# Impact of post-incarceration care engagement interventions on HIV transmission among young Black men who have sex with men and their sexual partners: an agent-based network modeling study

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## Summary

**Background** Understanding the impact of incarceration on HIV transmission among Black men who have sex with men is important given their disproportionate representation among people experiencing incarceration and the potential impact of incarceration on social and sexual networks, employment, housing, and medical care. We developed an agent-based network model (ABNM) of 10,000 agents representing young Black men who have sex with men in the city of Chicago to examine the impact of varying degrees of post-incarceration care disruption and care engagement interventions following release from jail on HIV incidence.

**Methods** Exponential random graph models were used to model network formation and dissolution dynamics, and network dynamics and HIV care continuum engagement were varied according to incarceration status. Hypothetical interventions to improve post-release engagement in HIV care for individuals with incarceration (e.g., enhanced case management, linkage to housing and employment services) were compared to a control scenario with no change in HIV care engagement after release.

**Finding** HIV incidence at 10 years was 4.98 [95% simulation interval (SI): 4.87, 5.09 per 100 person-years (py)] in the model population overall; 5.58 (95% SI 5.38, 5.76 per 100 py) among those with history of incarceration, and 12.86 (95% SI 11.89, 13.73 per 100 py) among partners of agents recently released from incarceration. Sustained post-release HIV care for agents with HIV and experiencing recent incarceration resulted in a 46% reduction in HIV incidence among post-incarceration partners [incidence rate (IR) per 100 py = 5.72 (95% SI 5.19, 6.27) vs. 10.61 (95% SI 10.09, 11.24); incidence rate ratio (IRR) = 0.54; (95% SI 0.48, 0.60)] and a 19% reduction in HIV incidence in the population overall [(IR per 100 py = 3.89 (95% SI 3.81–3.99) vs. 4.83 (95% SI 4.73, 4.92); IRR = 0.81 (95% SI 0.78, 0.83)] compared to a scenario with no change in HIV care engagement from pre-to post-release.

**Interpretation** Developing effective and scalable interventions to increase HIV care engagement among individuals experiencing recent incarceration and their sexual partners is needed to reduce HIV transmission among Black men who have sex with men.

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## Research in context

### Evidence before this study

Black men who have sex with men disproportionately experience HIV and incarceration, but few interventions to improve HIV prevention and care engagement following release from jail have been developed for Black men who have sex with men specifically, and such interventions are logistically challenging and difficult to evaluate empirically. We previously published a review of HIV, sexually transmitted infection (STI) and substance use interventions for Black men who have sex with men who experience incarceration. In December 2016, we searched PubMed, MEDLINE, Cochrane, CINAHL, and PsycINFO databases using the following search terms with no restriction by publication date: *(HIV OR "hiv"[MeSH] OR AIDS OR AIDS[sb] OR "human immunodeficiency virus" OR "HIV infection" OR "acquired immunodeficiency syndrome" OR "acquired immunodeficiency syndrome"[MeSH]) OR (STI OR STIs OR STD OR STDs OR "sexually transmitted infections" OR "sexually transmitted disease" OR "sexually transmitted diseases" OR "sexually transmitted diseases"[MeSH] OR syphilis OR chlamydia OR gonorrhea) OR ("risk behavior" OR "risk behaviors" OR "risk behavior" OR "risk behaviours" OR "risk taking" OR "risk-taking"[MeSH] OR "substance use" OR "unprotected sex" OR "unprotected intercourse") AND (probation OR parole OR parolee OR ex-offender OR release OR ex-prisoner OR ex-prisoners OR "released convict" OR "released convicts") OR (prisoner OR prisoners OR criminal OR criminals OR inmate OR inmates OR convicts OR convicts OR felon OR felons OR incarcerated) OR (prison OR incarceration OR "criminal justice system" OR corrections OR jail OR "correctional facility") AND (male OR men OR "black men who have sex with men" OR homosex* OR homosexual OR homosexuals OR homosexuality OR "homosexuality, ego dystonic" OR "homosexuality, ego-dystonic" OR "ego-dystonic homosexuality" OR bisex* OR bisexual OR bisexuals OR bisexuality OR "men who have sex with men" OR MSM OR MSMW OR BMSM OR gay OR gays OR queer OR queers OR transsexual OR transsexuals OR transsexuality OR transsexualism OR same-sex OR "sexual orientation")*. We identified 58 studies describing interventions conducted in the United States that focused on people experiencing incarceration, with outcomes related to behavior change, HIV, or sexually transmitted infections (STIs) published between 1992 and 2016. Only 3 focused on sexual or gender minorities and few focused on improving linkage and engagement in care for people with HIV who experience incarceration. Agent-based network models (ABNMs) can be useful for evaluating the potential impact of jail-based HIV prevention interventions before rolling them out in practice and thus can help intervention developers and policy makers make decisions about where to focus limited public health resources. However, no studies to date have used an ABNM to evaluate jail-based HIV interventions for Black men who have sex with men.

### Added value of this study

This study used an ABNM to examine the impact of interventions to improve engagement in HIV care following jail release on HIV transmission among young Black men who have sex with men and their sexual partners. We observed a 46% reduction in HIV incidence in the sexual partners of people with HIV who were recently released from jail and a 19% reduction in the overall model population in an intervention scenario that ensured sustained HIV care following release from jail relative to a scenario with no intervention.

