Title

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Journal

JAIDS Journal of Acquired Immune Deficiency Syndromes, 90(S1)

ISSN

1525-4135

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Publication Date

2022-07-01

DOI

10.1097/qai.0000000000002977

Peer reviewed

HHS Public Access
Author manuscript
J Acquir Immune Defic Syndr. Author manuscript; available in PMC 2023 July 01.

Published in final edited form as:
J Acquir Immune Defic Syndr. 2022 July 01; 90(Suppl 1): S167–S176. doi:10.1097/QAI.0000000000002977.

Using Microsimulation Modeling to Inform EHE Implementation Strategies in Los Angeles County

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Abstract

Background: Pre-exposure prophylaxis (PrEP) is essential to ending HIV. Yet, uptake remains uneven across racial and ethnic groups. We aimed to estimate the impacts of alternative PrEP implementation strategies in Los Angeles County (LAC).

Setting: Men who have sex with men (MSM), residing in LAC.

Methods: We developed a microsimulation model of HIV transmission, with inputs from key local stakeholders. With this model, we estimated the 15-year (2021–2035) health and racial and ethnic equity impacts of three PrEP implementation strategies involving coverage with 9,000

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additional PrEP units annually, above the Status-quo coverage level. Strategies included PrEP allocation equally (Strategy 1), proportionally to HIV prevalence (Strategy 2), and proportionally to HIV diagnosis rates (Strategy 3), across racial and ethnic groups. We measured the degree of relative equalities in the distribution of the health impacts using the Gini index (G) which ranges from 0 (perfect equality, with all individuals across all groups receiving equal health benefits) to 1 (total inequality).

Results: HIV prevalence was 21.3% in 2021 (Black [BMSM], 31.1%; Latino [LMSM], 18.3%, and White [WMSM], 20.7%) with relatively equal to reasonable distribution across groups (G, 0.28; 95% confidence interval [CI], 0.26–0.34). During 2021–2035, cumulative incident infections were highest under Status-quo (n=24,584) and lowest under Strategy 3 (n=22,080). Status-quo infection risk declined over time among all groups but remained higher in 2035 for BMSM (incidence rate ratio [IRR], 4.76; 95% CI, 4.58–4.95), and LMSM (IRR, 1.74; 95% CI, 1.69–1.80), with the health benefits equally to reasonably distributed across groups (G, 0.32; 95% CI, 0.28–0.35). Relative to Status-quo, all other strategies reduced BMSM-WMSM and BMSM-LMSM disparities, but none reduced LMSM-WMSM disparities by 2035. Compared to Status-quo, Strategy 3 reduced the most both incident infections (% infections averted: overall, 10.2%; BMSM, 32.4%; LMSM, 3.8%; WMSM, 3.5%) and HIV racial inequalities (G reduction, 0.08; 95% CI, 0.02–0.14).

Conclusion: Microsimulation models developed with early, continuous stakeholder engagement and inputs yield powerful tools to guide policy implementation.

Keywords

HIV; AIDS; PrEP; pre-exposure prophylaxis; implementation science; microsimulation model; equity

INTRODUCTION

A goal of Ending the HIV Epidemic: A Plan for America (EHE) is to accelerate uptake of and retention in pre-exposure prophylaxis (PrEP) in communities most affected by HIV, given the critical role of PrEP in curbing HIV transmission.[1] As one of the 48 highly impacted counties, Los Angeles County (LAC) received supplemental funding to implement a local EHE plan.[2] In this plan, the Division of HIV and STD Programs (DHSP) at the LAC Department of Public Health (DPH) emphasizes that health disparities stemming from structural racism, social inequity, and economic inequality have contributed to uneven progress to end HIV. [3] DHSP also recognizes that successful implementation of the plan requires consideration of the impact of these complex issues on awareness, access, and utilization of HIV prevention and treatment services.

DHSP supports several endeavors to increase access to and use of PrEP for those at highest risk of HIV[4] but utilization is low and persistently differential across racial and ethnic groups. Among men who have sex with men (MSM) with indications for PrEP, 22% of Black MSM (BMSM), 29% of Latino MSM (LMSM) and 36% of White MSM (WMSM) had used PrEP in 2017.[2,5] Thus, LAC efforts could benefit from information about the aggregate and distributional health impacts of different implementation strategies for increasing PrEP use. This requires understanding and closing gaps in PrEP care for racial and ethnic minority MSM.[6] Implementation science (IS) can inform such guidance.[7–11]

Mathematical models – which are abstract representations of real world phenomena that can be used to make predictions and test assumptions (particularly in situations when answering questions in the real world is not possible) – have played an important role in translating HIV research into health policies.[6,12–22] However models remain under-utilized in the context of IS for the HIV response to provide valuable insights into the potential costs, health and equity impacts of scaling up alternative HIV-prevention strategies and guide the design and implementation of policy solutions.[12,23–26]

One important family of mathematical models are microsimulation models, which are individual-based, state-transition models that track individuals as they change health states and strata, by simulating their probabilities of experiencing specific events (e.g., infection, diagnosis, disease progression, treatment initiation and discontinuation, death, etc.). These probabilities can vary by the attributes of the simulated individual (e.g., age, race and ethnicity, etc.), thus allowing for variability in outcomes by personal characteristics. As such, microsimulation models address many limitations of deterministic cohort models[27–34] including their ability to estimate how demographic, behavioral, and policy changes might differentially affect individual trajectories and outcomes.

