Optimal Allocation of Societal HIV Prevention Resources to Reduce HIV Incidence in the United States

Stephanie L. Sansom, PhD, MPP, MPH, Katherine A. Hicks, MS, Justin Carrico, BS, Evin U. Jacobson, PhD, Ram K. Shrestha, PhD, Timothy A. Green, PhD, and David W. Purcell, JD, PhD

See also Friedman et al., p. 12, and Galea and Vaughan, p. 17.

Objectives. To optimize combined public and private spending on HIV prevention to achieve maximum reductions in incidence.

Methods. We used a national HIV model to estimate new infections from 2018 to 2027 in the United States. We estimated current spending on HIV screening, interventions that move persons with diagnosed HIV along the HIV care continuum, pre-exposure prophylaxis, and syringe services programs. We compared the current funding allocation with 2 optimal scenarios: (1) a limited-reach scenario with expanded efforts to serve eligible persons and (2) an ideal, unlimited-reach scenario in which all eligible persons could be served.

Results. A continuation of the current allocation projects 331 000 new HIV cases over the next 10 years. The limited-reach scenario reduces that number by 69%, and the unlimited reach scenario by 94%. The most efficient funding allocations resulted in prompt diagnosis and sustained viral suppression through improved screening of high-risk persons and treatment adherence support for those infected.

Conclusions. Optimal allocations of public and private funds for HIV prevention can achieve substantial reductions in new infections. Achieving reductions of more than 90% under current funding will require that virtually all infected receive sustained treatment. (*Am J Public Health*. 2021;111:150–158. https://doi.org/10.2105/AJPH.2020.305965)

AJPH January 2021, Vol 111, No. 1

As HIV heads into its fifth decade in the United States, treatment has improved remarkably, so that even those diagnosed in their 20s can achieve nearly normal life expectancy, though at a lifetime cost approaching $500 000.[1,2] The annual number of new infections has dropped precipitously from an estimated 130 000 in 1985, but has stalled at about 39 000 a year since 2013.[3,4] An estimated 1.1 million persons are living with HIV, but only 86% are aware of their infection, and only 53% are receiving sustained treatment sufficient for transmission-eliminating, life-prolonging viral suppression.[5]

In 2019, the US Department of Health and Human Services (HHS) proposed the "Ending the HIV Epidemic: A Plan for America" initiative. This federal effort aims to reduce the annual number of new infections to fewer than 3000 or less than 1 per 100 000 population, which, per the World Health Organization, defines epidemic control. HHS plans to achieve this aim by coordinating the programs, resources, and infrastructure of its many agencies and offices.[6] In addition to federal agencies, state and local governments and the private sector also provide significant support for HIV prevention and treatment.

Optimal resource allocation methods can help determine the most efficient use of HIV prevention funds to reduce new infections. Previous HIV resource allocation models have examined the most efficient use of funds from 1 or 2 federal agencies.[7,8] However, given the ambitiousness of the current initiative to end the HIV epidemic, an evaluation of combined societal funding—public and private—may shed more light on whether and how elimination might be achieved. In this article, we estimate societal funding for HIV prevention and its optimal allocation to curtail HIV incidence in the United States.

METHODS

We applied the HIV Optimization and Prevention Economics (HOPE) model, a dynamic, compartmental model that simulates that portion of the US population aged 13 to 64 years that is sexually active or drug injecting.[9] Our analytic time horizon was 2018 through 2027. We built HOPE in MATLAB (MathWorks, Natick, MA). An extensive description of the model's design, inputs, assumptions, and calibration can be found in the appendix of Khurana et al.[9]

Key Model Inputs

The model required data to describe the US population, particularly persons with HIV (PWH), HIV risk behaviors and their associated transmission risks, the cost and efficacy of HIV prevention and treatment, and the transition rates of PWH along the care continuum and across disease stages. To obtain estimated values for most model inputs, we reviewed and summarized the published, peer-reviewed literature and surveillance data (Appendix, Section 1, Table A, available as a supplement to the online version of this article at http://www.ajph.org). To obtain transition rates along the HIV care continuum, as well as the values of other inputs for which data were limited or uncertain, we calibrated the inputs, selecting values within bounds informed by published literature, unpublished data, or expert opinion. We calibrated these inputs so that model outcomes matched surveillance data for 1 or multiple time points from 2010 to 2016. The matched outcomes included HIV incidence by transmission category and gender, HIV prevalence for the United States as a whole, and the proportion of PWH estimated to be in each continuum stage.