### Implications of all the available evidence

Our findings suggest that improving linkage and retention in HIV care at the time of release from jail among people who experience incarceration could have a substantial impact on the HIV epidemic among young Black men who have sex with men. The partners of people experiencing incarceration represent a priority population who may not otherwise be reached through standard public health interventions.

## Introduction

In the U.S., Black gay, bisexual, and other men who have sex with men continue to experience disproportionate rates of new HIV diagnoses and slower declines in incidence compared to those of other races and ethnicities.[1] These inequities are observed in the absence of differences in individual-level behavior, instead resulting from the intersection of factors such as incarceration, violence, and socioeconomic marginalization that impact sexual networks and engagement in HIV prevention and care.[2] Thus, interventions to increase engagement in HIV prevention and treatment will likely need to be combined with those that address distal influences on transmission to end the HIV epidemic among Black men who have sex with men.[3,4]

Black men in the U.S. and Black men who have sex with men in particular are disproportionately represented in the criminal legal system.[4,5] Incarceration has numerous public health and social consequences, affecting social and sexual network stability, employment

and housing opportunities, and access to medical care, all of which can lead to cycles of socioeconomic marginalization and adverse health outcomes.[4,6] Among men who have sex with men with HIV these disruptions in HIV care reduce the probability of being durably virally suppressed.[7] Incarceration may also impact HIV transmission among Black men who have sex with men as a group through disruptions of social support systems and sexual networks, resulting in partnerships with higher transmission potential and/or interruptions in HIV treatment and prevention.[6]

Carceral settings also offer opportunities for delivery of biomedical and socio-structural interventions to populations who may not otherwise access these services. However, few jail-based biomedical HIV prevention interventions have been developed specifically for Black men who have sex with men despite their disproportionate burden of HIV and interaction with the criminal legal system. Of the existing HIV care continuum interventions that have been developed for criminal legal settings, many have focused on screening, linkage to care, or behavioral risk reduction during incarceration or immediately after release with limited long-term follow-up, and most have not been tailored for men who have sex with men specifically.[4] Those that have focused on improving post-release linkage to care or adherence suggest that access to social services is critical to their success, but it remains unclear which combinations of interventions would have the most impact.[4] HIV treatment interventions, including antiretroviral therapy (ART) and pre-exposure prophylaxis (PrEP), that are specifically tailored to Black men who have sex with men in criminal legal settings are lacking but have the potential to be highly impactful for reducing HIV transmission in this population.

Guidance is needed to determine how interventions for Black men who have sex with men who experience incarceration can be most effectively deployed, but logistical and ethical challenges make empirical research difficult in contexts that restrict movement and other freedoms. Jail settings may offer limited access to researchers, and marginalized populations that are often highly mobile and cycle frequently between carceral and community settings are overrepresented in jails, making them also difficult to study in the community. Agent-based network models (ABNMs) can generate insights about the processes that drive HIV transmission and provide a virtual platform for evaluating potential candidate interventions, thus facilitating more efficient and focused intervention development.[8] Furthermore, the complex mechanisms by which incarceration likely impacts HIV transmission (i.e., through changes in sexual networks, changes in HIV prevention and care engagement, and combinations of these) limit purely empirical approaches to identifying and testing candidate interventions. The granularity of ABNMs can help disaggregate effects in various population subgroups, such as persons who experience incarceration and their sexual network members (i.e., sexual partners) and can allow for consideration of the impact of the timing and duration of incarceration. Computational modeling can also provide insights about emergent dynamics resulting from the intersection of incarceration-related changes in network composition and HIV care engagement.

To help provide guidance for interventions in this setting, we extended a previously developed ABNM9[9] by explicitly incorporating the process of incarceration and its associated effects on sexual networks and on HIV prevention and treatment and prevention engagement. We then conducted computational experiments to evaluate the impact of incarceration and potential interventions on HIV incidence overall and within key subgroups affected by incarceration.

## Methods

### Model development

The ABNM is a stochastic model that proceeds in discrete daily time steps and consists of 10,000 agents representing younger Black men who have sex with men between the ages of 18 and 34 in the city of Chicago. Chicago was chosen as the focus of the current work because it contains the largest single-site jail in the US,[10] and is a key site for Ending the HIV Epidemic (EHE) initiatives. The Cook County Jail has historically housed approximately 8000 to 10,000 people on any given day,[11] though the population has declined significantly over the past five years to approximately 5500 currently.[12] The majority of the jail population is Black (74%) and male (95%). Previous estimates suggest that HIV seroprevalence in U.S. jail populations in general range from approximately 1.7–2%,[13] which is consistent with estimates based on recent local data. As in non-jail settings, HIV prevalence is significantly higher among Black men who have sex with men who experience incarceration compared to other subgroups. In a recent study of Black men who have sex with men and transgender women in 6 US cities, 14% reported experiencing incarceration in the past 6 months, and HIV incidence was 3.6% (5/137) among those with previous incarceration compared to 2.8% (22/798) among those without.[14] Chicago also contains the third largest Black community in the US and is highly segregated.[15] Sexual networks among Black men who have sex with men in Chicago also tend to be geographically bounded, leading to dense sexual networks that have impacted HIV transmission in this community.[16] We focused exclusively on incarceration in jail settings in this study, given the differences between jails and prisons in terms of population characteristics, transmission potential, and feasibility of implementing interventions. In contrast to prisons where individuals are typically incarcerated for long durations, jail stays are typically much shorter.