To aid DHSP in operationalizing its EHE plan, we developed a microsimulation model to compare the potential population-level impact of four hypothetical PrEP implementation strategies in LAC, to answer: which strategy would avert the most infections? Which would be most impactful for addressing inequities in HIV burden? We simulated hypothetical scenarios of PrEP coverage and allocation strategies across select racial and ethnic groups comprising the MSM population in LAC, as prior studies have indicated that race and ethnicity are strongly associated with uptake of and retention in PrEP among PrEP-eligible MSM in the U.S.[35] While our simulated strategies do not represent proposed public health or implementation strategies, they permit analytic clarity for quantifying the impacts of interventions designed with explicit HIV disparity reduction goals. Findings from this study can therefore inform more actionable implementation strategies that meet current HIV disparity reduction goals both locally and nationally. This article describes how mathematical modeling, and microsimulation specifically, can serve as an effective tool for generating robust evidence for planning implementation of public health policies, particularly when developed in conjunction with stakeholders.[36]

METHODS

We developed a microsimulation model of HIV transmission and progression that tracks MSM in LAC across different health states, including the uninfected and the infected (i.e., CD4 ≥ 500, 200 ≤ CD4 < 500, CD4 < 200) states, stratified by diagnosis status (i.e., aware vs unaware of HIV+ status), PrEP use, ART use, viral suppression status (i.e., HIV-1 RNA < 200 copies/mL), age group (i.e., 15–29, 30–49, 50–64, ≥ 65 years), and race and ethnicity (White, Black, and Latino), to estimate HIV-related health outcomes (incidence and prevalence of both diagnosed and undiagnosed HIV, viral suppression, and mortality from HIV/AIDS complications) under alternate implementation strategies. While Asian, Native American and other racial and ethnic minority MSM groups are critical to our understanding of the HIV epidemic, we were unable to examine specific strategies for these groups for LAC due to small sample sizes. Accordingly, we omitted these groups from this analysis. We followed the process described in the logic model in Figure 1 to develop and apply our model, illustrated in the flow diagram in Figure 2.

Establishing scope and involving stakeholders

Stakeholder engagement in modeling is critical to define scope and ensure relevance to decision-making[37]. We defined the scope of the analysis through discussions between academic researchers and LAC DHSP and organizations like the LA LGBT Center. These discussions revealed the importance of focusing on the MSM population (which accounted for 85% of new HIV diagnoses in LAC in 2018[3]) and incorporating variability in HIV burden. Although we lacked detailed data to stratify by geography, we jointly determined that race and ethnicity information on the health and equity impacts of alternative PrEP implementation strategies would still be useful in informing PrEP prioritization in the LAC's health districts, as they are highly segregated by racial and ethnic composition. In February 2021, our group developed and published an online infographic[38] to illustrate the potential impacts of PrEP on HIV outcomes for different racial and ethnic groups in LAC, with significant interpretation and framing input from the California's "End The Epidemics" Statewide Working Group.[39]

Drawing from the insights from the stakeholders and evidence from the published clinical and epidemiological literatures, we developed a logic model to link EHE with outcomes relevant to stakeholders (Figure 1): inputs (e.g., funding and data) provide the foundation for EHE activities in LAC including implementation of "treatment as prevention" and PrEP strategies that ultimately affect group- and population-level HIV outcomes (e.g., incidence, viral suppression, deaths).

Model development

We developed a base model characterizing the current epidemic, based on epidemic surveillance and sexual mixing patterns data specific to LAC, and other published data. We initialized the model with data on the MSM population, stratified by HIV serostatus awareness, in year 2011. Each year, new sexually active men entered the model as uninfected (susceptible) at age 15. Once in the model, they initiate and discontinue PrEP and ART at specified rates. Each year, uninfected individuals face a non-zero risk of HIV infection, through unprotected sexual contacts with other infected MSM, depending on use of PrEP and the infectivity of their sexual partners. Sexual partners' infectivity depends on their HIV serostatus, ART use and viral suppression status. Finally, sexual mixing patterns vary by sociodemographic characteristics of age and race and ethnicity. Model parameters were sourced from DHSP and the LA LGBT Center data, the clinical literature, the natural history of HIV progression, and expert opinions. Full methodological details on the development, calibration, and validation of the model are provided in in the Supplemental Digital Content.

Interventions

In addition to Status-quo PrEP allocation, which uniformly allocates PrEP to all at-risk MSM, we considered three hypothetical strategies to add 9,000 PrEP units annually (i.e., the quantity needed to achieve complete PrEP coverage of the highest-incidence group: BMSM): (1) equal PrEP allocation to each racial and ethnic group, (2) allocation of PrEP proportional to HIV prevalence of each racial and ethnic group, and (3) and allocation of PrEP proportional to incident HIV diagnosis rates of each racial and ethnic group (Strategy 3). These scenarios are neither a comprehensive set nor proposed implementation strategies. Instead, they provide a framework for quantifying the impacts of racial and ethnic equity-based PrEP implementation strategies on HIV outcomes, under various definitions of what may be considered an equitable PrEP allocation.

Establishing impact

The model estimates outcomes for each simulated individual under each scenario. We calculated population-level outcomes by aggregating individual-level outcomes by demographic subgroups (age, race and ethnicity) over a fifteen-year period (2021–2035).

