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Attributing health benefits to preventing HIV infections versus improving health outcomes among people living with HIV: an analysis in six US cities

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Abstract

Objective: Combination strategies generate health benefits through improved health outcomes among people living with HIV (PLHIV) and prevention of new infections. We aimed to determine

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Contributors. EE, HAD, EK and BN conceptualized the study. EK, CM, ALMQ and EE wrote the first draft. EK and XZ conducted analyses. EK, XZ, JEM and BN contributed to the model development. EK, EE, CNB, CC, WG, MG, BDLM, LRM, AP, SS, PS, HET, HAD, and BN aided in the interpretation of results and provided critical revisions to the manuscript. BN secured funding for the study. All authors approved the final draft.

health benefits attributable to improved health among PLHIV versus HIV prevention for a set of combination strategies in 6 US cities.

Design: Dynamic HIV transmission model.

Methods: Using a model calibrated for Atlanta, Baltimore, Los Angeles, Miami, New York City (NYC) and Seattle, we assessed the health benefits of city-specific optimal combinations of evidence-based interventions implemented at publicly-documented levels and at ideal (90% coverage) scale-up (2020-2030 implementation, 20-year study period). We calculated the proportion of health benefit gains (measured as quality-adjusted life-years) resulting from averted and delayed HIV infections; improved health outcomes among PLHIV; and improved health outcomes due to medication for opioid use disorder (MOUD).

Results: The HIV-specific proportion of total benefits ranged from 68.3% (95% Credible Interval: 55.3%-80.0%) in Seattle to 98.5% (97.5%-99.3%) in Miami, with the rest attributable to MOUD. The majority of HIV-specific health benefits in five of six cities were attributable HIV prevention, and ranged from 33.1% (26.1%-41.1%) in NYC to 83.1% (79.6-86.6%) in Atlanta. Scaling up to ideal service levels resulted in three- to seven-fold increases in additional health benefits, mostly from MOUD, with HIV-specific health gains primarily driven by HIV prevention.

Conclusions: Optimal combination strategies generated a larger proportion of health benefits attributable to HIV prevention in five of six cities, underlining the substantial benefits of ART engagement for the prevention of HIV transmission through viral suppression. Understanding to whom benefits accrue may be important in assessing the equity and impact of HIV investments.

Keywords

HIV; localized HIV microepidemics; dynamic HIV transmission model; HIV treatment; HIV prevention; health benefits

INTRODUCTION

Evidence-based interventions for HIV treatment and prevention generate health benefits synergistically through individual health gains and reduced onward transmission.[1-4] While HIV prevention interventions such as pre-exposure prophylaxis (PrEP) provide benefits to uninfected individuals, antiretroviral therapy (ART) not only benefits people living with HIV (PLHIV) through reduced morbidity and mortality, but also confer second-order benefits to uninfected persons through viral suppression, making the virus untransmittable.[5-12]

Combination HIV interventions are key for reaching the U.S.' ambitious 'Ending the HIV Epidemic' (EHE) goals to reduce new infections by 75% by 2025 and at least 90% by 2030.[13] However, the narrow focus on reducing HIV incidence disregards the substantial benefits of ART derived by PLHIV, and in so doing, underrepresents these benefits. Focusing only on averting new HIV infections may promote investment decisions that disadvantage PLHIV who are in need of immediate as well as ongoing care.[14] In contrast, cost-effectiveness analyses using quality-adjusted life years (QALYs), the consensus standard health outcome that combines the quality and duration of life,[15-18] value both health benefits due to HIV infections averted and health benefits due to improved care and treatment for PLHIV.

The use of QALYs in decision-making thus aligns with the need for health systems to simultaneously improve patient care, improve population health, and reduce costs.[19] Combination strategies determined with the use of QALYs as the primary outcome capture improved care among PLHIV (not accounted for when focusing on averted infections as an outcome), improved population health (both for PLHIV and people at risk of HIV infection), and reduced costs (through savings from averted HIV infections from both HIV prevention programs and improved ART engagement among PLHIV).

