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Authors

Hamilton, Deven T
Katz, David A
Luo, Wei
et al.

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Effective strategies to promote HIV self-testing for men who have sex with men: Evidence from a mathematical model

Deven T. Hamilton^{a,*}, David A. Katz^b, Wei Luo^c, Joanne D. Stekler^{b,d,e}, Eli S. Rosenberg^f, Patrick S. Sullivan^{g,h}, Steven M. Goodreau^{a,i}, Susan Cassels^j

^aCenter for Studies in Demography and Ecology, University of Washington, Seattle, WA, United States

^bDepartment of Global Health, University of Washington, Seattle, WA, United States

^cDepartment of Geography, National University of Singapore, Singapore, Singapore

^dDepartment of Medicine, University of Washington, Seattle, WA, United States

^eDepartment of Epidemiology, University of Washington, Seattle, WA, United States

^fDepartment of Epidemiology and Biostatistics, School of Public Health, University at Albany, State University of New York, Albany, NY, United States

^gDepartment of Epidemiology, Emory University, Atlanta, GA, United States

^hDepartment of Global Health, Emory University, Atlanta, GA, United States

ⁱDepartment of Anthropology, University of Washington, Seattle, WA, United States

^jDepartment of Geography, University of California, Santa Barbara, CA, United States

Abstract

Background: HIV testing is the gateway to HIV treatment and prevention. HIV self-testing (HIVST) has potential to increase testing; however, the potential population-level impact of HIVST on the HIV epidemic and the best strategies for promoting HIVST are unknown. Our aim is to inform public health approaches for promoting HIVST as part of a comprehensive strategy to reduce HIV incidence.

Methods: Stochastic network-based HIV transmission models were used to estimate how different HIVST strategies would affect HIV incidence in Seattle and Atlanta over 10 years. We

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*Corresponding author. dth2@uw.edu (D.T. Hamilton).

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Conflicts of Interest

None of the authors has any potential conflicts of interest to disclose.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.epidem.2021.100518.

included four types of HIV testers and implemented nine replacement and eleven supplementation strategies for HIVST.

Results: Replacement of clinic-based tests with HIVST increased HIV incidence in Seattle and Atlanta. The benefits of supplementary strategies depended on the tester type using HIVST. Targeting non-testers averted the highest number of cases per test. In Seattle 2.2 (95%SI=-77, 100.4) and 4.7 (95%SI=-35.7, 60.1) infections were averted per 1000 HIVST when non-testers used HIVST once or twice per year respectively. In Atlanta the comparable rates were 8.0 (95%SI=-60.3 to 77.7) and 6.7 (95%SI=-37.7, 41.0). Paradoxically, increasing testing among risk-based testers using HIVST increased incidence.

Conclusions: The population-level impact of HIVST depends on who is reached with HIVST, how kits are used, and by characteristics of the underlying epidemic and HIV care infrastructure. Targeted HIVST can be an effective component of a comprehensive HIV testing strategy. More work is needed to understand how to identify and target non-testers for self-testing implementation.

Keywords

Network modeling; HIV transmission dynamics; HIV self-testing

1. Introduction

HIV testing is the first step in the HIV prevention and care continuum and critical to meeting the U.S. Ending the HIV Epidemic (EHE) goal of a 90% reduction in HIV incidence over the next 10 years (Fauci et al., 2019) as well as the UNAIDS 95-95-95 and 2030 global goals. The World Health Organization recommends HIV self-testing (HIVST) as one strategy for increasing access to, coverage, and frequency of HIV testing (WHO Policy Brief, 2019). Several studies of HIVST show that they can be a useful addition to comprehensive HIV prevention (Jamil et al., 2017; Katz et al., 2018; Edelstein et al., 2020; Carballo-Diequez et al., 2020; MacGowan et al., 2019; Wesolowski et al., 2019) and for facilitating partner testing, particularly among vulnerable populations (Carballo-Diequez et al., 2020; Hershov et al., 2019; Rael et al., 2020). The most effective strategies for implementing HIVST at the population level, however, are unknown.

HIVST provides convenience, privacy, and anonymity, and thus might reach individuals who otherwise would not test for HIV and those without convenient healthcare access. HIVST might also provide opportunities to increase testing frequency for MSM, resulting in earlier diagnosis and potentially fewer secondary transmissions. However, the only HIVST available in the U.S. is the OraQuick In-Home HIV Test, and oral fluid HIV tests have a relatively long window period (the time between exposure to HIV and when a test can give accurate results) compared to blood-based point-of-care or laboratory tests (Stekler et al., 2016; Stekler et al., 2013), potentially leading to false-negative results during early infection. False-negative results may delay treatment initiation and expose uninfected partners to HIV, especially during the highly infectious acute stage of infection (Wawer et al., 2005). People with reactive HIVSTs may also delay linkage to care.

Understanding how to maximize HIVST effectiveness while limiting risks will be essential to integrating this modality into comprehensive HIV prevention strategies. Our past work using compartmental modeling suggested that simply replacing clinic tests with HIVST could increase HIV prevalence in settings with high rates of testing like Seattle, WA (Katz et al., 2014). However, empiric evaluations of HIVST programs, including ours, have been limited partly because it is difficult to evaluate who is using kits and what the test results are (Tahlil et al., 2020). Epidemic modeling offers an opportunity to synthesize available information from studies of HIVST, design possible interventions, compare the potential impact in different epidemic settings, and estimate the likely impacts of scaling HIVST programs.

