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Predicting the Effect of Changing the Frequency of HIV Testing in Georgia Jails: A Mathematical Model

By

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Degree to be awarded: MPH

Epidemiology

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B.S.

Washington State University

2015

Faculty Thesis Advisor: Anne Spaulding, MD

An abstract of

A thesis submitted to the Faculty of the
Rollins School of Public Health of Emory University

in partial fulfillment of the requirements for the degree of
Master of Public Health
in Epidemiology

2017

Abstract

Predicting the Effect of Changing the Frequency of HIV Testing in Georgia Jails: A Mathematical Model

By Adrienne Dhian Tanus

The American South is an epicenter for both HIV and imprisonment. With many HIV-infected individuals traveling through jails in Georgia every day, the criminal justice system can be a high-yield setting for implementing HIV interventions. Additionally, HIV testing is an important intervention for population health, since knowledge of a person's status influences their sexual behavior. The purpose of this study was to determine whether HIV testing would influence the long-term dynamics of HIV when implemented upon entry to jails. This study used a compartmental model to predict the change upon increasing or decreasing HIV testing among men and men-who-have-sex-with-men (MSM) upon entry to Georgia jails. The model was run in Berkeley Madonna version 0.8.3.23.0. Results from the model found that removing HIV testing from jails would lead to 368 missed diagnoses in HIV-positive men over a 10-year period, while increasing HIV testing to 90% in jails would result in newly diagnosing 612 men over 10 years, a 66.3% increase from new HIV diagnoses found with current testing rates. These findings suggest that a multi-pronged approach including testing, treatment, and PrEP use within the criminal justice system could yield an even greater change in long-term HIV dynamics.

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Chapter I: Background/Literature Review

Introduction

HIV is a cause of global concern, and the United States holds no exception. At the end of 2013, there were about 1.2 million people living with HIV in the US alone, and one in eight of those did not know their HIV status (1). This epidemic continues to spread throughout many cities in the US, but among regions, HIV is most prominent in the South (2). Georgia is particularly affected, as the state was ranked fifth highest in the nation for the total number of adults living with HIV infection in 2013, as well as for the total number of new diagnoses of HIV infection in 2014 (3).

Just as HIV is more prominent in the South than other regions of the US, HIV also disproportionately affects several population groups in the US, including blacks, men, men who have sex with men (MSM), and young people. The rate of HIV diagnosis in the US is substantially higher among blacks than other races, at 49.4 per 100,000 people (3). The second highest rate is among Hispanics, at 18.4 per 100,000 people (3). African Americans make up only 13% of the US population, but account for 45% of the new diagnoses of HIV (1). In the US, 81% of new HIV infections occur among men (3). Of these, 70% of infections can be attributed to male-to-male sexual contact (3). Additionally, the rate of new diagnoses was highest among 25-29-year-olds, followed by 20-24-year-olds (3).

An additional concern in the United States is the size of the criminal justice system; both jails and prisons are overburdened. A jail is “a confinement facility usually administered by a local law enforcement agency that is intended for adults, but sometimes holds juveniles, for confinement before and after adjudication. […] Inmates sentenced to jail facilities usually have a sentence of 1 year or less" (4). A prison is "a long-term confinement facility, run by a state or the federal government, that typically holds felons and offenders with sentences of more than 1 year" (4). In 2014, there were approximately 6,851,000 adults in the US criminal justice system, or one in 36 adults (4). The state of Georgia has the highest rate of correctional supervision in the country, at 7,580 per 100,000 Georgians. This rate is nearly twice as high as the state with the second highest rate (4). Among these millions of inmates in the US, over two-thirds of those released, 67.8%, are arrested for a new crime within three years after release, and over three-fourths of released inmates, 76.6%, are arrested again within five years (5). Additionally, the prevalence of HIV in the US-CJS is 1.5% (6), which is currently over five times higher than the prevalence of HIV in the general population, at 0.2951% (2). Population discrepancies play a role in jails as well, with more black men incarcerated than any other group. Again, African Americans make up only 13% of the US population, but 40% of the US incarcerated population (7). This is five times the incarceration rate of whites (7). Given the overburdened criminal justice system and the high prevalence of HIV in the US, and because similar demographics are affected by both, the criminal justice system stands as an important setting to discuss HIV spread and prevention.

Current Research

Modeling is a beneficial approach when discussing the spread of HIV in the US because models help us learn about the underlying mechanisms of HIV within various systems to create strategies for control, even when there is limited data available (8). Compartment models, often called SIR models (or some variation thereof), split the study population into various compartments and apply assumptions about transfer rates between each compartment (8). The model moves over time and so is made up of sets of differential equations (8). Disease transmission models are also split into different types, including stochastic and deterministic. Stochastic models rely on patterns and probabilities of behavior, and are suitable when the population size is very small (8). Deterministic models work well when an epidemic has already started, because they rely on the history and known behavior of the disease (8). There are several compartmental models looking at the dynamics of HIV. Most model research at this point focuses on either treatment effectiveness or cost effectiveness of pre-exposure prophylaxis (PrEP) or highly active antiretroviral therapy (HAART) within a certain population.

Vickerman *et al.* created a model and used it extensively: to evaluate the cost effectiveness of preventative treatment (9), to investigate the impact of microbicide in various situations (10), and to explore the effect of microbicide on HIV (11). The model itself divides the population into subgroups by levels of sexual behavior, condom use, and HIV/STI status (9,10,11). The Vickerman model was also used and adapted by Cox *et al.*, who added circumcision among men and microbicide use among women as factors in the model, independent of each other (12).

There are several mathematical models aside from the Vickerman *et al*. model. One compartmental model was created by Nagelkerke *et al*. The model was created based on the assumption that unsafe sex work was the main driver of the HIV epidemics in Botswana and India, so compartments were assigned based on sex work status (13).

A stochastic compartmental model from Desai *et al.* investigated the effectiveness of a 5-year chemoprophylaxis program targeting high-risk men who have sex with men in New York. The population was stratified by age and sexual risk. Outcomes measured were prevention of HIV infection and cost-effectiveness of program implementation (14).

Granich *et al.* created two models to study a single phenomenon. One stochastic model and one deterministic transmission model were used to explore the effect of HIV testing and ART use on the HIV reproduction number and to visualize long-term HIV dynamics. Heterosexual transmission among South Africans was the study population (15).

