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Human Immunodeficiency Virus transmission by HIV risk group and along the HIV care continuum: A contrast of six US cities

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Abstract

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Background: Understanding the sources of HIV transmission provides a basis for prioritizing HIV prevention resources in specific geographic regions and populations. This study estimated the number, proportion, and rate of HIV transmissions attributable to individuals along the HIV care continuum, within different HIV transmission risk groups in six US cities.

Methods: We used a dynamic, compartmental HIV transmission model that draws on racial/ethnic- and risk-behavior-specific linkage to HIV care and use of HIV prevention services from local, state and national surveillance sources. We estimated the rate and number of HIV transmissions attributable to individuals in the stage of acute undiagnosed HIV, non-acute undiagnosed HIV, HIV diagnosed but antiretroviral therapy (ART) naïve, off ART, and on ART, stratified by HIV transmission group for the 2019 calendar year.

Results.—Individuals with undiagnosed non-acute HIV infection accounted for the highest proportion of total transmissions in every city, ranging from 36.8% [26.7%−44.9%] in New York City to 64.9% [47.0%−71.6%] in Baltimore. Individuals who had discontinued ART contributed to the second highest percentage of total infections in four of six cities. Individuals with acute HIV had the highest transmission rate per 100 person years, ranging from 76.4 [58.9–135.9] in Miami to 160.2 [85.7–302.8] in Baltimore.

Conclusion: These findings underline the importance of both early diagnosis and improved ART retention for ending the HIV epidemic in the US. Differences in the sources of transmission across cities indicate that localized priority-setting to effectively address diverse microepidemics at different stages of epidemic control is necessary.

Keywords

sources of HIV transmission; HIV care continuum; HIV transmission risk group; dynamic HIV transmission model

Introduction

Progress towards the control of HIV in the United States has stalled; approximately 38,000 new diagnoses of HIV have occurred annually since 2013.[1] In response, the United States' (US) declared the ambitious 'Ending the HIV Epidemic' (EHE) initiative, with goals to reduce the number of new HIV infections by 75% by 2025 and 90% by 2030.[2]

The HIV care continuum provides a population-level snapshot of the proportion of people living with HIV (PLHIV) at each stage of HIV clinical care, including diagnosis of HIV, access to antiretroviral therapy (ART) and continuous engagement on ART leading to viral suppression. Improving engagement across the HIV continuum of care has been part of the National HIV Strategy and is useful for measuring the performance of HIV care programs[3,4]. Estimates of the sources of HIV transmission along the HIV care continuum serve as a basis for understanding the number of deaths and cases that could be averted by focusing resources on individual continuum steps to maximize population health benefit. While previous analyses have estimated the number and rate of HIV transmissions arising from each step of the care continuum in 2009[5] and 2015[6] at the national level, these results are likely to differ across jurisdictions with varying epidemiological conditions and levels

of HIV services. Stratified analysis for each microepidemic is necessary to inform effective localized epidemic response.

To this end, we had previously published a series of articles using a dynamic, compartmental HIV transmission model that simulates HIV epidemics in six US cities, which accounted for nearly a quarter (24.1%) of all PLHIV nationally.[7–11] We used this model to reproduce city-level continuums of HIV care and identify localized combination strategies to help reach the EHE goals by 2030. Examining the sources of new HIV infections by steps along the care continuum is essential to help understand the underlying mechanisms for these recommendations and identify key transmission risk factors that may explain differences in recommendation across cities. This vital context has been cited as a critical gap in the effective dissemination of modeling results.[12] Doing so translates model outputs to better align with the types of evidence typically presented in surveillance reports, thus augmenting it and increasing the likelihood that this form of analysis is applied by decision makers.[12,13] These estimates can help reinforce the need for focused attention and resources in specific geographic regions and populations as a means of achieving the ambitious EHE goals – an approach consistent with the plan's conception.[2]

Our objective was to estimate the number and rate of HIV transmissions in 2019 attributable to individuals at each step of the HIV care continuum, and to stratify by HIV transmission risk group across six US cities, highlighting regional differences and focal populations for targeted intervention.

Methods

We estimated the number, proportion, and rate of HIV transmissions in 2019 attributable to individuals at each stage of the HIV continuum of care. HIV transmission was expressed as a rate per 100 person-years, with the number of PLHIV in each care continuum step as the denominator. City-level utilization of pre-exposure prophylaxis (PrEP), medication for opioid use disorder (MOUD), syringe service programs (SSP), HIV testing and ART engagement levels were held according to most recent data up to 2019[7] (Supplement A). To reflect current clinical care guidelines that recommend ART initiation immediately following HIV diagnosis,[14] we defined the following five continuum of care steps: (1) Acute undiagnosed HIV infection, (2) Non-acute undiagnosed HIV, (3) HIV diagnosed but ART naïve, (4) Off ART (i.e., diagnosed and initiated ART, but no ART prescription for at least 90 days), and (5) On ART. To assess heterogeneity across key population subgroups, results were stratified by sex, race/ethnicity, and HIV transmission risk group.