The impact (net effect) of each strategy was calculated as the difference between the estimated outcome under each strategy and the same outcome under Status-quo; the main outcome of interest for this analysis is the cumulative new HIV infections averted.

We estimated each strategy's equity impact using both absolute and relative measures of inequality. We used differences in HIV incidence rates between groups (BMSM and LMSM, compared to WMSM) as our absolute measure of inequality; and we measured relative inequality via the Gini index (G), a widely used measure of the degree of distributional inequality across population subgroups (range 0–1, details in Supplemental Digital Content, Figure S2). [40–45] To the best of our knowledge, this is among its first applications to assess equity of HIV implementation strategies. A higher G indicates greater inequality wherein the population subgroup least burdened by HIV receives disproportionate total health benefits of a given intervention.[40,45]

RESULTS

Status-quo HIV prevalence (21.3% among all MSM residing in LAC in 2021) was higher among BMSM (38.1%) and WMSM (20.7%), compared to LMSM (18.3%) (Table 2). By the end of 2021, Status-quo HIV incidence rate (IR) was 8.88 (95% CI, 8.48–9.29) per 1,000 person-years [PPY]. Rates were higher for BMSM (IR, 23.20; 95% CI, 21.05–25.52) and LMSM (IR, 8.83, 95% CI, 8.30–9.38), compared to WMSM (IR, 5.27; 95% CI, 4.75–5.83), representing a Gini index of 0.31 (95% CI, 0.27–0.33). Overall and group-specific rates were similar across strategies (Supplemental Digital Content, Figure S1 and Table S1). By year 2035, LMSM accounted for the largest share of cumulative incident HIV cases under all strategies (range, 57.3%−61.4%) but HIV risk (proxied by HIV incidence rate) remained highest for BMSM across all periods, albeit declining over time for all groups and under all strategies.

Alternative PrEP coverage strategies had differential impacts across groups. Strategy 3 (allocation proportional to incident HIV diagnoses) yielded the largest reductions in new infections (10.2%, n=2,504) relative to Status-quo and 71.9% of these reductions occurred among BMSM. Relative to Status-quo, Strategy 3 averted 32.4% of new infections among BMSM, compared with 3.8% and 3.5% reductions in infections among LMSM and WMSM, respectively. Strategy 1 (equal allocation) averted 1,870 new infections (7.6% reduction relative to Status-quo); 53.5% of these benefits accrued to BMSM, and 30.2% to LMSM. Relative to Status-quo, Strategy 1 averted 18% new infections among BMSM, 4.0% infections among LMSM, and 6.2% infections among WMSM. Strategy 2 (allocation proportional to HIV prevalence) averted 1,695 new infections (6.9% reduction), with the highest share of benefits (44.5%) accruing to LMSM, followed by BMSM (39.5%). Relative to Status-quo, this strategy averted 12.1% of new infections among BMSM, and 5.5% and 5.4% among WMSM and LMSM, respectively. Together, these results suggest that Strategy 3 produces the largest health impacts and may potentially yield the highest equity impact.

Relative to Status-quo, all strategies reduced BMSM-WMSM and BMSM-LMSM disparities in HIV burden, but not LMSM-WMSM disparities (IRR ranging from 1.74 to 1.78 across all strategies). The largest reductions occurred under Strategy 3 for BMSM, and Strategy 2 for LMSM, with respective absolute risk differences of 9.56 (95% CI, 9.10–10.02) and 3.17 (95% CI, 3.00–3.35) per 1,000 PPY, relative to WMSM. The Gini indices (G) suggest – except for Strategy 3 which significantly reduced HIV inequalities relative to baseline and yielded the most equitable distribution of PrEP's health benefits (cumulative G, 0.24; 95% CI, 0.20–0.26) – no strategy significantly impacted inequalities (Supplemental Digital Content, Figure S2). The equity impact of Strategy 3 emerged as early as in year 2023 (Supplemental Digital Content, Figure S3) when incidence rates for BMSM declined from 23.25 to 15.91 per 1000 PPY (Supplemental Digital Content, Figure S1).

To identify the optimal strategy, we ranked policies in terms of their health and equity impacts. Relative to Status-quo, Strategy 3 produced the largest health benefits (10.2% infections averted) and reductions in inequalities in the distribution of these health impacts (0.08-unit reduction in the Gini index, 95% CI, 0.02–0.14), making it the dominant strategy. Strategy 2 was strongly dominated by Strategy 1, producing more new infections (175 cases) but without significantly exacerbating inequalities in the distribution of these health harms.

DISCUSSION

Current HIV prevention strategies have not substantially lowered HIV incidence rates in the U.S. since 2015. This is a clear opportunity for IS research: there are numerous underutilized efficacious and cost-effective prevention methods, so, implementation strategies could improve outcomes. Modeling approaches can inform the optimal implementation of such interventions and provide more nuanced analyses of potential tradeoffs between health, cost and equity impacts of alternative strategies – as illustrated in this study.

While models have previously examined PrEP distribution, very few models were explicitly designed to examine health equity impacts, and with an IS lens. Notable exceptions include equity-based PrEP care analyses by Jenness et al.[6] and Goedel et al.[6,20]; our work is closest to this literature, and contributes to it by focusing on the LAC MSM population and measuring inequality via the composite Gini index. We leveraged the methodological and statistical rigor of mathematical modeling, critical insights from relevant stakeholders, and high-quality local data, to address policy-relevant questions about areas of opportunity and the relative impact of alternative implementation strategies.