High rates of recidivism result in frequent cycling in and out of jail, with high risk for transmission during the vulnerable period after release from jail. The model, which has been previously described,[9] incorporates demographic, biological and behavioral processes governing HIV transmission. Transmission is dependent on condom use, and viral load and stage of infection among agents with HIV and PrEP use among agents without HIV. Exponential random graph models (ERGMs) were used to model network formation and dissolution dynamics using the *statnet* suite of packages in R.[17] Other ABNM components, including incarceration interventions, were developed with the Repast HPC ABM toolkit using C++.[18] Parameters and code to reproduce the results are located in a public GitHub repository.[19] The study was approved by the Institutional Review Board at the University of Chicago.

**Incarceration related processes & impact on sexual networks and HIV prevention and care continuums**

Using our existing model as a starting point, we incorporated rules for sexual network and HIV prevention and treatment disruption due to incarceration. Values for incarceration-related parameters were computed using data from a local cohort study of young Black MSM conducted between 2013 and 2015.[16] Approximately 32% of participants had a history of incarceration at baseline, defined as having spent at least 1 night in jail or detention. Incidence of incarceration over the course of the study was estimated from a Poisson regression model and stratified by prior incarceration history. Incidence of incarceration was 7.9 per 100 person-years overall; 18.9 and 2.9 per 100 person-years among those with and without prior incarceration history respectively. These estimates were converted to daily probabilities in the model. The mean duration of incarceration among those who experienced incarceration during the study was 58.4 days (95% CI 19.1–97.7 days). We assumed that the primary mechanisms by which incarceration impacts HIV transmission are 1) disruptions in post-release ART and PrEP care engagement and 2) changes in formation and dissolution of sexual partnerships.

*ART and PrEP disruption*

We operationalized expected ART and PrEP care disruption in the following ways. Agents who were on ART at the time of jail entry remained on ART during incarceration and maintained the same level of ART adherence during incarceration as that prior to being incarcerated. ART use stopped at the time of release and agents remained off ART for a mean period of 90 days before returning to their pre-incarceration ART status; this is consistent with research that has shown disruption in HIV care associated with release from incarceration.[7,20] The disruption period varied across agents and was sampled from a geometric distribution rather than being entered into the model as a single value. The precise duration of disruption in care after incarceration is hard to estimate from existing empirical studies and estimates vary across the literature depending on the follow-up period over which disruption is measured. A 10-site study of HIV-positive men who have sex with men in cities across the US who were transitioning from jail to community settings found that only 41% (95% CI 20–89%) of young Black men who have sex with men living with HIV had an HIV care visit within 6 months after release.[21] Other studies report similarly low rates of linkage to care after release among reentry populations with HIV.[20] Due to the variability in the existing empirical data, we conducted experiments that varied the mean period of disruption from 60 to 720 days (additional results can be found in Supplementary Material, section A.9).

Agents who were taking PrEP prior to incarceration discontinued PrEP at the time of incarceration, which was consistent with standard practice in the Cook County jail at the time the model was developed, and remained off PrEP following incarceration for a mean period of 90 days (drawn from a geometric distribution as described above) before returning to their pre-incarceration PrEP status. Limited empirical data exist on the impact of incarceration on disruption in PrEP use and retention in PrEP care, so we assumed the same mean duration of post-release disruption in PrEP use as for ART use. No changes in PrEP or ART use were incorporated for the pre- and post-incarceration partners.

*Sexual network disruption*

We operationalized the impact of incarceration on sexual network stability by varying probabilities of partner retention (i.e., the probability that a partnership in existence prior to incarceration is maintained after release from jail). The distribution of retention of main and casual partnerships in the absence of incarceration was estimated using a nonparametric survival distribution ("baseline retention probability"). Scenarios considered a range of probabilities of partner retention, operationalized as multipliers ranging from 0.1 to 1, that were applied to the baseline main and casual partner retention probabilities, where multiplier values less than 1 result in lower partner retention probability, indicating a greater probability of partnership dissolution.

There is limited empirical data on the impact of incarceration on partnership retention among Black men who have sex with men who experience incarceration. Analysis of data from a longitudinal cohort study conducted by our team[16] found that among people with no history of incarceration, 25% of sex partners reported at the baseline visit were retained at the 9-month follow-up visit, compared to 20% among those who had experienced incarceration. A study of partnership dissolution among predominantly heterosexual partnerships of

people in prison found that 55% of ongoing primary relationships ended during incarceration,[22] while a more recent study estimated that 28% of primary partnerships among Black men in committed heterosexual relationships dissolved after incarceration.[23] Because these data were from different populations, time-periods, and partnership types, and sample sizes were small, we selected a range of retention probabilities, operationalized as multiplier values for sensitivity analysis.

### Data sources

Parameter values for sexual behaviors, sexual network characteristics, ART adherence and viral suppression, PrEP use, and incarceration incidence and prevalence were estimated from a cohort study of young Black men who have sex with men in Chicago (see Supplementary Table S5).[16] We compared estimates of incarceration with published local data on the characteristics of the Cook County Jail[11] and a multisite study of incarceration among Black men who have sex with men in the U.S.[24] Parameters describing PrEP uptake and retention were estimated from local empirical data.[25] Dynamics of viral load and CD4 evolution were derived from the published literature (see Supplementary Material, sections 4.4 and 4.5).