Model Description

We used a dynamic, compartmental HIV transmission model to simulate HIV microepidemics among adults aged 15–64 in six US cities: Atlanta (GA), Baltimore (MD), Los Angeles(LA) (CA), Miami (FL), New York City(NYC) (NY), and Seattle (WA).[11] The model tracked the population of adults susceptible to HIV infection through seroconversion, diagnosis, and treatment with ART, accounting for ART dropout and re-initiation. Disease progression was captured by transitions from acute infection to strata based on CD4 cell count (≥500, 200–499, and <200 cells/mL). For each city, the population was stratified by

biological sex (male or female), race/ethnicity (Black, Hispanic, non-Hispanic white/other), HIV transmission risk group (men who have sex with men [MSM], people who inject drugs [PWID], MSM-PWID, heterosexual), and sexual risk behavior intensity (high- or low-risk). The high-/low-risk stratification was defined by the proportion of MSM reporting condomless sex with casual partners (25%)[15] according to recommended indications for PrEP use[16] for MSM and MSM-PWID, and by the proportion of individuals who had 5 or more sexual partners in the past 12 months for heterosexuals.[17]

Within the model, the probability of HIV transmission was determined by: (i) the probability of selecting a sexual or injection partner living with HIV; (ii) the type of transmission risk (heterosexual or homosexual sexual activity, or sharing injection equipment); (iii) the infected individual's HIV disease stage (acute and then by CD4-based strata); (iv) the infected individual's ART status; (v) whether the uninfected individual was on PrEP; and (vi) the probability of condom use. We allowed for assortative mixing by race/ethnicity and sexual risk behavior intensity. According to a prior meta-analysis, individuals reduced their number of sexual partners by 68% (59%−76%) following HIV diagnosis.[18] We otherwise assumed PLHIV who discontinued ART (off ART) had the same HIV transmissibility and mortality rate as those who were ART naïve.

We previously published the results of an evidence synthesis executed to populate the model, which included local public health surveillance reports, peer reviewed publications and primary analyses of survey and health administrative data.[7] Of note, for this analysis we used HIV Research Network data which estimated ART engagement, dropout and re-initiation rates stratified by CD4-based strata, region, risk group, race/ethnicity and sex.[19] These CD4-based ART engagement estimates allowed us to capture recent initiation and re-initiation, individuals that may not be responding to their regimen as well as those with occasional non-adherence. ART initiation rates were supplemented with data from the Medical Monitoring Project 2010–2014 cycles.[20]

The model was calibrated to match HIV prevalence, new diagnoses and deaths, stratified by sex, race/ethnicity and HIV risk group and validated against additional external incidence estimates for each city.[11] From our prior research we have updated estimates for HIV services, including PrEP, MOUD, SSP and ART engagement, up to 2019 (Supplement Table 1). Based on the updated HIV service utilization data, the estimated proportion of people living with HIV along the HIV care continuum in 2019 are presented in Table 1. To standardize the estimates of transmission attributable to PLHIV on ART, we held ART effectiveness in reducing sexual transmissions at 91% according to a meta-analysis of prospective studies which provided estimates of ART effectiveness in real-life settings.[21] Further, the relative risk of transmission during acute HIV infection and the duration of acute infection were calibrated to fit local epidemiological targets in our previous applications. Differences across cities reflected population heterogeneity but also the uncertainty in other model parameters. For this exercise, we used our point estimates for the relative risk of transmission (5.3 times the transmission risk during non-acute stage)[22] and duration of acute HIV infection (1.7 months)[22] across all cities to ensure comparability in the percentage of HIV transmissions attributable to this stage. These estimates were drawn from a modeling analysis of a retrospective cohort of HIV serodiscordant couples in Rakai,

Uganda, which provided a reassessment of the relative infectivity and duration of the acute phase accounting for risk heterogeneity among study participants and potential biases from the retrospective cohort design.[22]

Sensitivity analysis

Probabilistic sensitivity analysis—To incorporate parameter uncertainty in our model, we estimated transmission projections as median values from 2,000 model runs for each city. The probabilistic sensitivity analysis samples were constructed by appending 2,000 best-fitting calibrated parameter sets with 2,000 random samples for all non-calibrated parameters simultaneously from predefined distributions.[11] We reported 95% credible intervals [CrIs] for projected transmission numbers, proportions, and rates at each step of the continuum.