Prevention Interventions Considered in the Model

Persons with HIV who through treatment are able to achieve and maintain a viral load of fewer than 200 copies per milliliter, hereafter referred to as viral suppression, have effectively no risk of sexual transmission.[10–13] As a result, important HIV prevention strategies include early diagnosis, prompt linkage to care, rapid initiation of antiretroviral therapy (ART), and maintenance in care and treatment. In addition, preexposure prophylaxis (PrEP)[14–16] and syringe services programs (SSPs)[17–19] are effective tools to prevent infection in persons at high risk of acquiring HIV (Figure 1). Thus, we considered allocations to 14 interventions:

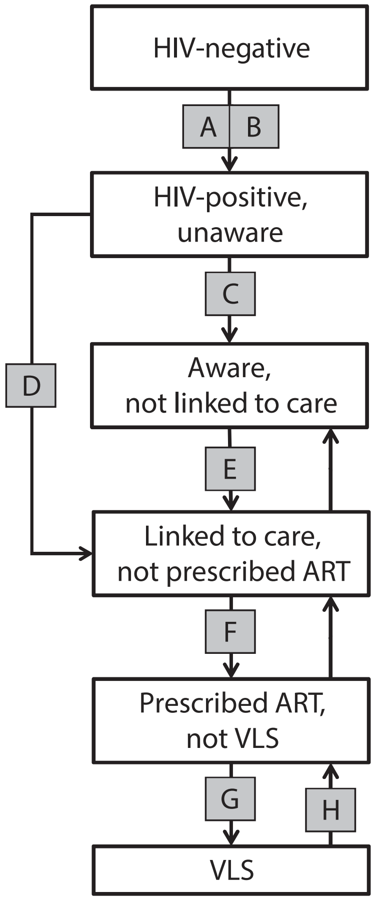
1. HIV screening for high- and low-risk men who have sex with men (MSM), high- and low-risk heterosexuals, and all persons who inject drugs (PWID; 5 interventions);
2. HIV care–continuum interventions influencing linkage to care at and after diagnosis, prescription of ART, and adherence to care and treatment to achieve and maintain viral suppression (5 interventions);
3. PrEP for high-risk MSM, high-risk heterosexuals, and all PWID (3 interventions); and
4. SSPs (1 intervention).

Estimation of Current Funds and Optimal Allocation

We derived total funding for each intervention by multiplying the cost per person served by the annual number served. For diagnosis in particular, we estimated the average cost per diagnosis for each risk group by dividing the costs of screening and diagnosis by the total number of diagnoses. For interventions that move PWH along the HIV care continuum, we assessed the average number of persons reaching each step of the continuum (e.g., linking to care, being prescribed ART, achieving and maintaining viral suppression) annually from 2018 to 2027. We determined the average annual number of persons reaching each step of the continuum by model calibration, so that the modeled number matched published HIV surveillance data on the care continuum in 2010, and either 2015 or 2016 (the most recent data for each step). We projected rates of change between the 2 time periods forward through 2027 in the current allocation. Per-person costs (Appendix, Table A) were based on published studies of interventions.

We based the per-person PrEP cost on the annual 2018 drug cost of $12 599[20] plus an annual monitoring cost of $1431.[21] The estimated number receiving PrEP in 2018 was 100 292.[22] Thus, the estimated total cost of PrEP delivery in the United States was $1.4 billion. We estimated the per-person cost in 2018 for syringe services programs, $234, by using data on the median annual number of syringes used by PWID[23] and the cost of injection equipment.[19,24] The cost of needle-using equipment per injection itself was derived from the estimate of the total costs of SSPs nationally ($24.5 million) and the number of syringes distributed under those programs (45.9 million).[19] All costs in the model were expressed in 2018 US dollars. We assumed that the current allocation of total HIV prevention funding remained fixed from 2018 through 2027 under the current allocation scenario.

Although not included in the optimization, we estimated care and treatment costs by disease stage and progress along the HIV care continuum. We assumed that everyone linked to care received care, and that those prescribed ART received ART, unless they dropped



	Intervention	How Intervention Affects Model Flow
A	PrEP	Decreases the number of individuals who become HIV-infected
B	SSP	Decreases the number of PWID who become HIV-infected
C	Screening	Increases the number of undiagnosed HIV-infected individuals who become diagnosed with HIV
D	Linkage to care at diagnosis	Increases the number of undiagnosed HIV-infected individuals who become diagnosed with HIV and are immediately linked to care
E	Linkage to care after diagnosis	Increases the number of individuals who are aware of their infection but not in care who are linked to care
F	ART prescription	Increases the number of individuals who are prescribed ART
G	Adherence to care and treatment to become virally suppressed	Increases the number of individuals who are prescribed ART but are not virally suppressed who become virally suppressed
H	Adherence to care and treatment to remain virally suppressed	Decreases the number of individuals who lose their VLS status

FIGURE 1— Diagram of How HIV Prevention Interventions Relate to HIV and the HIV Care Continuum: United States

Note. ART = antiretroviral therapy; PrEP = pre-exposure prophylaxis; PWID = persons who inject drugs; SSP = syringe services programs; VLS = viral load suppression.

out of care. The per-person annual ART cost used in the model was $25 059.[20] We included health-care utilization costs for HIV-related illness.

