Title

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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Title: The impact of interventions to increase post-incarceration engagement in care on HIV transmission dynamics among young Black men who have sex with men and their sexual partners: An agent-based modeling study

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RESEARCH IN CONTEXT

Evidence before this study: Black men who have sex with men (MSM) are disproportionately impacted by HIV and incarceration. Incarceration also impacts employment, housing, and medical care, and can disrupt HIV prevention and care engagement among incarcerated individuals. Opportunities exist to improve engagement in HIV prevention and care for jail detainees, but few interventions have been developed for this population, and such interventions are logistically challenging and difficult to test empirically. Agent-based models (ABMs) can be useful for evaluating the potential impact of jail-based HIV prevention interventions before rolling them out in practice. However, no studies to date have used an ABM to evaluate jail-based HIV interventions for Black MSM.

Added value of this study: This study used an agent-based network model to examine the impact of incarceration on HIV transmission among young Black MSM (YBMSM) experiencing incarceration and their sexual partners. Through simulated experiments, we identified sexual partners of recently released individuals as a population at high risk of HIV, likely due to disruptions in HIV care following release from jail among those living with HIV. The model also allowed us to quantify the potential reduction in HIV incidence associated with ensuring targeted and sustained HIV care after release for incarcerated individuals living with HIV among the partners of incarcerated individuals (46% risk reduction) and in the overall population of YBMSM (19% risk reduction).

Implications of all the available evidence: Taken together, this evidence suggests that improving linkage and retention in HIV care among incarcerated individuals at the time of release could have a substantial impact on the HIV epidemic among YBMSM. The partners of incarcerated individuals also represent candidates for focused interventions as a population at high risk for HIV who may not otherwise be reached through standard public health interventions.

ABSTRACT

Background: Understanding the impact of incarceration on HIV transmission among Black MSM is important given their disproportionate representation among those incarcerated and the potential impact of incarceration on social and sexual networks, employment, housing, and medical care.

Methods: We developed an agent-based network model (ABNM) of 10,000 agents representing young Black MSM to examine the impact of incarceration on HIV incidence. Exponential random graph models were used to model network formation and dissolution dynamics, and network dynamics and HIV care continuum engagement 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. We also examined the impact of varying degrees of post-release care disruption on HIV incidence.

Finding: HIV incidence at 10 years was 4.98 [95% simulation interval (SI): 4.87, 5.09 per 100 person-years (py)] in the 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 recently released individuals. Sustained post-release HIV care for incarcerated individuals with HIV resulted in a 46% reduction in HIV incidence among post-incarceration partners [incidence rate ratio (IRR) = 0.54; 95% SI 0.48-0.60] and a 19% reduction in HIV incidence in the population overall (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 recently incarcerated individuals and their sexual partners is needed to reduce HIV transmission among Black MSM.

Introduction

In the U.S., Black gay, bisexual, and other men who have sex with men, hereafter MSM, continue to experience disproportionate rates of new HIV diagnoses and slower declines in incidence compared to MSM 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 continua.(2) Thus, interventions to increase engagement in HIV prevention and treatment continuums will likely need to be combined with those that address distal influences on transmission, such as decriminalization, to end the HIV epidemic among Black MSM.(3,4)

Black men in the U.S. and Black MSM 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) Incarceration may also impact HIV transmission among Black MSM, through disruptions of social support systems and sexual networks, resulting in partnerships with higher transmission potential and/or interruptions in HIV treatment and prevention continuums.(6) Among MSM with HIV these disruptions in HIV care reduce the probability of maintaining durable viral suppression.(7)

