

Preexposure prophylaxis strategies for African–American women affected by mass incarceration

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Objective: We aimed to determine the effectiveness of various preexposure prophylaxis (PrEP) prescription strategies for African–American women impacted by mass incarceration within an urban setting.

Design: An agent-based model was utilized to evaluate prevention strategies in an efficient, ethical manner. By defining agents, their characteristics and relationships, we assessed population-level effects of PrEP on HIV incidence.

Methods: We tested hypothetical PrEP prescription strategies within a simulation representing the African–American population of Philadelphia, Pennsylvania. Four strategies were evaluated: PrEP for women meeting CDC indicators regarding partner characteristics, PrEP for women with a recently incarcerated male partner, PrEP for women with a recently released male partner and couples-based PrEP at time of release. Interventions occurred alongside scale-up of HAART. We evaluated reductions in HIV transmissions, the number of persons on PrEP needed to avert one HIV transmission (NNT) and the resulting proportions of people on PrEP.

Results: Scenarios prescribing PrEP based on criminal justice system involvement reduced HIV transmissions. The NNT ranged from 147 (couples-based scenario) to 300 (recently released scenario). The percentage of the female population covered by PrEP at any one time ranged from 0.14% (couples-based) to 10.8% (CDC-based). CDC-guideline scenarios were consistently less efficient compared to the justice-involved interventions.

Conclusion: Expanding PrEP for African–American women and their male partners affected by incarceration should be considered in national HIV prevention goals and correctional facilities leveraged as intervention sites. Partner characteristics in the current CDC indications may be more effective and efficient if guidelines considered criminal justice involvement.

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Introduction

The potential benefits of preexposure prophylaxis (PrEP) to reduce HIV acquisition risk are not currently being realized for women. Despite providing women with a method to control their own HIV risk, with a potentially high level of acceptability, and proven efficacy, PrEP prescription to women is rare [1]. A retrospective analysis of individuals with commercial health insurance in the U.S. estimated that 97% of PrEP users from 2010 to 2014 were male, and by 2017, only 5% of PrEP users were female [1,2]. Further, the use of PrEP is disproportionately low among African-American women, who account for nearly 60% of new adult female diagnoses, but comprise only 26% of female PrEP users [3]. The difficulty of identifying women most likely to benefit from PrEP has stymied implementation efforts [4,5]. Centers for Disease Control and Prevention guidelines recommend PrEP for women who are not in a mutually monogamous relationship with an HIV-negative partner and report either infrequent use of condoms with a male partner of unknown HIV status at substantial risk of HIV [i.e. person with injection drug use (PWID) or MSM] or a bacterial STI diagnosis in past 6 months [6]. These partner-level characteristics (i.e. MSMW, PWID, or HIV-diagnosed) are assumed to be the most influential in shaping HIV transmission risk for the female partner. However, recent studies have questioned if accounting for partner characteristics is the most effective strategy to prevent HIV acquisition, particularly for African-American women [5,7].

Social and structural factors, including the mass incarceration of African-American men, drive the disproportionate burden of HIV among African-American women in the U.S. [8]. African American women with incarcerated partners may benefit from PrEP given their elevated risk of STIs, having five or more partners in the past year, partner concurrency and exposure to networks with elevated infection risk compared with women who never had an incarcerated partner [9,10]. Offering PrEP to women during a partner's incarceration or after a partner's release may decrease community HIV incidence. However, current federal PrEP prescription guidelines do not recommend considering partner incarceration when assessing one's risk of HIV acquisition or suggest correctional facilities as a potential venue for PrEP-based interventions.

Traditional epidemiological methods face numerous challenges when attempting to identify subsets of women most likely to benefit from PrEP prescription, as these methods are often unable to account for the complexity of sexual network structures, overlapping risk factors and interference. Mathematical modelling can potentially overcome these challenges and is a promising method to estimate the likely impact of PrEP prescription strategies [4]. In this analysis, we evaluate hypothetical PrEP

prescription strategies accounting for criminal justice involvement using an agent-based model. We use the city of Philadelphia, Pennsylvania, as a case study. Philadelphia has high rates of both incarceration and heterosexual HIV transmission within the African-American population [11,12]. Furthermore, Philadelphia is one of the 48 'hotspot' counties named in the Department of Health and Human Services' recent report, which recommends increased funding in order to reduce new infections by 75% in the next 5 years [13]. This plan includes expansion of PrEP as one of its major components. Mathematical models can provide guidance in allocating resources and maximizing benefits of PrEP in at-risk populations.