The Lima *et al.* model investigated the effect of implementing an HIV-TTR strategy on new HIV infections, mortality, and HIV prevalence among black MSM (16). This deterministic compartmental model stratified the population by CJS status, stage of HIV infection, and HIV treatment status (16). Scenarios included increasing TTR as well as increasing TTR and condom use (16). The study found that there was a strong benefit to increased condom use in the community and that the lack of access to condoms in the criminal justice setting was a major contributor to high HIV incidence in CJS settings (16).

While there are several models to choose from and adapt for use in our research, we will consider the Lima *et al.* model since it is most relevant to our research topic. In this study, we present an update to the Lima *et al.* model using the most current data available. The goal of this study is to evaluate other aspects of the model with a larger study population, namely, the effect of increasing HIV testing upon entry to Georgia jails without considering condom use or treatment increases within the criminal justice system.

Study Data

Population data for our research were gathered for all men in Georgia, as well as men who have sex with men (MSM) in Georgia. Population data for each compartment in the model were determined, all for the entire state of Georgia: total population, jail population, prison population, HIV population, HIV unknown population, population of jail inmates with HIV, population of prison inmates with HIV and the population of HIV-infected individuals on HAART.

The most current data available for most compartments in this study were for 2014. Thus, the data used in this study were compiled from 2014 data when possible, and estimates were made based on other years for the rest of the data. Data were also gathered for the entire state of Georgia, where possible, else estimates were made based on comparable populations. A summary of the initial conditions for the model can be found in Table 1 of the Appendix.

The Georgia Department of Public Health creates an annual HIV surveillance summary (17). Their summary from 2014 includes data on the number of new HIV infections and the number of people living with HIV in the state (17). Results were stratified into age, sex, race, transmission, district, and by all HIV infection or Stage 3 (AIDS) (17). Pertinent results from the summary are displayed in Table 2 of the Appendix.

The Georgia Department of Community Affairs Office of Research creates a monthly county jail inmate population report (18). The report includes jail populations and capacities in every Georgia jail, separated by county (18). It also depicts 10-year trends in sentencing and population (18). In December 2014, there were 36,115 people in Georgia jails (18).

The Georgia Department of Corrections creates a monthly inmate statistical profile (19). The profile includes a wide range of data including demographic information; correctional information; educational, psychological, and physical information; crimes and criminal history information; and medical information (19). All data is stratified by sex (19). In 2014, there were 53,253 inmates of which 49,716 were male (19). Of these men, 766 were HIV-positive and 45,008 were not (3 indeterminate and 3,939 unreported) (19).

Spaulding *et al.* recently submitted a manuscript for publication which detailed the SUCCESS study, a case management intervention program to keep individuals retained in HIV care after release from jail (20). This study included data on the proportion of men in jail (86,4%) and the proportion of HIV-infected men whose transmission is attributable to MSM (72.7%) (20).

The US Census from July 2015 estimated the total population of Georgia to be 10,214,860 (21). The proportion of the female population was 51.2% (21). From this, we assume that the male population is approximately 48.8% of the population.

Grey *et al.* used the American Community Survey to estimate the MSM population in the United States (22). Results were separated by state. The population of MSM in Georgia was estimated to be 3.7% of all adult males in the population (22).

A study from Gardner *et al.* created a cascade of care for HIV in the United States (23). This study estimated that among HIV-infected people in the US, 79% are aware of their HIV diagnosis, 50% are engaged in care (25% not linked, 25% not retained), 80% require ART, 75% receive ART, and 80% have an undetectable viral load while on ART (23). A mathematical model used in this paper found that improving any one aspect of the continuum would not be enough to change the proportion of individuals with an undetectable viral load (23). But since everyone must move from the beginning of the cascade on sequentially, the paper concluded that it is essential to target the entire continuum using test and treat strategies to affect the proportion of individuals with an undetectable viral load (23).

Iroh *et al.* conducted a systematic review to create a cascade of care for HIV before, during, and after incarceration in the United States and Canada (24). Results from the review indicate that retention in care rises dramatically in prisons, then after release drops to lower rates than pre-incarceration (24). The categories used in the review include HIV diagnosis, linkage to care, retention in care, ART use, and undetectable viral load (24). Linkage to care upon entry to jail or prison means receiving any care before incarceration (24). Post-release linkage to care is one medical visit within six months of release, and post-release retention in care is two medical visits over six months (24). The cascade is as follows: HIV diagnosis (National average: 80%, Upon entry to jail/prison: 78%, During incarceration: 79%, After release: 79%), Linkage to care (National average: 62%, upon entry to jail/prison: 56%, during incarceration: 76%, after release: 36%), Retention in care (National average: 41%, upon entry to jail/prison: 40%, during incarceration: 76%, after release: 30%), ART use (National average: 36%, upon entry to jail/prison: 42%, during incarceration: 51%, after release: 29%), and undetectable viral load (National average: 28%, upon entry to jail/prison: 21%, incarceration: 40%, after release: 21%) (24). The full cascade data was adapted from the Iroh *et al.* graph and is displayed in Table 3 of the Appendix.

The Georgia Department of Public Health created a continuum of HIV care for individuals living in Georgia in 2014 (25). Linkage to care here refers to receiving a CD4 count or Viral Load within 30 days of diagnosis (25). Receiving any care means receiving a CD4 or Viral Load at all in 2014 (25). Retained in care means getting a CD4 or Viral Load two times within six months in 2014 (25). All percentages in this report are independent of other percentages (so each percentage is out of the total number of people living with HIV in Georgia in 2014) (25). The cascade for all adults and adolescents in Georgia was as follows: 75% linked to care, 61% receiving any care, 48% retained in care, and 45% virally suppressed (25). The cascade for Men in Georgia was as follows: 75% linked to care, 56% receiving any care, 47% retained in care, and 45% virally suppressed (25). The cascade for MSM in Georgia was as follows: 73% linked to care, 62% receiving any care, 48% retained in care, and 45% virally suppressed (25). This report did not specify the percentage of people living with HIV who were aware of their HIV status (25).

Georgia Code O.C.G.A. §42-5-52.1 states that "Where any person is committed to the custody of the commissioner to serve time in any penal institution of this state on and after July 1, 1988, the department shall require that person to submit to an HIV test within 30 days after the person is so committed unless that person is in such custody because of having committed an AIDS transmitting crime and has already submitted to an HIV test pursuant to Code Section 17-10-15" (26). This means all inmates entering prison must take an HIV test.