Carceral settings also offer opportunities for delivery of biomedical and social service interventions to populations who may not otherwise access these services. However, few jail-based biomedical HIV prevention interventions have been developed specifically for Black MSM despite their disproportionate rates 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 MSM 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) ART and PrEP interventions that are specifically tailored to Black MSM 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 MSM experiencing incarceration can be most effectively deployed, but logistical and ethical challenges make empirical research difficult in contexts that that restrict movement and other freedoms. Jail settings may offer limited access to research and frequently include marginalized communities that are often highly mobile and cycle frequently between carceral and community settings.. 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) limits 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 ABNM(9) by explicitly incorporating the process of incarceration and its associated effects on sexual networks and HIV prevention and treatment and prevention continuums. 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 MSM (YBMSM, ages 18-34) 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 8,000 to 10,000 detainees on any given day(11), though the population has declined significantly over the past five years to approximately 5,500 detainees currently.(12) The majority of the jail population is Black (74%) and male (95%). Previous estimates and calculations based on recent local data suggest that HIV seroprevalence in the jail population is approximately 1.7-2%(13), though it is much higher in certain subgroups, including Black MSM. In a recent study of Black MSM and transgender women in 6 US cities, 14% reported experiencing incarceration in the past 6 months, and HIV incidence among those who were negative at baseline 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 MSM 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. The model, which has been previously described(9), incorporates demographic, biological and behavioral processes governing HIV transmission and rules for sexual network and HIV prevention and treatment disruption due to incarceration. Transmission between serodiscordant partners is dependent on condom use, and viral load and stage of infection among HIV-positive agents and PrEP use among HIV negative agents. 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)

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

Values for incarceration-related parameters were computed using data from a local cohort study of young Black MSM. 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 incarcerated 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 MSM in cities across the US who were transitioning from jail to community settings found that only 41% (95% CI 20-89%) of YBMSM 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 HIV-positive detainees.(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 Appendix 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 designed, 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. There is limited empirical data on the impact of incarceration on partnership retention among incarcerated Black MSM. Analysis of data from a longitudinal cohort study conducted by our team(16) found that among persons without incarceration histories, 25% of sex partners reported at the baseline visit were retained at the 9-month follow-up visit, compared to 20% among persons with incarceration history. A study of partnership dissolution among predominantly heterosexual partnerships of prison inmates 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) These studies did not include male sex partners. 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. Multiplier values less than 1 result in lower partner retention probability compared to the baseline scenario, indicating a greater probability of partnership dissolution during incarceration.

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 MSM in Chicago (see appendix Table A.5).(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 MSM 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 Appendix Section 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.(27) 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 (Appendix Section A.6). The baseline model was simulated 30 times to assess the inherent variability in model outputs for each parameter set (Appendix 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 HIV positive agents (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 HIV-positive agents, including those not on ART prior to incarceration, were placed on ART and were maximally adherent) 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 pulication

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 for up to 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 un-incarcerated partner (see Appendix 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 neither the index agent nor any of their partners was incarcerated.

Outcome

The primary outcome for analysis was mean 10-year HIV incidence, set in accordance with Getting to Zero (GTZ) timelines for HIV elimination, 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 1,000 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. Confidence 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 10^{th}-year HIV incidence rate among those with history of incarceration 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 incarcerated agents, 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 partnerships with incarcerated agents 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, Figure 1).

Impact of ART care disruption

HIV incidence increased with increasing duration of post-release HIV care disruption among incarcerated agents, and particularly among the partners of HIV-positive individuals 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 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, Figure 2).

DISCUSSION

An agent-based modeling approach helped identify the sexual partners of recently incarcerated persons as a subgroup with particularly high HIV incidence. This finding suggests that interventions to improve HIV care engagement among detainees leaving jail could have a substantial impact on the HIV epidemic among YBMSM 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 the incarcerated persons themselves. Furthermore, current HIV incidence rates would require recruitment of large samples of 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 incarcerated persons 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 HIV positive jail detainees, HIV incidence in the partners of recently released detainees was 5.72 (95% SI 5.19, 6.27) per 100 person-years. Although all HIV positive agents leaving jail were assigned to the highest adherence category, 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. However, this result may suggest that some of the increased risk in the post-incarceration partners is driven by partners who are not recently incarcerated due to increased turnover in sexual partnerships. 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.(30)

Contrary to our original hypothesis, 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 exchange sex or condomless sex with new partners among the non-incarcerated partner), disruption of sexual partnerships may have had a greater impact on HIV incidence among pre-incarceration partners. Adams et. al. 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.(30) Some might also find surprising the relatively low HIV incidences that we identified among those who had ever experienced incarceration. However, this is a population with high rates of recidivism that has substantially reduced risk of HIV infection while in custody compared to risk following incarceration.(31) Longer cumulative duration of incarceration may have thus offset the increased transmission risk associated with the post-incarceration period.