Deterministic sensitivity analysis—We performed one-way sensitivity analysis on two parameters that our model differed from prior national studies and ones that were influential on the outcomes: (1) multiplier for the transmission probability during acute stage compared to non-acute stage, and (2) change in the number of sexual partners following diagnosis. More details for this sensitivity analysis and its results are presented in Supplement C.

Results

Of all projected new HIV transmissions in 2019, we estimated the highest percentage were attributable to people living with undiagnosed acute and non-acute HIV infection, ranging from 51.7% in NYC to 85.8% in Baltimore (Table 2). Among undiagnosed PLHIV, individuals with non-acute HIV accounted for the highest percentage of total transmissions in every city, ranging from 37.5% [95% CrI, 31.4%−42.3%] in NYC to 64.8% [51.0% −70.9%] in Baltimore. The percentage of transmissions from individuals with undiagnosed acute HIV ranged from 10.2% [8.0%−18.1%] in Miami up to 21.0% [11.5%−39.4%] in Baltimore. The percentage of transmissions attributable to those diagnosed with HIV but not yet on ART were no greater than Miami's 6.5% [4.9%−8.0%]. Individuals who discontinued ART (off ART) accounted for the second highest percentage of total infections in Atlanta (14.7% [11.5%−21.0%]), LA (28.4% [15.4%−42.3%]), Miami (18.0% [12.2%−28.0%]), and NYC (29.5% [16.4%−41.2%]). Transmissions attributable to individuals on ART were low in most cities but highest in NYC (13.2% [8.9%−17.0%]) and Seattle (13.9% [10.6% −18.3%]).

In all cities, transmission rates decreased with each successive step of the HIV continuum of care. People with undiagnosed acute HIV had the highest transmission rate per 100 person years (PYs) in every city, ranging from 76.4 [58.9–135.9] in Miami to 160.2 [85.7–302.8] in Baltimore. People with non-acute undiagnosed HIV had the second highest transmission rate in each city, and the highest in Baltimore (27.6 [18.1–31.1]). Comparatively, transmission rates among individuals off ART ranged from 1.8 [1.3–2.5] (Baltimore) to 5.5 [3.5–8.1] (LA), and were 0.5 or less in all cities among people on ART.

By HIV risk category, men who have sex with men accounted for the greatest percentage of transmissions (Supplement Table 2). Among MSM, transmissions largely occurred in those

with non-acute undiagnosed HIV, though relatively high proportions also occurred among PLHIV who were off ART in LA and NYC (Fig. 1). Overall, transmission rates per 100 person years were highest among MSM in Baltimore (8.8 [4.6–12.5]), LA (5.1 [4.1–6.9]) and NYC (2.3 [1.4–4.1]) and highest among PWID in Atlanta (4.8 [2.9–7.9]), Miami (5.5 [3.3–9.0]), and Seattle (2.6 [1.3–3.9]).

Discussion

In this modeling study of six cities which account for almost one-quarter of all PLHIV in the United States, we identified three major sources of incident HIV transmissions, including people with undiagnosed acute and non-acute HIV infection as well as people who discontinued ART. While these major sources identified are generally consistent, the order and magnitude of the proportions and rates of transmission from each step may differ from the prior national studies[5,6] given the large differences in city-level microepidemics and access to services therein. We also identified significant differences in the proportions of transmission across cities and population subgroups, indicating that localized priority-setting to effectively address diverse microepidemics at different stages of epidemic control is necessary.

These results underline the importance of the first pillar of the EHE initiative, which is to ‘diagnose all individuals with HIV as early as possible’.[2] Efforts across all cities to reduce transmission to meet EHE goals should target undiagnosed PLHIV through increased access to rapid, free or low-cost HIV testing coupled with effective linkage to care. We previously estimated that expanding HIV testing interventions (including MOUD-integrated rapid testing for PWID) was cost-effective or cost-saving in each of the 6 cities we considered, with long-term cost savings of up to $235.6 million in LA for electronic medical record testing reminders.[8] However, HIV testing interventions alone delivered at publicly-documented levels were estimated to have limited impact on incidence; with the most impactful testing intervention reducing incidence no more than 8% over 20 years.[8] These projections stress the need for more aggressive scale-up and likely more carefully-considered implementation strategies for HIV testing, including routine, universal HIV screening in health care settings,[23] the potential reach of interventions delivered outside of clinical settings (e.g., HIV self-testing),[24] and expanded screening among populations at high risk of HIV infection.[23] These efforts will be particularly crucial in Atlanta, Baltimore and Miami, three cities where undiagnosed PLHIV contributed to higher proportions of new HIV transmissions. Given the low rate of transmission from those on ART, it is equally important that newly diagnosed PLHIV should initiate ART as early as possible both to achieve the greatest reduction in transmission and for its direct clinical benefits.[22]