Georgia Code O.C.G.A. §42-5-52.2 states that "any state inmate who has been in the custody of a state penal institution for one year or longer and who has not previously tested positive for HIV shall be tested for HIV within 30 days prior to his or her expected date of release from the custody of the department" (27). This means all inmates leaving prison must take an HIV test.

A model created by Steven D. Pinkerton assessed the number of HIV infections attributable to acute phase transmission (28). He estimates that 0.5% of all people living with HIV are in the acute phase, and that 8.6% of all sexually-acquired HIV infections are due to acute-phase transmission (28).

Marks *et al.* conducted a meta-analysis to compare the prevalence of unprotected anal and vaginal sex among HIV-positive individuals who were aware *vs.* unaware of their infection status (29). The study found that the prevalence of unprotected sex was 53% lower among those who were aware of their HIV-positive status than among those who were unaware of their status (29). Results were also adjusted to include knowledge of partner's status; in this scenario, the prevalence of unprotected sex was 68% lower among those who were aware of their HIV-positive status than among those who were unaware of their status (29). From this study, we learn that knowledge of HIV status changes sexual behavior.

We also need to consider the cost effectiveness and feasibility of expanding an HIV testing program in the Georgia criminal justice system. A study by Beckwith *et al.* followed four HIV testing programs within jails in major cities across the US and determined that HIV testing is a feasible intervention and was effective at finding new, previously undiagnosed cases of HIV among entrants to jails (30). We also know that HIV testing programs in jails are cost-effective: the CDC supports some of the financial burden of implementing these programs (31), and a study by Varghese and Peterman showed that the cost of providing individual HIV care is much higher for society than it is to diagnose and prevent cases within the criminal justice system (32).

We used several data sources to fill in the initial conditions for the model. Based on the Georgia Department of Public Health HIV Surveillance Summary for 2014, the total population in Georgia was 10,097,343 (17). At year-end, the total population with HIV was 53,230 (17). Approximately 75% of HIV infections occurred in men (17), or 40,063 infections. Approximately 77% of these infections were attributable to MSM (17), so 30,845 infections.

From US Census Data, gathered on July 1, 2015, 48.8% of the people living in Georgia were male (21), or 4,927,503 people. Given the number of men in Georgia, and the number of HIV-infected men from the GDPH surveillance, we can determine that there were approximately 4,887,440 men in Georgia who were not infected with HIV at year-end 2014.

The Grey et al. article, written in 2013, determined that about 3.7% of the total male population in Georgia was MSM (22). So, we know that there were approximately 182,318 MSM in Georgia at year-end 2014. Since we already determined the number of MSM with HIV in Georgia, and know the total number of MSM in Georgia, we can determine that approximately 151,473 MSM were not infected with HIV in 2014.

From the Georgia Department County of Affairs Office of Research Jail Population Report for 2014, we know that there were 36,115 inmates incarcerated in Georgia jails at year-end 2014 (18). We know the proportion of men in jails and the proportion of men with HIV in jails whose infections are attributable to MSM from the Spaulding *et al.* data (20). We assume that the proportion of men in jails with HIV is the same as the proportion of men in prisons with HIV, which we know from the Georgia Department of Corrections Inmate Statistical Profile for 2014 (19). From this information, we can determine that there were 31,203 men in jails at year-end 2014: 481 were HIV-positive and 30,722 were HIV-negative. Additionally, there were 1,155 MSM in jails at year-end 2014: 350 were HIV-positive and 805 were HIV-negative.

The Georgia Department of Corrections Inmate Statistical Profile for 2014 is very thorough. We gathered almost all information we needed for the prison setting directly from this report. From the Inmate Statistical Profile, we know that there were 53,253 inmates incarcerated in Georgia prisons at year-end 2014 (19). Of these inmates, 49,716 were male: 766 men were HIV-positive and 45,008 were HIV-negative (19). Three were indeterminate and 3,939 were not reported (19), but for the purposes of this study we will include them as HIV-negative. We assume the proportion of MSM in each setting is the same, so from the Grey *et al.* article (22), we determined that there were 1,839 MSM in prisons at year-end 2014. We assume that the proportion of MSM with HIV entering prisons is the same as the proportion of MSM with HIV entering jails which we know from the Spaulding *et al.* data (20), so there were 557 HIV-positive MSM and 1,282 HIV-negative MSM in prisons at year-end 2014.

Community data from this study was derived from total population estimates, subtracted by the jail and prison estimates. We determined that the population in the Georgia community was 10,007,975 at year-end 2014. There were 4,846,584 men in the community: 38,816 were HIV-positive and 13,974 were HIV-negative. There were 179,324 MSM in the community: 29,938 were HIV-positive and 149,386 were HIV-negative.

Although several cascades of care are available, the one created by Iroh *et al.* has the most appropriate data for the purposes of this study. So, using the Iroh cascade, we can say that in the community, 20% are unaware of their HIV infection, 44% are aware of their infection but are not on HAART, and 36% are on HAART (24). In jails and prisons, 21% are unaware of their HIV infection, 28% are aware of their infection but are not on HAART, and 51% are on HAART (24). However, since HIV testing is mandatory by Georgia law upon entry to prison (26), we will assume 0% are unaware of their HIV infection, so 49% are aware but not on treatment. Using this data and the population numbers determined above, we found the proportion of HIV-infected men and MSM who were unaware of their infection, aware but not on treatment, and on HAART in each setting at year-end 2014. Among men in jails with HIV, there were 101 unknowns, 135 knowns, and 245 on HAART. Among MSM in jails with HIV, there were 74 unknowns, 98 knowns, and 178 on HAART. Among men in prisons with HIV, there were 375 knowns and 391 on HAART. Among MSM in prisons with HIV, there were 273 knowns and 284 on HAART. Among men in the community with HIV, there were 7,763 unknowns, 17,079 knowns and 13,974 on HAART. Among MSM in the community with HIV, there were 5,987 unknowns, 13,173 knowns, and 10,778 on HAART.

We determined that the proportion of acute infections in all settings for men and MSM was 0.5% from the article by Pinkerton *et al.* (28), and that the proportion of late stage infections in all settings was 53.71% for men and 52.49% for MSM from the Georgia Department of Public Health HIV Surveillance Summary for 2014 (17). So, the proportion of chronic stage was 45.79% for men and 47.01% MSM. Among unknowns in jail, there were 0 acute, 35 chronic, and 39 late stage MSM, and there were 1 acute, 46 chronic, and 54 late stage men. Among knowns in jail, there were 0 acute, 46 chronic, and 52 late stage MSM, and there were 1 acute, 62 chronic, and 73 late stage men. There are no unknowns in prison, but among knowns in prison, there are 1 acute, 128 chronic, and 143 MSM, and there are 2 acute, 172 chronic, and 201 late stage men. Among unknowns in the community, there are 30 acute, 2,814 chronic, and 3,143 MSM, and there are 39 acute, 3,555 chronic, and 4,170 late stage men. Among knowns in the community, there are 66 acute, 6,193 chronic, and 6,915 MSM, and there are 85 acute, 7,820 chronic, and 9,173 late stage men.