Large-scale evaluations of the strategies explored in this study would be infeasible for logistical and ethical reasons. We thus aimed to demonstrate how modeling can serve a unique and important role in the IS methods “toolbox,” by describing how a rigorously constructed, contextually informed, policy-relevant microsimulation model can compare implementation strategies in order to achieve policy goals and maximize population health. By simulating HIV outcomes among different groups (e.g., age, race and ethnicity), we examined potential tradeoffs between health and equity impacts of alternative PrEP allocation strategies among MSM in LAC, the population most at-risk of HIV infection. A strategy that allocates additional PrEP proportionally to incident HIV diagnosis rates, across racial and ethnic groups, dominates other strategies considered and would reduce cumulative incident infections by 10.2% and lessen racial and ethnic inequalities in HIV burden (0.08-unit reductions in Gini index). We found little evidence of significant trade-offs between reducing infections and improving equity across racial and ethnic groups. Through a global look at outcomes, simulation models can therefore inform optimal and more equitable decision-making and increase buy-in among various interest groups.

Prior studies reported on profound racial and ethnic disparities in the uptake of and retention on PrEP, and the consequences of these inequities on exacerbating existing inequities in HIV incidence among racial and ethnic groups in the U.S.[46] Our findings suggest that equity-based PrEP implementation strategies can reduce racial and ethnic inequities in HIV by closing each of the five critical gaps along the PrEP care-continuum. Specifically, strategies focused on identifying and addressing structural barriers to the uptake of and retention in PrEP among BMSM and LMSM are likely to be of the greatest value.[47–50] This could be achieved, for example, by incentivizing and equipping PrEP providers with the necessary skills and resources for making improvements in PrEP awareness, access, prescription, adherence, and retention for BMSM and LMSM, both individually and collectively.[6] Incentive mechanisms could include pay-for-performance approaches (i.e., value-based health care), which are already being used in LAC and at PrEP Centers of Excellence, to incentivize linkage to PrEP and PrEP-related services across different geographies, venues, and populations.

While we did not model geographically-stratified strategies, our findings can still guide PrEP allocation strategies and target prevention services to potential hotspot areas including geographies with high HIV infection risk, given that a substantial number of persons at high risk for HIV transmission (e.g., BMSM) live in neighborhoods with no proximate PrEP provider[51] and the persistent gentrification of many U.S. cities and neighborhoods[52]. This approach must also consider how transportation burden affects access in “PrEP deserts”; community-based implementation strategies may particularly hold potential for reaching these diverse groups: e.g., removing the requirement of physician prescription, delivering PrEP through nontraditional outlets like barber shops and via telemedicine as has been implemented on a temporary basis during the COVID-19 pandemic. A third strategy might target persisting financial barriers: while the Affordable Care Act significantly expanded insurance coverage in the U.S., many non-White MSM in need of PrEP services remain, or are at high risk of becoming, uninsured. Expanding and promoting insurance coverage and robust PrEP cost assistance programs (like the California Pre-Exposure Prophylaxis Assistance Program[53]) could significantly improve HIV outcomes and reduce disparities. The recent federal requirement that health insurance companies cover PrEP/PrEP-related services with no cost sharing is a promising step.[54]

This study has several limitations. First, not all key stakeholders were involved in developing the model; we have begun conversations for follow-on studies to reflect their diverse constituencies and perspectives. Second, disparities can be measured in a variety of ways. The Gini index can be critiqued for lacking the subgroup consistency property found in other measures of inequality, including the Atkinson and Kolm indices.[55–57] In future analyses, we will examine additional equity measures. Third, the model did not include Asian, Native American and other racial and ethnic minority MSM groups which are an important part of understanding the HIV epidemic in LAC. More comprehensive data for these important groups are needed and would have permitted a more nuanced analysis of the health and equity impacts of alternative PrEP allocation strategies. Fourth, our model did not account for COVID-19, as the evidence on its effects are not yet robust. There is growing evidence that the pandemic disrupted PrEP services among other prevention activities[58,59]; and local and statewide COVID-19 physical distancing measures may have also induced greater demand for supportive services (e.g., housing, food, financial support) disproportionately across communities.[58,60–63] On the other hand, some have reported reductions in risky sexual behaviors during the pandemic.[64–66] Whether and how these changes have affected HIV outcomes in different groups remains to be determined. We plan to incorporate emerging evidence on the impacts of COVID-19 on HIV into the model. Fifth, due paucity of data, we were unable to model migrations and adaptive behavioral responses, capture sociodemographic heterogeneities in PrEP uptake, retention and adherence, and track all critical domains of the social determinants of health and health behaviors relevant to HIV risk. Thus, we only characterized heterogeneity in sexual mixing patterns by age, race and ethnicity. Lastly, we parameterized our model with data drawn from disparate sources. As data were not always stratified by relevant sociodemographic characteristics of interest, adjustments were made, sometimes relying on simplifying assumptions. When local estimates were unavailable, we used estimates from other populations (e.g., national estimates), adding more uncertainties to the model. For example, as the LA LGBT Center sample may not be representative of the LAC MSM population, our mixing parameters estimated from these data may have limited applicability for characterizing sexual behaviors of this population. We conducted sensitivity analyses to assess the impacts of uncertainty in and assumptions about select critical model parameters such as the sexual mixing parameters which characterize transmission. We assessed alternative assumptions about the mixing patterns (e.g., homogeneous vs assortative) by age, race and ethnicity and found that results were sensitive to assumptions about mixing patterns, although general trends remained consistent.[67] We did not conduct more comprehensive multivariate sensitivity analyses with all parameters, to avoid making further assumptions about the correlation structures of our parameters.