Using the estimated total prevention funds and the current allocation of those funds, we explored optimal allocations of the funding across interventions and populations in 2 scenarios: a limited-reach scenario in which estimates of the maximum percentage of eligible persons who could be reached by each intervention reflected expanded efforts to serve such persons, and an idealistic, unlimited-reach scenario in which all eligible persons could be reached by each intervention, given sufficient funding. Changes in allocations to interventions under the 2 scenarios slowed the annual rate of movement to related care continuum steps when funding decreased, and accelerated it when funding increased.

Assumptions about the expected proportion of eligible persons who could be reached under the limited-reach scenario fall between the proportion currently reached and 100% in the unlimited reach scenario (Appendix, Table A). To model the effect of prevention funding, which is typically provided in 5-year increments, we estimated the optimal allocation of these funds for the 5-year time periods 2018 to 2022 and 2023 to 2027. We reported the results of the 2 consecutive 5-year allocations that, when combined, produced the greatest reduction in new HIV infections over 10 years.

For our current allocation scenario, we estimated the number of HIV infections that would occur from 2018 through 2027 if the current allocation of total HIV prevention funding remained fixed throughout that period. Then, assuming the same amount of funding, we used optimization techniques (from MATLAB's Optimization Toolbox) and the HOPE model to estimate the 2018–2022 and 2023–2027 allocations that would prevent the most HIV infections from 2018 through 2027. We outline the full optimization formulation in Sections 2 and 3 of the Appendix.

Key outcomes included the optimal allocations to HIV screening, the HIV care–continuum interventions, PrEP, SSPs, and the resulting number of new HIV infections from 2018 to 2027. We projected changes in the proportions of PWH who had achieved each step along the HIV care continuum by 2027, and we noted changes in average annual treatment costs.

Uncertainty and Sensitivity Analyses

We conducted sensitivity and uncertainty analyses, and we present the methods and results of those analyses in Section 4 of the Appendix.

RESULTS

We estimated total 2018 national HIV prevention funding of $2.6 billion (Table 1). Among prevention interventions, we estimated 30.0% currently was allocated to HIV screening, including 25.3% for low-risk heterosexuals and 1.2% for high-risk MSM; 16.7% to interventions that move people along the HIV care continuum, including 5.7% and 9.7% to interventions that support adherence to care and treatment to achieve and to maintain viral suppression, respectively; 52.5% to PrEP, including 6.0% to high-risk heterosexuals and 46.4% to high-risk MSM; and 0.9% to SSPs. When we continued the estimated current allocation through 2027, the model projected a total HIV incidence over that period of 331 051 cases, or 33 100 a year on average (Figure 2; Table 2).

Limited-Reach Scenario

The optimal allocation for the limited-reach scenario was largely influenced by the percentage of eligible persons who we specified as reachable. For both 5-year time periods, the model allocated the maximum amount possible to 10 of the 14 interventions given the limit on the percentage of eligible persons who could be reached, indicating that even more would be spent on those interventions (and less on others) in the absence of those limits. The interventions funded to the maximum level included the screening of all risk groups except low-risk heterosexuals, all HIV care–continuum interventions, and SSPs.

For the first 5 years of the limited-reach scenario, the optimal allocation included 14.9% for screening, 36.7% for the HIV care–continuum interventions, 46.0% for PrEP, and 2.4% for SSPs. Major increases (defined as 5 or more rounded percentage points) in the proportion of prevention funding allocated to a particular intervention between the current and optimal scenarios during the first 5-year time period occurred in screening high-risk heterosexuals (2.4% to 9.3%), interventions that support adherence to care and treatment to achieve viral suppression (5.7% to 13.7%), and interventions that support adherence to care and treatment to sustain viral suppression (9.7% to 19.1%; Table 1). Major decreases occurred in screening of low-risk heterosexuals (25.3% to 0.4%) and PrEP for high-risk heterosexuals (6.0% to 0.0%). In the second time period, a major increase in funding, compared with the first 5-year period in the limited-reach scenario, occurred in PrEP for high-risk MSM (from 46.0% to 59.5%). A major decrease occurred in interventions that support adherence to care and treatment to achieve viral suppression (13.7% to 5.1%).

These consecutive 5-year optimal allocations were associated with a decrease in 10-year cumulative HIV incidence of 69% compared with the current allocation, from 331 051 cases to 103 359 cases (or 10 400 cases per year on average; Table 2). At the end of the 10 years, among all risk groups with the exception of low-risk heterosexuals, 99% of persons with HIV were diagnosed (for low-risk heterosexuals, 85% of those infected were diagnosed), 98% were linked to care, 98% had been prescribed ART, and 86% had achieved viral suppression.