Due to the high HIV incidence among the partners of incarcerated individuals, focusing PrEP and ART interventions on incarcerated individuals and their networks could be an efficient way to distribute limited public health resources to reduce HIV transmission. Further research 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) The results have implications for interventions that can reduce post-release disruptions in HIV care among incarcerated individuals. Interventions 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 may be useful for reducing disruptions in HIV care among incarcerated individuals after release.

Limitations

There are several limitations worth noting. As with all agent-based models, the results may be sensitive to assumptions that if changed, could have produced different results. Additionally, empirical data for some parameters was limited or measured with a high degree of uncertainty. We did not vary sexual risk behaviors among incarcerated individuals or their sexual partners before and after incarceration, though there may be changes in sexual risk among individuals and their partners at and around the time of incarceration.(33,34) This may thus have resulted in an underestimate of the extent to which network disruption impacts HIV transmission. Additionally, we did not incorporate changes in care engagement during incarceration in the experimental scenarios, which could have over or underestimated the potential benefits of care engagement interventions. Whether adherence improves, declines, or remains the same during incarceration is likely to be 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 but plan to incorporate PrEP interventions in our upcoming work in order to understand the full potential impact of jail-based biomedical interventions. Substance use and other socio-structural barriers to HIV prevention and care engagement were not incorporated in the current model though we plan to incorporate these factors into the model in future work. Substance use has an important impact on HIV prevention and care engagement(35); opportunities for facilitating linkage to substance use treatment among incarcerated individuals could also have an important impact on the HIV epidemic and warrant further study. We also did not model cost-effectiveness of any interventions since that was beyond the scope of this paper, but cost assessments are warranted in future work.

Our results may not be generalizable to other incarcerated populations 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 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 incarcerated individuals on HIV transmission among YBMSM overall, and particularly among the sexual partners of recently released detainees. 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 incarcerated persons.

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: none, JAS: none, ASK: none.

Author contributions:

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

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Data sharing

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, including. 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 sources of those standardized names and metadata are included wherever applicable.

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

Label	Definition	Time at which label is applied	Time period length	Measurement
Pre-incarceration partner (only)	Individuals 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 (only)	Individuals partnering with incarcerated individuals within 720 days of their release, but not partnered with these persons prior to their incarceration	At initiation of partnership, if this occurs within 720 (~2 years) days 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.	Individuals partnering with incarcerated individuals 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	Persons who are	Time of incarceration	Following incarceration,	HIV incidence is calculated as newly incarcerated persons

persons	incarcerated at least once during their life course in the model		remainder of agent's life course in the model	become infected.
Never incarcerated persons	Persons who are never incarcerated during their life course.	Time of agent entry into the model	Agents' life course in the model	HIV incidence for remaining population is updated as agents become incarcerated and leave this group.
Partners are not CJI, at least one active partnership	Persons 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*	NA*	HIV incidence is measured to compare with other key subpopulations, particularly pre-incarceration and post-release partners (overlaps with above 2 groups)

*Defined at a given point in time consistent, classification can vary over time.

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

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)
Pre-incarceration only partners[d]	4.52 (4.01, 5.03)
Post-release only partners[e]	12.86 (11.89, 13.73)
Both pre-incarceration and post-release partners[f]	12.31 (11.40, 13.31)
Non-CJI partners[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. Individuals 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. Individuals who partnered with an individual 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. Individuals 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. Individuals who partnered with an individual released from jail during the past 2 years who were not partnered with the incarcerated individual 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. Individuals 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 partners were not pre-incarceration or post-release partners (i.e., neither partner had recently been incarcerated)
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 3: Year 10 HIV incidence by post-release reconnection probability

Retention Probability Multiplier	Pre-Incarceration Partners		Overall population	
	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[a]	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. 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.