We undertook a new modeling project to estimate how different strategies of HIVST affected HIV incidence and assess how local epidemic characteristics might affect the impact of HIVST programs. We modeled HIVST interventions among MSM in Seattle, WA and Atlanta, GA, exemplar settings with qualitatively different HIV epidemics among MSM with respect to demographics, testing frequency, and HIV-related clinical infrastructure (Panagiotoglou et al., 2018).

2. Methods

We used data from Seattle and Atlanta to parameterize a stochastic network-based HIV transmission model (Luo et al., 2018; Jenness et al., 2016). HIV transmission dynamics were a function of anal intercourse (AI) and related HIV transmission probabilities, including condom use, sexual partnership characteristics, HIV testing frequency, disclosure, HIV care seeking and PrEP. The sexual contact networks employed separable-temporal exponential random graph models (STERGMs)—a flexible statistical framework for simulating partnership formation and dissolution across networks (Hunter et al., 2008; Krivitsky and Handcock, 2014). The epidemic model was built on the EpiModel platform (Jenness et al., 2017). Details of the model, data parameterization, and the protocol for the modeling strategy for this study have been published elsewhere (Luo et al., 2018; Sullivan et al., 2014). Since publication of the technical paper, PrEP modules have been updated to reflect current CDC guidelines as described in Jenness et al., 2016 (Jenness et al., 2016). This work was classified as exempt from human subjects considerations by the UCSB Office of Research (#1–14–0967).

2.1. HIV testing typologies

The model included four HIV tester types, based on a previous qualitative typology (Hussen et al., 2013): 1) *non-testers*: men who do not test; 2) *opportunistic testers*: men who test only when presented the opportunity; 3) *regular testers*: men who test on an episodic basis; and 4) *risk-based testers*: men who test following a high-risk sexual episode. Each tester type had specific baseline testing behavior and responded uniquely to opportunistic tests. In the Seattle model 2.5%, 13.8%, 64.9% and 18.8% of MSM were non-testers, opportunistic testers, regular testers and risk-based testers, respectively, compared to 3.5%, 37.0%, 44.0% and 15.5% in the Atlanta model (Luo et al., 2018). In this typology, both regular testers and risk-based testers also test opportunistically, but the likelihood that they take advantage of a

testing opportunity when it arises is much lower than the likelihood that an individual who exclusively tests opportunistically would take advantage of the same opportunity (Luo et al., 2018).

2.2. Model scenarios and outcomes

We modeled 9 and 11 scenarios for replacing and supplementing clinic tests, respectively. All scenarios are described in Table 1. In scenario one, 25% of clinic-based opportunistic tests were replaced with HIVST. This scenario influenced all opportunistic tests taken by exclusively opportunistic testers as well as those taken by regular and risk-based testers. In scenarios two and three, we replaced 25% of the (non-opportunistic) regular and risk-based tests for each of the two tester types respectively. In scenario four, we combined the replacement strategies in the first three scenarios. Scenarios 5–8 repeated scenarios 1–4 with 50% of the clinic tests replaced with HIVST. In scenario 9, we replaced just 5% of all tests with HIVST.

In scenario 10, all three tester types that take opportunistic tests tested one additional time annually with an HIVST. In scenario 11, regular testers took one additional test each year. In scenario 12, risk-based testers had an additional 10% chance of taking a test following a risk event with an HIVST. In scenario 13, the non-testers tested annually with an HIVST. In scenario 14, all of the tester types supplemented their testing with HIVST at the levels described in scenarios 11–13. The supplementation strategies were then repeated in scenarios 15–19 with the number of annual tests increased to 2 and the additional chance that a risk-based tester tests increased to 20%. In scenario 20, we reduced the intertest interval for regular testers so that they took one additional test annually.

The model used for simulation was a discrete time model with 1-week time intervals. For all scenarios, we assumed a 13-week window period to approximate the 90-day window period reported on the package insert for the OraQuick In-Home HIV Test (Stekler et al., 2016). Clinic-based tests had 4- and 3-week window periods in Atlanta and Seattle respectively, assuming the use of both IgG/IgM-sensitive antibody tests and antigen/antibody combination assays (Branson and Stekler, 2012).

In addition to the primary replacement and supplementation scenarios described above, we conducted two supplementary analyses. The first was a sensitivity analysis to determine the impact of the HIVST window period on our results. Recent evaluations of the time from HIV infection to earliest detection indicate that the published OraQuick window period may be conservative and not reflect the true window period in practice. For example, Delaney et al. reported that 75% of infections were detectable with the OraQuick *ADVANCE*® HIV-1/2 Antibody Test on oral fluids at 45 days (~6 weeks) following HIV acquisition (Delaney et al., 2018), far earlier than the 90-day window. Additionally, researchers are working on self-tests that have capacity to detect p24 antigen or even nucleic acids, so knowing the impact of different window periods on epidemic outcomes will be useful for program development. We applied five different window periods (2, 4, 6, 9, 13 weeks) in three different testing scenarios. For the analyses using replacement and supplement strategies, we repeated scenarios 8 and 19 respectively. The second supplementary analysis assessed the impact of differences in the baseline distribution of testing behavior in Atlanta and Seattle

on the epidemic outcomes in each city by interchanging the distributions of tester types between cities.

