Potential population-level effects of HIV self-test distribution among key populations in Côte d'Ivoire, Mali, and Senegal: a mathematical modelling analysis

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Summary

Background During 2019–21, the AutoTest VIH, Libre d'accéder à la connaissance de son Statut (ATLAS) programme distributed around 380 000 HIV self-testing kits to key populations, including female sex workers, men who have sex with men, and their partners, in Côte d'Ivoire, Mali, and Senegal. We aimed to estimate the effects of the ATLAS programme and national scale-up of HIV self-test distribution on HIV diagnosis, HIV treatment coverage, HIV incidence, and HIV-related mortality.

Methods We adapted a deterministic compartmental model of HIV transmission in Côte d'Ivoire, parameterised and fitted to country-specific demographic, behavioural, HIV epidemiological, and intervention data in Côte d'Ivoire, Mali, and Senegal separately during 1980–2020. We simulated dynamics of new HIV infections, HIV diagnoses, and HIV-related deaths within scenarios with and without HIV self-test distribution among key populations. Models were separately parameterised and fitted to country-specific sets of epidemiological and intervention outcomes (stratified by sex, risk, age group, and HIV status, if available) over time within a Bayesian framework. We estimated the effects on the absolute increase in the proportion of people with HIV diagnosed at the end of 2021 for the ATLAS-only scenario and at the end of 2028 and 2038 for the HIV self-testing scale-up scenario. We estimated cumulative numbers of additional HIV diagnoses and initiations of antiretroviral therapy and the proportion and absolute numbers of new HIV infections and HIV-related deaths averted during 2019–21 and 2019–28 for the ATLAS-only scenario and during 2019–28 and 2019–38 for the HIV self-testing scale-up scenario.

Findings Our model estimated that ATLAS could have led to 700 (90% uncertainty interval [UI] 500–900) additional HIV diagnoses in Côte d'Ivoire, 500 (300–900) in Mali, and 300 (50–700) in Senegal during 2019–21, a 0·4 percentage point (90% UI 0·3–0·5) increase overall by the end of 2021. During 2019–28, ATLAS was estimated to avert 1900 (90% UI 1300–2700) new HIV infections and 600 (400–800) HIV-related deaths across the three countries, of which 38·6% (90% UI 31·8–48·3) of new infections and 70·1% (60·4–77·3) of HIV-related deaths would be among key populations. ATLAS would avert 1·5% (0·8–3·1) of all HIV-related deaths across the three countries during this period. Scaling up HIV self-testing would avert 16·2% (90% UI 10·0–23·1) of all new HIV infections during 2019–28 in Senegal, 5·3% (3·0–8·9) in Mali, and 1·6% (1·0–2·4) in Côte d'Ivoire. HIV self-testing scale-up among key populations was estimated to increase HIV diagnosis by the end of 2028 to 1·3 percentage points (90% UI 0·8–1·9) in Côte d'Ivoire, 10·6 percentage points (5·3–16·8) in Senegal, and 3·6 percentage points (2·0–6·4) in Mali.

Interpretation Scaling up HIV self-test distribution among key populations in western Africa could attenuate disparities in access to HIV testing and reduce infections and deaths among key populations and their partners.

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Introduction

HIV testing is the first stage of the HIV prevention and care cascade; UNAIDS established a target of less than 5% of people living with undiagnosed HIV by 2025.[1] However, a third of people living with HIV in western Africa were undiagnosed in 2020,[2] hindering progress towards HIV elimination. This large gap has been partly attributed to low rates of diagnosis among key populations, including female sex workers and men who have sex with men.[2,3] Key populations who are disproportionally affected by HIV regularly experience stigma and discrimination, which can result in less frequent use of HIV-testing services than in the general population.[4] HIV self-testing is a relatively new, confidential testing method that has been proposed as a possible solution to reduce diagnosis gaps[5] and as

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See Online for appendix

For the **2025 AIDS targets** see https://aidstargets2025.unaids.org/

Research in context

Evidence before this study

Almost a third of people living with HIV in western Africa were undiagnosed in 2020, yet the extent to which HIV self-testing might improve coverage of HIV diagnoses and reduce new HIV infections and HIV-related deaths in this region has not been evaluated. We searched PubMed from database inception to June 28, 2023, with the terms ("HIV" AND "self-test*") AND "Africa*" and no language restriction; we identified no studies estimating the population-level epidemiological effects of HIV self-testing in western Africa. Several modelling analyses suggest that HIV self-testing might have an important epidemiological effect, but all focus on eastern and southern Africa.

Added value of this study

We made the first evaluation of HIV self-testing in Côte d'Ivoire, Mali, and Senegal with a detailed and carefully calibrated mathematical model. Our analysis provides novel evidence of the effects of the AutoTest VIH, Libre d'accéder à la connaissance de son Statut programme, which distributed around 380 000 HIV self-testing kits to female sex workers, clients of female sex workers, and men who have sex with men during 2019–21. In all three countries, distribution of HIV self-tests to key populations and their partners was estimated to improve HIV diagnosis and to reduce new HIV infections and HIV-related deaths.

Implications of all the available evidence

HIV self-testing can help meet prevention and treatment needs of key populations, reduce inequities across population groups, and reduce HIV morbidity and mortality. Distribution of HIV self-testing kits among female sex workers, clients of female sex workers, men who have sex with men, and their partners should be scaled up in western Africa, where three-quarters of new HIV infections occur in these populations.

effective in reaching people who have never been tested for HIV.[6] However, because of the anonymous nature, characterisation of people who use self-testing kits, measuring linkage to care, and evaluation of direct (ie, to users) and indirect (ie, to non-users by averting chains of transmission) effects of HIV self-testing on transmission and morbidity are challenging.[7]

For **estimated prevalences** see https://aidsinfo.unaids.org/

In western Africa, estimated prevalences of HIV-1 and HIV-2 among adults in 2022 were relatively low in Mali (0·9%) and Senegal (0·4%), but higher in Côte d'Ivoire (2·2%). However, prevalences among key populations are about ten times higher than national averages in Senegal and Mali[8] and three times higher than the national average in Côte d'Ivoire,[9] with clients and partners of key populations estimated to have acquired 28% of all new HIV infections in western and central Africa in 2021.[10] These countries progressively included outreach HIV prevention and testing programmes, including point-of-care rapid testing, among female sex workers early in their national plans and among men who have sex with men from the mid-2000s.[11,12] Rates of HIV diagnosis are lower among most key populations, particularly men who have sex with men, than among the general population in these countries.[13] Addressing the unmet testing needs of key populations could increase population-level viral suppression and reduce HIV infections and HIV-related mortality.