One limitation of the data is that not all the information could be found using 2014 estimates, thus assumptions had to be made based on other years. Another is that since not all parameter data were compiled from the same site, there are variations in the estimates. Additionally, some data for the state of Georgia could not be found, so estimates were made by assuming the same proportion in a given group as in the Georgia male or MSM population.

Research Question

Given the current findings, I propose exploring the dynamics of HIV in the Georgia CJS by adapting the Lima *et al*. model. I will use the model to investigate the effect of changing the frequency of HIV testing upon entry to jail. By doing this, I hope to predict the influence of intervention strategies in Georgia jails, namely increasing HIV testing, on the distribution of HIV throughout the state.

Hypothesis

I hypothesize that increasing HIV testing in Georgia jails will have an impact on the force of infection of HIV in the community. I believe that knowledge of one's HIV status may have a substantial impact on sexual behavior, and so it follows that HIV infections averted will increase.

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Chapter II: Manuscript

Predicting the Effect of Changing the Frequency of HIV Testing in Georgia Jails: A Mathematical Model

Adrienne D Tanus, Anne Spaulding, MD

Abstract

The American South is an epicenter for both HIV and imprisonment. With many HIV-infected individuals traveling through jails in Georgia every day, the criminal justice system can be a high-yield setting for implementing HIV interventions. Additionally, HIV testing is an important intervention for population health, since knowledge of a person's status influences their sexual behavior. The purpose of this study was to determine whether HIV testing would influence the long-term dynamics of HIV when implemented upon entry to jails. This study used a compartmental model to predict the change upon increasing or decreasing HIV testing among men and men-who-have-sex-with-men (MSM) upon entry to Georgia jails. The model was run in Berkeley Madonna version 0.8.3.23.0. Results from the model found that removing HIV testing from jails would lead to 368 missed diagnoses in HIV-positive men over a 10-year period, while increasing HIV testing to 90% in jails would result in newly diagnosing 612 men over 10 years, a 66.3% increase from new HIV diagnoses found with current testing rates. These findings suggest that a multi-pronged approach including testing, treatment, and PrEP use within the criminal justice system could yield an even greater change in long-term HIV dynamics.

Introduction

In the United States, HIV is most prominent in the South, especially in Georgia, which was ranked the fifth highest state in the nation for the total number of new diagnoses of HIV infection in 2014 (1). Additionally, the criminal justice system in Georgia is overburdened, with by far the highest rate of correctional supervision of any state in the country (2). With the prevalence of HIV in the US criminal justice system over five times higher than in the general population (3, 4), and over three-fourths of detainees in the US being released into the community and arrested again within five years of their release (5), the criminal justice system in Georgia stands as an important setting to discuss HIV spread and prevention. Currently, HIV testing is being implemented in Fulton County Jail through the SUCCESS study (6). HIV testing is also required by law upon entry to and exit from Georgia prisons (7, 8).

Mathematical models can be used to predict the effectiveness of interventions such as increasing HIV testing. A mathematical model created by Lima *et al.* addressed the potential effect of implementing condom usage and a Test-Treat-Retain (TTR) strategy within the Fulton County Criminal Justice System (9). However, given that condom distribution within a US criminal justice system is not currently a feasible intervention, and treatment is difficult to continue when inmates leave the prison system, we would like to adjust the model to address the sole impact of increasing HIV testing upon entry to the Georgia Criminal Justice System. In doing this, we hope to assess whether inmates “knowing their status” has a substantial beneficial effect on the community as a whole.

Methods

Data

Total population data, the proportion of the population that is HIV-infected, and the proportion of the population that is male were gathered from the Georgia Department of Public Health surveillance and the US census (10, 11). The proportion of MSM in the general population was determined from an article by Grey *et al.*, and the number of HIV infections attributable to MSM was determined by the Georgia Department of Public Health (10, 12). The jail population, proportion of males in jail, and proportion of HIV-infected males with HIV attributable to MSM were obtained by the Georgia Department of County Affairs and Spaulding *et al.* data (13, 14). Prison data were obtained from the Georgia Department of Corrections inmate population report (15). HIV knowledge and treatment status were extracted from the Iroh *et al.* cascade of HIV care (16). Proportion of the population in each stage of HIV (acute, chronic, late stage) were gathered from the Georgia Department of Public Health surveillance and an article by Pinkerton *et al.* (10, 17). Since some data are not stratified by gender, sexual orientation, knowledge of status, or disease progression within CJS surveillance data, proportions were assumed to be the same as within the entire population of Georgia. Due to Georgia law, inmates are required to be tested for HIV upon entry to and exit from prison (7, 8), so the testing rate for entry to and exit from prison was changed to 100%. However, to keep the integrity of the model, all other rates from the Lima *et al.* study were used in our study model.

Model

The model from this study was built off a deterministic, compartmental HIV transmission model created by Lima *et al.* which was used to estimate the effect of implementing a test, treat, and retain strategy given access to condoms within jails and prisons in Fulton County (9). The model was split into four compartments: Susceptible, HIV-positive/Unknown, HIV-positive/Known/Not on Treatment, and HIV-positive on Highly Active Antiretroviral Therapy (HAART) (9). Additionally, the model was further stratified by level of HIV infection (Acute, Chronic, and Late Stage Phase) and viral load (0 copies/mL, $<3 \log_{10}$ copies/mL, ≥ 3 and $<4 \log_{10}$ copies/mL, and $\geq 4 \log_{10}$ copies/mL) (9). Like the Lima *et al.* model, the model in this study was run in Berkeley Madonna version 8.3.23.0 using the Runge-Kutta 4 integration method. A diagram of the model is depicted in Figure 1.