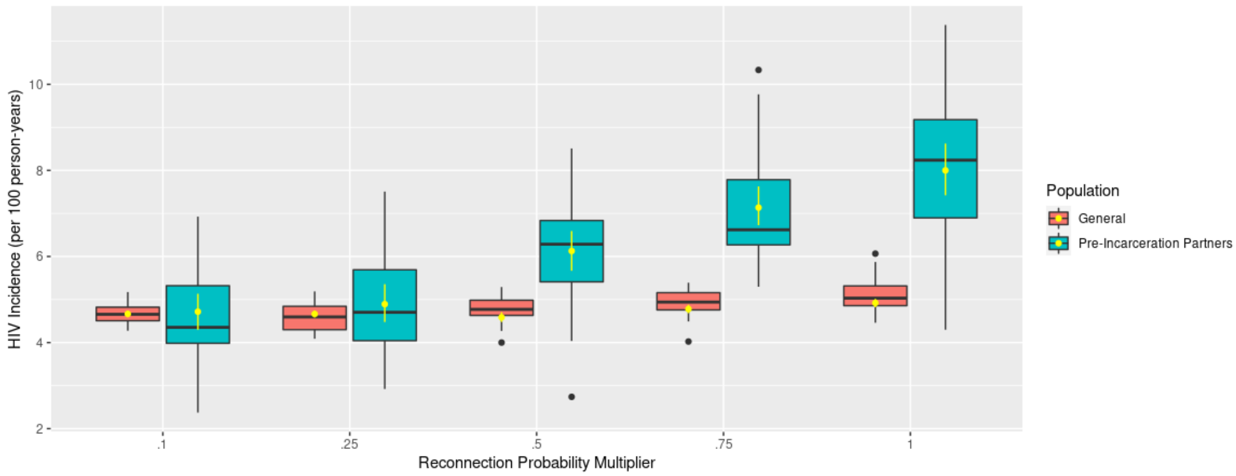
Table 4: Year 10 incidence under different HIV prevention and care disruption scenarios

	Post-Release Partners		Overall population	
	HIV incidence (95% SI*)	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[a]	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

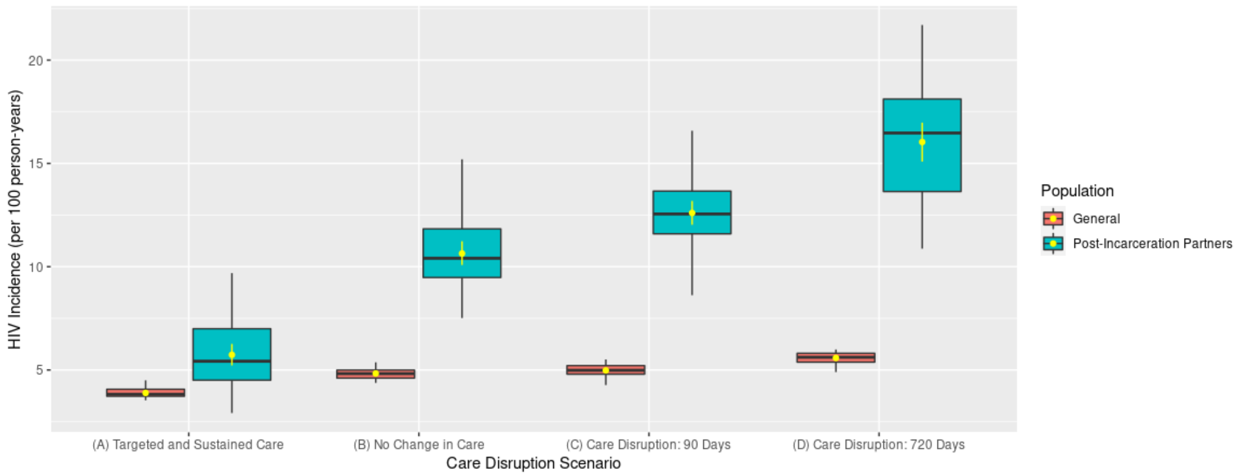
a. Differences in the estimates for these scenarios differ slightly from those reported in table 2 due to slight differences in the random number generation at the initial parameterization when running the experiments and do not affect the results substantively.

Figure 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 general population; teal bars represent pre-incarceration partners.

Figure 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 general population; teal bars represent post-incarceration partners.

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