Despite these limitations, this microsimulation model provides information that policymakers can use in discussing efficiency and equity trade-offs. Also, although most models in HIV research have focused on estimating the cost-effectiveness and impact of scaling up interventions, our model takes an explicitly IS lens to questions of policy implementation. By capturing subpopulation dynamics otherwise computationally difficult to include in other types of models, microsimulation models, such as the one we have developed, can be powerful tools for shaping local, national and global HIV prevention policies, by informing pre-implementation planning and implementation, guiding strategic resource allocation decisions, and supporting advocacy. To that end, our academic and public health partners at the LAC-DHSP plan to present these findings to the local Ryan White planning body to inform the development of the Integrated HIV Prevention Plan for LAC. Feedback from these discussions will be incorporated into the model, to enhance its continued relevance to local planning and decision-making. With support from California HIV/AIDS Research Program, we are also partnering with the California State Office of AIDS to use microsimulation models to understand HIV transmissions in San Diego and San Francisco counties and guide locally relevant implementation strategies to stakeholders in those jurisdictions.

There has been much discussion of disparate health outcomes experienced by diverse groups, but little ability to forecast the distribution of likely HIV outcomes resulting from policy implementation across subpopulations. Simulation models, such as the one described here, can provide precisely this type of implementation guidance, by explicitly considering equity and the needs of key populations who remain at greater risk for poor HIV-related outcomes due to social, economic and demographic factors. Guiding principles of IS and collaboration between researchers, public health officials and community stakeholders can ensure that implementation and equity considerations hold weight in shaping the development of robust models, generating relevant results, and ensuring input throughout. It is therefore critical now, more than ever, to strengthen the integration of mathematical modeling into IS, in order to optimally guide the implementation of evidence-based public health interventions.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the contributions of the following individuals and groups without whom this project would not be possible: (1) Mario J. Pérez of the Division of HIV and STD Programs, County of Los Angeles, Department of Public Health; (2) Division of HIV and STD Programs staff that collect, manage, analyze and provide oversight for HIV case reporting and HIV surveillance in Los Angeles County including Yuwen, Yu, Virginia Hu and Zhijuan Sheng; and (3) the community of persons living with HIV in Los Angeles County whose aggregated health information were utilized. We are also grateful to David W. Dowdy, Associate Professor at Johns Hopkins Bloomberg School of Public Health, and other affiliates of JHU-CFAR for their critical reviews of earlier drafts of the manuscript. We thank Citina Liang for assistance with writing code for the Gini calculations, and Elizabeth Wu for assistance with literature reviews and illustrations. We are indebted to all the anonymous reviewers and the JAIDS editorial team for their constructive feedback on earlier drafts of this article.

Sources of Support:

The authors are supported by the California HIV/AIDS Research Program Grants RP15-LA-007 and H21PC3446 (Suen, Nguyen, Holloway, Leibowitz and Drabo), the Center for HIV Identification, Prevention, and Treatment (CHIPTS) NIMH Grant MH58107 (Suen, Nguyen, Moucheraud, Holloway, Leibowitz and Drabo), the UCLA Center for AIDS Research (CFAR) Grant #5P30AI028697 (Moucheraud, Holloway and Leibowitz); and the NIH/National Center for Advancing Translational Science (NCATS) UCLA CTSI Grant Number UL1TR000124 (Moucheraud, Holloway and Leibowitz). The funding sources had no role in the design and conduct of this study. The results and views expressed in this article are the sole responsibility of the authors and do not represent the views of the funding sources, the partner organizations, or the authors' institutions (i.e., Johns Hopkins University, University of Southern California, University of California at Los Angeles and the Los Angeles County Department of Public Health).

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CALLOUT BOX

- **Evidence-based innovation:** Pre-exposure prophylaxis (PrEP)
- **Innovation recipients:** Men who have sex with men (MSM)
- **Setting:** Los Angeles County (LAC)
- **Implementation gap:** PrEP is currently being offered in LAC but there are substantial disparities in uptake. Understanding tradeoffs between the health benefits and equity impacts of PrEP implementation strategies is critical to optimize the benefits of PrEP but have not been sufficiently examined.
- **Primary research goal:** To help select PrEP implementation strategies that optimize the health and racial and ethnic equity impacts of PrEP in LAC, using microsimulation models.
- **(Implementation strategies):** To tailor strategies (four alternative PrEP implementation strategies, including Status-quo and three strategies involving coverage with 9,000 additional PrEP units annually, above the Status-quo coverage level).