We also found differences in the sources and rates of transmission across cities. Many social and clinical factors may contribute to these differences, including the distribution of the population across HIV transmission risk groups, population demographics, mixing patterns in sexual contact networks, the heterogeneity in HIV risk behaviors, and different levels of HIV prevention and treatment services engagement. The highest proportions of HIV transmissions attributable to individuals on ART were observed in NYC (13.2%) and SEA (13.9%), which also have the highest populations of PLHIV on ART. The proportion

of on-ART HIV transmissions is thus likely to rise as ART coverage increases, but the rate of transmission during this step remains the lowest and will help lower the overall transmission rate. HIV transmission arising from individuals off ART was highest in LA (28.4%), a setting that had relatively poor ART engagement. We previously recommended the inclusion of an intervention that reduces ART dropout (i.e., electronic medical records ART engagement reminder) for these three cities (LA, NYC and Seattle) and Miami.[10] Meanwhile, in cities with relatively higher estimated rates of HIV transmission (Atlanta, Baltimore and Miami), targeted PrEP for high-risk MSM was recommended for further expansion in our prior study. Similarly, expanding SSP was recommended for cities with high rates of transmission from HIV-infected PWID. The HIV epidemic in the US is characterized by geographic regions with disparate epidemiological conditions, demographics, and healthcare infrastructure.[25] The differences across cities identified in this study underline the importance of developing targeted prevention strategies informed by local epidemiological conditions. While surveillance reports have primarily focused on care engagement, explicating the sources of HIV transmission allows for further identification of the underlying drivers of each microepidemic and potential ramifications for HIV prevention.

Unlike previous studies (Skarbinski model[5], CDC model[6]) that analyzed the proportions of transmissions along each step of the care continuum at the national level, our analysis provided city-specific estimates accounting for their heterogeneities in healthcare access, socioeconomic and transmission risk behaviours. Our analysis otherwise differed in several key respects. First, definitions of the steps in the care continuum differed: we disaggregated undiagnosed HIV infection by acute and non-acute stages, differentiated those diagnosed with HIV but not retained on ART as ART naïve (HIV diagnosed but ART naïve) and ART experienced (off ART), and characterized change in HIV transmissibility during non-acute stage only by whether PLHIV are on ART. These distinctions result in recommendations for more focused intervention strategies, specifically for those undiagnosed following acute infection, and those having discontinued ART. There were also notable differences in the proportion of transmissions attributable to undiagnosed PLHIV. We estimated that people living with undiagnosed HIV infection accounted for the majority (51.7%−85.5%) of HIV transmission in all six cities, whereas the Skarbinski model[5] and CDC model[6] estimated a more moderate 30.2% and 37.6% from this population subgroup. These differences may be setting-related, as we focused exclusively on major urban centers where HIV care resources are more concentrated with higher percentages of PLHIV diagnosed and retained in treatment (61%−83% in our model) compared to the national average (33% and 51% in Skarbinski and CDC models).[26] According to HIV surveillance data in the US, 80% of all PLHIV, and 81% of new diagnoses were recorded in large metropolitan areas (population > 500,000) in 2018.[27] In addition, in contrast to the Skarbinski model[5] which assumed a higher number of sexual partners and injection drug use and needle sharing among individuals diagnosed with HIV (but not in care) than those with undiagnosed HIV, we allowed for a reduced average number of sexual partners (68%) following diagnosis according to a meta-analysis comparing high-risk sexual behavior in PLHIV aware and unaware of their serostatus.[18] This resulted in a significantly lower transmission rate when PLHIV were diagnosed in our model and lower proportions of transmissions from these

stages in each city. The deterministic sensitivity analysis found that a change to this parameter might result in very different estimates for proportions of transmissions from undiagnosed and diagnosed stages (Supplement C). Our estimates indicate that the benefits of early detection and treatment may be greater, and more important in achieving epidemic control than previously thought. Another major difference in this analysis is the HIV transmission rate during the acute stage; our estimates (4–6 times the rate of non-acute) were substantially higher than the CDC model[6] (only 90% higher than non-acute), while the Skarbinski model[5] did not account for the acute stage. This higher transmission rate in acute HIV infection was based on a prior modeling study that fitted closely with the cohort data in Rakai, Uganda, which provided a rigorous assessment of HIV infectivity and the duration of the acute phase.[22] This study has accounted for possible sources of bias in previous published estimates and provided revised estimates considerably lower than all previous studies. The resulting estimated rates of transmission per 100 person years from the acute stage in our model were more in line with a highly cited statistical analysis that was fitted directly to the same Rakai, Uganda cohort data.[28] The deterministic sensitivity analysis also confirmed the sensitivity of model results to this parameter (Supplement C). Our results highlight the important role the acute stage may play in the spread of HIV, as well as the population impact of prevention interventions such as PrEP for persons at high risk of HIV infection to mitigate such high risk of transmission.