The current study estimates the potential reduction in HIV transmission among African-American women living in an urban setting attributable to making PrEP accessible to women affected by partner incarceration. Specifically, we use agent-based modelling to evaluate the effectiveness of strategies accounting for partner incarceration compared with the partner characteristics used within CDC indicators.

Materials and methods

This analysis uses a previously developed agent-based model (referred to as TITAN) to identify PrEP prescription strategies that could decrease HIV incidence for African-American women [14,15]. Briefly, TITAN simulates HIV transmission, disease progression, testing and treatment, as well as incarceration of male agents, within a virtual population representing the African-American population of Philadelphia. Informed by observational studies described within the supplemental digital content, <http://links.lww.com/QAD/B900>, a high-risk period lasting approximately 6 months occurs following release from a correctional facility (for male agents) or upon a partner's incarceration or dissolution of a relationship during incarceration (for female agents). During these high-risk periods, agents are more likely to have an increased number of sexual partners and double the likelihood of acquiring HIV (to approximate the impact of a current sexually transmitted infection). Our model incorporated sexual assortative mixing where men who experienced incarceration were more likely to partner with women who had previously had an incarcerated partner, and vice versa [10]. Detailed information regarding model processes and sources are available in the Supplemental Digital Content (see Tables S1-S10, Figures S1-S2), <http://links.lww.com/QAD/B900>.

We extended TITAN to include PrEP provision to eligible HIV-negative agents informed by clinical trials of serodiscordant couples in Africa as well as smaller studies in the U.S. In our model, 80% of agents on PrEP are

assumed to be highly adherent (equivalent to 6–7 doses/week), and therefore, have a 94% reduction in relative risk of HIV acquisition [16–20]. The remaining 20% of agents on PrEP fail to achieve high adherence and only have a reduction of 59%. Once an agent begins PrEP, they have a 15% probability of discontinuing per month [21]. As a result, agents are on PrEP for a median duration of 6 months. The model was run for 10 years. Key parameters are summarized in Table 1.

Intervention scenarios

A status quo scenario was calibrated to project HIV transmission dynamics over a 10-year period (2015–2025) based on current HIV surveillance trends. This status quo scenario incorporates targets set by the city related to the HIV care continuum. For all model runs, over 90% of individuals living with HIV are diagnosed and HAART coverage for HIV-infected men increases from 66% in 2015 to 74% by 2025. For the status quo scenario, PrEP was not used by any agent due to the rarity of PrEP use within this population. We then projected how HIV incidence would be affected by prescribing PrEP using differing strategies informed by partner characteristics. For each of the scenarios, we varied the probability of PrEP initiation for eligible agents (criminal justice

informed scenarios) or population coverage (CDC scenario) to 10, 30, 60 and 100%. Agents selected to initiate PrEP are randomly selected from the eligible pool. PrEP adherence and retention levels did not systematically vary across scenarios within the main analyses. The modelled scenarios are described as follows:

- (1) Status quo scenario: no preexposure prophylaxis utilized by any agent.
- (2) Recently incarcerated intervention simulated an intervention wherein women with a male partner entering a correctional facility initiates PrEP.
- (3) Recently released intervention simulated an intervention wherein women who are in an existing partnership with a male partner who leaves a correctional facility as well as women who initiate a relationship with a male partner who has left a correctional facility in the past 6 months initiate PrEP. PrEP initiation commences when the partner leaves the correctional facility (if an existing relationship) or when the relationship begins (if a new relationship).
- (4) Couples-based PrEP intervention simulated an intervention in which women with a primary male partner (serodiscordant if the male partner is HIV-infected; or both are HIV-negative) initiate PrEP when the male

Table 1. Overview of key model parameters and processes impacted by incarceration and partner incarceration or related to the use of preexposure prophylaxis.^a