The model outcomes are the number of incident cases per 100 person years at risk over the simulated 10 years, percent of infections averted (PIA) and number of infection averted (NIA) per 100,000 person-years at risk, and the number of infections averted per 1000 HIVST. For each outcome we report the mean over 100 simulations and the 95% simulation interval (SI), the range of simulation outputs that include 95% of those observed. Note that the SI are not measures of confidence in the estimated means, rather they indicate stochasticity in the simulation. We also show the 52-week moving average incidence, at each time point the value reported is the mean incidence across the prior 52 weeks, over ten years for each of the replacement strategies. The moving average is plotted because the variability in weekly values make it difficult to see temporal trends.

3. Results

3.1. Replacing clinic-based HIV tests with HIVST

Table 2 presents results from the 9 replacement scenarios. Replacing 25% of clinic tests within any single testing strategy in Atlanta had a detrimental impact on HIV infections with a PIA ranging from -0.1 when replacing either risk-based or opportunistic tests to 0.0 for regular tests. When 25% of all clinic tests were replaced with HIVST, the cumulative effect was a PIA of -0.4 (95%SI= $-7.6, 8.0$) and an NIA of -12 (95%SI= $-265, 299$). Increasing the rate of replacement to 50% increased incidence and reduced the PIA to -1.7 (95%SI= $-9.3, 6.4$) and NIA to -57 (95%SI= $-325, 241$). The 5% replacement scenario had a small negative effect, producing a PIA of -0.18 (95%SI= $-8.0, 8.3$).

In Seattle, replacing 25% of clinic tests within any one testing strategy also increased HIV infection. The mean PIA ranged from -1.4 when replacing regular tests to -1.1 for risk-based tests, and NIA ranged from -4 to -2 in these scenarios, respectively. In the combined scenario the PIA was -3.7 (95%SI= $-37.1, 23.7$) and NIA was -23 (95%SI= $-261, 224$). Increasing the proportion of all clinic tests replaced to 50% further increased incidence and reduced the PIA to -8.6 (95%SI= $-35.6, 18.5$) and NIA to -64 (95%SI= $-267, 176$). Replacing 5% of tests in Seattle had a far more deleterious impact in Seattle compared to Atlanta, producing a PIA of -2.0 (95%SI= $-34.7, 24.0$). Fig. 1 shows the 52-week moving average incidence.

3.2. Supplementing clinic-based HIV tests with HIVST

Table 3 presents results from the supplementation scenarios. In Atlanta, supplementing with 1 additional annual test in any one group modestly reduced HIV incidence, producing a PIA from 0.2 (regular testers) to 0.8 (never testers). However, when risk-based testers increased their probability of testing by using HIVST, incidence increased. The largest PIA was found when non-testers took an annual HIVST, even though non-testers were only 3.5% of the population, with 8 (95% SI $-60.3, 77.7$) infections averted per 1000 HIVST taken. Fig. 2 shows the 90-day moving average incidence over ten years for each of the supplementation strategies.

Supplementing with 2 additional annual tests or increasing the likelihood of testing after a risk event by 20% in Atlanta resulted in similar patterns as the lower level of supplementation but with larger magnitudes. Adding two HIVST for non-testers generated a PIA of 1.3 (95% SI -8.2, 8.2) and 6.7 (95%SI=-37.7, 410) infections averted per 1000 HIVST taken. Reducing the intertest interval for regular testers had a small positive effect, with PIA of 0.3 (95%SI: -9.8, 7.9) and NIA of 12 (95%SI: -339,295). However, increasing the likelihood of testing for risk-based testers increased incidence, producing an NIA of -6.0 (95%SI: -8.5, 6.6).

Supplementing by increasing the likelihood of testing by 10% for risk-based testers in Seattle had a worse impact than it had in Atlanta, producing a PIA of -1.1 (95%SI=-30.4, 21.8) and NIA of -2 (95%SI=-208, 211). Conversely, supplementation by opportunistic testers had a positive impact on the PIA (1.6; 95%SI=-28.4, 26.5) and NIA (19; 95%SI=-200, 254). The impact on infections when either regular testers or non-testers supplemented was negligible.

Doubling supplementation to 2 additional tests per year or increasing the likelihood of testing after a risk event by 20% in Seattle increased the magnitude of the effects and clarified the direction of the effect for regular and non-testers. Supplementation by risk-based testers resulted in a PIA of -1.2 (95%SI=-32.6, 28.6). Supplementation by regular testers and non-testers resulted in PIAs of 2.9 (95%SI=-28.9, 25.5) and 2.1 (95%SI=-23.7, 30.3), respectively. Adding two HIVSTs for the non-testers also resulted in 4.7 (95%SI=-35.7, 60.1) infections averted per 1000 HIVST taken. Reducing the intertest interval for regular testers had almost no effect.

The results of our sensitivity analysis exploring the impact of the HIVST window period on our findings are in the supplemental digital content. With longer window periods, incidence increased when 50% of regular and opportunistic testers replaced clinic tests with HIVST, and when risk-based testers increased the likelihood of testing by 20% but used HIVST. In Atlanta, the NIA was -57.4 (95%SI=-324.6, 240.6) with a 13-week window and remained negative even as the window period was reduced to 4 weeks (NIA=-14.1; 95% SI:-313.2, 238). When the window period was reduced to 2 weeks, two week shorter than the clinic test window in Atlanta, the NIA was positive (10.4; 95%SI=-308.9, 292.6). Results in Seattle were similar, with negative NIA for all window periods and the size of the effect diminishing with the window period.