For **Unitaid** see https://unitaid.org/#en

For **Solthis** see https://www.solthis.org/en/

For the **French National Research Institute for Sustainable Development** see https://en.ird.fr/

In 2019, the global health initiative Unitaid[14] implemented the AutoTest VIH, Libre d'accéder à la connaissance de son Statut (ATLAS) programme through a partnership with the non-governmental organisation Solthis and the French National Research Institute for Sustainable Development to address the diagnosis gap and evaluate the potential effects of HIV self-testing in Côte d'Ivoire, Mali, and Senegal.[15] The ATLAS programme emphasised secondary distribution of HIV self-testing, whereby key populations directly reached by the programme could redistribute some of their HIV self-testing kits to their sexual partners, clients, and peers.[16] In addition to the distribution of around 380 000 HIV self-testing kits to people at increased risk of HIV during 2019–21 (of which 340 000 were distributed through activities focusing on female sex workers and men who have sex with men) the programme included different work packages to understand the practicality, costs, and population-level effects of HIV self-testing, combining population studies,[7,17] qualitative studies,[16,18] and economic analyses,[19] and mathematical modelling.

Because of the challenges in empirically measuring the effects of HIV self-testing due to its anonymous nature, the potential population-level effects of HIV self-testing on HIV infections in western Africa have not been quantified.[20] We aimed to estimate the effects of the ATLAS programme and of national scale-up of HIV self-test distribution on HIV diagnosis, HIV treatment coverage, HIV incidence, and HIV-related mortality among key populations and the overall population in Côte d'Ivoire, Mali, and Senegal.

Methods

Model design

For this modelling analysis, we adapted a deterministic compartmental model of HIV transmission in Côte d'Ivoire,[21] parameterised and fitted to country-specific demographic, behavioural, HIV epidemiological, and intervention data in Côte d'Ivoire, Mali, and Senegal separately during 1980–2020. The models were then used to simulate the dynamics of new HIV infections, HIV diagnoses, and HIV-related deaths within scenarios with and without HIV self-test distribution among key populations. Intervention effects were estimated by comparing outcomes in scenarios with and without HIV self-testing.

The models simulated an open, increasing population stratified into eight groups: female sex workers, clients of female sex workers, men who have sex with men who reported sex only with male partners, men who have sex with men who reported sex with male and female partners, non-key-population female individuals at low risk of HIV (ie, no or one partner per year), non-key-population female individuals at intermediate risk of HIV (ie, more than one partner per year), non-key-population male individuals at low risk of HIV (ie, no, one, or two partners per year), and non-key-population male individuals at intermediate risk of HIV (ie, more than two partners per year; appendix pp 1–8). We included four age groups: 15–19 years, 20–24 years, 25–49 years, and 50–59 years. Individuals entered the sexually active population at age 15 years and left it at age 59 years; they could also leave the sexually active population via background or HIV-related mortality. Immigration in the age 25–49 years group was informed by demographic data from 1998.[22] HIV transmission could occur during heterosexual non-commercial and commercial sex and non-commercial sex between men (appendix pp 9–11). We modelled HIV-1 and HIV-2 combined as most studies do not differentiate between them and because data suggest that more than 90% of people currently living with HIV in western Africa live with HIV-1.[23]

People acquiring HIV progress through five infection stages, from acute HIV to AIDS. We explicitly modelled HIV diagnosis and linkage to treatment, including self-testing, conventional testing, and confirmation tests after reactive self-tests (appendix p 29). Diagnosed people living with HIV could initiate antiretroviral therapy and have reduced HIV-related mortality; the majority of treated people living with HIV achieve viral suppression and cannot transmit HIV.

HIV acquisition rates per person depended on annual number of new partners and sex acts with or without condoms, sexual mixing by risk or age group, HIV prevalence, coverage of viral suppression among sexual partners, and per-sexual-act probabilities of HIV transmission (appendix pp 14–27). The model estimated changes in intervention rates (ie, condom use, HIV testing, and antiretroviral therapy) over time by risk and age groups with available data from 1991 to 2020 (appendix pp 23–33). Future intervention rates remained the same as the most recent data estimates, whereas proportions of people living with HIV taking antiretroviral therapy with a suppressed viral load slowly increased over time.

Data sources and model fitting

The models were separately parameterised and fitted to country-specific sets of epidemiological and intervention outcomes (stratified by sex, risk, age group, and HIV status if available) over time within a Bayesian framework (appendix pp 38–52). The fitting outcomes were age distribution, HIV prevalence, annual number of new HIV infections, annual number of HIV-related deaths, incidence rate of HIV, proportion of people ever tested for HIV, proportion of people ever diagnosed with HIV, coverage of antiretroviral therapy and viral suppression, annual number of conventional tests, and proportion of conventional tests that were positive (appendix pp 64–98). Most fitting outcomes were available for all countries and risk groups, except for clients of female sex workers, particularly in Mali.

Data informing demography were sourced from the UN Population Division World Prospects,[24] whereas data on most sexual behaviours (including sexual mixing), trends in condom use, and HIV prevalence among non-key populations were sourced from population-based surveys from each country (appendix p 19). The relative size of each key population and clients of female sex workers varied across simulations to reflect heterogeneities in country-specific estimates (appendix p 10), but were constant over time within simulations. The sizes of the client population were estimated by triangulating the estimated sizes of the population female sex workers and the number of paid sex acts reported by both clients and female sex workers.[25] As no client data were available for Mali, we used estimates of the number of sex acts paid for by clients in Côte d'Ivoire. Sexual behaviours, trends in condom use, and HIV prevalence among key populations were based on local surveys in each country (appendix pp 19–20, 23–24, 40–41, 45, 49).