Limitations of the model itself are documented in previous publications,[7–11] and those most pertinent to this analysis are largely due to limitations in the underlying evidence base. First, there is a dearth of high-quality, externally valid data pertaining to the numbers of HIV tests administered and the size of infected but undiagnosed PLHIV for each city. Our HIV testing rates were derived during model calibration and validation. This indirect estimation of HIV testing rates may result in uncertainty in the size of the population with undiagnosed HIV and, subsequently, the number of transmissions attributable to this population. Second, although the ongoing COVID-19 pandemic may have profoundly affected the course of the HIV epidemic across the US, we did not attempt to extend our analysis to the year of 2020 given that evidence on HIV service provision and potential changes in HIV risk behaviours is still emerging.[29] In addition, we did not explicitly account for HIV transmissions that may occur across boundaries of each city. However, one previous HIV transmission network analysis has shown that persons residing in large central metro counties were least often linked to viruses outside the same or adjacent counties at HIV diagnosis.[30]

The estimates of the number of transmissions attributable to each step of the care continuum highlight how undiagnosed HIV infections and inadequate retention in care lead to onward transmission and undermine progress towards epidemic control. Rather than a homogeneous national epidemic, the HIV epidemic in the US is a collection of diverse local microepidemics featuring different levels of engagement in HIV services and varying degrees of epidemic control. Comprehensive and targeted strategies are therefore needed to address these localized priorities to maximize epidemiological impact towards achieving EHE goals in each setting.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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References

1. CDC. Estimated HIV incidence and prevalence in the United States, 2010–2016. HIV Surveillance Supplemental Report. In. Vol 242019.
2. Fauci AS, Redfield RR, Sigounas G, Weahkee MD, Giroir BP. Ending the HIV epidemic: a plan for the United States. Jama. 2019;321(9):844–845. [PubMed: 30730529]
3. Obama B Executive Order - HIV Care Continuum Initiative. https://obamawhitehouse.archives.gov/the-press-office/2013/07/15/executive-order-hiv-care-continuum-initiative. Published 2013. Accessed October 15, 2020.
4. U.S. Department of Health and Human Services. HIV National Strategic Plan for the United States: A Roadmap to End the Epidemic 2021– 2025. Washington, DC. https://hivgov-prod-v3.s3.amazonaws.com/s3fs-public/HIV-National-Strategic-Plan-2021-2025.pdf. Published 2021. Accessed February 5, 2021.
5. Skarbinski J, Rosenberg E, Paz-Bailey G, et al. Human immunodeficiency virus transmission at each step of the care continuum in the United States. JAMA Intern Med. 2015;175(4):588–596. [PubMed: 25706928]
6. Li Z, Purcell DW, Samson SL, Hayes D, Hall I. Vital Signs: HIV Transmission Along the Continuum of Care — United States, 2016 Morbidity and Mortality Weekly. 2019;68(11):267–272.
7. Krebs E, Enns B, Wang L, et al. Developing a dynamic HIV transmission model for 6 U.S. cities: An evidence synthesis. PLOS ONE. 2019;14(5):e0217559. [PubMed: 31145752]
8. Krebs E, Zang X, Enns B, et al. The impact of localized implementation: determining the cost-effectiveness of HIV prevention and care interventions across six U.S. cities. AIDS. 2020;34(3):447–458. [PubMed: 31794521]
9. Nosyk B, Zang X, Krebs E, et al. Ending the Epidemic in America Will Not Happen if the Status Quo Continues: Modeled Projections for Human Immunodeficiency Virus Incidence in 6 US Cities. Clin Infect Dis. 2019;69(12):2195–2198. [PubMed: 31609446]
10. Nosyk B, Zang X, Krebs E, et al. Ending the HIV epidemic in the USA: an economic modelling study in six cities. Lancet HIV. 2020.
11. Zang X, Krebs E, Min J, et al. Development and calibration of a dynamic HIV transmission model for 6 US cities. Medical Decision Making. 2020;40(1):3–16. [PubMed: 31865849]
12. Nosyk B, Weiner J, Krebs E, et al. Dissemination Science to Advance the Use of Simulation Modeling: Our Obligation Moving Forward. Medical Decision Making. 2020;40(6):718–721. [PubMed: 32755285]
13. Estabrooks PA, Brownson RC, Pronk NP. Dissemination and implementation science for public health professionals: an overview and call to action. Preventing chronic disease. 2018;15.
14. Adolescents." PoAGfAa. Guidelines for the use of antiretroviral agents in adults and adolescents living with HIV. US Department of Health and Human Services.
15. Control CfD, Prevention. HIV Risk, Prevention, and Testing Behaviors—National HIV Behavioral Surveillance System, Men Who Have Sex with Men, 20 US Cities, 2011. HIV surveillance special report. 2014;8:1–40.
16. Prevention CfDCa. Preexposure prophylaxis for the prevention of HIV infection in the United States - 2017 Update: a clinical practice guideline. https://www.cdc.gov/hiv/pdf/risk/prep/cdc-hiv-prep-guidelines-2017.pdf. Published 2018. Accessed August 25, 2020.