Modeling Scenarios Used

For this study, the force of infection equation from the Lima *et al.* model was adapted to include the effect of “knowing your status”. A meta-analysis by Marks *et al.* found that the prevalence of unprotected intercourse was 53% lower among HIV-positive individuals who knew their HIV status as opposed to HIV-positive individuals who were unaware of their status (18). The force of infection equation in the model was modified to reflect this finding by multiplying the force of infection by 0.47 for the HIV-positive/Known/Not on Treatment and HIV-positive/Known/On HAART compartments. We also investigated the impact of increasing or decreasing testing upon entry to jail. The baseline scenario included an HIV testing rate of 50.82% upon entry to jail for unknown individuals at all stages of HIV. Reduced testing scenarios had HIV testing rates of 0%, 10%, and 25.41%, which is half of the baseline scenario. Increased testing scenarios had HIV testing rates of 60%, 76.32%, which is an increase in testing by half, and 90%, which is the highest rate we wished to consider as a testing rate of 100% would imply coercion.

Results

Baseline Scenario

The baseline scenario reflects the current testing situation in Georgia, with approximately 50.82% of inmates receiving testing upon entry to jail (9). Table 1 shows the number of newly diagnosed infections among MSM after 10 years (in the year 2024). Table 2 depicts the same information, but for all men, including MSM. The model predicted that at a testing rate of 50.82%, there would be an estimated 368 newly diagnosed among men upon entry to jail at year-end 2024, with 175 of these diagnosed among MSM.

Decreased Testing Scenario

We explored decreased testing scenarios for men and MSM upon entry to Georgia jails. Scenarios included decreases from the baseline of 50.82% down to 25.41% (a decrease by half), 10%, and 0%. Table 1 shows the results of the model for MSM, and Table 2 shows the results of the model for all men, including MSM. When HIV testing is decreased by half, the model predicts 192 new diagnoses among men, with 91 of these among MSM. This means that over 10 years, compared to the baseline scenario, 176 diagnoses in men would be missed, 84 of which were MSM. When HIV testing is decreased to 10% in jails, the model predicts 37 diagnoses in men, including 7 MSM diagnoses. By reducing testing to 10%, jails would miss 291 HIV diagnosis, including 138 MSM diagnoses. By reducing testing to 0% in jails, all 368 diagnoses from baseline would be missed. This amounts to an average of about 37 cases per year missed.

Increased Testing Scenario

We also explored increased testing scenarios for men and MSM upon entry to Georgia jails. Scenarios included increases from the baseline of 50.82% up to 60%, 76.32% (an increase by half from baseline), and 90%. Table 1 shows the results of the model for MSM, and Table 2 shows the results of the model for all men, including MSM. When HIV testing is increased to 60% upon entry to Georgia jails, there are 428 new HIV diagnoses among men, with 204 among MSM. This means 60 undiagnosed cases among men over 10 years, and 29 among MSM, will be averted with an approximately 10% increase in testing. In other words, an average of 6 additional undiagnosed cases per year will be averted given a 10% increase from the current testing rate in Georgia jails. When HIV testing is increased by half to 76.32%, 531 newly diagnosed cases are found among men, with 253 among MSM. This translates to an additional 163 undiagnosed cases of HIV in men, 78 among MSM, averted over 10 years upon entry to Georgia jails when testing is increased to 76.32% from baseline. When HIV testing is increased to 90% upon entry to jails, 612 HIV infections among men, with 293 among MSM, are newly diagnosed over 10 years. 244 undiagnosed cases of HIV in men, with 118 in MSM, are averted with an increase of HIV testing to 90% in Georgia jails. This is a 66.3% increase in newly diagnosed cases found in men compared to the current testing rate. For MSM, the increase is even higher, at 67.43%.

Discussion

In this study, we modeled the impact of changing the HIV testing rate upon entry to Georgia jails. The model showed that increasing testing would cause a substantial number of newly diagnosed cases to be found, while decreasing testing would cause more infections in the community due to lack of diagnosis in jail. We see the results of variation in HIV testing rates among MSM in Table 1, and among all men in Table 2.

Implementing an HIV testing program in jails is feasible and has already been conducted in several large urban jails throughout the United States (19). It is also a cost-effective intervention, especially with CDC-supported funding (20). Every new HIV diagnosis made averts potential new cases of HIV, and lowers the financial burden of HIV care in the community (21). Increasing HIV testing in Georgia jails has the potential to find more undiagnosed individuals in a cost-effective manner.

The Lima *et al.* study considered treatment and condom use variations in their model, and determined that “retention in treatment is essential for the success of any expansion of HIV testing and treatment aimed at preventing future HIV infections” (9). Since condom use is not a feasible intervention within the criminal justice system, it may be practical to focus public health efforts on implementing a test-treat-retain (TTR) system within both jails and prisons.

Strengths to this study include the ability to picture the long-term effect of a single intervention on the entire state criminal justice system of Georgia. Limitations include data collection due to the lack of detailed surveillance data available for jail populations and MSM populations in general.

In conclusion, jails are an important setting for HIV interventions. Knowing your HIV status has an impact on a person's sexual behavior, and with the high turnover rate in jails, many people can be tested. It is crucial to consider HIV testing in the criminal justice system in addition to other community interventions to substantially reduce levels of HIV within the population, as the criminal justice system is an integrated part of that population. Public health professionals should focus on multi-pronged approaches to HIV testing, care, and prevention, keeping in mind to include CJS settings in their methods. We hope that this study allows incarcerated individuals to have increased access to HIV testing and care in the future.

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Tables

Table 1.
Estimates at Year-end 2024 of New HIV Diagnoses Among Men Who Have Sex with Men (MSM), Given Various HIV Testing Frequencies, Starting Year-end 2014.
Entry Rate: Approximately 10,500 MSM Jail Entrants/6 Months.
Location: Jails in Georgia, USA