Annual HIV testing rates and proportions of people with HIV who had ever tested were mostly obtained from secondary analyses of local population-based and key-population surveys by age, sex, and HIV status, if available (appendix pp 38–52). Proportions of all people living with diagnosed HIV over time were based on national UNAIDS Shiny90 model-based estimates,[26] whereas self-reported knowledge of HIV status among key populations was sourced from local surveys (appendix pp 42, 47, 52). UNAIDS and key-population surveys (appendix pp 42, 47, 52) informed annual numbers of new HIV infections and HIV-related deaths, HIV incidence-rate estimates, antiretroviral-therapy coverage by sex, proportion of treated people living with HIV with a suppressed viral load by sex over time, and annual number and positivity of conventional tests. Biological parameters and efficacy parameters for condom use and antiretroviral therapy were sourced from published literature (appendix pp 21–22).

We retained all simulations from original samples of 50 million parameter sets, sampled with Latin hypercube, which agreed with prespecified data prior constraints (ie, fitting targets obtained by expanding uncertainty intervals around data points; appendix p 38). Subsequently, the 100 fitted simulations with the highest likelihood were identified for each country via the study sample size in the likelihood calculation. The resulting posterior parameter sets were used to simulate the counterfactual scenario (ie, no HIV self-testing) and the two HIV self-test distribution scenarios, which represented the most likely HIV self-testing distribution and use during the modelled period (figure 1; appendix pp 57–59). The ATLAS-only scenario represented HIV self-testing distribution through ATLAS activities that prioritised female sex workers and men who have sex with men during 2019–21 only (appendix pp 52–61), with no HIV self-testing distribution after January, 2022. The HIV self-testing scale-up scenario represented the ATLAS programme during 2019–21 plus further national scale-up of HIV self-test distribution to female sex workers and men who have sex with men, increasing from January, 2022, onwards and assuming constant numbers of kits distributed each year from 2025 onwards. The validity of each model was tested through comparisons with country-specific empirical data.

Modelling analysis

We used ATLAS programmatic data on the number of HIV self-testing kits distributed through activities focusing on female sex workers and men who have sex with men during 2019–21 and specific surveys estimating the number of HIV self-testing kits received by risk groups through secondary distribution and linkage to care after a reactive self-test (appendix pp 52–61).[27] Following current WHO guidelines,[28] a reactive HIV self-test needs to undergo confirmatory testing through conventional testing to be considered an HIV diagnosis. The HIV self-testing scale-up scenario assumed that HIV self-test distribution would reach our predefined target of two self-tests distributed to 95% of eligible female sex workers or men who have sex with men (ie, people without HIV or untreated people living with HIV, regardless of their awareness of HIV status, on the basis of WHO recommendations of testing members of key populations twice a year)[29] from 2025 onwards. This plateau in number of tests distributed corresponded to medians of 365 000, 89 000, and 103 000 kits distributed annually through female sex workers and men who have sex with men in 2025 in Côte d'Ivoire, Mali, and Senegal, respectively. After accounting for secondary distribution, these data indicated that 0·8 kits were received per eligible female sex worker in 2025 and 1·6 kits were received per man who has sex with men in 2025 (appendix p 61). HIV self-tests among key populations would comprise 48·7–86·9% of all tests (ie, HIV self-testing and conventional tests) done by key populations across countries in 2025, whereas HIV self-testing among key populations and non-key populations combined would comprise 6·9–15·2% of all HIV tests done across countries in 2025.

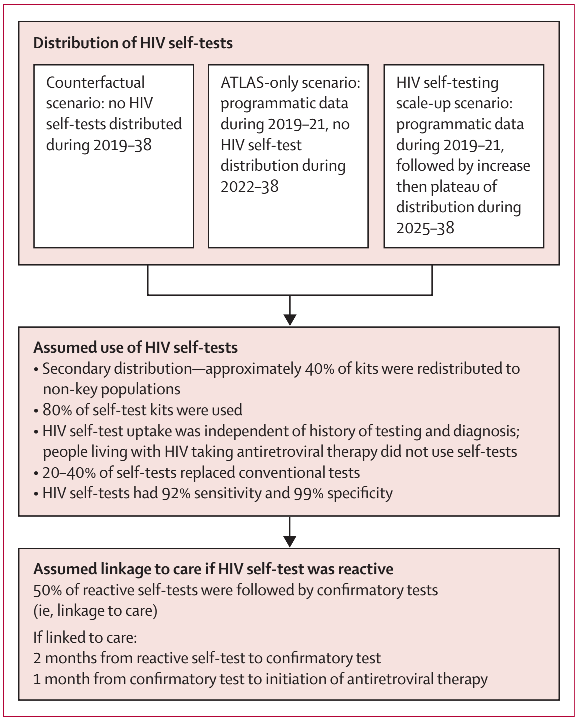

***Figure 1:* Model assumptions of the counterfactual scenario, ATLAS-only scenario, and HIV self-testing scale-up scenario**

Assumptions were established via ATLAS programmatic data (appendix pp 52–61), ATLAS studies,[6,7,17,27] and the literature (ie, proportion of tests used and the sensitivity and specificity of tests; appendix pp 57–59).[8] ATLAS=AutoTest VIH, Libre d'accéder à la connaissance de son Statut programme.

