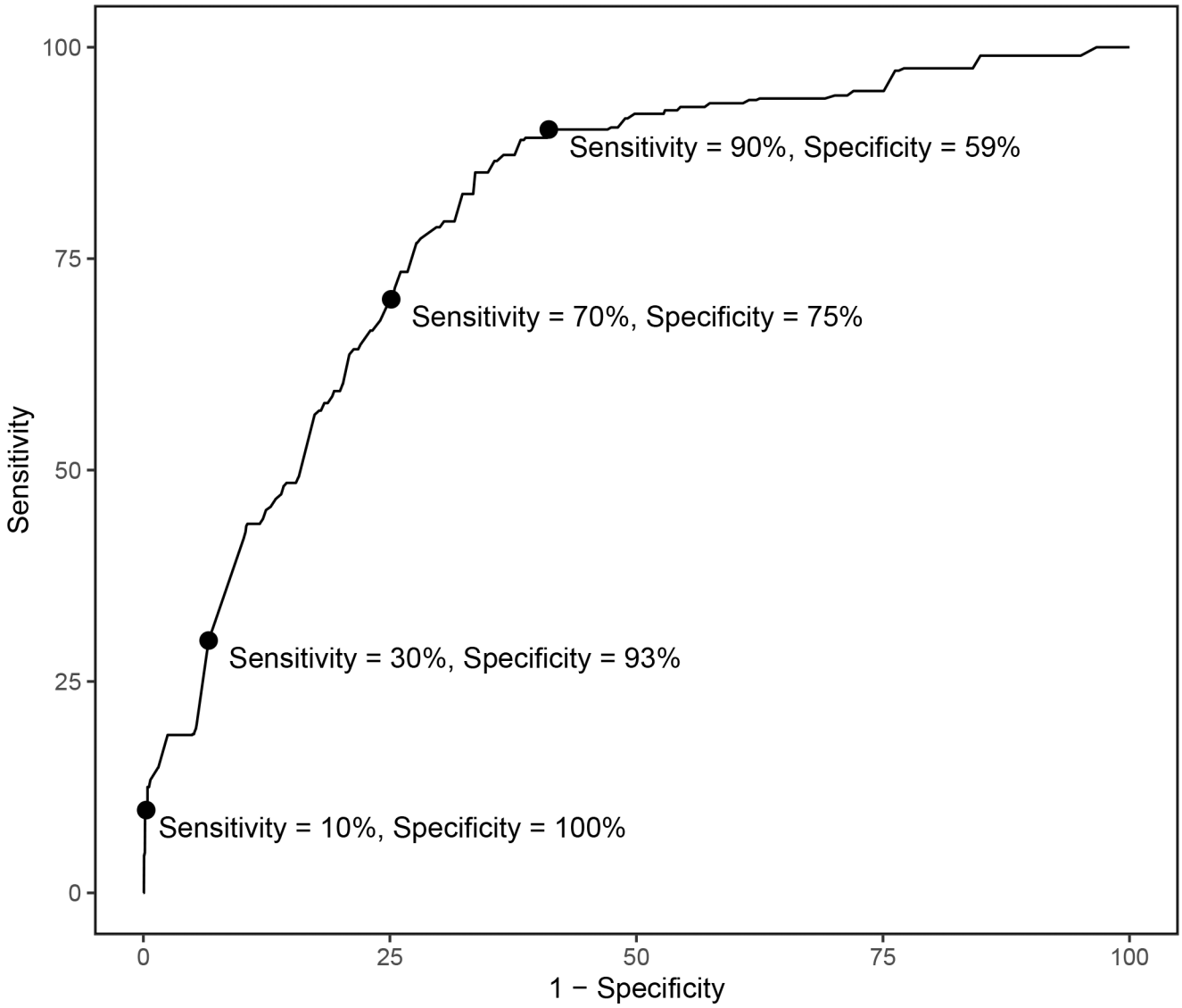


Figure 2. Receiver operating characteristic curve displaying Lasso model performance with respect to recent HIV-1 prediction

Figure 2 displays the ROC curve depicting overall performance of the LASSO model at predicting recent HIV-1 in the target population of men from 13 countries. Four sensitivity values, and their corresponding specificity levels are shown along the ROC curve.