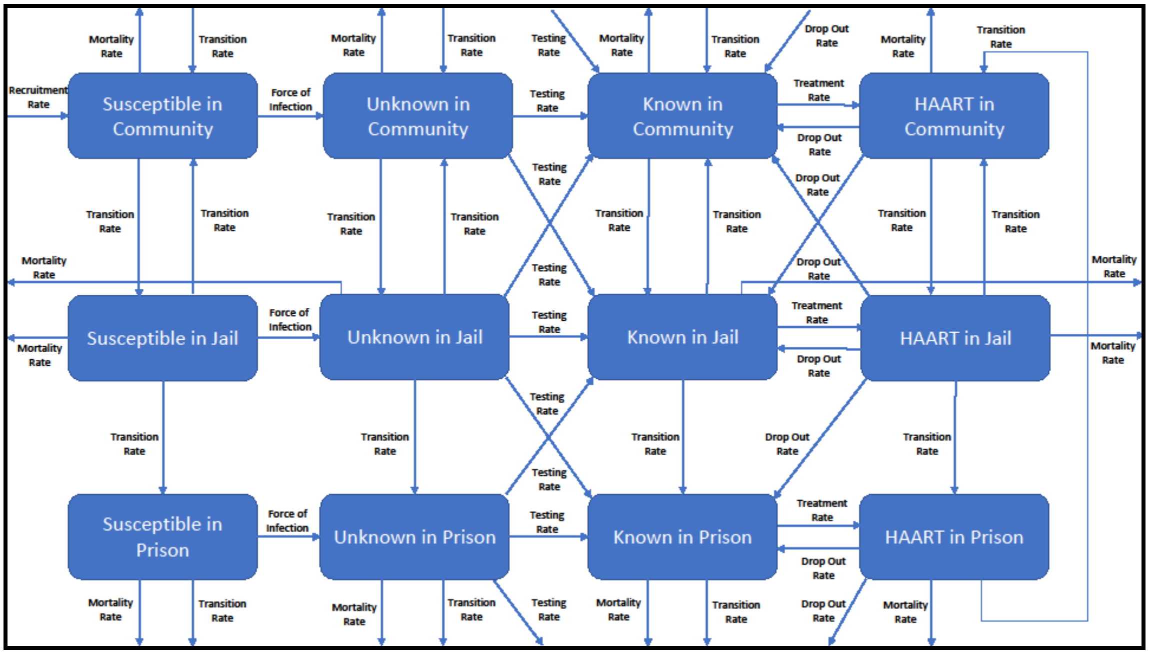
Testing Frequency (%)	Number Tested Upon Entry	Number Testing Positive Among Those Tested	Number of New Diagnoses (% of New Diagnoses Among Those Tested)	Number of Cases Averted Over 10 Years due to Testing, Compared to Baseline (% Change from Baseline)
Baseline				
50.42	5,325	1,179	175 (3.30)	-
Decreased Testing				
0	0	0	0 (0)	-175 (-100%)
10	1,049	233	37 (3.51)	-138 (-78.86%)
25.41	2,664	592	91 (3.43)	-84 (-48.00%)
Increased Testing				
60	6,285	1,390	204 (3.25)	29 (16.57%)
76.32	7,992	1,764	253 (3.17)	78 (44.57%)
90	9,421	2,076	293 (3.11)	118 (67.43%)

Table 2. Estimates at Year-end 2024 of New HIV Diagnoses Among All Men, Given Various HIV Testing Frequencies, Starting Year-end 2014.
Entry Rate: Approximately 233,700 Male Jail Entrants/6 Months.
Location: Jails in Georgia, USA

Testing Frequency (%)	Number Tested Upon Entry	Number Testing Positive Among Those Tested	Number of New Diagnoses (% of New Diagnoses Among Those Tested)	Number of Cases Averted Over 10 Years due to Testing, Compared to Baseline (% Change from Baseline)
Baseline				
50.82	118,778	1,914	368 (0.31)	-
Decreased Testing				
0	0	0	0 (0)	-368 (-100%)
10	23,374	380	77 (0.33)	-291 (-79.08%)
25.41	59,392	963	192 (0.32)	-176 (-47.83%)
Increased Testing				
60	140,231	2,255	428 (0.31)	60 (16.30%)
76.32	178,367	2,857	531 (0.30)	163 (44.29%)
90	210,333	3,359	612 (0.29)	244 (66.30%)

Figures/Figure Legends

Figure 1. Diagram of the Compartment Model, Movement Among Men and MSM in Georgia Through Community, Jail, and Prison



Chapter III: Summary, Public Health Implications, Possible Future Directions

In this thesis, we examined the idea that knowing your HIV status plays a crucial role in sexual behavior. Limiting the number of unprotected sexual encounters can help reduce individual risk of contracting HIV. An effective means of testing the population for HIV is to test people in jail since many HIV-infected people who don't know their status pass through every day. HIV testing in jail is also a feasible and cost-effective intervention, with many jails already implementing HIV testing while reducing the burden of HIV cost in the community. Results show that diagnoses of previously undiagnosed individuals increase when HIV testing is increased upon entry to jail and decrease when HIV testing is decreased upon entry to jail. Variations in testing rates can substantially affect the number of infections found. The feasibility and potential success of implementing HIV testing in Georgia jails suggests that additional interventions, such as treatment for those who test positive and pre-exposure prophylaxis (PrEP) for those at high risk, can be implemented in conjunction with HIV testing to make an even larger impact on long-term HIV dynamics.

Benefits to this model include the ability to picture long-term HIV dynamics on the entire state given a single intervention and the ability to adapt the model to consider several different intervention scenarios. Limitations include lack of detailed data available from criminal justice surveillance and HIV surveillance. Based on this potential limitation, initial conditions and model results may vary slightly from the true population of Georgia. But from the model data available, we can still conclude that increasing HIV testing in jails is the first step in achieving long-term HIV reduction in Georgia.

Future work can include additional adjustments to the model, such as testing the impact of increasing testing within jails, and performing calibration given an available dataset. There are many types of studies that can expand on this work. A policy requiring implementation of testing upon entry to jail could validate the model. In addition, it is reasonable to assume that those whose diagnoses are missed by jails will be tested in the community sometime after release. In Georgia, about half of all HIV diagnoses are made in late stage (AIDS) (1). An MMWR detailing HIV testing in Fulton County Jail, Georgia, found that the average CD4 count when testing upon entry is 372 cells/mm^3, which is much higher than the CD4 count during late stage (AIDS) (2). Future adaptations of the model could include adding in the factor of postponing HIV testing until reaching late stage after release. Our model may be overstating the transmission of HIV among undiagnosed persons, but delayed diagnoses when missed in jail will likely result in future cases in the community. These future works, when implemented in the Georgia criminal justice system, may have a greater effect on the community than focusing on community-based approaches alone.