Because of the second-order preventive benefits of achieving viral suppression, as well as the nature of combination HIV strategies that involve both prevention-oriented interventions (e.g., PrEP) and HIV care improvement interventions, it is not immediately apparent how overall QALY gains are distributed between PLHIV and those not living with HIV. Yet, decision-makers need to determine which intervention combinations may provide the most value under different circumstances to promote sustainable, efficient, and fair use of limited public health and healthcare resources. Quantifying the proportion of health benefits that accrue due to averted HIV infections ("prevention") versus improvements in the health of PLHIV ("care") can help decision-makers better understand to whom the benefits accrue and whether benefits are being conferred equitably.[20]

Attributing the resulting benefits to HIV prevention versus improved health among PLHIV presents unique challenges. When measuring prevention benefits, infections averted must be translated into QALYs for a direct comparison. Furthermore, HIV prevention may only delay infections, but not entirely avert them, yielding only partial benefits. For benefits attributable to improved health among PLHIV, an intuitive approach would be to simply sum the total QALYs accrued among PLHIV. However, such an approach would underestimate the benefits of care, because when prevention effects occur in a combination strategy, HIV infections will be averted. These averted infections reduce the number of PLHIV and potentially result in a net decrease in the total QALYs accrued among PLHIV over the long-term. These challenges suggest the need for new methods to quantify the distribution of health benefits resulting from HIV prevention versus improved health outcomes among PLHIV.

In a recent publication, we identified city-specific, health-maximizing combinations of evidence-based strategies to prevent, diagnose and treat HIV in Atlanta, Baltimore, Los Angeles, Miami, New York City, and Seattle.[3] In this study, we extend this analysis to determine the distribution of health benefits attributable to HIV prevention versus improved health outcomes among PLHIV resulting from combinations of interventions to diagnose, treat and prevent against HIV/AIDS.

METHODS

Model description

Our analysis builds on a previously published dynamic, compartmental HIV transmission model adapted and calibrated to replicate city-level HIV micro epidemics in six U.S. cities.[21] This simulation model was based on a synthesis of the best available evidence on epidemiological and structural conditions for each city and has been described in detail

elsewhere.[22] The model tracked HIV-susceptible individuals through infection, diagnosis, treatment with ART, ART discontinuation and re-initiation. In each city, the adult population aged 15-64 was partitioned by sex at birth, HIV risk group (men who have sex with men [MSM], people who inject drugs [PWID], MSM who inject drugs [MWID] and heterosexuals), race/ethnicity (Black/African American, Hispanic/Latinx and non-Hispanic white/others) and sexual risk behavior level (high- vs. low-risk). The model captured heterogeneity in maturation (e.g., rates at which individuals age out of the model) and mortality, and the inequities in accessing health, prevention and treatment services, including HIV testing, ART, syringe service programs (SSPs), medication for opioid use disorder (MOUD), and targeted PrEP for high-risk MSM.

Combination HIV prevention and treatment strategies

To serve as a baseline for comparison (status quo), the model projected city-level HIV epidemics holding service levels of prevention, testing and treatment at 2015 levels, except for PrEP which was held at 2017 levels to account for rapid uptake among MSM between 2015-2017 (Supplement Table 1).[22-26] For each city, we compared this status quo to two implementation scenarios based on our previously identified optimal city-specific combination strategies (i.e., health-maximizing strategies that are cost-effective in comparison to the next-most resource intensive strategy, using the conventional cost-effectiveness threshold of $100,000 per QALY gained) [3]. In determining these optimal strategies, we considered 16 interventions for inclusion selected from the US Centers for Disease Control and Prevention (CDC) compendium of evidence-based interventions and best practices for HIV prevention and from the published literature (Supplement Table 2). [27, 28]

We first estimated the impact of combination strategies scaled up to real-world implementation levels (Supplement Table 2),[3] approximating what is achievable within current social and structural constraints on access to HIV services.[27] Scale up levels were based on the best available evidence documented in the public domain with sources, calculations and methodology used to derive implementation levels detailed elsewhere.[27] Our second scenario consisted of closing the implementation gap with service levels scaled up to reach ‘ideal’ levels (i.e., 90% target population coverage, see Supplement Table 2). Full details on interventions, evidence determining the scale of delivery, and the cost-effectiveness analysis to determine the composition of city-specific optimal combination strategies are published elsewhere.[3, 27] Combination strategies were sustained for a period of 10 years (2020-2030) to match the EHE initiative timeline, and we evaluated outcomes over 20 years (2020-2040) to capture long-term individual health benefits (as measured by QALYs) and second-order transmission effects (i.e., prevented cases beyond those directly resulting from the interventions). We adhered to best-practice guidelines for health economic evaluation and reported QALYs using a 3% annual discount rate.[18, 29]