### Model calibration

The model was calibrated to HIV incidence and prevalence estimates from local HIV surveillance data,[26] and incarceration outcomes (proportion of persons experiencing first-time incarceration and recidivism, and duration of stay in jail) derived from longitudinal population-based cohort-based data.[16] We also examined differences in HIV incidence and prevalence by age and prior incarceration history to determine if the results were consistent with existing literature. For parameters in which there was uncertainty or wide variability in the estimates, we conducted sensitivity analyses to refine the parameter values and selected the set of parameters that produced outputs most consistent with empirical calibration targets (Supplementary Material, section A.6). The baseline model was simulated 30 times to assess the inherent variability in model outputs for each parameter set (Supplementary Material, section A.6). The mean HIV prevalence across the 30 runs was 33.48 (SD 0.86); range 31.81–34.78 and the mean HIV incidence rate was 5.15 (SD 0.26) per 100 py (range 4.75–5.64 per 100 py). For computational feasibility and since the replicates did not differ meaningfully from each other, we chose one of the 30 replicates for the subsequent analyses to assess the difference between the baseline model and the scenario-specific computational experiments described below.

### Computational experiments

We conducted experiments to quantify network and care continuum disruption associated with incarceration. HIV incidence was examined in scenarios 1.) with varying levels of partnership dissolution when agents were incarcerated and 2.) with varying levels of post-release disruption in HIV care for agents with HIV (e.g., interventions to facilitate care engagement by reducing barriers to insurance, housing, and employment following reentry). For the intervention experiments, we compared a control scenario in which there was no change in post-release care engagement (relative to pre-incarceration care engagement) to intervention scenarios where the mean duration of post-release disruption was varied. We also simulated a "best case" scenario in which all HIV-positive agents who were incarcerated received targeted and sustained HIV care post-release (i.e., all agents with HIV, including those not on ART prior to incarceration, were placed on ART and assigned to the highest adherence category which assumed a 95% probability of being fully adherent over the course of the model) for approximately 2 years (720 days) after release. We did not conduct experiments to increase PrEP use or adherence after release.

### Role of the funding source

The funder had no role in data collection, analysis, interpretation, writing of the manuscript, or decision to submit the manuscript for publication.

### Subgroups

After calibrating the model with the incarceration-dependent processes incorporated, we examined HIV incidence in relevant subpopulations. Detailed definitions of these dynamic subpopulations are provided in Table 1. At the partnership level, these included pre-incarceration partners (those who were partnered with an agent at the time of incarceration), post-release partners (those who formed partnerships with agents released from jail within 2 years after their release), pre-incarceration and post-release partners (intersection of the pre-incarceration and post-release partners as defined above), ever incarcerated individuals (those who had ever been incarcerated during the simulation), and never incarcerated individuals (those who had never been incarcerated up to that point in the simulation).

The HIV incidence in the post-release partners was examined under two counterfactuals with widely different periods of post-release disruption in HIV care engagement: 90 days vs. 720 days. HIV incidence among pre-incarceration partners was measured starting from the time of the partner incarceration to 180 days thereafter to capture the potentially increased transmission associated with any new partnerships formed by the unincarcerated partner (see Supplementary Material, section A.8). Because the overall HIV incidence in the population includes agents without partners at a given time, as a comparison to post-release partners, we calculated HIV incidence among agents in a current relationship (i.e., at least one active partnership) where

| Label | Definition | Time at which label is applied | Time period length | Measurement |
|---|---|---|---|---|
| Pre-incarceration partner (exclusively) | Agents whose partners were incarcerated and the partnership did not continue post-release. | At partner's incarceration | 182 days | Measures HIV incidence in the 182 days (~6 months) following partner's incarceration. |
| Post-release partner (exclusively) | Agents who partner with an incarcerated agent within 720 days of their release, but not partnered with these agents prior to their incarceration | At initiation of partnership, if this occurs within 720 days (~2 years) of partners' release from custody. | Up to 720 days | Measures HIV incidence up to 720 days after release or dissolution of the partnership, whichever is earlier. |
| Pre-incarceration + post-release partner. | Agents who partner with incarcerated agents within 720 days of their release, who were also partnered with the incarcerated agent prior to incarceration | At partner's incarceration | 182 + X days, where X is the length of the post-release partnership | HIV incidence is measured in the 6 months following incarceration and in the period of their relationship post-release. |
| Ever- incarcerated | Agents who are incarcerated at least once while in the model | Time of incarceration | Following incarceration, remainder of agent's time in the model | HIV incidence is calculated as newly incarcerated agents become infected. |
| Never- incarcerated | Agents who are never incarcerated during the simulation. | Time of agent entry into the model | Agents' time in the model | HIV incidence for remaining population is updated as agents are incarcerated and leave this group. |
| Active partnerships in which neither agent experiences incarceration | Agents who are not pre-incarceration partners, not post-release partners (as per definitions above), and who have at least one partnership at a given time | NA[a] | NA[a] | HIV incidence is measured to compare with other key subpopulations, particularly pre-incarceration and post-release partners (overlaps with above 2 groups) |

[a]Defined at a given point in time, classification can vary over time.

*Table 1:* **Definitions for agent classifications.**

neither the index agent nor any of their partners was incarcerated.