Supplementation for all tester types in Atlanta produced a PIA of 1.5 (95%SI=-7.6, 9) with a 3-week window and increased to 5.8 (95%SI=-2.3, 14.4) when the window was reduced to 2 weeks, while in Seattle the PIAs were 4.2 (95%SI=-20.3, 27.1) and 10 (95%SI=-19.3, 32.1), respectively. In scenarios where only risk-based testers supplemented with HIVST in Atlanta, supplementation had a negative NIA at 13 weeks, but the NIA was positive for window periods 9 weeks. In Seattle, supplementation by risk-based testers increased incidence with window periods greater than 4 weeks, and the effects were ambiguous at 4 weeks and below.

Interchanging the two city's distributions of tester types increased the incidence rate in Seattle by 8% from 0.8 to 0.86 per 100 person years and the number of new infections increase by 7.1%. Atlanta, on the other hand, had a reduction in incidence from 3.58 to 3.48 per 100 person years at risk and new infections declines with a PIA of 2.4% (Appendix).

4. Discussion

The EHE goals of reducing HIV incidence by 90% over 10 years is extremely ambitious and will require a comprehensive approach to HIV prevention utilizing all available resources to expand HIV testing and PrEP access when appropriate. Several modeling studies have examined how different testing strategies could impact the epidemic. Delaney et al. used an agent-based network model to evaluate testing interventions among MSM in the US and reported that improving testing alone would not reduce incidence, but when viral suppression was improved among diagnosed individuals, improving testing frequency and testing sensitivity reduced incidence (Delaney et al., 2015). Khanna et al. also used an agent-based model to illustrate the potential benefits of individualized HIV testing programs for reducing HIV transmissions in MSM (Khanna et al., 2015), while Kok et al. used a compartmental systems model to determine optimal resource allocations across targeted and routine testing programs and found that prioritizing routine testing resulted in the largest number of infections averted (Kok et al., 2015). These models did not specifically account for the use of HIVST.

In our previous study using deterministic compartmental models to evaluate the use of HIVST in Seattle (Katz et al., 2014), we found that any replacement of clinic based tests with home testing resulted in an increased HIV prevalence among Seattle MSM, regardless of impact on testing frequency. Our findings from this stochastic network-based model are generally consistent with the prior results, suggesting that HIVST can reduce the number of new infections even in places like Seattle where testing rates among MSM are high, the time from diagnosis to treatment is short, and ART coverage and viral suppression is high only if HIVST use does not reduce the use of clinic based testing. This trend held even when replacement rates were extremely low, suggesting that even a small amount of miscommunication or unclear messaging when promoting the use of HIVST could undermine progress towards ending the HIV epidemic. Additionally, there may be circumstances, like the current SARS-CoV-2 pandemic, that limit access to testing facilities and replacement becomes the only option for continued testing. Under such circumstances, replacement is preferable to not testing, but public health officials should be prepared for the possible uptick in new HIV cases if clinic-based testing has declined, even if HIVST have been used to compensate.

Our findings further suggest that focusing HIVST on non-testers may be an effective means of reducing incidence even when HIVST have long window periods. Targeting this group had the largest overall impact on HIV incidence in Atlanta despite comprising only 3.5% of the population. Targeting never-testers in Seattle, a setting with a robust HIV testing program and high rates of regular testing, was also the most efficient in terms of cases averted per HIVST. Prioritizing non-testers for HIVST interventions represents a high yield, potentially low-cost opportunity to both reduce HIV incidence and get individuals not

engaged with care connected to resources, especially since others have demonstrated that non-testers are often willing to take an HIVST (Clark et al., 2019; Patel et al., 2019). The impact of increasing self-testing among non-testers on the epidemic will depend on the proportion of non-testers in the population and the underlying HIV incidence, with the benefit being greater in settings where more MSM have never tested and the HIV incidence is higher. An analysis of National Survey of Family Growth data from 2011 to 2015 found that 29% of MSM reported never having been tested, and a similar analysis of Behavioral Risk Factor Surveillance System data found that 34% of MSM had never been tested (Febo--Vazquez et al., 2018; Pitasi et al., 2017). More work is needed to understand how to identify this large population of MSM who have never tested and how to reach non-testers with HIVST.

The largest reduction in incidence in Seattle resulted from supplementation among regular testers because this group includes 65% of the MSM population in Seattle compared to 44% in Atlanta. Supplementation among opportunistic testers may also reduce new HIV infections as long as the use of HIVSTs does not replace or reduce clinic testing frequency over time. For these groups, the magnitude of the reduction in incidence was modest, but the impact may be larger with more frequent testing. In our simulations we had a maximum of two additional tests per year, but recently published results from the eSTAMP study reported a median of 5 tests per year when HIVST were liberally provided (MacGowan et al., 2019).

Sensitivity analyses indicated that replacement of clinic tests with HIVST continued to increase incidence until the window period for the HIVST becomes shorter than the clinic test window period, which was only the case when the HIVST window period was 2 weeks. With supplementation, the NIA increased as the HIVST window period declined. Among risk-based testers, for whom supplementation with HIVST had increased incidence, HIVST became an effective means of reducing incidence once the window period was shorter than the time between potential exposure and testing. In our simulations, individuals tested 6 weeks following condomless anal intercourse with a non-main partner, 7 weeks following anal intercourse with a known sero-discordant partner, and 9 weeks after acquiring a new main partner on average (Luo et al., 2018).

Finally, the distribution of tester types influenced incidence. If individuals in Atlanta tested in patterns seen in Seattle, the PIA was larger than any of the HIVST supplementation scenarios. Similarly, a shift away from regular testing to more opportunistic testing in Seattle increased the number of infections by 7%, a change similar in magnitude to replacing 50% of all tests in Seattle with HIVST.