Attributing Health Benefits

To determine the incremental health benefits under each scenario compared to the status quo, we calculated the benefits accrued from HIV prevention versus improved health among PLHIV (including testing and treatment interventions). Because combination strategies

included interventions that addressed outcomes related to treatment of opioid use disorder, we also calculated the non-HIV-related health benefits arising from MOUD programs due to reduced mortality and improved quality-of-life (equations are presented in Figure 1).

The number of QALYs gained from an averted HIV infection depends on when that infection is averted and among which subpopulation, since different subpopulations have different life expectancies. We therefore first used the model to generate remaining quality-adjusted life expectancy (QALE) estimates for each subpopulation at each time step *t* for individuals who never become infected with HIV. We then repeated the process, but for an individual in a given subpopulation newly infected with HIV at time step *t*. The total prevention benefit was then calculated by multiplying the number of infections averted at a time step and in a specific subpopulation by the difference in remaining QALE with and without HIV, summed over all subpopulations and time steps. By stratifying infections averted and remaining QALE by time, we are able to capture the QALY gains of delayed HIV infections as well as fully averted infections.

To calculate the benefits from improved HIV care, we summed health benefits among all PLHIV over the study horizon, accounting for the timing of new HIV infections. We distinguished benefits attributable to MOUD from benefits attributable to improved HIV care among PWID living with HIV, also accounting for the timing of new HIV infections.

Finally, we calculated health benefits from MOUD among all PWID who are newly infected and those who may later become infected over the time horizon. We derived total health benefits and HIV-specific health benefits (excluding MOUD benefits), and calculated the proportion of health benefits attributable to preventing HIV infections versus improve health among PLHIV.

Sensitivity analysis

We performed probabilistic sensitivity analysis using the previously-determined 100 best-fitting calibrated parameter sets[21] on the city-specific combination strategies to evaluate the variability in the attribution of health benefits to HIV prevention or care arising from parameter uncertainty. We calculated 95% credible intervals for incremental QALYs from each scenario compared to the status quo, and for proportions of health benefits attributable to HIV prevention versus to improved health among PLHIV.

RESULTS

City-specific combination strategies included 9 (Seattle) to 13 (Miami) individual evidence-based interventions (Supplement Figure 1).[3] All combinations included expansion of MOUD (both buprenorphine and methadone), EMR testing reminders, nurse-initiated rapid testing and case management for ART initiation while expansion of opt-out testing (ER and primary care) and care coordination was not included in any combination. The additional scale-up of SSP was only recommended in cities with insufficient availability of existing services (Atlanta, Los Angeles, and Miami), analogous to targeted PrEP for high-risk MSM, which was included in combinations for Atlanta, Baltimore, and Miami.

Implementing optimal combination strategies specific to each city at service levels documented in the public domain resulted in incremental QALY gains ranging from 1,935 (95% Credible Interval 1,418-2,453) in Seattle to 23,377 (17,141-29,573) in New York City (Figure 2 & Table 1) compared to the status quo over the 20-year study time horizon. A larger proportion of incremental QALYs were attributable to preventing new HIV infections than to improved health for PLHIV in all but New York City (Figure 3). The range of total benefits attributed to HIV prevention ranged from 28.8% (22.2-35.3%) in New York City to 79.2% (75.3-82.8%) in Atlanta. Health benefits attributable to MOUD ranged from 1.5% (0.7-2.5%) in Miami to 31.7% (20.0-44.7%) in Seattle. Among HIV-specific health benefits, the majority of incremental QALYs in five of six cities were attributable to preventing new HIV infections, ranging from 53.3% (42.7-63.1%) in Seattle to 83.1% (79.6-86.6%) in Atlanta. The exception was New York City in which incremental health benefits attributable to improved health among PLHIV accounted for 66.9% (58.9-73.9%) of HIV-specific benefits gained.