Processes	Description
Sexual Behavior and Sexual Network	
Partner acquisition rate	Agents assigned a personal annual mean number of partners, which is allowed to vary stochastically year-to-year.
Relationship length	Varies stochastically based on empirical data on mean and median relationship lengths. Agents have a 50% likelihood of relationship dissolution during incarceration.
Incarceration	
Incarceration rate	Derived from 2005 data from the Philadelphia Commission on Sentencing for African–American men, held constant through model run. Varies by type of correctional facility (jail vs. prison), recidivism status (prior offense vs. first offence). Higher rates for HIV-infected and current PWID male agents.
Sentence length	Derived from 2005 data from the Philadelphia Commission on Sentencing for African–American men, held constant through model run. Varies by type of correctional facility (jail vs. prison).
HIV/AIDS	
Initial HIV prevalence	Based on HIV surveillance data for African–American men and women in Philadelphia. Higher rates for PWID, MSMW and male agents who experience incarceration.
Testing	Agents test stochastically throughout the year with differing probabilities based on sex and IDU. Diagnosed agents are less likely to transmit to HIV-negative partners.
Viral suppression	Only HIV-diagnosed agents are eligible for viral suppression (operationalized as HAART adherence level > 90%). Virally suppressed agents are less likely to transmit to HIV-negative partners (0.0001 probability of transmission for unprotected vaginal sex act and 0.0002 for needle or works injection sharing).
HAART discontinuation	Only HIV-diagnosed agents on HAART are eligible to discontinue HAART. Annual probability of discontinuation differed by gender.
Transmissibility	Based on diagnosis status, HAART adherence, disease stage. Individuals with a current STI are more likely to acquire HIV.
Preexposure prophylaxis (PrEP)	
PrEP uptake	Probability of PrEP initiation for eligible agents (criminal justice informed scenarios) or population coverage (for the CDC guideline scenario) was varied at 10, 30, 60 and 100%.
Efficacy of PrEP use	94% reduction in the relative risk of HIV acquisition with high adherence (6–7 doses/week) or 59% reduction with suboptimal adherence.
Adherence to PrEP	80% of agents have high adherence (6–7 doses/week), 20% have sub-optimal adherence. Adherence does not change over time and does not differ by gender, PWID-status, or any other characteristic.
Retention on PrEP	Every month, agents on PrEP have a 15% probability of discontinuing PrEP. This probability does not change over time or vary by any agent characteristic.

MSMW, men who have sex with men and women; PrEP, preexposure prophylaxis; PWID, persons who inject drugs; STI, sexually transmitted infection.

^aParameter values and sources available in the supplemental materials, <http://links.lww.com/QAD/B900>.

Table 2. Description of preexposure prophylaxis prescription strategies, population prioritized for preexposure prophylaxis, potential setting and providers.

Intervention	Population prioritized for PrEP	Average <i>N</i> (%) on PrEP at any one time point	Cumulative <i>N</i> of PrEP initiates at end of 10 years	Setting for intervention	Providers for intervention
Recently incarcerated intervention	Any African–American woman in a relationship >1 month whose partner enters prison or jail	~650 women, 0.25% of total African American female population	~13 000	Correctional facility, FQHCs, STI clinics	Correctional health providers, primary care physicians
Recently released intervention	Any African–American women with a prior or new partner who has been released in the past 6 months	~6500, 2.5% of total African–American female population	~150 000	Community-based (FQHCs, STI clinics and so on)	Primary care physicians, OB-GYNs
Couples-based PrEP intervention	African American women and their male partners (HIV-negative/HIV-negative or HIV-positive man and HIV-negative woman) at time man is released from a correctional facility	~360, 0.14% of total African–American female population and ~180, 0.10% of total African American male population	~11 880	Correctional facility	Correctional health providers
CDC-based intervention	African–American women with a partner who is HIV-diagnosed, currently injecting drugs or has sex with men	~28 500 (10.8%) of total African American female population	~550 000	Community-based (emergency rooms, FQHCs, STI clinics, general practice)	Primary care physicians, OB-GYNs

N-number, FQHC- federally qualified health centre; OB-GYN, obstetrician-gynecologist; PrEP, preexposure prophylaxis; STI, sexually transmitted infection.

partner leaves a correctional facility, and the male partner also initiates PrEP if HIV-negative.

- (5) CDC-based partner characteristics intervention [6] simulated an intervention in which women initiate PrEP if they begin a relationship with a male partner who has been diagnosed with HIV, is currently injecting drugs or has sex with other men.

Table 2 summarizes the population prioritized for PrEP prescription in each scenario, potential settings and medical providers, and the number and percentage of the population reached when the probability of PrEP initiation or coverage level is set to 30%. Scenarios were run 400 times with one-fourth population size ($n = 110\,000$).

Uncertainty analyses

Due to uncertainty on selected parameters, we ran additional scenarios varying PrEP adherence by assuming only 50% were optimally adherent (i.e. took 6–7 doses/week), varying retention for agents prescribed PrEP (8 or 30% discontinue per month) and decreasing the incarceration rate by 25 and 50%.

Outcomes

The status quo scenario wherein no PrEP was prescribed to any agent was compared with the counterfactual scenarios with differing PrEP prescription strategies. Outcomes of interest were the absolute reduction in HIV

transmission and efficiency as measured by the number of individuals initiating PrEP needed in order to prevent one HIV transmission (NNT). We also compared the resulting percentage of women covered by PrEP at any one time, averaged over the 10-year study period.