We assumed that 80% of HIV self-tests distributed were used with uniform use across population groups[30] and, on the basis of ATLAS survey data, that 50% of reactive self-tests were confirmed with conventional testing and linked to care.[27] From programmatic data from HIV testing services in Côte d'Ivoire and Senegal, we assumed that 20% of ATLAS HIV self-tests replaced conventional tests in Côte d'Ivoire, 30% replaced conventional tests in Mali, and 40% replaced conventional tests in Senegal.[17] HIV self-testing was assumed to have 92% sensitivity and 99% specificity.[31]

We estimated the effects of ATLAS and scale-up of HIV self-test distribution on the absolute increase in the proportion of people living with HIV diagnosed at the end of 2021 for the ATLAS-only scenario and at the end of 2028 and 2038 for the HIV self-testing scale-up scenario. We estimated the cumulative numbers of additional HIV diagnoses and initiations of antiretroviral therapy and the proportion and absolute numbers of new HIV infections and HIV-related deaths averted during 2019–21 and 2019–28 for the ATLAS-only scenario and during 2019–28 and 2019–38 for the HIV self-testing scale-up scenario. All estimates were calculated compared with the counterfactual scenario. We included reductions in the distribution of HIV self-testing kits during April to June, 2020, due to the COVID-19 pandemic. We estimated the change in median time from HIV infection to diagnosis, or death if before diagnosis, between the HIV self-testing scale-up and the counterfactual scenarios by calculating the median time from January, 2020, when half of undiagnosed people with HIV would have become diagnosed, assuming no new infections during the period (appendix pp 62–63). We report median estimates and 90% uncertainty intervals (UIs) of model estimates on the basis of 100 posterior parameter sets.

As a sensitivity analysis, we assessed the influence of key assumptions (eg, proportion of confirmed reactive self-tests) of our HIV self-testing scale-up scenario on new HIV infections and HIV-related deaths during 2019–28.

We used R version 4.1.2 for all analyses.

Role of the funding source

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

Results

Our model reproduced available empirical demographic, epidemiological, and intervention data across risk groups in each country fairly well (appendix pp 64–98), with between 579 and 1550 simulations of the 50 million agreeing with all prespecified fitting targets across countries. However, data triangulation indicated discrepancies between relatively low proportions of people living with HIV estimated as self-reporting ever having tested for or being diagnosed with HIV, and high coverages of HIV treatment and viral suppression for the same populations.[32] Similar to UNAIDS estimates, our modelled national HIV prevalence was highest in Côte d'Ivoire, whereas prevalent HIV infections were estimated to be more concentrated among key populations in Mali and Senegal (table). Côte d'Ivoire had a smaller median proportion of people living with undiagnosed HIV among key populations (6·9%, 90% UI 4·4–11·4) than Mali (7·2%, 4·9–12·1) and Senegal (42·8%, 27·2–60·0; appendix p 99).

ATLAS could have led to 700 (90% UI 500–900) additional HIV diagnoses in Côte d'Ivoire, 500 (300–900) in Mali, and 300 (50–700) in Senegal during 2019–21 compared with the counterfactual scenario, 80·8% (82·1–92·3) of which were among key populations across all three countries (figure 2A: appendix p 100) and a 0·4 percentage point (0·3–0·5) increase overall by the end of 2021. Overall coverage of HIV diagnosis at the end of 2021 due to ATLAS was about 1·0 percentage point higher than in the counterfactual scenario in Mali and Senegal, and less than 0·2 percentage points (0·2–0·3) higher in Côte d'Ivoire. Estimated increases in the coverage of HIV diagnosis (ie, the proportion of people living with HIV who are diagnosed) were larger among key populations than among non-key populations (figure 2A; appendix p 99) and were highest among men who have sex with men, with a 4·6 percentage point (90% UI 3·1–8·3) increase compared with the counterfactual scenario in Côte d'Ivoire, a 5·7 percentage point (1·0–17·2) increase in Senegal, and a 9·3 percentage point (3·9–14·7) increase in Mali (figure 2A; appendix p 104). Effects of ATLAS on initiations of antiretroviral therapy were similar to effects on new diagnoses (appendix p 101).

	Côte d'Ivoire	Mali	Senegal
Relative size of populations			
Proportion of FSWs among all female individuals	1·4% (0·9–1·9)	0·6% (0·4–0·9)	0·6% (0·5–0·8)
Proportion of clients of FSWs among all male individuals	13·9% (8·4–18·4)	10·8% (5·1–18·1)	4·2% (2·6–7·2)
Proportion of MSM among all male individuals	1·3% (0·9–1·6)	0·4% (0·2–0·5)	0·5% (0·3–0·9)
HIV prevalence in 2019			
All female individuals	3·1% (2·7–3·9)	0·8% (0·6–1·0)	0·4% (0·4–0·5)
All male individuals	1·9% (1·5–2·3)	0·5% (0·4–0·7)	0·3% (0·2–0·4)
FSWs	9·5% (6·7–12·7)	9·6% (8·4–13·2)	4·5% (2·6–7·4)
Clients of FSWs	2·8% (1·9–4·3)	2·2% (1·4–3·8)	1·9% (1·1–3·6)
MSM	9·4% (6·2–13·3)	15·0% (10·7–18·7)	21·4% (15·4–27·7)
Proportion of people living with HIV with a diagnosed infection in 2019			
All female individuals	77·7% (74·5–81·7)	53·1% (51·2–57·5)	87·2% (83·6–90·0)
All male individuals	58·3% (53·3–63·5)	40·1% (35·0–47·0)	61·2% (56·2–67·7)
FSWs	64·7% (56·4–72·8)	54·1% (41·2–65·9)	70·8% (58·3–80·0)
Clients of FSWs	58·5% (53·5–64·2)	40·6% (33·4–49·0)	74·3% (64·1–82·2)
MSM	51·4% (39·4–57·2)	60·6% (49·4–68·9)	40·9% (30·2–53·2)

Data are median (90% uncertainty interval) of posterior distributions in January, 2019. FSWs=female sex workers. MSM=men who have sex with men.

Table: **Model-based estimates of relative sizes of key populations, HIV prevalence, and HIV diagnosis in 2019**

During 2019–28, ATLAS might avert 1900 (90% UI 1300–2700) new HIV infections and 600 (400–800) HIV-related deaths across the three countries, of which 38·6% (90% UI 31·8–48·3) of new infections and 70·1% (60·4–77·3) of HIV-related deaths would be among key populations and 17·8% (9·4–26·7) of new infections and 12·1% (8·6–19·2) of HIV-related deaths would be among clients of female sex workers (figure 2B, C; appendix p 100). Most new HIV infections and HIV-related deaths averted by ATLAS in Senegal would be among men who have sex with men (figure 2C). ATLAS was estimated to avert 3·3% (90% UI 1·7–6·3) of all new HIV infections in Senegal during 2019–28, 2·1% (1·1–3·7) in Mali, and 0·4% (0·3–0·6) in Côte d'Ivoire. Furthermore, ATLAS would avert 0·4% (0·3–0·6) of all HIV-related deaths across the three countries during this period (figure 2B). For the period 2019–28, the proportion of new HIV infections and HIV-related deaths averted was higher among men who have sex with men than in other groups in all three countries, but also high among clients of female sex workers in Mali (figure 2) due to a higher number of kits having been distributed to their sexual partners.