Ideal implementation resulted in even greater incremental QALY gains in all cities, ranging from 13,073 (8,619-17,711) in Seattle to 76,024 (59,628-93,038) in New York City (Figure 2 & Table 1). These large QALY gains were driven by MOUD in all cities, mostly among HIV negative PWID, and now ranged from 27.3% (17.8-39.8%) in Miami (up from 1.5%; an 18-fold increase) to 85.9% (78.6-91.1%) in Seattle (up from 31.7%; a 2.7-fold increase) of total health benefits. Consequently, the proportion of total health benefits attributable to HIV prevention and to improved health among PLHIV were now relatively smaller; however, incremental HIV-specific QALYs also increased in all cities, ranging from a 38.3% increase in New York City (from 20,338 to 28,129 incremental QALYs) to 138.6% in Atlanta (from 10,806 to 25,788).

Under ideal implementation, HIV prevention accounted for the majority of HIV-specific benefits in all cities except New York City (Figure 3). Compared to implementation at levels documented in the public domain, the increased proportion of benefits attributable to HIV prevention was relatively small in Los Angeles (1.5%) and Seattle (2.0%) and larger in Atlanta (9.5%), Baltimore (7.8%) and Miami (11.1%). In contrast, the proportion of health benefits attributable to HIV prevention decreased by 0.5% in New York City. Increases in the number of infections averted between 2020-2040 under ideal implementation compared to combinations implemented at levels documented in the public domain ranged from 31.4% in New York City (from 4,813 to 6,324) to a near threefold increase in Atlanta (from 6,072 to 16,665).

DISCUSSION

This study demonstrates that implementing health-maximizing combination strategies resulted in a larger proportion of health benefits being attributable to HIV prevention (as compared to improved health outcomes among PLHIV) in five of six cities, underlining the substantial benefits of ART engagement for the prevention of HIV transmission through viral suppression. Scaling up the combination strategies to ideal service levels resulted in large increases in QALY gains, which were primarily attributable to expanded access to MOUD. Gains in HIV-specific benefits were primarily attributable to prevention, with

increases when scaling up the combination strategies to ideal service levels ranging from approximately 40% in Seattle and New York City to more than doubling in Atlanta. In both implementation scenarios, the proportion of health benefits attributable to improved health among PLHIV was highest in settings with higher levels of epidemiologic control (e.g., New York City) and diminished at higher levels of implementation due to the resulting decreases in prevalence.

Our findings demonstrate that identifying optimal localized combination HIV prevention and care strategies by maximizing incremental QALYs can serve as a guiding framework for ensuring health equity in HIV investment decisions. Decomposing health benefits can help us understand whether efficiency-vs-equity tensions are present, and can serve as a quantitative starting point for decision-makers to weight potential trade-offs between efficiency and equity when faced with difficult decisions.[30, 31] Distributional cost-effectiveness analysis, which aims to balance the priorities of maximizing total population health and promoting equity in the distribution of health benefits across population subgroups such as racial/ethnic groups, is another framework for exploring the health equity implications of potential interventions.[32, 33] Combining these approaches has the potential to further help decision-makers determine public health interventions that promote fair and efficient use of limited resources.

The distribution of HIV health benefits in each city largely mirrored the inclusion of PrEP expansion in their respective optimal strategies. Cities with higher HIV incidence (i.e., less epidemiological control) derived more value from combination interventions that included expanded targeted PrEP for high-risk MSM (Atlanta, Baltimore and Miami),[3, 27, 34] and had larger proportions of HIV-related benefits attributable to HIV prevention than cities without targeted PrEP expansion. These cities also had larger increases in HIV-related benefits attributable to HIV prevention when scaling up PrEP to ideal levels. Though effective in preventing HIV transmission, PrEP is a costly intervention, which can result in uncertainty when determining whether to focus HIV efforts on PrEP expansion in diverse contexts.[35] Our findings help clarify when and in what contexts PrEP expansion targeted to high-risk MSM is likely to be most cost-effective. Moreover, national efforts of the ‘Ready, Set, PrEP’ campaign to provide no-cost medication to individuals at risk of HIV who lack outpatient prescription drug coverage[36] would provide health benefits in all cities, including those with optimal strategies that did not include targeted PrEP expansion.