The absolute reduction in HIV transmissions over the 10-year study period was calculated by averaging the number of averted HIV transmissions for men and women for each intervention scenario compared to the status quo scenario. We utilized 95% simulation intervals to account for the stochastic framework of these models by reporting the middle 95% of simulated data. We compared the efficiency of interventions by comparing the NNT.

Role of funding sources

Funding sources had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

Results

Projected trends in HIV incidence and prevalence for African–American women using HIV surveillance statistics were successfully reflected within the status quo scenario (see Supplemental Digital Content, S3–4 Figures, <http://links.lww.com/QAD/B900>). Over the

Table 3. Outcomes of interest.

	Total number of HIV transmissions (N, 95% Simulation Interval [SI])	Total Infections averted ^a (N, %)	Average cumulative number of PrEP prescriptions over ten years	Number of persons initiating PrEP in order to avert one HIV transmission (NNT) ^a	Average N (%) of total female population on PrEP at any one time point
Main analyses (30% probability of PrEP uptake or coverage)					
Status quo scenario	3325 (2797–3940)	n/a	n/a	n/a	0 (0%)
Partner recently incarcerated scenario (incarceration)	3274 (2759–3797)	54 (2%)	13 486	250	649 (0.25%)
Partner recently released scenario (release)	2831 (2411–3272)	496 (15%)	148 636	300	6622 (2.5%)
Couples-based at release scenario (couple)	3247 (2747–3868)	81 (2%)	11 947	147	367 (0.14%)
CDC guideline scenario (CDC) ^b	3091 (2558–3574)	236 (7%)	550 044	2331	28 516 (10.8%)
Sensitivity analyses ^c					
10% PrEP uptake/coverage					
Incarceration	3302 (2797–3860)	25 (1%)	4559	182	220 (0.08%)
Release	3093 (2696–3595)	235 (7%)	68 210	290	3038 (1.15%)
Couple	3314 (2801–3935)	14 (0%)	4373	312	125 (0.05%)
CDC	3266 (2776–3780)	62 (2%)	211 967	3,419	11 019 (4.2%)
60% PrEP uptake/coverage					
Incarceration	3225 (2713–3843)	104 (3%)	26 417	254	1270 (0.48%)
Release	2706 (2234–3112)	622 (19%)	214 478	345	9,494 (3.59%)
Couple	3175 (2730–3637)	152 (5%)	22 002	145	717 (0.27%)
CDC	2886 (2415–3284)	442 (13%)	905 278	2048	46 583 (17.6%)
100% PrEP uptake/coverage					
Incarceration	3144 (2650–3692)	184 (6%)	42 940	233	2062 (0.78%)
Release	2622 (2196–3137)	706 (21%)	261 030	370	11 507 (4.40%)
Couple	3139 (2680–3620)	189 (6%)	34 218	181	1165 (0.44%)
CDC	2747 (2234–3473)	581 (17%)	1 234 861	2125	63 334 (24.0%)
PrEP adherence					
Incarceration	3278 (2751–3818)	49 (1%)	13 568	277	653 (0.25%)
Release	2861 (2436–3389)	467 (14%)	149 407	320	6639 (2.5%)
Couple	3296 (2784–3880)	32 (1%)	11 899	372	365 (0.14%)
CDC	3069 (2587–3671)	259 (8%)	543 640	2099	28 021 (10.7%)
Halved PrEP discontinuation					
Incarceration	3180 (2722–3784)	147 (4%)	13 325	91	1180 (0.45%)
Release	2682 (2293–3217)	645 (19%)	126 563	196	10 877 (4.11%)
Couple	3219 (2751–3700)	107 (3%)	11 830	111	655 (0.25%)
CDC	2986 (2402–3616)	341 (10%)	962	880	30 244 (11.5%)
Doubled PrEP discontinuation					
Incarceration	3312 (2780–4066)	16 (0%)	13 666	854	312 (0.11%)
Release	3024 (2625–3591)	304 (9%)	179 813	591	3396 (1.29%)
Couple	3321 (2923–3872)	7 (0%)	11 962	1709	175 (0.07%)
CDC	3172 (2683–3843)	155 (5%)	979 432	6319	26 276 (10.0%)
Incarceration rate lowered by 25%					
Status quo	3766 (3314–4628)	n/a	n/a	n/a	
Incarceration	3540 (2759–4196)	226 (6%)	10 125	45	487 (0.18%)
Release	3049 (2486–3671)	717 (19%)	124 571	174	5558 (2.10%)
Couple	3530 (2990–4112)	235 (6%)	9071	39	282 (0.11%)
CDC	3369 (2759–4078)	396 (11%)	544 576	1375	28 308 (10.7%)
Incarceration rate lowered by 50%					
Status quo	4603 (3419–5981)	n/a	n/a	n/a	
Incarceration	4230 (3318–5279)	373 (8%)	6753	18	324 (0.12%)
Release	3634 (2877–4582)	969 (21%)	95 603	99	4271 (1.6%)
Couple	4185 (3402–5137)	418 (9%)	6268	15	197 (0.08%)
CDC	3950 (3112–4922)	654 (14%)	539 275	825	28 011 (10.6%)