HIV self-testing scale-up among key populations was estimated to increase HIV diagnosis by the end of 2028 to 1·3 percentage points (90% UI 0·8–1·9) in

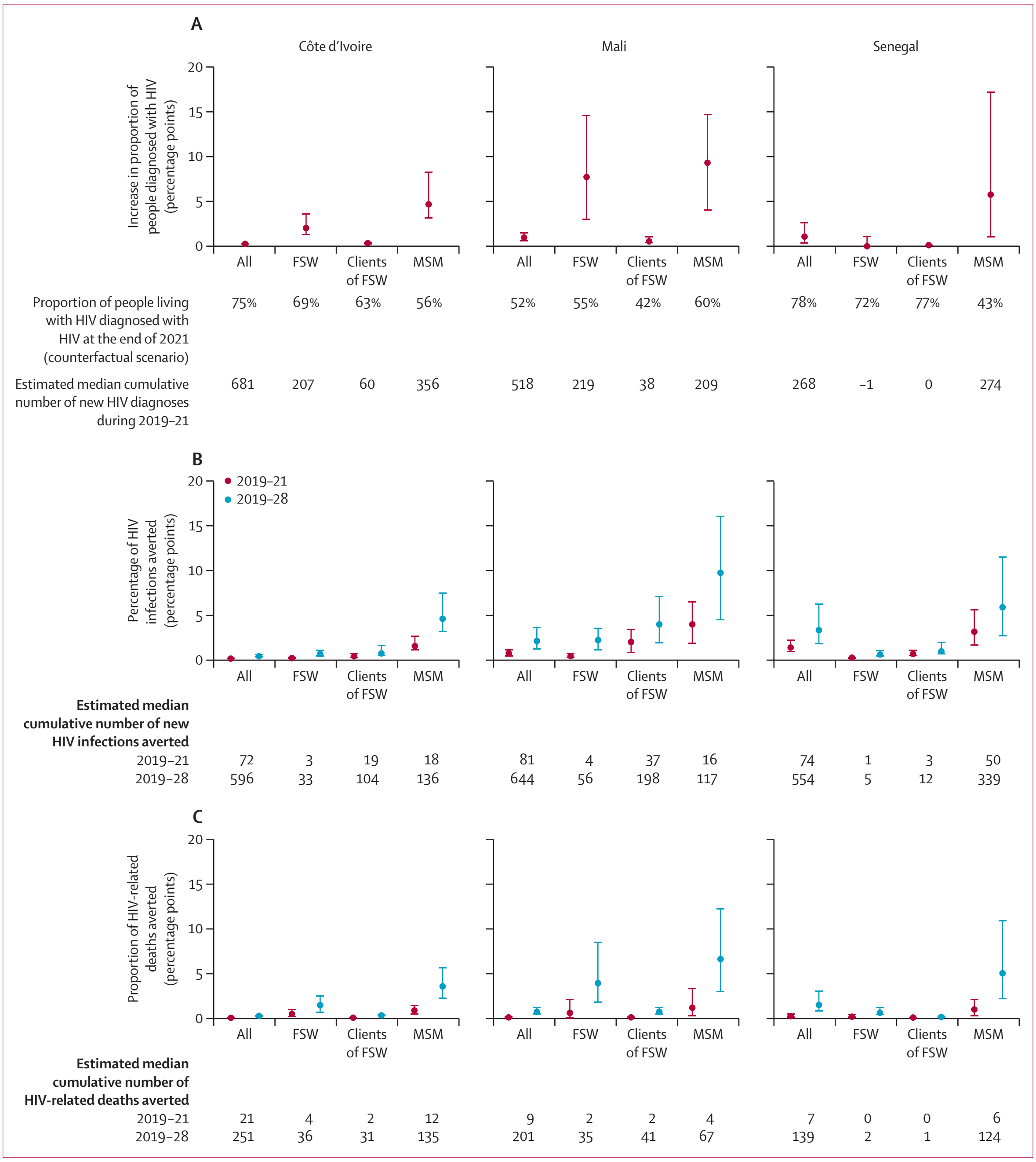

***Figure 2:* Estimated effects of the ATLAS-only scenario compared with the counterfactual scenario**
(A) Coverage of HIV diagnoses at the end of 2021. (B) Estimated new HIV infections averted by ATLAS. (C) Estimated HIV-related deaths averted by ATLAS. Points show the median of model estimates; error bars show the 90% uncertainty interval. ATLAS=AutoTest VIH, Libre d'accéder à la connaissance de son Statut programme. FSW=female sex workers. MSM=men who have sex with men.

Côte d'Ivoire, 10·6 percentage points (5·3–16·8) in Senegal, and 3·6 percentage points (2·0–6·4) in Mali.