### Outcome

The primary outcome for analysis was mean year 10 HIV incidence, set in accordance with Getting to Zero (GTZ) timelines for HIV elimination which aim to end the epidemic in Illinois by 2030, computed across the 30 simulation runs per scenario in units of 100 person-years. Uncertainty around these estimates was quantified using bootstrap estimates derived via simulation. Since these are stochastic models with inherent uncertainty, we took the 30 simulation runs for each experimental scenario at each time point and sampled them 1000 times with replacement. We chose n = 30 because previous analysis suggested that this number provided sufficient characterization of overall sampling uncertainty, and larger values of n yielded similar variance. The mean for each of the resampled datasets was computed, and the 2.5% and 97.5% quantiles of the means were taken to obtain the 95% bootstrap simulation interval (SI). To compare HIV incidence across different scenarios, we computed incidence rate ratios by taking the ratio of the mean incidence rate across 30 simulations for each of the comparison scenarios. Simulation intervals around the rate ratios were computed via bootstrapping as described above.

## Results

### HIV incidence

Overall incidence in the population at 10 years was 4.98 (95% SI 4.87, 5.09) per 100 person-years. The 10th-year HIV incidence rate was 5.58 [95% SI 5.38, 5.76]) among those with incarceration history compared to 4.72 [95% SI 4.61, 4.85]) among those without (Table 2). Among partners of agents who were incarcerated, HIV incidence was highest among post-release partners (12.86; 95% SI 11.89, 13.73) and lowest among pre-incarceration partners who did not re-form these partnerships post-release (4.52; 95% SI: 4.01, 5.03). Tenth-year HIV incidence among those with at least one active partnership in which neither partner had a history of incarceration was 7.95 (95% SI 7.75, 8.13) per 100 person-years.

### Impact of network disruption

Higher levels of network disruption reduce the likelihood that a pre-incarceration partner will reconnect with an agent post-incarceration. Ten-year HIV incidence rates increased among pre-incarceration partners with increases in the probability of reconnection to the incarcerated agent: the HIV incidence rate nearly doubled—from 4.71 (95% SI 4.29, 5.16) per 100 person-years for a 10% probability of reconnection to 8.00 (95% SI 7.43, 8.59) per 100 person-years—for a 100% probability of reconnection following release (Table 3, Fig. 1).

### Impact of ART care disruption

HIV incidence increased with increasing duration of post-release HIV care disruption among agents who experienced incarceration, and particularly among the partners of agents with HIV whose care was disrupted post-release. For the scenario with no change in care post-release compared with pre-incarceration, mean HIV incidence among post-release partners was 10.61 (95% SI 10.09, 11.24) per 100 person-years. In contrast, the mean HIV incidence rate under a mean 90-day

| Population | HIV Incidence (95% SI) |
|---|---|
| *Partners* | |
| All pre-incarceration partners[b] | 7.17 (6.69, 7.66) |
| All post-release partners[c] | 12.61 (11.98, 13.21) |
| Exclusively pre-incarceration partners[d] | 4.52 (4.01, 5.03) |
| Exclusively post-release partners[e] | 12.86 (11.89, 13.73) |
| Pre-incarceration and post-release partners[f] | 12.31 (11.40, 13.31) |
| Active partnerships among partners who are not incarcerated[g] | 7.95 (7.75, 8.13) |
| *Individuals* | |
| Overall[h] | 4.98 (4.87, 5.09) |
| Ever-incarcerated[i] | 5.58 (5.38, 5.76) |
| Never-incarcerated[j] | 4.72 (4.61, 4.85) |

SI: bootstrap simulation interval. [a]Incarceration status and partnership type can vary over time and individuals can occupy different subpopulations over the course of the simulation. [b]Agents partnered with an incarcerated agent, whether or not the partnership dissolved after release. HIV incidence is calculated over the 6 months following incarceration of the index partner. [c]Agents partnered with an agent released from jail during the past 2 years (720 days) whether or not the partnership existed prior to incarceration. HIV incidence is measured from the date of partnership formation to the first of: dissolution of the partnership or 720 days. [d]Agents who were partnered with the incarcerated agent at the time of incarceration, where the partnership did not re-form after the index partner's release from jail. HIV incidence is calculated over the 6 months following the index partner's incarceration. [e]Agents who partnered with an individual released from jail during the past 2 years who were not partnered with the incarcerated agent prior to incarceration. HIV incidence is measured from the date of partnership formation to the first of: dissolution of the partnership or 720 days. [f]Agents who were partnered with the incarcerated agent at the time of incarceration, where the partnership re-formed after the index partner's release from jail. HIV incidence is measured from the date of index partner incarceration +6 months, and during the post-release period. [g]Active partnerships in which neither agent were not pre-incarceration or post-release partners (i.e., neither partner experienced recent incarceration). [h]HIV incidence averaged across the entire agent population. [i]Any history of incarceration up to the point at which HIV incidence is calculated. Agents enter this category at the time of incarceration and remain there for the remainder of the simulation. [j]No history of incarceration at any point in the model.

***Table 2*: Year 10 HIV incidence by subpopulation[a].**

disruption of ART increased to 12.61 (95% SI 12.02, 13.24), and to 16.01 (95% SI 14.93, 16.99) when post-release ART was disrupted for a mean of 720 days.

Among post-incarceration partners, targeted and sustained post-release care for agents with incarceration resulted in a substantially lower HIV incidence (5.72; 95% SI 5.19, 6.27) per 100 person-years compared to the scenario in which there was no change in pre-incarceration and post-release care for incarcerated agents (10.61; 95% SI 10.09, 11.24; IRR 0.54 (95% SI 0.48, 0.60)). Similar but less pronounced associations were observed for population-level HIV incidence under these scenarios (IRR 0.81 (95% SI (0.78–0.83); Table 4, Fig. 2).