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Appendix

Differential Equations

Susceptible Compartment:

Community: $$\frac{\partial S_c}{\partial t} = \beta + \alpha_{jc}^{S} S_j + \alpha_{pc}^{S} S_p - (\alpha_{cj}^{S} + \mu_c^{S}) S_c - \frac{\lambda_c S_c}{N_c}$$

Jail: $$\frac{\partial S_j}{\partial t} = \alpha_{cj}^{S} S_c - (\alpha_{jc}^{S} + \alpha_{jp}^{S} + \mu_j^{S}) S_j - \frac{\lambda_j S_j}{N_j}$$

Prison: $$\frac{\partial S_p}{\partial t} = \alpha_{jp}^{S} S_j - (\alpha_{pc}^{S} + \mu_p^{S}) S_p - \frac{\lambda_p S_p}{N_p}$$

HIV-positive/Acute Phase/Not Tested Compartment:

Community:
$$\frac{\partial UA_c}{\partial t} = \frac{\lambda_c S_c}{N_c} + \alpha_{jc}^{UA}(1-\tau_{jc}^{UA})UA_j + \alpha_{pc}^{UA}(1-\tau_{pc}^{UA})UA_p - (\psi_{AC} + \alpha_{cj}^{UA} + \tau_{cc}^{UA} + \mu_c^{UA})UA_c$$

Jail: $$\frac{\partial UA_j}{\partial t} = \frac{\lambda_j S_j}{N_j} + \alpha_{cj}^{UA}(1-\tau_{cj}^{UA})UA_c - (\psi_{AC} + \alpha_{jc}^{UA} + \alpha_{jp}^{UA} + \tau_{jj}^{UA} + \mu_j^{UA})UA_j$$

Prison: $$\frac{\partial UA_p}{\partial t} = \frac{\lambda_p S_p}{N_p} + \alpha_{jp}^{UA}(1-\tau_{jp}^{UA})UA_j - (\psi_{AC} + \alpha_{pc}^{UA} + \tau_{pp}^{UA} + \mu_p^{UA})UA_p$$

HIV-positive/Chronic Phase/Not Tested Compartment:

Community:
$$\frac{\partial UC_c}{\partial t} = \psi_{AC} UA_c + \alpha_{jc}^{UC}(1-\tau_{jc}^{UC})UC_j + \alpha_{pc}^{UC}(1-\tau_{pc}^{UC})UC_p - (\psi_{CL} + \alpha_{cj}^{UC} + \tau_{cc}^{UC} + \mu_c^{UC})UC_c$$

Jail: $$\frac{\partial UC_j}{\partial t} = \psi_{AC} UA_j + \alpha_{cj}^{UC}(1-\tau_{cj}^{UC})UC_c - (\psi_{CL} + \alpha_{jc}^{UC} + \alpha_{jp}^{UC} + \tau_{jj}^{UC} + \mu_j^{UC})UC_j$$

Prison: $$\frac{\partial UC_p}{\partial t} = \psi_{AC} UA_p + \alpha_{jp}^{UC}(1-\tau_{jp}^{UC})UC_j - (\psi_{CL} + \alpha_{pc}^{UC} + \tau_{pp}^{UC} + \mu_p^{UC})UC_p$$

HIV-positive/Late Stage Phase/Not Tested Compartment:

Community: $$\frac{\partial UL_c}{\partial t} = \psi_{CL} UC_c + \alpha_{jc}^{UL}(1-\tau_{jc}^{UL})UL_j + \alpha_{pc}^{UL}(1-\tau_{pc}^{UL})UL_p - (\alpha_{cj}^{UL} + \tau_{cc}^{UL} + \mu_c^{UL})UL_c$$

Jail: $$\frac{\partial UL_j}{\partial t} = \psi_{CL}UC_j + \alpha_{cj}^{UL}(1-\tau_{cj}^{UL})UL_c - (\alpha_{jc}^{UL} + \alpha_{jp}^{UL} + \tau_{jj}^{UL} + \mu_j^{UL})UL_j$$

Prison: $$\frac{\partial UL_p}{\partial t} = \psi_{CL}UC_p + \alpha_{jp}^{UL}(1-\tau_{jp}^{UL})UL_j - (\alpha_{pc}^{UL} + \tau_{pp}^{UL} + \mu_p^{UL})UL_p$$

HIV-positive/Acute Phase/Tested/Not on HAART Compartment:

Community: $$\frac{\partial KA_c}{\partial t} = \tau_{cc}^{UA}UA_c + \alpha_{jc}^{UA}\tau_{jc}^{UA}UA_j + \alpha_{pc}^{UA}\tau_{pc}^{UA}UA_p + \alpha_{jc}^{KA}KA_j + \alpha_{pc}^{KA}KA_p$$
$$-(\psi_{AC} + \alpha_{cj}^{KA} + \eta_c^{A} + \mu_c^{KA})KA_c$$

Jail: $$\frac{\partial KA_j}{\partial t} = \tau_{jj}^{UA}UA_j + \alpha_{cj}^{UA}\tau_{cj}^{UA}UA_c + \alpha_{cj}^{KA}KA_c - (\psi_{AC} + \alpha_{jc}^{KA} + \alpha_{jp}^{KA} + \eta_j^{A} + \mu_j^{KA})KA_j$$

Prison: $$\frac{\partial KA_p}{\partial t} = \tau_{pp}^{UA}UA_p + \alpha_{jp}^{KA}KA_j + \alpha_{jp}^{UA}\tau_{jp}^{UA}UA_j - (\psi_{AC} + \alpha_{pc}^{KA} + \eta_p^{A} + \mu_p^{KA})KA_p$$

HIV-positive/Chronic Phase/Tested/Not on HAART Compartment:

Community: $$\frac{\partial KC_c}{\partial t} = \tau_{cc}^{UC}UC_c + \psi_{AC}KA_c + \alpha_{jc}^{UC}\tau_{jc}^{UC}UC_j + \alpha_{pc}^{UC}\tau_{pc}^{UC}UC_p + o_{cc}H_c + \alpha_{jc}^{H}o_{jc}H_j$$
$$+\alpha_{pc}^{H}o_{pc}H_p + \alpha_{jc}^{KC}KC_j + \alpha_{pc}^{KC}KC_p - (\psi_{CL} + \alpha_{cj}^{KC} + \eta_c^{C} + \mu_c^{KC})KC_c$$

Jail: $$\frac{\partial KC_j}{\partial t} = \tau_{jj}^{UC}UC_j + \psi_{AC}KA_j + \alpha_{cj}^{UC}\tau_{cj}^{UC}UC_c + \alpha_{cj}^{KC}KC_c + \alpha_{cj}^{H}o_{cj}H_c + o_{jj}H_j$$
$$-(\psi_{CL} + \alpha_{jc}^{KC} + \alpha_{jp}^{KC} + \eta_j^{C} + \mu_j^{KC})KC_j$$