Amidst an epidemic of opioid use disorder and opioid-related overdose deaths, our findings further emphasize the large gap for delivering evidence-based treatment of OUD, and that closing this gap can provide tremendous health benefits. In the U.S., it is estimated that only one-fifth of the 2.4 million individuals with OUD received specialty care in a given year, and only one-third of these individuals received any MOUD.[37, 38] Miami and Atlanta, the cities with the lowest MOUD coverage levels, had the largest increases in the proportion of health benefits attributable to MOUD. Expanding access to MOUD is cited as a key element of the country’s National Drug Control Strategy[39] and a number of state-level initiatives.[40, 41] In addition to reducing the risk of mortality,[42, 43] prolonged retention in MOUD typically results in reductions of broader societal costs associated with acquisitive crime,[44, 45] a factor we did not incorporate in this analysis. Despite having a relatively small impact on

HIV incidence, expanding access to MOUD also offers the promise of providing excellent value for money[46] and should be a key element in the public health response to the opioid and HIV syndemics.[47, 48]

This study has several limitations. We have previously detailed limitations in the structure of the model and in the evidence base on which it was built.[3, 22, 26, 27] Our evidence on PrEP coverage among high-risk MSM and ART initiation in Seattle in particular may have underestimated the extent of epidemic control. The magnitude of potential benefits accumulated in Seattle may therefore have been overestimated though the direction of effect on the distribution of these benefits are unclear. Higher quality data will reduce uncertainty in both epidemiological projections and questions of value in competing intervention strategies. While the six studies included in our study accounted for nearly a quarter of all PLHIV in the US and were selected to show the extent of epidemiological, demographic and structural differences across cities,[49] our findings may not be generalizable to HIV microepidemics in other settings. Additionally, this study did not consider all possible prevention and care interventions for inclusion in the combination strategies (e.g., behavioral interventions, HIV self-testing, improvements in the organization of HIV care, structural interventions addressing social determinants of health), including new and emerging biomedical interventions (e.g., long-acting ART and PrEP). The inclusion of such interventions, and their potential to be highly effective in populations disproportionately affected by HIV, could change the proportions of HIV-related benefits attributable to improved health among PLHIV versus prevention. Evidence supporting non-clinical interventions such as social network strategies for HIV testing and prevention, [50] couple-based HIV counselling and testing[51] also present opportunities for expansion. Nonetheless, the set of evidence-based interventions considered for inclusion corresponded to interventions with established effectiveness data and promising scalability to prevent, diagnose and treat HIV.[27, 28] Furthermore, results were based on scaling up interventions to implementation levels proportional to population subgroups' existing levels of access (stratified by race/ethnicity and HIV risk), which might continue to promulgate existing barriers in accessing health care services.[27] Disparities in risk and service access are widely documented,[52-54] and strategies aiming to reduce these disparities may result in different distributions of health benefits attributable to HIV prevention and care. While the method presented can allow decision-makers to better understand potential tradeoffs between HIV prevention and improved health among PLHIV, our approach does not offer explicit recommendations on how to weigh these tradeoffs. This is in contrast with cost-effectiveness thresholds used to guide decision-making for tradeoffs between incremental health gains and costs, and remains an area for future development. Additionally, in absence of evidence on how different interventions may become incrementally less effective at higher scales of delivery than what is documented in the public domain, we assumed constant effectiveness for each intervention when scaling up interventions at ideal levels of implementation. Lastly, our probabilistic sensitivity analysis was limited to the 100 best-fitting calibrated parameter sets. While sufficient for the purposes of this study, it may be necessary to extend the reporting of uncertainty when using this new framework to guide decision making.[55]

Determining localized combination strategies on the basis of cost-effectiveness analysis estimated with QALYs resulted in benefits mostly attributable to preventing new HIV infections in six US cities. The proportion of HIV-related health benefits attributable to improved health among PLHIV was highest in settings with high levels of epidemic control and diminished at higher levels of implementation due to the resulting decreases in prevalence. These results highlight how capacity to benefit from prevention versus care interventions is dependent on local epidemiological context and existing service levels. Understanding to whom benefits accrue can be important in assessing the equity and impact of HIV-related investments.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Conflicts of Interest and Source of Funding:

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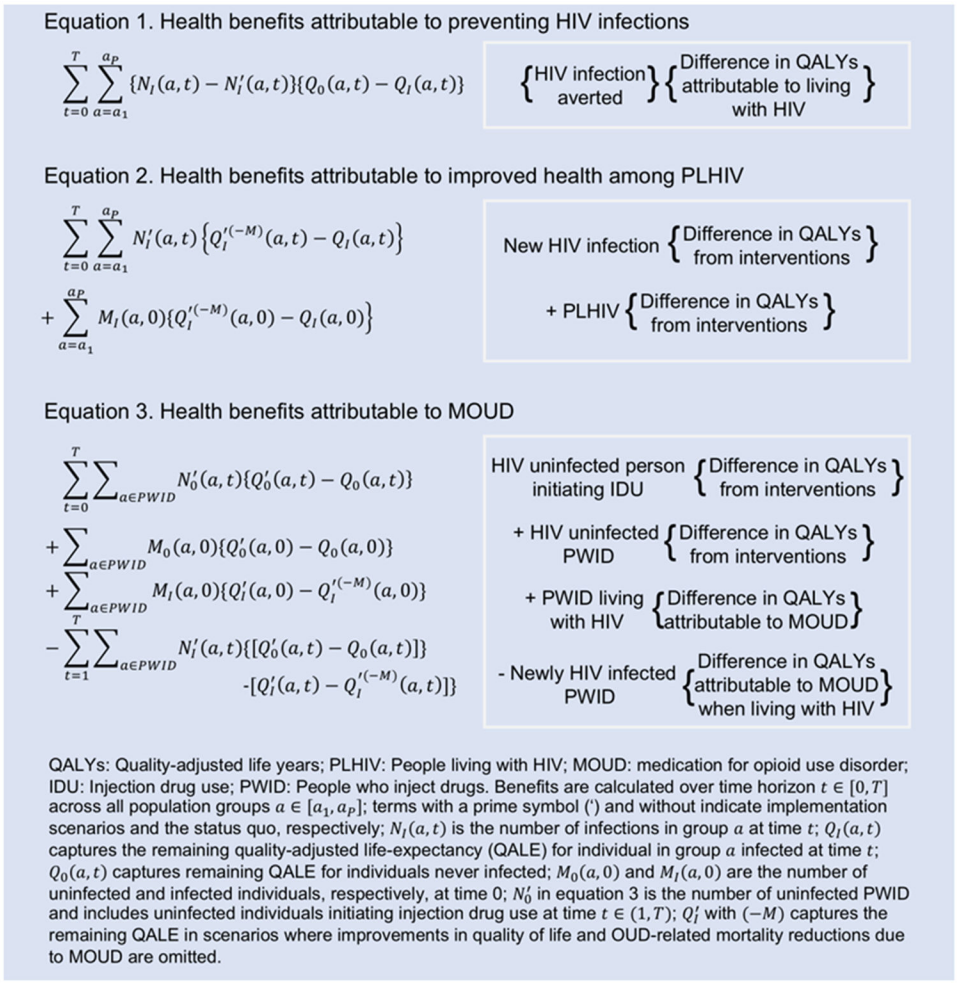

Figure 1. Attributing health benefits from combination implementation strategies to preventing HIV infections, improved HIV care and MOUD.

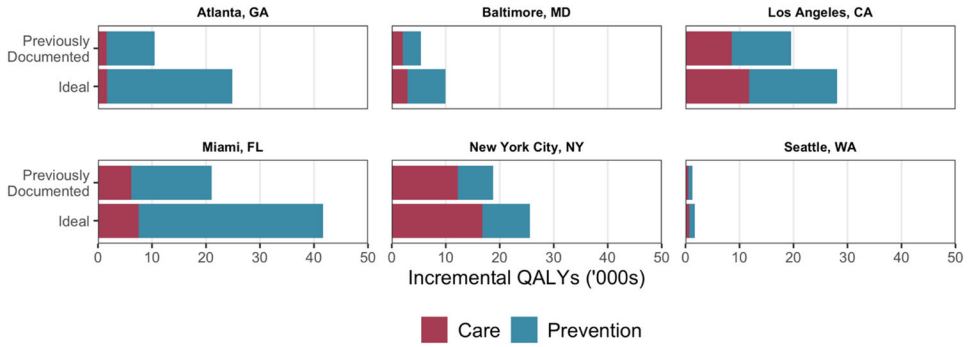

Figure 2. Incremental HIV health benefits attributable to preventing HIV infections (Prevention) versus improved health outcomes among people living with HIV (Care) across 6 cities*.