Public health messaging should emphasize supplementing with HIVST rather than replacing clinic-based tests. However, in some cases, supplementation must be conducted with caution because of the difference in window periods. As our results demonstrate, supplementation with HIVST by risk-based testers too soon after a potential exposure could have the unintended consequence of increasing incidence because HIVST are not able to detect infections as quickly as most risk-based testers seek out a test. Unless this is clearly understood by those using the tests, individuals could erroneously believe they are negative.

For risk-based testers this can lead to long periods of undetected infection if they do not engage in what they perceive to be a risky event for some time into the future.

Developing or utilizing HIVSTs with shorter window periods, particularly those able to detect the earliest stages of acute infection, would have potential to reduce this concern and improve the effectiveness of HIVST strategies. But until more sensitive tests are available, HIVST kit packaging instructions should emphasize the window period and that these tests are not appropriate for risk-based testing. Although only OraQuick is approved for use in the U.S. at this time, there are a number of other HIVST products available globally (Unitaid WHO, 2018), including several blood-based products that may have shorter window periods which may eventually make HIVST following a potential exposure an effective testing strategy. The consequences of a false negative HIVST among regular testers is much smaller at the population-level because their time undiagnosed will be limited to their intertest interval. However, for the individual and their partners, the consequences can be significant.

Our study had several limitations. First, the data used to parameterize the behavioral aspects of the models were from convenience samples (Luo et al., 2018), and thus they may not be representative of the MSM populations in these cities. Second, the overall effect size of the HIVST intervention on incidence is quite small, and there is substantial stochasticity in the transmission model, which produces very large SIs. SIs are not a measure of uncertainty in the mean estimated effect and therefore do not impact our confidence in our findings. However, they do reflect the fact that in a single population of the size modeled, HIVST might, with reasonable chance, have no effect on incidence. Consequently, we believe the key takeaway here is not the specific PIA or NIA values, but rather the consistent trends in reduced incidence with targeted HIVST. Third, there are alternative interventions that were not explored here that may increase the impact of HIVST like leveraging partner or social networks for HIVST distribution (Carballo-Diequez et al., 2020; Lightfoot et al., 2018) which could increase overall rates of testing, reach non-testers or reach individuals at increased risk for HIV. Finally, our model used weeks to represent time so our representation of the window periods is the nearest approximation to the published durations, which are reported in days.

In conclusion, HIVST should be a component of interventions to reduce incidence. The most effective HIVST strategies involve supplementing regular testers and non-testers. Future HIVST intervention campaigns will need to account for epidemic context, including current testing behaviors in the population, and provide clear messaging around the timing of a risk exposure and the ability of the HIVST to detect infection.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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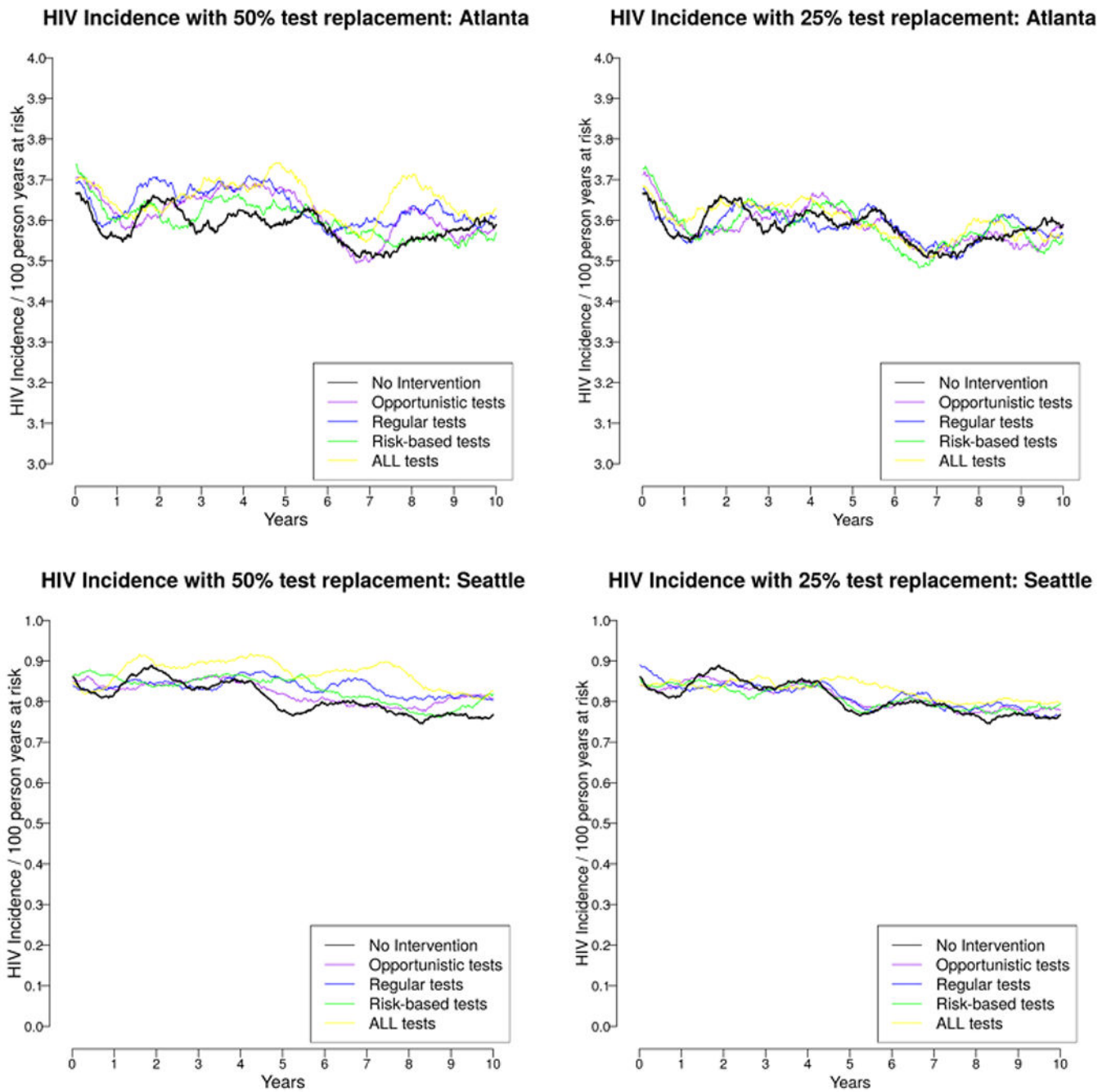