^aCompared to the *status quo* scenario where PrEP was not prescribed to any agent.

^bDue to computing limits, means were calculated from less than 100 simulations (92 for 10% coverage, 82 for 60% and 78 for 100% coverage).

^cDue to computing limits, means were calculated from less than 100 simulations (.5 PrEP adherence: 93 for CDC; halved PrEP discontinuation: 92 for CDC; doubled PrEP discontinuation: 96 for Incarceration, 84 for Release, 94 for Couples scenarios and 92 for CDC).

10-year study period, there was an average of 3325 HIV transmissions (95% simulation interval: 2797–3940) and the incidence rate was 68 (simulation interval: 60–78) and 80 (simulation interval: 66–97) per 100 000 person-years for women and men, respectively. Over 10 years, 12% of men and 35% of HIV-infected men experienced at least one period of incarceration.

All of the criminal justice informed scenarios, at every level of probability of PrEP initiation for eligible agents, averted more HIV transmissions, on average, compared with the *status quo* scenario (Table 3). The CDC-based scenario prescribing PrEP to 30% of women meeting criteria informed by partner characteristics averted 236 (7%) transmissions. The CDC scenario resulted in the

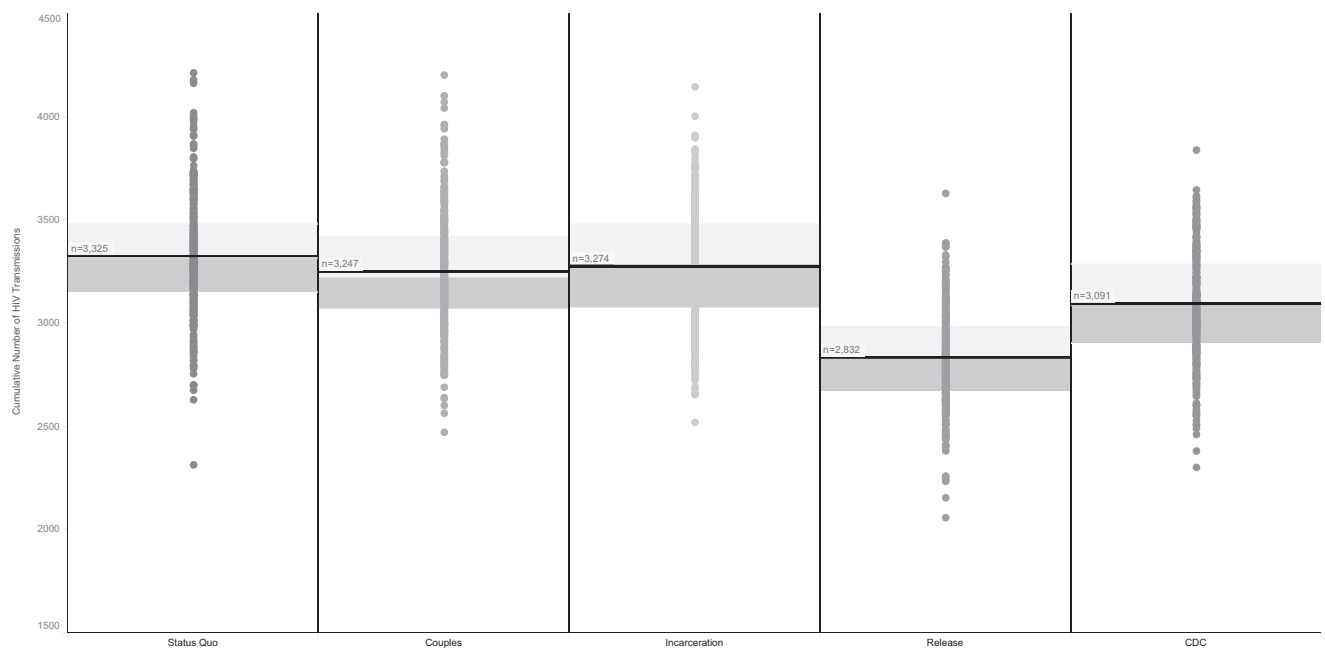


Fig. 1. The distribution of total HIV transmissions for each scenario at 30% probability of initiation.