## Discussion

An agent-based modeling approach helped identify the sexual partners of recently incarcerated persons as a subgroup with particularly high HIV incidence resulting from interruptions in HIV care. Our findings are similar to those of a recent modeling study of HIV transmission risk among the female partners of incarcerated heterosexual men in Philadelphia that found that reduced engagement in care among recently incarcerated individuals accounted for a substantial proportion of transmission risk among women.[27]

This finding suggests that interventions to improve HIV care engagement after release from jail among people who experience incarceration could have a substantial impact on the HIV epidemic among young Black men who have sex with men by reducing transmission risk to their partners. This result might not have been readily apparent without the appropriate modeling tools or from an empirical study focused exclusively on those with incarceration histories. Empirical studies typically tend to focus on individuals with incarceration and not their sexual partners due to the logistical, ethical, and resource-related challenges associated with recruiting partners, and incarceration-related interventions often limit their focus to the impacts on people experiencing incarceration themselves. Furthermore, current HIV incidence rates would require recruitment into intervention studies of large

| Retention Probability Multiplier | Pre-Incarceration Partners | | Overall population[a] | |
|---|---|---|---|---|
| | HIV incidence (95% SI) | Incidence ratio | HIV incidence (95% SI) | Incidence ratio |
| 0.1 | 4.71 (4.29, 5.16) | 0.66 (0.59, 0.74) | 4.66 (4.58, 4.74) | 0.95 (0.92, 0.97) |
| 0.25 | 4.89 (4.45, 5.32) | 0.68 (0.61, 0.77) | 4.58 (4.48, 4.69) | 0.93 (0.90, 0.96) |
| 0.5 | 6.12 (5.70, 6.58) | 0.86 (0.79, 0.94) | 4.78 (4.67, 4.88) | 0.97 (0.94, 1.00) |
| 0.75[b] | 7.13 (6.71, 7.61) | 1.0 (Ref) | 4.92 (4.81, 5.02) | 1.0 (Ref) |
| 1 | 8.00 (7.43, 8.59) | 1.12 (1.02, 1.62) | 5.14 (5.01, 5.28) | 1.05 (1.01, 1.08) |

SI: bootstrap simulation interval. [a]Overall population refers to the agent population of young Black men who have sex with men in Chicago. [b]Differences in the estimates for these scenarios differ slightly from those reported in Table 2 due to slight differences in the random number generation at the initial parameterization when running the experiments and do not affect the results substantively.

***Table 3*: Year 10 HIV incidence by post-release reconnection probability.**

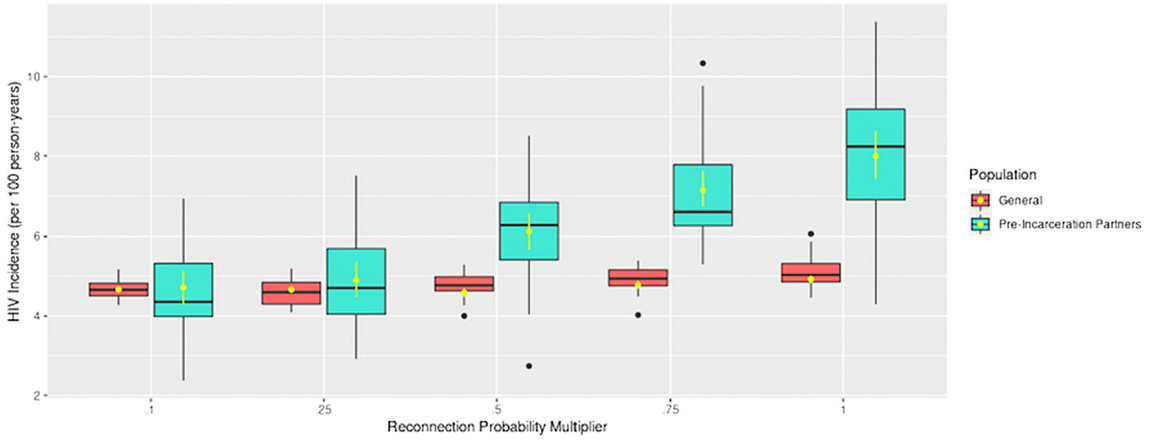


***Fig. 1:*** **HIV incidence by partner reconnection probability after release from jail**. The vertical yellow line represents the 95% bootstrap simulation interval with the yellow point depicting the mean. The vertical black line in the box plot depicts the 25%, 50% and 75% quantiles of all 30 runs. The black dots outside the boxplot constitute outliers. Orange bars represent the overall population of young Black men who have sex with men in Chicago; teal bars represent pre-incarceration partners.

samples from populations who may be particularly hard to enroll given their stigmatized statuses related to HIV and sexuality.