*HIV health benefits capture by incremental quality-adjusted life years (QALYs) resulting from optimal combination implementation strategies under two different implementation scenarios compared to the status quo. Values represent the average result obtained by the probabilistic sensitivity analysis over 100 simulations and the 95% credible intervals are presented in Table 1.

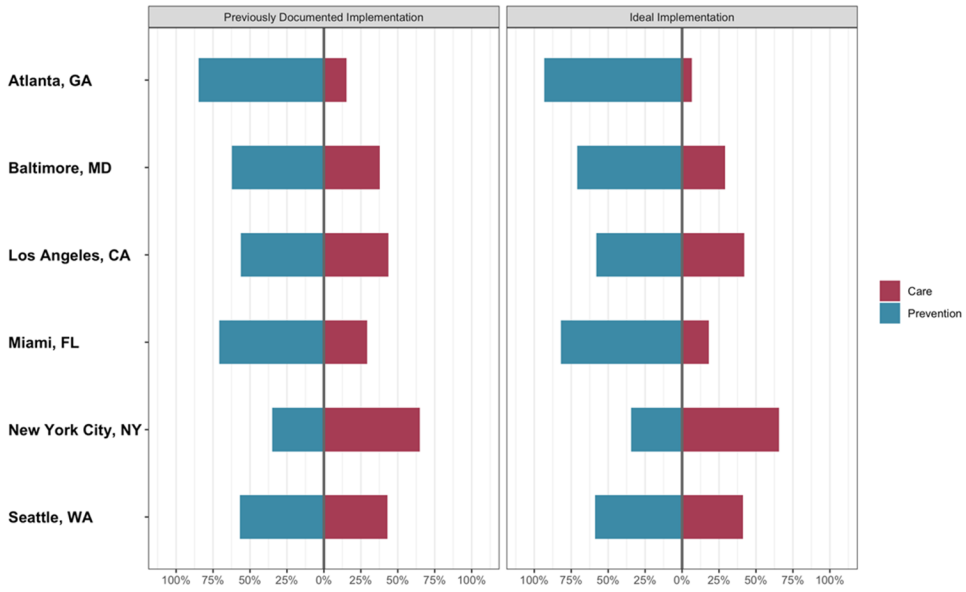

Figure 3. Proportion of HIV health benefits attributable to preventing HIV infections (Prevention) versus improved health outcomes among people living with HIV (Care) across 6 cities*.

* HIV health benefits capture by incremental quality-adjusted life years (QALYs) resulting from optimal combination implementation strategies under two different implementation scenarios compared to the status quo. Values represent the average result obtained by the probabilistic sensitivity analysis over 100 simulations; the 95% credible intervals are presented in Table 1.

Table 1.

Incremental health benefits from optimal combination implementation strategies with proportions of health benefits attributable to medication for opioid use disorder, preventing HIV infections and improved health outcomes among people living with HIV across 6 cities.