Fig. 1. The estimated 52-week moving average of HIV incidence in Atlanta and Seattle with 25% and 50% testing replacement with HIV self-tests by tester type.

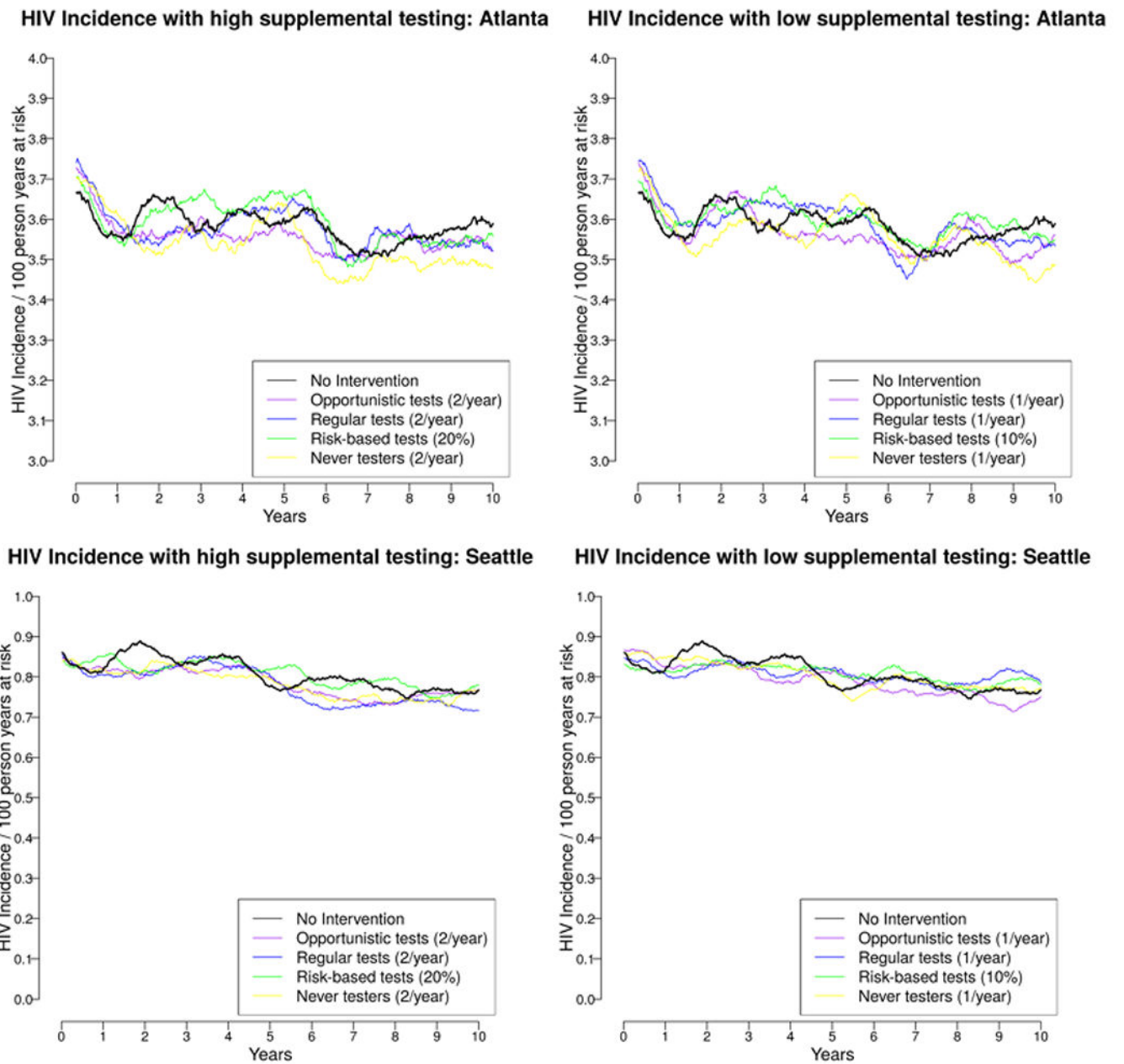


Fig. 2. The estimated 52-week moving average of HIV incidence in Atlanta and Seattle with high and low levels of testing supplementation with HIV self-tests by tester type.

Table 1

Table of HIV self-testing replacement and supplementation by tester type.