Prison: $$\frac{\partial KC_p}{\partial t} = \tau_{pp}^{UC}UC_p + \psi_{AC}KA_p + \alpha_{jp}^{UC}\tau_{jp}^{UC}UC_j + \alpha_{jp}^{KC}KC_j + \alpha_{jp}^{H}o_{jp}H_j + o_{pp}H_p$$
$$-(\psi_{CL} + \alpha_{pc}^{KC} + \eta_p^{C} + \mu_p^{KC})KC_p$$

HIV-positive/Late Stage Phase/Tested/Not on HAART Component:

Community: $$\frac{\partial KL_c}{\partial t} = \tau_{cc}^{UL}UL_c + \psi_{CL}KC_c + \alpha_{jc}^{UL}\tau_{jc}^{UL}UL_j + \alpha_{pc}^{UL}\tau_{pc}^{UL}UL_p + \alpha_{jc}^{KL}KL_j$$
$$+\alpha_{pc}^{KL}KL_p - (\alpha_{cj}^{KL} + \eta_c^{L} + \mu_c^{KL})KL_c$$

Jail: $$\frac{\partial KL_j}{\partial t} = \tau_{jj}^{UL}UL_j + \alpha_{cj}^{UL}\tau_{cj}^{UL}UL_c + \alpha_{cj}^{KL}KL_c + \psi_{CL}KL_c - (\alpha_{jc}^{KL} + \alpha_{jp}^{KL} + \eta_j^{L} + \mu_j^{KL})KL_j$$

Prison: $\frac{\partial KL_p}{\partial t} = \tau_{pp}^{UL} UL_p + \alpha_{jp}^{KL} KL_j + \alpha_{jp}^{UL} \tau_{jp}^{UL} UL_j + \psi_{CL} KC_p - (\alpha_{pc}^{KL} + \eta_p^{L} + \mu_p^{KL}) KL_p$

HIV-positive/Tested/on HAART Compartment:

Community:

$$\frac{\partial H_c}{\partial t} = \eta_c^A KA_c + \eta_c^C KC_c + \eta_c^L KL_c + \alpha_{jc}^H (1 - o_{jc}) H_j + \alpha_{pc}^H (1 - o_{pc}) H_p - (\alpha_{cj}^H + o_{cc} + \mu_c^H) H_c$$

Jail: $\frac{\partial H_j}{\partial t} = \eta_j^A KA_j + \eta_j^C KC_j + \eta_j^L KL_j + \alpha_{cj}^H (1 - o_{cj}) H_c - (\alpha_{jc}^H + \alpha_{jp}^H + o_{jj} + \mu_j^H) H_j$

Prison: $\frac{\partial H_p}{\partial t} = \eta_p^A KA_p + \eta_p^C KC_p + \eta_p^L KL_p + \alpha_{jp}^H (1 - o_{jp}) H_j - (\alpha_{pc}^H + o_{pp} + \mu_p^H) H_p$

Table 1. Initial Conditions for Men and MSM in Georgia for year-end 2014

Parameter	MSM	All Men	Description	References
Sc(0)	149,386	4,807,768	Susceptible in the community	17-22
Sj(0)	805	30,722	Susceptible in jail	18-20, 22
Sp(0)	1,282	48,950	Susceptible in prison	19, 20, 22
UAc(0)	30	39	HIV-positive and not tested during the acute phase in the community	17-20, 22, 24, 28
UAj(0)	0	1	HIV-positive and not tested during the acute phase in jail	17-20, 22, 24, 28
UAp(0)	0	0	HIV-positive and not tested during the acute phase in prison	19, 20, 24, 26
UCc(0)	2,814	3,555	HIV-positive and not tested during the chronic phase in the community	17-20, 22, 24, 28
UCj(0)	35	46	HIV-positive and not tested during the chronic phase in jail	17-20, 22, 24, 28
UCp(0)	0	0	HIV-positive and not tested during the chronic phase in prison	19, 20, 24, 26
ULc(0)	3,143	4,170	HIV-positive and not tested during the late stage phase in the community	17-20, 22, 24, 28
ULj(0)	39	54	HIV-positive and not tested during the late stage phase in jail	17-20, 22, 24, 28
ULp(0)	0	0	HIV-positive and not tested during the late stage phase in prison	19, 20, 24, 26
KAc(0)	66	85	HIV-positive and tested, not on HAART, during the acute phase in the community	17-20, 22, 24, 28
KAj(0)	0	1	HIV-positive and tested, not on HAART, during the acute phase in jail	17-20, 22, 24, 28
KAp(0)	1	2	HIV-positive and tested, not on HAART, during the acute phase in prison	17, 19, 20, 24, 26, 28

KCc(0)	6,193	7,820	HIV-positive and tested, not on HAART, during the chronic phase in the community	17-20, 22, 24, 28
KCj(0)	46	62	HIV-positive and tested, not on HAART, during the chronic phase in jail	17-20, 22, 24, 28
KCp(0)	128	172	HIV-positive and tested, not on HAART, during the chronic phase in prison	17, 19, 20, 24, 26, 28
KLc(0)	6,915	9,173	HIV-positive and tested, not on HAART, during the late stage phase in the community	17-20, 22, 24, 28
KLj(0)	52	73	HIV-positive and tested, not on HAART, during the late stage phase in jail	17-20, 22, 24, 28
KLp(0)	143	201	HIV-positive and tested, not on HAART, during the late stage phase in prison	17, 19, 20, 24, 26, 28
Hc(0)	10,778	13,974	HIV-positive and on HAART in the community	18-20, 22, 24
Hj(0)	178	245	HIV-positive and on HAART in jail	16-19, 21, 23
Hp(0)	284	391	HIV-positive and on HAART in prison	18, 19, 23

Table 2. Pertinent Information from GDPH Surveillance Summary for 2014

Total Population	10,097,343	
Population with HIV	53,230	
Persons living with Diagnosed HIV and Stage 3 (AIDS)	Count	Percent
Male (HIV)	40,033	75%
Male (AIDS)	21,453	76%
MSM (HIV)	30,845	77%
MSM (AIDS)	16,190	75%

Table 3. Cascade of Care for HIV from Iroh *et al.*

	HIV Diagnosed (%)	Linkage to Care (%)	Retention in Care (%)	ART (%)	Undetectable Viral Load (%)
National Average	80	62	41	36	28
Upon entry to jail/prison	78	56	40	42	21
During Incarceration	79	76	76	51	40
After Release	79	36	30	29	21