17. Centers for Disease Control and Prevention. Public use data file documentation. 2011–2013. National Survey of Family Growth. User's guide. Hyattsville, Maryland: Centers for Disease Control and Prevention, National Center for Health Science; December, 2014 2014.
18. Marks G, Crepaz N, Senterfitt JW, Janssen RS. Meta-analysis of high-risk sexual behavior in persons aware and unaware they are infected with HIV in the United States: implications for HIV prevention programs. Journal of acquired immune deficiency syndromes. 2005;39(4):446–453. [PubMed: 16010168]
19. Wang L, Krebs E, Min JE, et al. Combined estimation of disease progression and retention on antiretroviral therapy among treated individuals with HIV in the USA: a modelling study. The Lancet HIV. 2019;6(8):e531–e539. [PubMed: 31303557]
20. CDC. Behavioral and Clinical Characteristics of Persons Receiving Medical Care for HIV Infection—Medical Monitoring Project, United States. In:2016.
21. Baggaley RF, White RG, Hollingsworth TD, Boily MC. Heterosexual HIV-1 infectiousness and antiretroviral use: systematic review of prospective studies of discordant couples. Epidemiology. 2013;24(1):110–121. [PubMed: 23222513]
22. Bellan SE, Dushoff J, Galvani AP, Meyers LA. Reassessment of HIV-1 acute phase infectivity: accounting for heterogeneity and study design with simulated cohorts. PLoS medicine. 2015;12(3):e1001801. [PubMed: 25781323]
23. Owens DK, Davidson KW, Krist AH, et al. Screening for HIV infection: US preventive services task force recommendation statement. Jama. 2019;321(23):2326–2336. [PubMed: 31184701]
24. Johnson CC, Kennedy C, Fonner V, et al. Examining the effects of HIV self-testing compared to standard HIV testing services: a systematic review and meta-analysis. Journal of the International AIDS Society. 2017;20(1):21594. [PubMed: 28530049]
25. Panagiotoglou D, Olding M, Enns B, et al. Building the Case for Localized Approaches to HIV: Structural Conditions and Health System Capacity to Address the HIV/AIDS Epidemic in Six US Cities. AIDS and behavior. 2018;22(9):3071–3082. [PubMed: 29802550]
26. Schafer KR, Albrecht H, Dillingham R, et al. The Continuum of HIV Care in Rural Communities in the United States and Canada: What Is Known and Future Research Directions. J Acquir Immune Defic Syndr. 2017;75(1):35–44. [PubMed: 28225437]
27. Centers for Disease Control and Prevention. Diagnoses of HIV infection among adults and adolescents in metropolitan statistical areas - United States and Puerto Rico, 2018. HIV Surveillance Data Tables 2020. http://www.cdc.gov/hiv/library/reports/hiv-surveillance.html. Published 2020. Accessed October 15, 2020.
28. Hollingsworth TD, Anderson RM, Fraser C. HIV-1 transmission, by stage of infection. The Journal of infectious diseases. 2008;198(5):687–693. [PubMed: 18662132]
29. Zang X, Krebs E, Chen S, et al. The Potential Epidemiological Impact of Coronavirus Disease 2019 (COVID-19) on the Human Immunodeficiency Virus (HIV) Epidemic and the Cost-effectiveness of Linked, Opt-out HIV Testing: A Modeling Study in 6 US Cities. Clinical Infectious Diseases. 2021;72(11):e828–e834. [PubMed: 33045723]
30. Board AR, Oster AM, Song R, et al. Geographic distribution of HIV transmission networks in the United States. JAIDS Journal of Acquired Immune Deficiency Syndromes. 2020;85(3):e32–e40. [PubMed: 32740373]