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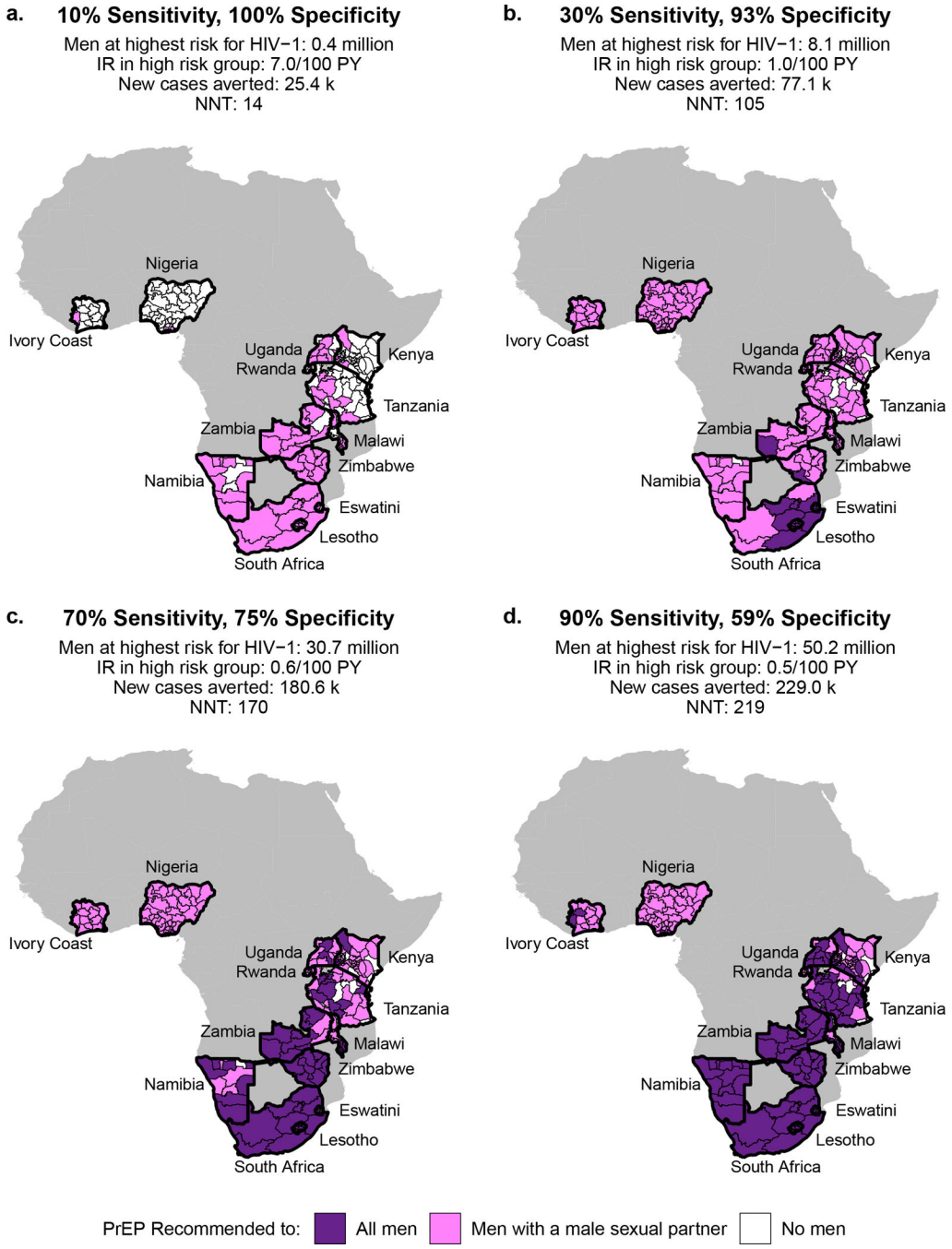


Figure 3. Locations of men prioritized for PrEP in the 13 countries at four sensitivity levels