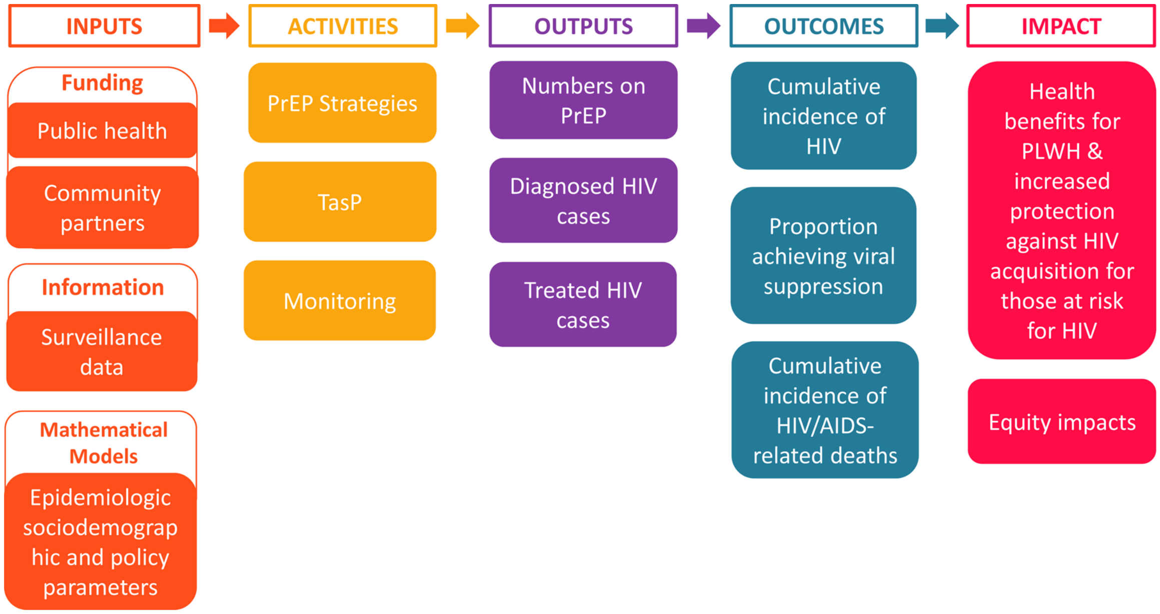

Figure 1:
Logic model of the development of a microsimulation model of HIV transmission among MSM in LAC.

Abbreviations: HIV, human immunodeficiency virus; MSM, men who have sex with men; LAC, Los Angeles County; PrEP, pre-exposure prophylaxis; TasP, treatment as prevention; AIDS, acquired immunodeficiency syndrome.

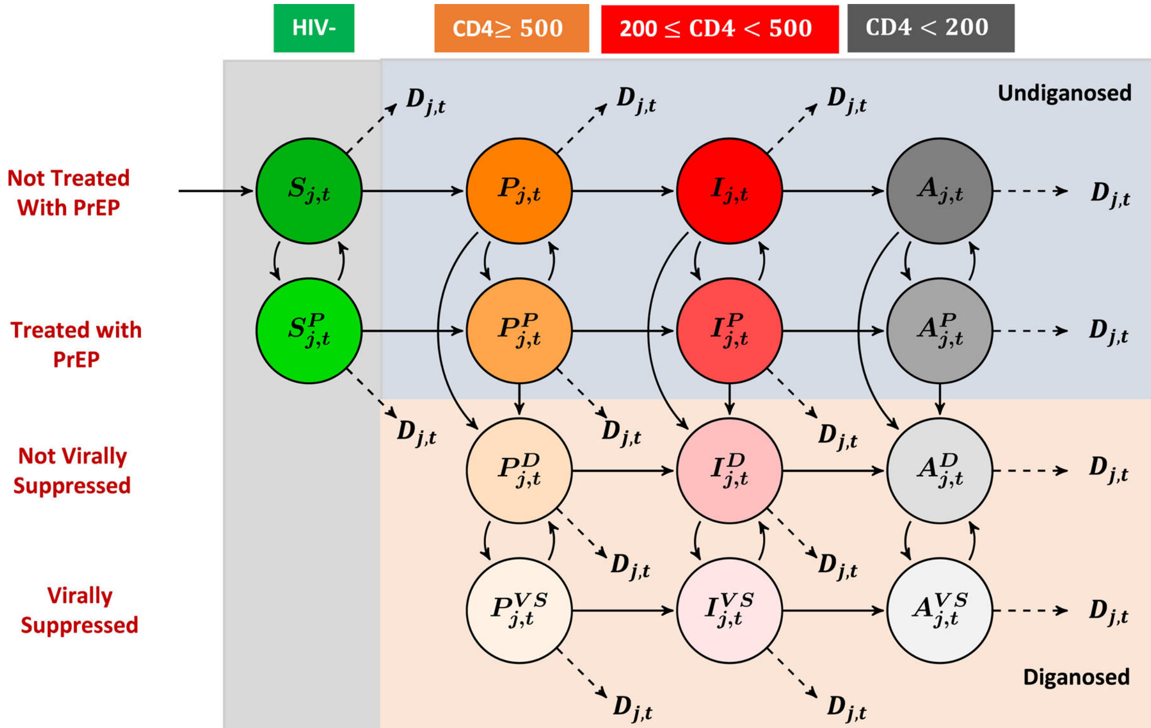

Figure 2:

Flow diagram of the microsimulation model of HIV transmission among MSM in LAC. Abbreviations: HIV, human immunodeficiency virus; MSM, men who have sex with men; LAC, Los Angeles County; PrEP, pre-exposure prophylaxis; AIDS, acquired immunodeficiency syndrome.