highest proportion of women on PrEP (~10.8% at any one time, averaged over the ten-year study period) of all the modelled scenarios. Within the CDC scenario, 27% of women received PrEP because they had a partner who injected drugs, 49% had a male partner who had sex with men and 61% had a partner diagnosed with HIV (percentages do not add up to 100% as multiple criteria could apply). Approximately one-fifth of the total African-American female population qualified for PrEP according to these CDC indicators at some point over the ten-year model run.

Figure 1 presents the distribution of total HIV transmissions for each scenario at 30% probability of initiation. Each of the model runs began by building sexual and injection networks, and although each run was based on the same set of parameters, the resulting networks and number of transmissions varied widely. Therefore, we present mean number of transmissions while noting that the cumulative number of transmissions within the intervention scenarios fall within the range of transmissions seen within the status quo scenario. On average, the prescription of PrEP upon release scenario had the greatest absolute reduction (–15%) in HIV transmissions of all the scenarios. The scenario reached more women (~2.5% of total female population, Table 3) compared with the other two criminal justice informed scenarios as men initiate sexual partnerships with five female partners, on average, during the 6 months postrelease. Prescribing PrEP to 30% of the women with a recently incarcerated partner averted 2% of total infections and resulted in around 0.25% of the total female population on PrEP at any one time. Prescribing PrEP to 30% of recently released men and their primary female partners averted

2% of total transmissions and resulted in 0.14% of the total female population on PrEP at any one time.

Efficiency of the PrEP interventions ranged from an NNT of 147 (couples-based scenario) to 300 (recently released scenario) when assessing the number of infections averted compared with the status quo scenario where no PrEP was prescribed. All three criminal justice informed scenarios were more efficient than the CDC scenario which, on average, had an NNT of 2331 (Table 3). For the recently released and incarcerated scenarios, efficiency decreased as the probability of initiation increased. This pattern was not seen for the CDC or couples-based scenarios.

Increasing the probability of PrEP initiation increased the number of averted infections across all three scenarios and decreased efficiency. Overall, for any given probability/coverage level, the recently incarcerated scenario and couples-based scenarios were most efficient, followed by the recently released scenario. The CDC scenario was the least efficient of all tested interventions (Fig. 2).

Uncertainty analyses found that intervention outcomes were generally attenuated when optimal adherence was lowered to 50 from 80%; however, this resulted in minimal impact on studied outcomes. Halving the probability of discontinuation (i.e. improved retention) significantly increased the number of averted transmissions and improved efficiency. Conversely, doubling the probability of discontinuing PrEP resulted in less averted transmissions and lower efficiency. When incarceration rates were reduced by 25 and 50%, the number of HIV transmissions increased in the status quo scenario. Despite