Implementation scenarios*	Incremental Health Benefits (QALYs)^	Averted HIV Infections^	Proportion of Health Benefits (QALYs)^				
			% of Total Benefits^			% of Total HIV Benefits^	
			MOUD	Improved Health for PLHIV	HIV Prevention	Improved Health for PLHIV	HIV Prevention
Atlanta, GA							
Scaled up to implementation levels documented in the public domain	11,339 [9,227–13,896]	6,072 [4,726–7,435]	4.7% [1.8%–7.7%]	16.1% [12.7%–19.3%]	79.2% [75.3%–82.8%]	16.9% [13.4%–20.4%]	83.1% [79.6%–86.6%]
Scaled up to reach 'ideal' levels (90% target population coverage)	56,060 [44,475–70,733]	16,665 [13,823–21,854]	54.0% [43.7%–63.7%]	3.4% [2.3%–4.6%]	42.6% [33.0%–51.9%]	7.4% [5.1%–9.4%]	92.6% [90.6%–94.9%]
Baltimore, MD							
Scaled up to implementation levels documented in the public domain	6,874 [5,427–8,163]	3,120 [2,286–3,716]	18.9% [11.9%–27.3%]	32.3% [26.1%–39.2%]	48.8% [41.4%–58.1%]	39.8% [33.2%–46.5%]	60.2% [53.5%–66.8%]
Scaled up to reach 'ideal' levels (90% target population coverage)	42,356 [31,381–52,571]	6,603 [4,706–7,924]	76.1% [68.0%–83.9%]	7.6% [5.0%–10.7%]	16.3% [9.9%–22.5%]	32.0% [23.5%–39.3%]	68.0% [60.7%–76.5%]
Los Angeles, CA							
Scaled up to implementation levels documented in the public domain	21,897 [16,687–27,831]	7,808 [5,374–10,251]	9.8% [6.1%–14.8%]	40.6% [33.2%–49.3%]	49.6% [42.1%–58.3%]	45.0% [36.4%–53.9%]	55.0% [46.1%–63.6%]
Scaled up to reach 'ideal' levels (90% target population coverage)	62,655 [50,220–77,965]	11,506 [8,082–15,604]	54.3% [45.7%–64.3%]	19.9% [14.4%–25.6%]	25.8% [19.5%–31.5%]	43.5% [36.4%–52.6%]	56.5% [47.4%–63.6%]
Miami, FL							
Scaled up to implementation levels documented in the public domain	20,362 [14,654–24,934]	8,618 [5,655–12,022]	1.5% [0.7%–2.5%]	30.4% [22.5%–40.5%]	68.1% [58.0%–76.4%]	30.9% [22.8%–41.1%]	69.1% [58.9%–77.2%]
Scaled up to reach 'ideal' levels (90% target population coverage)	54,272 [38,413–76,375]	20,858 [11,313–30,737]	27.3% [17.8%–39.8%]	14.3% [9.4%–21.3%]	58.5% [45.0%–69.6%]	19.8% [12.7%–31.0%]	80.2% [69.0%–87.3%]
New York City, NY							
Scaled up to implementation levels documented in the public domain	23,377 [17,141–29,573]	4,813 [3,022–6,646]	13.0% [9.1%–19.0%]	58.2% [50.6%–66.2%]	28.8% [22.2%–35.3%]	66.9% [58.9%–73.9%]	33.1% [26.1%–41.1%]
Scaled up to reach 'ideal' levels (90% target population coverage)	76,024 [59,628–93,038]	6,324 [4,238–8,709]	63.0% [53.8%–71.5%]	24.9% [17.9%–32.4%]	12.0% [8.8%–15.7%]	67.4% [60.6%–74.3%]	32.6% [25.7%–39.4%]
Seattle, WA							
Scaled up to implementation levels documented in the public domain	1,935 [1,418–2,453]	582 [341–850]	31.7% [20.0%–44.7%]	31.8% [24.6%–40.0%]	36.5% [25.8%–48.1%]	46.7% [36.9%–57.3%]	53.3% [42.7%–63.1%]

Implementation scenarios*	Incremental Health Benefits (QALYs)^	Averted HIV Infections^	Proportion of Health Benefits (QALYs)^				
			% of Total Benefits^			% of Total HIV Benefits^	
			MOUD	Improved Health for PLHIV	HIV Prevention	Improved Health for PLHIV	HIV Prevention
Scaled up to reach 'Ideal' levels (90% target population coverage)	13,073 [8,619–17,711]	804 [471–1,202]	85.9% [78.6%–91.1%]	6.3% [3.9%–9.6%]	7.8% [4.3%–13.5%]	44.7% [35.7%–55.0%]	55.3% [45.0%–64.3%]

QALY: quality-adjusted life year; MOUD: Medications for opioid use disorder; PLHIV: People living with HIV.

*Interventions were sustained for 10 years with outcomes evaluated over 20 years to capture long-term health benefits and 2nd-order transmission effects.

^Values represent the average result obtained by the probabilistic sensitivity analysis over 100 simulations; brackets indicate the 95% credible interval.