Compared with the counterfactual scenario, the estimated overall proportion of people living with diagnosed HIV at the end of 2038 with HIV self-testing scale-up increased more in Senegal (13·6 percentage points, 90% UI 6·3–21·4) than in Mali (4·8, 2·5–9·7) and Côte d'Ivoire (1·2, 0·7–2·0; figure 3; appendix pp 99–104). The estimated proportion of men who have sex with men living with diagnosed HIV at the end of 2038 increased to 92·4% (88·4–95·2) with intervention versus 59·0% (42·6–75·7) without intervention in Mali, 91·3% (89·4–93·3) with intervention versus 62.9% (43·9–75·9) without intervention in Côte d'Ivoire,

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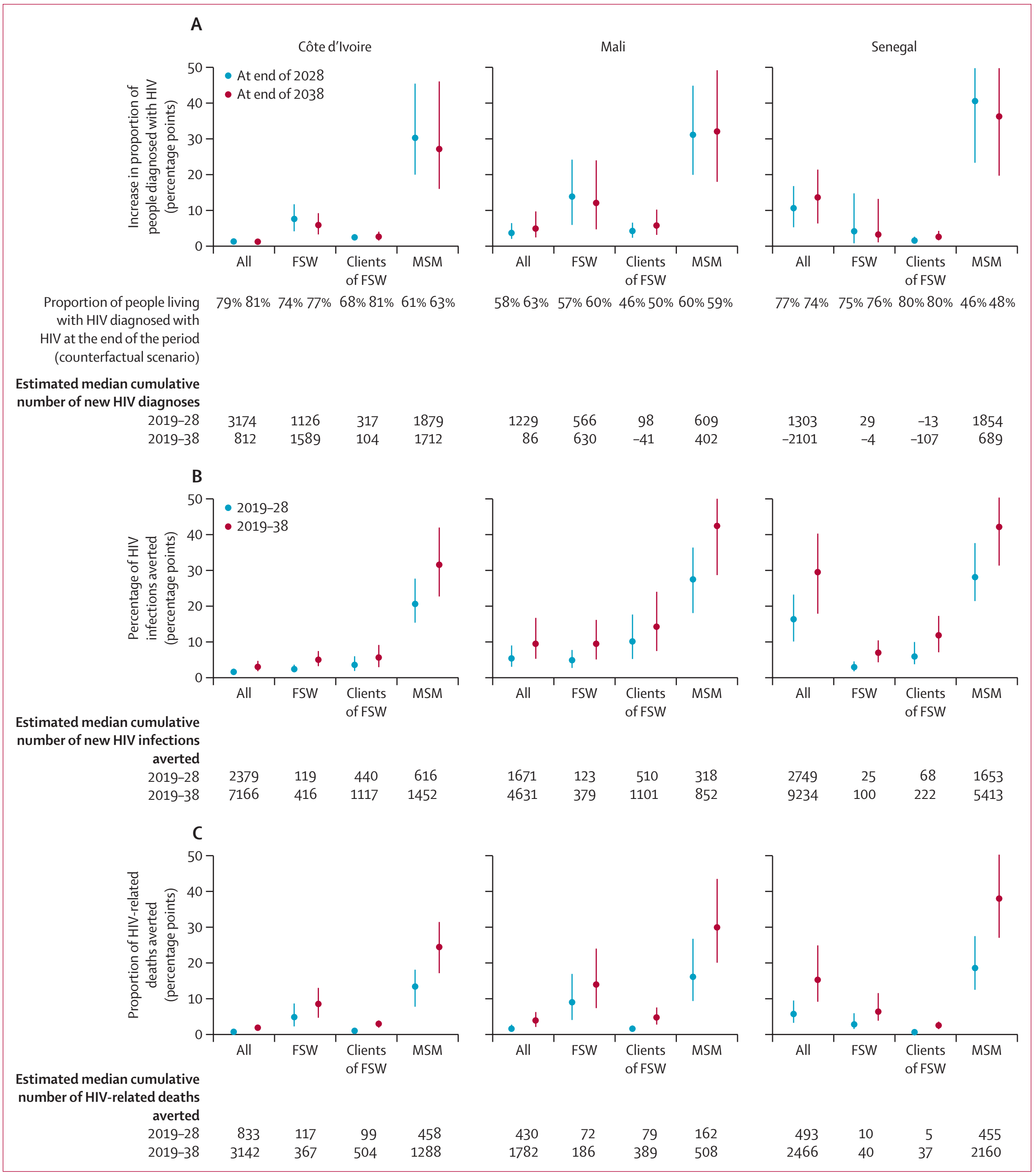

Figure 3: **Estimated effects of the HIV self-testing scale-up scenario compared with the counterfactual scenario**
(A) Estimated coverage of HIV diagnoses. (B) Estimated new HIV infections averted by scale-up of HIV self-tests. (C) Estimated HIV-related deaths averted by scale-up of HIV self-tests. Points show the median of model estimates; error bars show the 90% uncertainty interval. FSW=female sex workers. MSM=men who have sex with men.

and 82·5% (79·6–86·3) with intervention versus 47·8% (25·9–62·6) without intervention in Senegal. Among female sex workers, the estimated proportion living with diagnosed HIV at the end of 2038 increased to 83·1% (76·7–87·7) in Côte d'Ivoire (*vs* 77·0% [66·8–84·0] in the counterfactual scenario), 74·0% (64·0–79·7) in Mali (*vs* 59·7% [44·5–74·0] in the counterfactual scenario), and 80·0% (72·3–85·6) in Senegal (*vs* 76·3% [62·7–83·4] in the counterfactual scenario).

Overall median estimated time from infection to death for people acquiring HIV in January, 2020, was longer for male individuals than female individuals (figure 4) and was longest for men who have sex with men. Scaling up HIV self-testing was estimated to reduce time to diagnosis by about 2 years among men who have sex