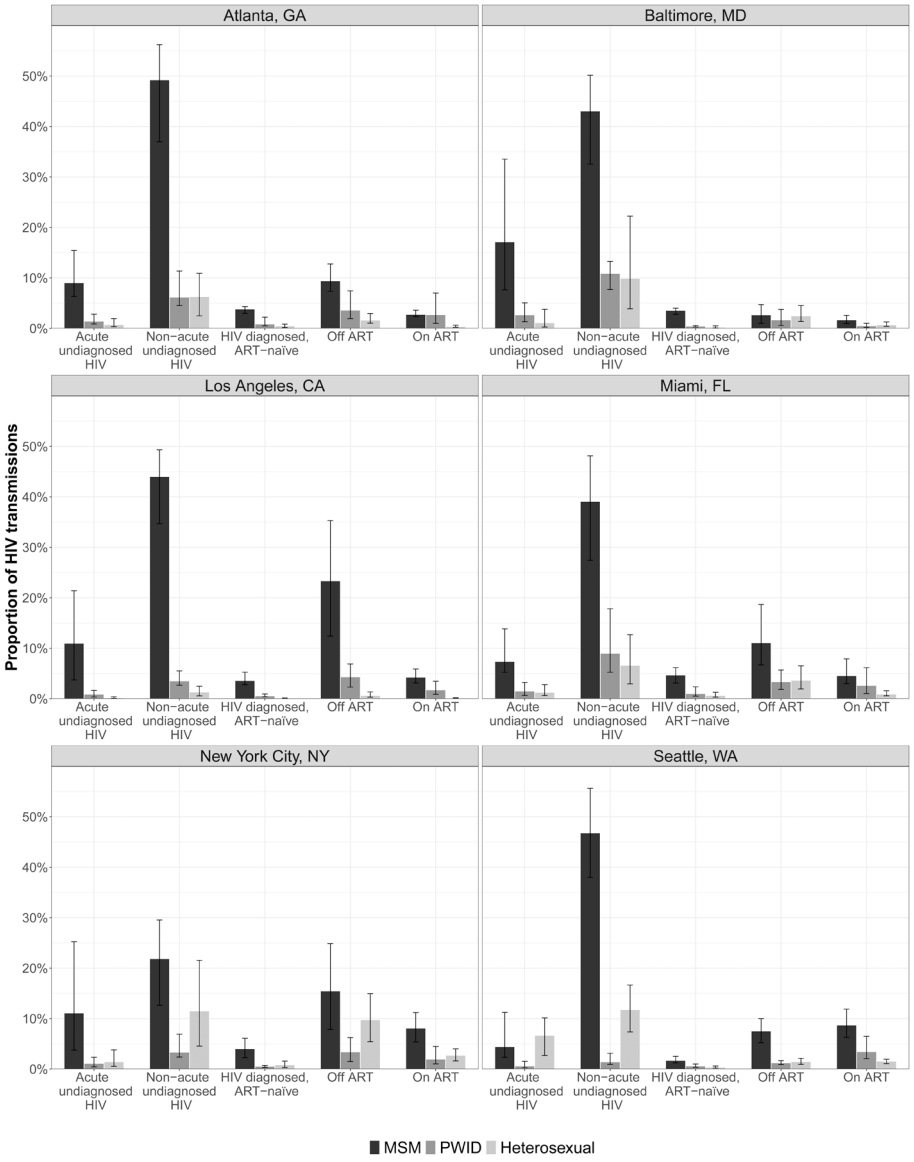

Figure 1. Estimated proportion of HIV transmissions along the HIV care continuum in 2019, by HIV transmission risk group, in six US cities.

MSM: men who have sex with men; PWID: people who inject drugs (including MSM who inject drugs). Percentages in each city (5 HIV care continuum steps * 3 HIV risk groups) sum to 100%.

Table 1.

Estimated proportion of persons living with HIV along the HIV care continuum in 2019, in six US cities.