Scenario number	Intervention	Impacted tester types
0	No intervention	NA
1	Replacement of 25% of opportunistic tests	All testers
2	Replacement of 25% of regular tests	Regular testers
3	Replacement of 25% of risk based tests	Risk-based testers
4	Replacement of 25% of all tests	All testers
5	Replacement of 50% of opportunistic tests	All testers
6	Replacement of 50% of regular tests	Regular testers
7	Replacement of 50% of risk based tests	Risk-based testers
8	Replacement of 50% of all tests	All testers
9	Replacement of 5% of all tests	All testers
10	Supplementing +1 annual opportunistic test	All testers
11	+1 annual test regular test	Regular testers
12	+10% after risk event	Risk-based testers
13	+1 annual never testers	Never testers
14	All above	All individuals
15	+2 annual opportunistic test	All testers
16	+2 annual test regular test	Regular testers
17	+20% after risk event	Risk-based testers
18	+2 annual never testers	Never testers
19	All above	All individuals
20	Reduced intertest interval	Regular testers

Table 2

HIV incidence, number of infections averted per 100,000 person years at risk, the percent of infections averted and the number of infections averted per 1000 HIV self-tests with replacement strategies in Atlanta and Seattle.

Location	Scenario number	Intervention	Incidence / 100 person years at risk	Number of infections averted / 100,000 person years at risk	Percent of infections averted	Number of infections averted per 1000 HIV self-tests
Atlanta	0	No intervention	3.58 (95% SI: 3.34, 3.8)	NA	NA	NA
	1	25% of opportunistic tests	3.58 (95% SI: 3.35, 3.83)	-2 (95% SI: -274, 279)	-0.1 (95% SI: -7.9, 7.6)	-0.1 (95% SI: -22.4, 22.6)
	2	25% of regular tests	3.58 (95% SI: 3.37, 3.82)	1 (95% SI: -252, 287)	0 (95% SI: -7.3, 7.7)	0 (95% SI: -16.6, 18.8)
	3	25% of risk based tests	3.58 (95% SI: 3.28, 3.81)	0 (95% SI: -275, 311)	-0.1 (95% SI: -8, 8.4)	0 (95% SI: -57.5, 65)
	4	25% of all tests	3.59 (95% SI: 3.36, 3.83)	-12 (95% SI: -265, 299)	-0.4 (95% SI: -7.6, 8)	-0.4 (95% SI: -8.2, 9.3)
	5	50% of opportunistic tests	3.61 (95% SI: 3.34, 3.87)	-23 (95% SI: -266, 285)	-0.7 (95% SI: -7.7, 7.7)	-0.9 (95% SI: -10.7, 11.6)
	6	50% of regular tests	3.63 (95% SI: 3.36, 3.88)	-45 (95% SI: -318, 263)	-1.3 (95% SI: -9.2, 7.1)	-1.5 (95% SI: -10.5, 8.6)
	7	50% of risk based tests	3.59 (95% SI: 3.35, 3.85)	-9 (95% SI: -339, 248)	-0.3 (95% SI: -9.8, 6.8)	-0.8 (95% SI: -34.5, 26.2)
	8	50% of all tests	3.65 (95% SI: 3.42, 3.86)	-57 (95% SI: -325, 241)	-1.7 (95% SI: -9.3, 6.4)	-0.9 (95% SI: -5, 3.7)
Seattle	9	5% of all tests	3.58 (95% SI: 3.26, 3.80)	-4 (95% SI: -273, 309)	-0.2 (95% SI: -8.0, 8.3)	-1.3 (95% SI: -89.5, 102)
	0	No intervention	0.80 (95% SI: 0.67, 1.01)	NA	NA	NA
	1	25% of opportunistic tests	0.81 (95% SI: 0.62, 1.03)	-4 (95% SI: -238, 260)	-1.3 (95% SI: -30.9, 27.3)	-0.7 (95% SI: -41.3, 45.3)
	2	25% of regular tests	0.81 (95% SI: 0.61, 1)	-4 (95% SI: -218, 266)	-1.4 (95% SI: -29.6, 28.9)	-0.2 (95% SI: -14.5, 17.6)
	3	25% of risk based tests	0.81 (95% SI: 0.66, 0.96)	-2 (95% SI: -217, 214)	-1.1 (95% SI: -30.7, 22.3)	0 (95% SI: -63.8, 66.9)
	4	25% of all tests	0.83 (95% SI: 0.64, 1.01)	-23 (95% SI: -261, 224)	-3.7 (95% SI: -37.1, 23.7)	-0.9 (95% SI: -10.7, 9.2)
	5	50% of opportunistic tests	0.82 (95% SI: 0.65, 1.01)	-14 (95% SI: -221, 206)	-2.4 (95% SI: -29.9, 22.1)	-1.2 (95% SI: -18.7, 17.6)
	6	50% of regular tests	0.83 (95% SI: 0.66, 1.02)	-29 (95% SI: -243, 209)	-4.5 (95% SI: -32.7, 22.5)	-0.9 (95% SI: -7.8, 6.8)
	7	50% of risk based tests	0.83 (95% SI: 0.67, 1.01)	-23 (95% SI: -284, 227)	-4 (95% SI: -40.3, 23.4)	-3.2 (95% SI: -41.6, 35.1)
8	50% of all tests	0.87 (95% SI: 0.68, 1.05)	-64 (95% SI: -267, 176)	-8.6 (95% SI: -35.6, 18.5)	-1.3 (95% SI: -5.4, 3.6)	
9	5% of all tests	0.81 (95% SI: 0.65, 1.0)	-10 (95% SI: -243, 219)	-2.0 (95% SI: -34.7, 24)	-3.3 (95% SI: -80.1, 72.8)	

Table 3

HIV incidence, number of infections averted per 100,000 person years at risk, the percent of infections averted and the number of infections averted per 1000 HIV self-tests with supplementation strategies in Atlanta and Seattle.