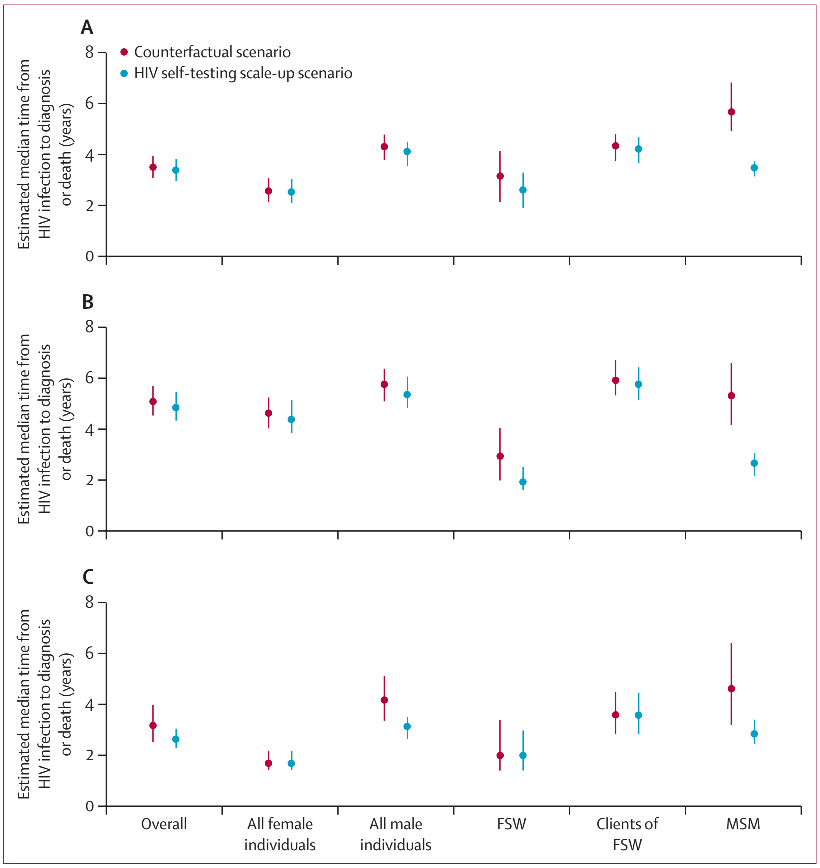

Figure 4: **Estimated median time from HIV infection to diagnosis, or death if before diagnosis, for people acquiring HIV in January, 2020**

(A) Côte d'Ivoire. (B) Mali. (C) Senegal. Points show median estimates across model fits; error bars show the 90% uncertainty interval. FSW=female sex workers. MSM=men who have sex with men.

with men in all three countries and 1·5 years among female sex workers in Mali and Côte d'Ivoire (figure 4). There was no estimated change for female sex workers in Senegal due to high rates of conventional testing and the low number of HIV self-testing kits distributed to them.

Scaling up of HIV self-testing was estimated to avert 16·2% (90% UI 10·0–23·1) of all new HIV infections during 2019–28 in Senegal, 5·3% (3·0–8·9) in Mali, and 1·6% (1·0–2·4) in Côte d'Ivoire. We predicted 20–28% of infections averted among men who have sex with men and 2–5% among female sex workers. Effects were two-fold larger among clients of female sex workers because of greater increases in viral suppression among their female partners (figure 3B; appendix pp 102–06). 2700 (90% UI 1600–4500) new HIV infections were estimated to be averted during 2019–28 in Senegal, 2400 (1500–3400) in Côte d'Ivoire, and 1700 (900–3100) in Mali, with approximately three-times more infections estimated to be averted during 2019–38 (figure 3B).

HIV self-testing scale-up was estimated to avert less than 5·5% (90% UI 3·2–9·4) of HIV-related deaths in Senegal, 1·5% (0·8–2·7) in Mali, and 0·7% (0·4–1·3) in Côte d'Ivoire during 2019–28 (figure 3C; appendix p 106). Among men who have sex with men, scale-up was estimated to avert a median of 13·2–18·4% of HIV-related deaths in 2019–28 (appendix p 106); 2·7–8·8% of deaths were averted mong female sex workers; less than 1·5% were averted among clients of female sex workers. Two-fold to three-fold more HIV-related deaths were averted during 2019–38 (figure 3C; appendix p 106).

Substantial proportions of HIV infections were estimated to be averted during 2019–38 among non-key populations: 73·0% (90% UI 58·4–83·4) in Côte d'Ivoire, 71·6% (51·8–82·1) in Mali, and 40·4% (28·5–52·1) in Senegal; and 12–59% of HIV-related deaths were averted (appendix p 103). Sensitivity analysis (appendix pp 107–09) showed little influence of variations in our assumptions on the estimated proportions of new HIV infections and HIV-related deaths averted by a scale-up of HIV self-testing among key populations.

Discussion

Our modelling analysis suggests that the ATLAS programme could have a sizeable effect on HIV infections, HIV diagnoses, and HIV-related deaths in Côte d'Ivoire, Mali, and Senegal considering the relatively small number of HIV self-testing kits distributed. ATLAS could have already resulted in hundreds of additional HIV diagnoses among key populations during 2019–21 and could avert around 4–9% of new HIV infections and HIV-related deaths among men who have sex with men and 1–3% among female sex workers in the three countries during 2019–38. In western Africa, national scale-ups of HIV self-testing among key populations were estimated not only to improve access to HIV testing, but also to reduce inequity in coverage of HIV diagnosis and affect HIV incidence in the overall population. Reduction of current inequities in HIV response between key populations and non-key populations was shown via the estimated reduction in time from HIV acquisition to diagnosis across key populations in all three countries, especially in populations among whom diagnosis gaps were the largest.

To our knowledge, ours is the first modelling analysis to estimate the population-level effects of HIV self-testing in western Africa. However, other modelling analyses evaluated it in southern Africa,[33,34] a region with ten-fold higher HIV prevalence and where a lower proportion of people with HIV are among key populations.[20] Our analysis shows differences in the potential effects of an HIV self-test scale-up among key populations across Côte d'Ivoire, Mali, and Senegal due to diversity in HIV epidemic contexts and existing amounts of HIV diagnosis. The lower overall effect of HIV self-test scale-up on HIV diagnosis, new infections, and related deaths among key populations in Côte d'Ivoire might be due to the higher overall HIV prevalence among adults (2·2%) than in Mali and Senegal (<1·0%), with many HIV infections occurring among non-key populations and to smaller diagnosis gaps than in Mali

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(appendix p 99). This lower estimated effect in Côte d'Ivoire contrasts with the highest estimated overall effect of ATLAS in Senegal, where an increasing proportion of all people living with HIV are estimated to be men who have sex with men (16% in 2020 in our study), who had suboptimal use of HIV testing and could have benefited from substantial HIV self-test distribution.