	HIV Care Continuum Step (95% CrI)				
	Acute undiagnosed HIV	**Non-acute undiagnosed HIV**	**HIV diagnosed; ART naive**	**Off ART**	**On ART**
Atlanta (GA)	0.5% (0.3–0.6)	11.2% (9.0–12.7)	2.9% (2.5–3.3)	20.4% (19.2–21.9)	65.0% (63.2–67.3)
Baltimore (MD)	0.6% (0.3–0.8)	10.0% (8.1–12.3)	1.7% (1.4–2.1)	15.8% (14.6–17.1)	71.9% (68.7–74.8)
Los Angeles (CA)	0.6% (0.5–0.8)	10.9% (9.3–12.6)	2.6% (2.3–3.1)	24.7% (22.3–27.2)	61.1% (57.6–64.3)
Miami (FL)	0.4% (0.3–0.6)	9.7% (7.8–13.0)	3.1% (2.7–3.6)	17.7% (16.5–18.9)	68.9% (65.7–71.3)
New York City (NY)	0.2% (0.1–0.3)	3.0% (2.2–4.1)	1.1% (0.8–1.5)	15.7% (14.5–17.0)	79.9% (77.5–82.0)
Seattle (WA)	0.3% (0.3–0.4)	9.7% (8.3–11.1)	0.9% (0.8–1.1)	5.7% (4.6–6.9)	83.4% (81.1–85.4)

CrI: credible interval.

Table 2.

Estimated HIV transmissions along the HIV care continuum in 2019, in six US cities.

	HIV Care Continuum Step (95% CrI)				
	Acute undiagnosed HIV	**Non-acute undiagnosed HIV**	**HIV diagnosed, ART naïve**	**Off ART**	**On ART**
Atlanta (GA)					
No. of transmissions	189 (88–322)	1013 (523–1412)	86 (47–120)	236 (174–303)	91 (58–157)
Percentage of total transmissions	11.3% (9.0–18.3)	61.8% (54.1–66.8)	5.2% (4.8–6.0)	14.7% (11.5–21.0)	6.0% (4.0–10.1)
Transmission rate per 100 PY	83.9 (65.8–135.4)	19.9 (12.7–24.3)	6.5 (4.3–7.9)	2.6 (1.9–3.3)	0.3 (0.2–0.5)
Baltimore (MD)					
No. of transmissions	170 (56–505)	519 (287–698)	34 (18–51)	54 (36–79)	23 (18–29)
Percentage of total transmissions	21.0% (11.5–39.4)	64.8% (51.0–70.9)	4.2% (3.7–4.7)	6.8% (3.5–11.7)	2.9% (1.8–4.5)
Transmission rate per 100 PY	160.2 (85.7–302.8)	27.6 (18.1–31.1)	10.6 (6.9–12.4)	1.8 (1.3–2.5)	0.2 (0.1–0.2)
Los Angeles (CA)					
No. of transmissions	324 (107–852)	1347 (970–2042)	120 (79–210)	780 (488–1192)	174 (133–243)
Percentage of total transmissions	12.2% (4.5–22.7)	49.3% (40.0–53.4)	4.3% (3.4–6.1)	28.4% (15.4–42.3)	6.2% (4.4–8.4)
Transmission rate per 100 PY	91.0 (33.6–171.4)	21.5 (16.8–27.2)	7.8 (5.9–11.5)	5.5 (3.5–8.1)	0.5 (0.4–0.7)
Miami (FL)					
No. of transmissions	92 (53–231)	500 (280–793)	58 (37–82)	163 (123–223)	75 (54–114)
Percentage of total transmissions	10.2% (8.0–18.1)	56.0% (44.0–63.0)	6.5% (4.9–8.0)	18.0% (12.2–28.0)	8.4% (5.5–13.0)
Transmission rate per 100 PY	76.4 (58.9–135.9)	17.2 (11.4–23.6)	6.3 (4.4–8.0)	3.1 (2.4–4.2)	0.4 (0.3–0.6)
New York City (NY)					
No. of transmissions	229 (70–754)	641 (342–1149)	92 (46–184)	492 (338–663)	224 (163–290)
Percentage of total transmissions	14.2% (5.8–28.7)	37.5% (31.4–42.3)	5.5% (4.0–7.4)	29.5% (16.4–41.2)	13.2% (8.9–17.0)
Transmission rate per 100 PY	109.3 (44.0–227.8)	19.3 (13.5–26.7)	7.8 (5.1–11.5)	2.9 (2.1–3.7)	0.3 (0.2–0.3)
Seattle (WA)					
No. of transmissions	22 (10–42)	108 (79–145)	5 (3–8)	18 (13–26)	25 (19–33)
Percentage of total transmissions	12.2% (6.8–19.5)	60.5% (52.8–66.8)	2.8% (2.0–3.9)	10.4% (7.4–13.2)	13.9% (10.6–18.3)
Transmission rate per 100 PY	91.5 (50.7–146.8)	15.4 (12.6–18.1)	7.6 (5.6–10.7)	4.4 (3.4–5.6)	0.4 (0.3–0.5)

CrI: credible interval; PY: person year.