Our modeling approach is particularly useful because it allows us to characterize differences in HIV incidence in the sexual networks of agents experiencing incarceration under different intervention scenarios. Examination of partner-level effects and identification of emergent properties in sexual networks is difficult or impossible in other commonly used modeling approaches.[28,29] The resulting sexual network structure in such contexts is complex, with partnerships going through cyclical periods of activity and inactivity. Even in the presence of a highly effective intervention in which targeted and sustained treatment was provided to people with HIV upon release from jail, HIV incidence in their partners was 5.72 (95% SI 5.19, 6.27) per 100 person-years. Although all agents with HIV were assigned to the highest adherence category in the intervention scenario, there is some built-in variation in the probability that they will be fully adherent, so there is still potential for transmission to sexual partners. PrEP disruption among agents without HIV also likely contributed to the observed incidence among post-incarceration partners since we did not implement any PrEP interventions, and agents infected during the post-incarceration chaos period[30] may have transmitted HIV to their HIV-negative post-release sexual partners during the acute stage of infection. These findings may also suggest that some HIV transmission among the post-incarceration partners is driven by partners who are not recently incarcerated due to increased turnover in sexual partnerships.

HIV incidence decreased among pre-incarceration partners of incarcerated agents with increasing network disruption (i.e., decreasing probability of reconnecting with partners after release). This may be due to reduced opportunity for transmission due to the dissolution of these sexual partnerships. Had we modeled other behavioral changes associated with disruption of ongoing partnerships due to partner incarceration (e.g., increased likelihood of exchanging sex or of condomless sex with new partners among the non-incarcerated partner), disruption of sexual

| | Post-Release Partners | | Overall population[a] | |
|---|---|---|---|---|
| | HIV incidence (95% SI[b]) | Incidence ratio (95% SI) | HIV incidence (95% SI) | Incidence ratio (95% SI) |
| Targeted and sustained care | 5.72 (5.19, 6.27) | 0.54 (0.48, 0.60) | 3.89 (3.81, 3.99) | 0.81 (0.78, 0.83) |
| No change in care | 10.61 (10.09, 11.24) | 1.0 (Ref) | 4.83 (4.73, 4.92) | 1.0 (Ref) |
| Care Disruption: 90 Days[b] | 12.61 (12.02, 13.24) | 1.18 (1.10, 1.27) | 4.98 (4.87, 5.09) | 1.03 (1.00,1.06) |
| Care Disruption: 720 Days | 16.01 (14.93, 16.99) | 1.51 (1.38, 1.63) | 5.58 (5.49, 5.67) | 1.15 (1.13, 1.19) |

SI: bootstrap simulation interval. [a]Overall population refers to the agent population of young Black men who have sex with men in Chicago. [b]Differences in the estimates for these scenarios differ slightly from those reported in Table 2 due to slight differences in the random number generation at the initial parameterization when running the experiments and do not affect the results substantively.

***Table 4:*** **Year 10 incidence under different HIV prevention and care disruption scenarios.**

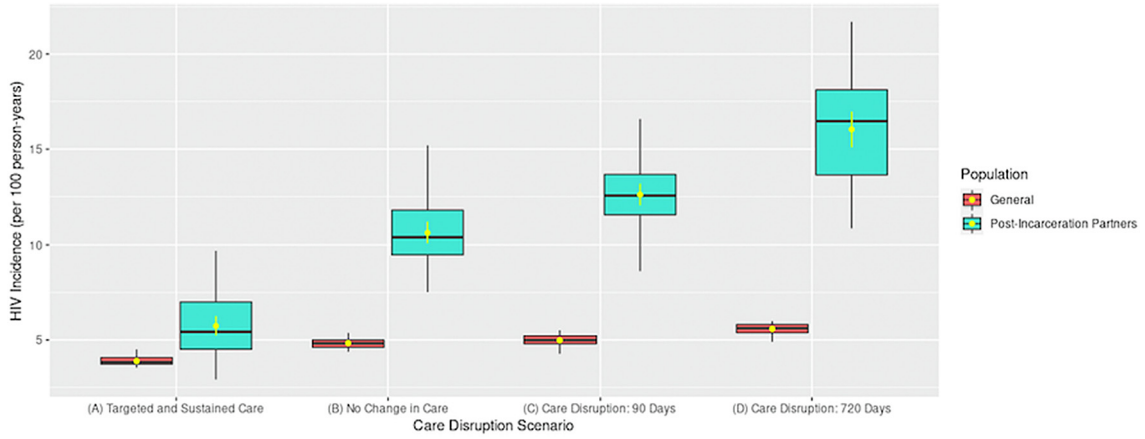


***Fig. 2:*** **HIV incidence under care disruption counterfactuals**. The vertical yellow line represents the 95% bootstrap simulation interval with the yellow point depicting the mean. The vertical black line in the box plot depicts the 25%, 50% and 75% quantiles of all 30 runs. The black dots outside the boxplot constitute outliers. Orange bars represent the overall population of young Black men who have sex with men in Chicago; teal bars represent post-incarceration partners.

partnerships may have had a greater impact on HIV incidence among pre-incarceration partners. Adams et al. also found that changes in male risk behavior around the time of incarceration had an important impact on HIV transmission to female partners of recently incarcerated men.[27] Some might find surprising the relatively low HIV incidence among those who had ever experienced incarceration. This may also be partially explained by the fact that incarceration was not associated with post-release changes in sexual behavior in the model. Additionally, this is a population with high rates of recidivism, and the risk of HIV infection while in custody is significantly lower compared to that prior to or following incarceration.[31] Because HIV incidence is calculated at the population level and averaged over time, history of incarceration is calculated cumulatively throughout the simulation, and HIV acquisition risk is lower while in jail, longer duration of incarceration may have offset the increased acquisition risk associated with the post-incarceration period. Furthermore, if the duration of incarceration is short relative to the total time an agent exists in the model (i.e., for agents with short jail stays who remained in the model for a long time after release without being reincarcerated), HIV incidence among those with vs. without a history of incarceration would be expected to converge over time.