Figure 3 displays the subnational areas in the 13-country analysis that have men with elevated HIV-1 acquisition risk based on 10%, 30%, 70%, and 90% sensitivity thresholds. In some subnational areas and at certain thresholds, all men fall above the sensitivity threshold (purple), whereas in other areas only men with a male partner fall above the threshold (pink). At each sensitivity threshold, five additional values are provided: specificity, number of men with predicted HIV-1 acquisition risk above the threshold (i.e. to prioritize for PrEP), number of cases averted if each man above the threshold adhered to PrEP, the HIV-1

incidence rate among men above the threshold, and the number of men to treat to avert one new case of HIV-1.

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Table 1.

Men in the survey sample and target population by country: overall and with recent HIV-1

	Overall				Men with recent HIV-1 infection			
	Study sample		National target population		Study sample		National target population	
	N	%	N	%	N	%	N	%
Southern Africa								
Eswatini	3,160	1.9	243,421	0.2	8	7.1	694	0.8
Lesotho	3,755	2.2	476,499	0.4	12	10.7	1,707	1.8
Malawi	6,286	3.8	3,689,313	3.0	10	8.9	3,097	3.4
Namibia	6,309	3.8	596,171	0.5	4	3.6	292	0.3
South Africa	5,194	3.1	14,746,224	12.1	13	11.6	40,737	44.1
Zambia	7,372	4.4	3,560,413	2.9	9	8.0	3,674	4.0
Zimbabwe	6,929	4.1	3,323,928	2.7	8	7.1	3,671	4.0
Eastern Africa								
Kenya	10,795	6.5	12,361,243	10.1	4	3.6	5,983	6.5
Rwanda	12,995	7.8	3,186,265	2.6	4	3.6	1,010	1.1
Tanzania	11,764	7.0	13,710,888	11.2	10	8.9	8,474	9.2
Uganda	11,377	6.8	8,455,594	6.9	16	14.3	12,711	13.8
West Africa								
Côte d'Ivoire	8,458	5.1	6,727,595	5.5	2	1.8	747	0.8
Nigeria	72,727	43.5	51,014,491	41.8	12	10.7	9,590	10.4
Total	167,121	100%	122,092,045	100%	112	100%	92,387	100%

This table displays the numbers and percentages of men overall and with recent HIV-1 in each of the 13 survey samples and the estimated number in the national target populations. The estimated number of men with recent HIV-1 in the national target population (N=92,387) is smaller than the estimated number of annual infections (N=256,000), as a recent infection testing algorithm is needed to convert recent HIV-1 cases to new annual infections.

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Table 2.

Tradeoffs at four sensitivity thresholds along the ROC curve: 10%, 30%, 70%, and 90%

Sensitivity % (CI)	Specificity % (CI)	IR per 100 PYs IR (CI)	Men on PrEP N (in millions) (CI)	Cases averted N (in thousands) (CI)	NNT (N)
10% (0–38%)	>99% (99%-100%)	7.0 (0.0–15.7)	0.4 (0–1.0)	25.4 (0–97.4)	14
30% (9–82%)	93% (71%-100%)	1.0 (0.3, 1.7)	8.1 (0.7–36.0)	77.1 (17.8, 282.1)	105
70% (17%-100%)	75% (4%-99%)	0.6 (0.3, 0.9)	30.7 (0.7–116.7)	180.6 (32.0, 335.1)	170
90% (22–100%)	59% (0–99%)	0.5 (0.3, 0.6)	50.2 (0.8–122.0)	229.0 (39.1, 336.7)	219

CI=confidence interval; IR=incidence rate; PY=person-years, N=number; PrEP=pre-exposure prophylaxis, NNT=number needed to treat

Table 2 examines tradeoffs at four sensitivity thresholds (10%, 30%, 70%, and 90%) along the ROC curve presented in Figure 2. At low sensitivity thresholds, a fraction of cases are averted, but the NNT is low, indicating high efficiency. In contrast, at high sensitivity thresholds, most cases are averted, but the NNT is high, indicating low efficiency.