Notes: This simplified flow diagram is a representation of the various health states of the model, as well as transitions between them. The figure captures disease and treatment progression for individuals in one age and racial and ethnic group demographic pair, $j \in \mathscr{D} = \mathscr{D}_a \times \mathscr{D}_r$, where $\mathscr{D}_a$ denotes the set of all age groups, $\mathscr{D}_r$ denotes the set of all race and ethnic groups, and $\mathscr{D}$ denotes the set of all pairwise combinations of the age groups and race and ethnicity groups. All other pairs of age group and race and ethnicity are modeled, but not represented in the flow diagram for simplicity. Each circle represents a health state in the model: ***S*** represents susceptible individuals not treated with PrEP, while ***P***, ***I*** and ***A*** denote, respectively the state of undiagnosed infected individuals (thus unaware of their HIV serostatus) in Stage 1 (CD4≥500), Stage 2 ($200 \leq CD4 < 500$), and Stage 3 (AIDS; $CD4 < 200$) of HIV infection. The superscripts *P*, *D*, and *VS* denote, respectively, treatment with PrEP, diagnosed, and virally suppressed. The subscripts *j* and *t* index the demographic subgroup and period of observation, respectively. The solid arrows connecting the circles represent possible transitions between health states within any particular pair of age group and race and ethnic group. The dashed lines represent transitions out of a given health state due to mortality from HIV or AIDS-related complications and/or other causes of death.

Table 1.

Selected model input parameters in 2011.

Parameter	Total	Black	Latino	White	Source
Total LAC MSM population, N	251,521	—	—	—	68,69
PLWH, % total MSM	18.30	—	—	—	Calculated[70]
Infected (PLWH) MSM, % total PLWH	—	19.00	43.00	38.00	*
Uninfected MSM, % total uninfected	—	10.00	57.00	33.00	71,72
Undiagnosed PLWH, % total PLWH	13.50	—	—	—	73
Viral suppression, % diagnosed PLWH					
15+ y	—	44.00	56.00	59.00	*
15–29 y	40.00	—	—	—	*
30–49 y	54.00	—	—	—	*
50–64 y	62.00	—	—	—	*
65+ y	63.00	—	—	—	*
Age group, % total PLWH					
15–29 y	11.00	—	—	—	*
30–49 y	58.00	—	—	—	*
50–64 y	28.00	—	—	—	*
65+ y	3.00	—	—	—	*
Infection stage, % undiagnosed PLWH					
CD4 ≥ 500	41.30	—	—	—	74
200 ≤ CD4 < 500	50.30	—	—	—	74
CD4 < 200	8.40	—	—	—	74
Infection stage, % diagnosed PLWH					
CD4 ≥ 500	29.00	—	—	—	*
15–29 y	—	33.90	47.10	22.90	†
30–49 y	—	30.00	43.70	18.50	†
50–64 y	—	12.50	6.30	6.50	†
65+ y	—	1.00	0.70	0.80	†
200 ≤ CD4 < 500	34.00	—	—	—	*
15–29 y	—	34.40	56.00	23.00	†
30–49 y	—	30.20	54.00	18.40	†
50–64 y	—	10.60	5.10	5.50	†
65+ y	—	1.10	0.40	0.40	†
CD4 < 200	37.00	—	—	—	*
15–29 y	—	95.90	98.20	97.90	†
30–49 y	—	96.80	98.40	98.30	†
50–64 y	—	92.70	97.40	96.90	†
65+ y	—	28.00	1.41	16.60	†
Annual PrEP uptake rate, %					
2012–2013	0.04	—	—	—	75,76
2014–2016	0.48	—	—	—	75,76

Parameter	Total	Black	Latino	White	Source
2017-Present	2.41	—	—	—	[75,76]
PrEP discontinuation, %	59.00	—	—	—	[77,78]

Abbreviations: LAC, Los Angeles County; MSM, men who have sex with men; PLWH, persons living with HIV; HIV, human immunodeficiency virus; PrEP, pre-exposure prophylaxis.

Notes: A complete list of the model's input parameters is provided in the supplementary digital content.

* HIV surveillance data from LAC Department of Public Health

† Calculated using HIV surveillance data from LAC Department of Public Health

Table 2.

Baseline distribution of health and health, and equity impacts of increasing PrEP by 9,000 doses annually for MSM in LAC, by race and ethnicity and by allocation strategy: 2021–2035.