Due to the high HIV incidence among the partners of people who go to jail, focusing PrEP and ART interventions on individuals experiencing incarceration and their networks could be an efficient way to distribute limited public health resources to reduce HIV transmission. Future modeling studies should explicitly compare incarceration-focused PrEP interventions with non-targeted, network-focused, or other PrEP allocation strategies.[9] Agent-based models are also well suited to quantify direct and indirect intervention effects in the presence of the spillover (i.e., one individual's exposure affects the outcome of another) that is always present in infectious disease transmission.[32] Interventions designed to reduce post-release disruptions in HIV care among reentry populations. Will need to address the short-term chaotic circumstances surrounding incarceration and release, as well as the longer-term impact of incarceration on care engagement. For example, interventions to facilitate care engagement by reducing insurance, employment, or housing barriers and supporting care coordination may be useful for reducing disruptions in HIV care after jail release.

## Limitations

There are several limitations worth noting. Empirical data for some parameters was limited or measured with a high degree of uncertainty. The model assumes complete homophily among the sexual networks of young Black men who have sex with men (i.e., that young Black men who have sex with men partner exclusively with other young Black men who have sex with men). This was largely the case in the Chicago-area network studies with Black men who have sex with men on which the parameters were based but may vary substantially by location. Sex with female partners, as well as men who have sex with men of other races and ethnicities and age groups may be relatively common in some settings. Because of the high HIV prevalence and systematic barriers to engagement in HIV treatment and biomedical prevention among young Black men who have sex with men, this assumption could have overestimated HIV incidence, as well as the potential impact of the interventions we evaluated. Several dynamics and potential incarceration-related changes were

not incorporated into our model and may have led to bias in either direction. We did not vary sexual risk behaviors among people who experienced incarceration or their sexual partners before or after incarceration, though there may be changes at and around the time of incarceration.[33,34] Additionally, we did not incorporate changes in care engagement during incarceration in the experimental or base model scenarios. Whether adherence changes during incarceration is likely location-specific based on the HIV care program within the jail so it is hard to determine the direction of bias this might have resulted in. We did not model interventions to increase PrEP uptake and retention for agents leaving jail or their partners. We also did not incorporate substance use and other socio-structural barriers to HIV prevention and care engagement. Substance use has an important impact on HIV prevention and care engagement[35]; opportunities for facilitating linkage to substance use treatment among people who experience incarceration could also have an important impact on the HIV epidemic and warrant further study. We plan to incorporate these factors in future modeling work.

Our results may not be generalizable to other populations experiencing incarceration or geographic contexts, as the population-level impact on HIV incidence depends on prevalence of incarceration, HIV, and the degree of HIV care disruption associated with incarceration, as well as partnership characteristics and behaviors. Finally, the degree to which incarceration-based interventions can realistically be implemented likely varies widely based on the political realities and the geographic location and characteristics of local criminal legal and healthcare systems. Implementation science approaches are needed and can be tested using ABMs in future work.

## Conclusions

Our findings demonstrate the potential impact of improving engagement in HIV care among people experiencing incarceration on HIV transmission among young Black men who have sex with men overall, and particularly among the sexual partners of people recently released from jail. This study sets the stage for future planned modeling work that will incorporate structural drivers of incarceration and HIV and expand the scope of evaluation of biomedical and socio-structural interventions for people experiencing incarceration.

### Contributors

JS, KF, and NH obtained funding for the research. ALH conceived the study design and experiments with JS, KF, RB, NH, and KS. ASK led the modeling team, consisting of FL, DS, JO, NC, ME, BMA, and ALH. The modeling team coded the model, generated data, analyzed simulated data, and produced the figures and tables. DS supported the programming aspects of the modeling conducted. Input data were analyzed by ALH. ALH and ASK wrote the first draft of the manuscript and the supplementary materials respectively. All authors contributed to the study design, data interpretation, writing, and revision of the manuscript and the supplementary material. ALH, FL, and ASK have accessed and verified the data. All authors are responsible for the decision to submit the manuscript.

### Data sharing statement

The study was approved by the Institutional Review Board at the University of Chicago. Due to ethical and legal considerations, individual level participant data from research studies used to parameterize our models will not be shared. Summaries and aggregate level data used in our models are available via a public Github repository (https://github.com/khanna7/BARS). This includes source code used to create all figures and tables and links to any publicly available data sources used to parameterize the models. Metadata, summaries, and source code are stored in common and open formats. Information needed to make use of the data, including sample metadata, variable names, code, information regarding missing or imputed data, and other experimental metadata along with references to the original sources wherever applicable.

### Declaration of interests

The authors have no competing interests to declare. ALH: none, FL: none, DS: none, JO: none, NC: none, ME: none, BMA: none, RB: none, KMS: none, KF: none, NTH: Nina T. Harawa has received honoraria for speaking at events co-sponsored by Gilead Sciences, Inc and for participating in a one-time advisory panel for the company. She is a co-investigator, with in-kind support, on a Gilead Sciences-focused on HIV prevention center and has previously received research support from the company. She was a member of the Scientific Advisory Board for the Black AIDS Institute and has provided expert testimony for potential lawsuits related to COVID-19 in carceral settings., JAS: none, ASK: none.

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### Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2023.100628.

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