Location	Scenario number	Intervention	Incidence / 100 person years at risk	Number of infections averted / 100,000 person years at risk	Percent of infections averted	Number of infections averted / 1000 HIV self-tests	
Atlanta	0	No intervention	3.58 (95% SI: 3.34, 3.8)	NA	NA	NA	
	10	+1 annual opportunistic test	3.56 (95% SI: 3.35, 3.83)	27 (95% SI: -286, 318)	0.7 (95% SI: -8.3, 8.5)	0.3 (95% SI: -3.3, 3.6)	
	11	+1 annual test regular event	3.58 (95% SI: 3.37, 3.79)	9 (95% SI: -257, 296)	0.2 (95% SI: -7.5, 7.9)	0.3 (95% SI: -7, 8)	
	12	+10% after risk event	3.59 (95% SI: 3.35, 3.84)	-10 (95% SI: -305, 254)	-0.3 (95% SI: -8.7, 6.9)	-3.1 (95% SI: -95.2, 78.5)	
	13	+1 annual never testers	3.55 (95% SI: 3.32, 3.81)	30 (95% SI: -230, 295)	0.8 (95% SI: -6.7, 8)	8 (95% SI: -60.3, 77.7)	
	14	All above	3.51 (95% SI: 3.28, 3.75)	68 (95% SI: -259, 306)	1.8 (95% SI: -7.6, 8.2)	0.5 (95% SI: -2, 2.3)	
	15	+2 annual opportunistic test	3.55 (95% SI: 3.29, 3.78)	32 (95% SI: -289, 320)	0.8 (95% SI: -8.4, 8.8)	0.2 (95% SI: -1.7, 1.8)	
	16	+2 annual test regular event	3.57 (95% SI: 3.31, 3.85)	9 (95% SI: -355, 320)	0.2 (95% SI: -10.3, 8.7)	0.1 (95% SI: -4.8, 4.3)	
	17	+20% after risk event	3.59 (95% SI: 3.37, 3.82)	-6 (95% SI: -291, 244)	-0.2 (95% SI: -8.5, 6.6)	-0.9 (95% SI: -45.1, 38.6)	
	18	+2 annual never testers	3.53 (95% SI: 3.27, 3.77)	49 (95% SI: -281, 301)	1.3 (95% SI: -8.2, 8.2)	6.7 (95% SI: -37.7, 41)	
	19	All above	3.52 (95% SI: 3.25, 3.76)	57 (95% SI: -261, 334)	1.5 (95% SI: -7.6, 9)	0.2 (95% SI: -1, 1.3)	
	20	Reduced intertest interval	3.57 (95% SI: 3.36, 3.83)	12 (95% SI: -339, 295)	0.3 (95% SI: -9.8, 7.9)	0.3 (95% SI: -9, 7.8)	
	Seattle	0	No intervention	0.8 (95% SI: 0.67, 1.01)	NA	NA	NA
		10	+1 annual opportunistic Test	0.78 (95% SI: 0.62, 0.94)	19 (95% SI: -200, 254)	1.6 (95% SI: -28.4, 26.5)	0.3 (95% SI: -2.9, 3.7)
		11	+1 annual test regular event	0.8 (95% SI: 0.66, 0.98)	0 (95% SI: -216, 232)	-0.8 (95% SI: -29.7, 24.9)	0 (95% SI: -5.3, 5.7)
		12	+10% after risk event	0.81 (95% SI: 0.68, 0.95)	-2 (95% SI: -208, 211)	-1.1 (95% SI: -30.4, 21.8)	-0.7 (95% SI: -100.2, 101.4)
		13	+1 annual never testers	0.8 (95% SI: 0.64, 0.94)	6 (95% SI: -190, 249)	-0.2 (95% SI: -27, 26.4)	2.2 (95% SI: -77, 100.4)
		14	All above	0.76 (95% SI: 0.63, 0.92)	44 (95% SI: -156, 285)	4.7 (95% SI: -22, 29.3)	0.4 (95% SI: -1.4, 2.5)
		15	+2 annual opportunistic Test	0.78 (95% SI: 0.64, 0.99)	21 (95% SI: -213, 212)	1.9 (95% SI: -27, 22.2)	0.2 (95% SI: -1.6, 1.5)
		16	+2 annual test regular event	0.77 (95% SI: 0.64, 0.93)	30 (95% SI: -204, 237)	2.9 (95% SI: -28.9, 25.5)	0.4 (95% SI: -2.5, 2.9)
17		+20% after risk event	0.81 (95% SI: 0.63, 1)	-3 (95% SI: -234, 278)	-1.2 (95% SI: -32.6, 28.6)	-0.3 (95% SI: -54.6, 67.8)	
18		+2 annual never testers	0.78 (95% SI: 0.62, 0.94)	24 (95% SI: -171, 296)	2.1 (95% SI: -23.7, 30.3)	4.7 (95% SI: -35.7, 60.1)	
19	All above	0.76 (95% SI: 0.6, 0.91)	40 (95% SI: -145, 253)	4.2 (95% SI: -20.3, 27.1)	0.2 (95% SI: -0.6, 1.1)		
20	Reduced intertest interval	0.8 (95% SI: 0.64, 0.99)	4 (95% SI: -208, 228)	-0.3 (95% SI: -28.3, 23.6)	0.1 (95% SI: -5, 5.5)		