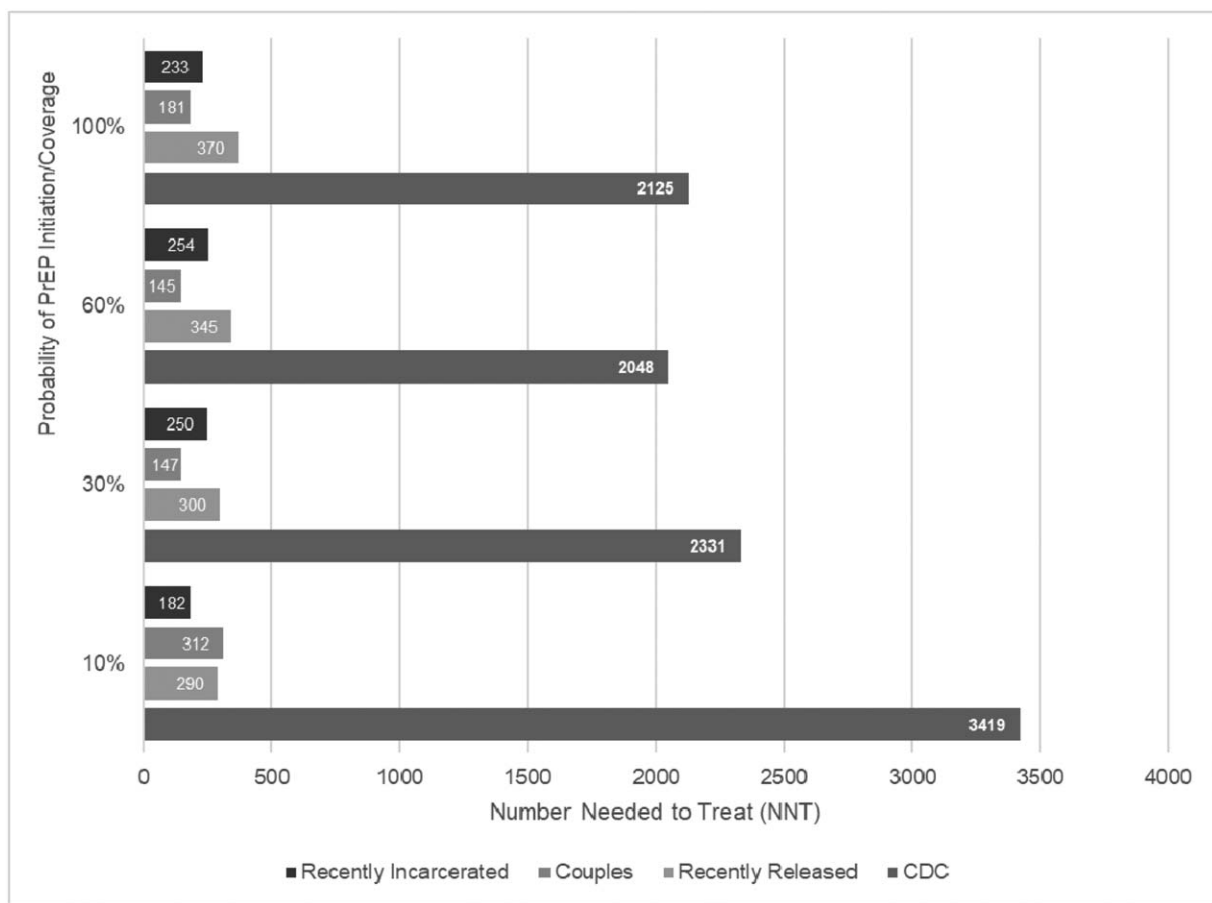


Fig. 2. Number of individuals initiating preexposure prophylaxis needed in order to prevent one HIV transmission (NNT) for hypothetical PrEP strategies at varying levels of either coverage (CDC scenario) or probability of PrEP initiation for eligible agents (all other scenarios).

this increase, the criminal justice informed scenarios prevented a greater share of transmissions. When the incarceration rate was halved, the percentage of infections averted doubled. The impact of decreasing incarceration rates on the percentage of agents who experienced incarceration or partner incarceration over the 10-year period and the number of HIV transmissions are summarized with the Supplemental Digital Content (see Table S11), <http://links.lww.com/QAD/B900>.

Discussion

Results from our model suggest that increasing PrEP uptake for women has the potential to decrease HIV transmissions in areas disproportionately affected by HIV and mass incarceration. Increasing uptake of PrEP with a more focused prescription strategy for women impacted by partner criminal justice involvement, and offering PrEP services in correctional settings, could potentially help close the racial disparity gap seen for African American women in PrEP uptake and HIV incidence

rates. Moreover, these strategies were estimated to be more efficient than partner characteristics included within current CDC guidelines.

Currently, providers generally follow CDC guidelines to prescribe PrEP to women. Our findings suggest that the partner characteristics used within the CDC guidelines are not the most efficient nor effective strategy to prevent HIV acquisition for African-American women. The CDC scenario likely had limited utility in this setting, as over 90% of individuals living with HIV were diagnosed and over 70% were on HAART. Agents also had a high probability of HIV testing. Therefore, in the CDC scenario, the majority of agents on PrEP due to a partner's HIV-status were probably at a relatively low likelihood of HIV acquisition. It should be noted that this study was not designed to evaluate the overall CDC guidelines for PrEP for women. We did not account for individual risk factors (i.e. women with current IDU and recent bacterial STI) in any of the scenarios in order to make a direct comparison between partner characteristics included in the CDC indicators and partner characteristics related to criminal justice involvement. However, these results

suggest that other partner characteristics should be considered when determining PrEP eligibility.