41–74% of averted HIV infections were estimated to have occurred among non-key populations, despite these populations receiving 40% of the HIV self-testing kits. Estimated increases in HIV diagnosis among key populations after HIV self-test distribution could also have averted HIV-related deaths by lengthening life expectancy due to a subsequent increase in coverage of treatment and by averting HIV infections among key populations and non-key populations as a result of increases in population-level viral load suppression. The estimated effects of HIV self-testing on new HIV infections among men who have sex with men could have been due to increases in their viral suppression that translated to reductions in risk of acquiring HIV, as well as their risk of transmitting it. By contrast, the effects among female sex workers were around half that among their clients, potentially because increasing antiretroviral-therapy coverage among female sex workers first needs to reduce HIV risk among clients before subsequently preventing HIV among female sex workers not living with HIV. Despite these differences, the estimated effects of HIV self-testing were sizeable in all three countries, suggesting that our conclusions are generalisable to other countries in western Africa.

Our estimated time from HIV acquisition to diagnosis of 4 years overall in Côte d'Ivoire, Mali, and Senegal was similar to estimates published in 2021 for western Africa (ie, 5 years).[2] However, variation across countries and risk groups was large (ie, almost 2 years longer in Mali than in Senegal and Côte d'Ivoire and 1·1–2·3 times longer among men who have sex with men than in non-key populations across the three countries, especially than among non-key-population women). These gaps in HIV diagnosis support the need for alternative, anonymous testing methods for key populations; scale-up of HIV self-testing attenuated disparities in HIV diagnosis by decreasing the time from infection to diagnosis among men who have sex with men by up to two-fold. However, ATLAS only reached clients of female sex workers through secondary distribution of HIV self-testing kits via female sex workers (appendix p 53), which emphasises the need for specific HIV self-test direct distribution strategies for clients of sex workers.

Our analysis has some limitations and highlights data gaps in Côte d'Ivoire, Mali, and Senegal, especially regarding clients of female sex workers, for whom no population-size or HIV-prevalence estimates were available in Mali and scarce data were available in the other two countries. We addressed this lack of data for clients of female sex workers by representing wider uncertainty in HIV prevalence, diagnosis, and treatment for this population and by using client sexual behaviour data from Côte d'Ivoire. The number of HIV self-testing kits distributed during scale-up were proportional to the size of the key populations, thus our estimated effects of HIV self-testing did not depend on uncertainties in size estimates. ATLAS distribution data were available by distribution channel, sex, and age, whereas data for secondary distribution and linkage to care after a reactive self-test were characterised during anonymous telephone surveys, from which participants might not accurately reflect the population receiving the tests.[7,27] However, our sensitivity analysis found a modest influence of these possible biases on our estimated effects. Furthermore, our model might have under-estimated the total effects of ATLAS because we did not include specific distribution channels focusing on partners of people living with HIV, patients of clinics for sexually transmitted infections (STIs), and people who use drugs, who received only 12% of the kits distributed (appendix p 52).[26] These populations are not necessarily well characterised in terms of size or HIV prevalence and diagnosis, and often overlap with our modelled key populations (eg, the clients of female sex workers might visit STI clinics). Moreover, our analysis relied on mathematical models that simplify the dynamics of transmission in populations but consider uncertainty in data during their calibration. Although we included reductions in the distribution of HIV self-testing kits during April to June, 2020, due to the COVID-19 pandemic, changes in conventional testing during this period were not modelled as routine programmatic data from Côte d'Ivoire suggest that they might have been few.[17]

Our analysis relied on comprehensive reviews of data characterising past and current states of the HIV epidemic and interventions in each of the three countries, including integrated biological and behavioural surveillance surveys from 2020, while integrating a comprehensive knowledge of HIV self-test use in countries through programmatic and survey data from the ATLAS programme and expertise from our country partners and collaborators (appendix pp 110–12). The number of kits distributed within our scale-up scenario was based on WHO recommendations and similar to country anticipated purchases during the near future,[29] which allowed us to estimate the most probable effects of HIV self-test distribution in each modelled group. We triangulated information from various outcomes and data sources, such as HIV testing history or viral load suppression among people living with HIV, and considered uncertainties in parameter estimates and possible biases in data we used (eg, programmatic data), especially self-reported HIV diagnosis, which is often under-reported due to social desirability bias and HIV-related stigma.[32] We believe these considerations increased the robustness of our estimates. Increases in diagnosis coverage translated into potential effects on onward transmissions, which can only be estimated with mathematical models. Finally, our sensitivity analysis explored the effects of uncertainties in use of HIV self-testing and linkage to care and suggested that our estimated effects were fairly robust.

HIV self-testing has promise to increase diagnosis coverage among key populations and their partners; our analysis shows that its scale-up could substantially reduce disparities in HIV diagnosis in western Africa by reaching and improving health outcomes of hard-to-reach populations, especially male key populations.[35] Although more informed recommendations would be obtained from further cost-effectiveness analyses, the modest overall estimated effects of HIV self-testing scale-up on new HIV infections, especially in Côte d'Ivoire and Mali, suggest that distributing self-test kits to male populations at increased risk of transmitting HIV, such as clients of female sex workers, could improve the effect of HIV self-test distribution and accelerate the decrease in HIV incidence.

Contributors

MM-G and RS co-developed the HIV transmission model used for this analysis, with input from M-CB and JL. MM-G and NS conducted data reviews for each country, with additional support from the representatives of each country (AK and CTN). CD-A, AV, PV, and CM contributed to additional data used in model parameterisation and calibration. Data collection for the AutoTest VIH, Libre d'accéder à la connaissance de son Statut programme (ie, programmatic and survey data) was coordinated by AV, CD-A, OG, NR, OKK, ASF, and JL. RS and MM-G accessed and verified the data. RS wrote the first version of the manuscript. MM-G, M-CB, PV, and JL made substantial contributions to the interpretation of the results and edited the manuscript. ASF and AV provided further contributions to the analysis description and interpretation of the results. All authors had full access to all the data in the analysis, reviewed manuscript drafts, read and approved the final version of the manuscript, and had final responsibility for the decision to submit for publication.

Declaration of interests

We declare no competing interests.

Data sharing

The data and R code that support the findings of this analysis are available from the corresponding author upon reasonable request. The mathematical model that contains aggregated HIV self-testing distribution data from the programme can be obtained from the corresponding author after approval of a proposal, whereas the data used for model fitting are detailed in the appendix (pp 38–51).

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