		Race and ethnicity		
PrEP allocation strategy	**Total**	**Black**	**Latino**	**White**
		Baseline distributions of the population and health (start of 2021)		
Baseline population, n (% Total)	261,079	29,151 (11.2)	143,283 (54.9)	88,646 (34.0)
Baseline HIV prevalence rate, % (95% CI)	21.3 (21.2–21.5)	38.1 (37.5–38.7)	18.3 (18.1–18.5)	20.7 (20.4–20.9)
Rate difference, % (95% CI)	–	17.4 (16.7–18.2)	2.3 (2.0–2.7)	Reference
Rate ratio, RR (95% CI)	–	1.84 (1.80–1.89)	0.89 (0.87–0.90)	Reference
Gini index, G (95% CI)		0.28 (0.26–0.34)		
		Person-years at risk of HIV infection during 2021–2035, n (% Total)		
Status-quo *	3,146,429	258,917 (8.2)	1,792,441 (57.0)	1,095,071 (34.8)
Strategy 1 (equal allocation) †	3,158,669	265,745 (20.1)	1,795,459 (56.8)	1,097,464 (34.7)
Strategy 2 (count-based allocation) ‡	3,156,041	263,013 (21.4)	1,795,832 (56.9)	1,097,195 (34.8)
Strategy 3 (rate-based allocation) §	3,161,156	270,270 (8.5)	1,794,241 (56.8)	1,096,645 (34.7)
		Cumulative incident HIV infections during 2021–2035, n (% Total)		
Status-quo *	24,584	5,559 (22.6)	14,089 (57.3)	4,936 (20.1)
Strategy 1 (equal allocation) †	22,711	4,558 (20.1)	13,522 (59.5)	4,631 (20.4)
Strategy 2 (count-based allocation) ‡	22,887	4,888 (21.4)	13,334 (58.3)	4,665 (20.4)
Strategy 3 (rate-based allocation)	22,080	3,758 (17.0)	13,557 (61.4)	4,764 (21.6)
		HIV infections averted during 2021–2035, n (% Reference)		
Status-quo *	Reference	Reference	Reference	Reference
Strategy 1 (equal allocation) †	1,870 (7.6)	1,001 (18.0)	564 (4.0)	305 (6.2)
Strategy 2 (count-based allocation) ‡	1,695 (6.9)	670 (12.1)	754 (5.4)	271 (5.5)
Strategy 3 (rate-based allocation) §	2,504 (10.2)	1,800 (32.4)	531 (3.8)	173 (3.5)
		Incidence rates, per 1,000 person-years (PY) during 2021–2035, IR (95% CI)		

PrEP allocation strategy	Total	Race and ethnicity: Black	Latino	White
Status-quo *	7.81 (7.72–7.91)	21.47 (20.91–22.04)	7.86 (7.73–7.99)	4.51 (4.38–4.64)
Strategy 1 (equal allocation) †	7.19 (7.10–7.28)	17.15 (16.66–17.66)	7.53 (7.40–7.66)	4.22 (4.10–4.34)
Strategy 2 (count-based allocation) ‡	7.25 (7.16–7.35)	18.58 (18.07–19.11)	7.42 (7.30–7.55)	4.25 (4.13–4.38)
Strategy 3 (rate-based allocation)	6.98 (6.89–7.08)	13.91 (13.46–14.36)	7.56 (7.43–7.68)	4.34 (4.22–4.47)
Incidence rate ratios during 2021–2035, IRR (95% CI)				
Status-quo *	–	4.76 (4.58–4.95)	1.74 (1.69–1.80)	Reference
Strategy 1 (equal allocation) †	–	4.06 (3.90–4.23)	1.78 (1.73–1.85)	Reference
Strategy 2 (count-based allocation) ‡	–	4.37 (4.20–4.55)	1.75 (1.69–1.81)	Reference
Strategy 3 (rate-based allocation)	–	3.20 (3.07–3.34)	1.74 (1.68–1.80)	Reference
Measure of absolute inequality: Differences in HIV incidence rates (per 1,000 PY) by race and ethnicity during 2021–2035, RD (95% CI)				
Status-quo *	–	16.96 (16.38–17.54)	3.35 (3.17–3.53)	Reference
Strategy 1 (equal allocation) †	–	12.93 (12.42–13.44)	3.31 (3.14–3.49)	Reference
Strategy 2 (count-based allocation) ‡	–	14.33 (13.80–14.87)	3.17 (3.00–3.35)	Reference
Strategy 3 (rate-based allocation)	–	9.56 (9.10–10.02)	3.21 (3.03–3.39)	Reference
Measure of relative inequality: Gini index during 2021–2035, G (95% CI)				
Status-quo *	0.32 (0.28 – 0.35)			
Strategy 1 (equal allocation) †	0.29 (0.25 – 0.31)			
Strategy 2 (count-based allocation) ‡	0.30 (0.27 – 0.33)			
Strategy 3 (rate-based allocation) §	0.24 (0.20 – 0.26)			

Abbreviations: PrEP, pre-exposure prophylaxis; MSM, men who have sex with men; LAC, Los Angeles County; HIV, human immunodeficiency virus; n, counts; CI, 95% confidence interval; IR, incidence rate; IRR, incidence rate ratio; RD, incidence rate difference; RR, rate ratio; G, Gini index.

Notes: Authors' analysis of the microsimulation model's outputs. Under each strategy, PrEP coverage is increased by 9,000 units annually above the Status-quo PrEP coverage levels, from 2021 to 2035. The model's outputs may vary due to stochastic noise; hence, means were calculated using 1,000 bootstrapped samples from 30 iterations. Values reported in the table are bootstrapped means. HIV infections averted under strategy was calculated as the bootstrapped means of the difference between the cumulative incidence under the Status-quo strategy and the cumulative incidence under the strategy considered, over the 2021–2035 period. These bootstrapped means may therefore not correspond exactly to the difference between the reported cumulative HIV incidence under the Status-quo strategy and each strategy.

*Status-quo refers to the allocation strategy which uniformly allocates currently available PrEP units (hence, no additional units of PrEP) to all at-risk MSM without consideration of equity.

†Strategy 1 equally allocates the 9,000 additional PrEP units to each racial and ethnic group.

‡Strategy 2 allocates the 9,000 additional PrEP units to each racial and ethnic group proportionally to the count of PLWH in each group.

§Strategy 3 allocates the 9,000 additional PrEP units to each racial and ethnic group proportionally to new HIV diagnosis rates in each group in 2016.