The criminal justice informed PrEP prescription strategies were modelled on potential interventions feasible in real-world settings. Guidance for implementing PrEP linkage for individuals with criminal justice involvement was recently published [22]. The recently released and couples-based scenarios could be delivered by correctional systems by integrating PrEP prescription into existing HIV testing and counselling programmes in prison or jail settings. Couples-based HIV prevention programmes for individuals within community supervision programs have been shown to decrease risky sexual behaviours and could augment PrEP linkage [23]. The modelled scenario prescribing PrEP to women with a recently released partner could be delivered by clinicians working with STI clinics, FQHCs or other health centres that provide care for women who may be impacted by partner incarceration. Additional research is needed to clarify how these interventions should be implemented without furthering stigma related to incarceration and HIV. However, particularly in areas with high rates of incarceration, it is possible that discussing a partner's incarceration may be less stigmatizing than disclosing having a partner who has sex with men or injects drugs. One potential model for facilitating this discussion is a tool for self-assessing PrEP eligibility for women developed with community input that includes the following question: 'In the last 6 months, have you had a sexual partner who has ever been in jail or prison?' [24].

Observational studies and pilot projects used to parameterize model processes can also provide context regarding the reach of modelled interventions as well as potential barriers. These studies indicate that achieving high levels uptake of PrEP may be a challenge. The first demonstration project focused on U.S. heterosexual women and PrEP enrolled heterosexual men and women at community health centres and found that only 14% of individuals at elevated risk for HIV and referred for PrEP actually initiated PrEP [25]. However, the authors note that same-day initiation of PrEP may eliminate this drop-off [25]. The provision of no-cost or low-cost PrEP may also improve the probability of PrEP initiation. In one study of mostly African-American heterosexual men and women in Philadelphia, 76% would hypothetically take PrEP if offered at no cost but only 47% would take PrEP with a monthly co-pay of US\$20 [26]. Our findings emphasize the need for a low-cost generic option for PrEP in consideration of the financial limitations associated with even low-cost co-pays and the need to achieve high levels of PrEP uptake for optimal impact.

The uncertainty analyses demonstrate that concerns about reduced medication adherence among women should not prevent the adoption of PrEP. Lowering the

percentage of optimal adherence among the PrEP-taking population to 50% had a minor impact on outcomes, even when accounting for differences in PrEP efficacy for women compared to MSM by dosage. However, when retention was doubled, the impact was comparable to that of doubling the probability of PrEP initiation. This suggests that programs should aim to maximize retention on PrEP.

Incarceration rates have recently begun to decline as policymakers are increasingly aware of systemic racism within the carceral system and the negative consequences of mass incarceration [27]. Within our model, uncertainty analyses decreasing the incarceration rate resulted in more HIV transmissions within the community. Lowering incarceration rates meant that individuals living with HIV were more likely to be in the community rather than correctional settings (where HIV transmission could not occur), thus increasing the probability of transmission. This finding highlights the need to ensure linkage to HIV care for individuals who have experienced incarceration and improve retention for men. A previously published article using this model also found that linkage to HIV care postincarceration was crucial to preventing HIV transmission within community settings [15]. However, when the incarceration rate was decreased, the criminal justice informed scenarios had an even greater impact as individuals prescribed PrEP were more likely to encounter an HIV-infected agent within the model. Overall, these findings provide strong support for criminal justice informed interventions alongside efforts to end mass incarceration.

Our study was subject to several limitations. First, like all simulations, this modelling study cannot fully capture all factors related to mass incarceration or HIV transmission, including poverty, unemployment and reduced access to medical care. We used observational studies to parameterize model processes which introduces the potential for bias. In particular, the assumed effects of incarceration and partner incarceration on HIV risk behaviours could be under or overestimated. Second, we did not model the development of drug-resistance. However, previous studies have shown that increases in resistance related to PrEP expansion are small (<5%) and that the number of averted HIV transmissions far exceeds the increase in drug-resistant infections [28]. Third, we were not able to evaluate PrEP prescription for women with a history of incarceration as the model did not include incarceration of female agents. There is strong evidence to suggest that women experiencing incarceration would benefit from PrEP [29]. Finally, the couples-based intervention did not include PrEP provision to HIV-negative men with HIV-positive female partners, as this analysis focused on PrEP provision to women. Despite these limitations, this study has several strengths, including the use of local surveillance data to parametrize model inputs, the inclusion of complex processes related to incarceration and HIV, and

accounting for stochasticity through individual-based modelling.

In summary, these findings demonstrate population-level impact of PrEP prescription strategies for men and heterosexual women impacted by criminal justice involvement, even in a relatively low HIV incidence setting with increasing uptake of HAART. Criminal justice informed PrEP strategies have the potential to decrease HIV incidence within African-American populations and should be considered alongside scale-up of strategies based on CDC criteria and efforts for criminal justice reform to decrease rates of mass incarceration and its detrimental effects on individuals and their communities.

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Conflicts of interest

No actual or potential conflicts of interest to declare. The funders had no role in study design, data collection and analysis, decision to publish or preparation of the manuscript.

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