Unlimited-Reach Scenario

In the optimal allocation for the unlimited-reach scenario, of the 14 interventions, 6 were funded for everyone eligible during the first 5 years and 7 during the second 5 years. During the first 5 years, fully funded interventions included screening of high-risk MSM and interventions that increase linkage to care at and after diagnosis, increase ART prescription, and support adherence to care and treatment to achieve and maintain viral suppression. During the second 5 years, interventions that were fully funded were the same as during the first 5 years but also included SSPs.

For the first 5 years of the unlimited-reach scenario, the optimal allocation included 35.4% for HIV screening, 64.6% for interventions that move people along the HIV care continuum, 0.0% for PrEP, and 0.0% for SSPs. Major increases in the proportion of prevention funding allocated to a particular intervention in the first 5 years of the unlimited-reach scenario compared with the first 5 years of the limited-reach scenario included screening high-risk heterosexuals (from 9.3% to 14.1%), screening high-risk MSM (from 2.7% to 16.2%), interventions that

AJPH January 2021, Vol 111, No. 1

TABLE 1— Allocations Under the Current and Optimal HIV Prevention–Related Allocation Scenarios: United States, 2018–2027

Outcome	Current Allocation, $ Million (% of HIV Prevention Funding), 2018–2027	Optimal Allocation With Limited Reach, $ Million (% of HIV Prevention Funding)		Optimal Allocation With Unlimited Reach, $ Million (% of HIV Prevention Funding)	
		2018–2022	2023–2027	2018–2022	2023–2027
Prevention funding for screening					
High-risk HETs	62.5 (2.4)	243.1 (9.3)[a]	230.2 (8.8)[a]	368.0 (14.1)	247.5 (9.5)
Low-risk HETs	662.8 (25.3)	11.4 (0.4)	4.0 (0.2)	0.2 (0.0)	1 276.9 (48.8)
High-risk MSM	30.3 (1.2)	69.5 (2.7)[a]	56.8 (2.2)[a]	425.3 (16.2)[a]	200.0 (7.6)[a]
Low-risk MSM	17.9 (0.7)	29.2 (1.1)[a]	34.3 (1.3)[a]	94.7 (3.6)	45.8 (1.7)
PWID	10.9 (0.4)	29.2 (1.1)[a]	26.7 (1.0)[a]	38.9 (1.5)	76.8 (2.9)
Proportion of prevention budget for screening	(30.0)	(14.9)	(13.4)	(35.4)	(70.5)
Prevention funding for care continuum					
Linkage to care at diagnosis	18.4 (0.7)	64.1 (2.4)[a]	7.7 (0.3)[a]	9.1 (0.3)[a]	2.9 (0.1)[a]
Linkage to care after diagnosis	15.4 (0.6)	33.6 (1.3)[a]	8.2 (0.3)[a]	189.6 (7.2)[a]	2.5 (0.1)[a]
ART prescription	1.2 (0.0)	3.7 (0.1)[a]	1.5 (0.1)[a]	35.9 (1.4)[a]	16.2 (0.6)[a]
Adherence to care and treatment to become virally suppressed	148.9 (5.7)	358.9 (13.7)[a]	132.4 (5.1)[a]	807.4 (30.8)[a]	4.9 (0.2)[a]
Adherence to care and treatment to remain virally suppressed	253.6 (9.7)	499.7 (19.1)[a]	499.1 (19.1)[a]	649.3 (24.8)[a]	625.8 (23.9)[a]
Proportion of prevention budget for care continuum	(16.7)	(36.7)	(24.8)	(64.6)	(24.9)
Prevention funding for PrEP					
For high-risk HETs	158.1 (6.0)	0.1 (0.0)	0.3 (0.0)	0.0 (0.0)	0.0 (0.0)
For high-risk MSM	1 215.4 (46.4)	1 205.3 (46.0)	1 557.4 (59.5)	0.0 (0.0)	0.0 (0.0)
For PWID	0.0 (0.0)	0.1 (0.0)	0.3 (0.0)	0.0 (0.0)	0.0 (0.0)
Proportion of prevention budget for PrEP	(52.5)	(46.0)	(59.5)	(0.0)	(0.0)
Prevention funding for syringe services programs	23.1 (0.9)	63.6 (2.4)[a]	59.4 (2.3)[a]	0.0 (0.0)	119.1 (4.5)[a]
Total prevention funding	2 618.5	2 618.5	2 618.5	2 618.5	2 618.5
Average annual treatment and care funding	35 199 (93.1)	35 731 (93.2)	34 845 (93.0)	36 615 (93.3)	33 693 (92.8)
Total funding	37 520.7	38 349.6	37 463.6	39 233.7	36 311.1

Note. ART = antiretroviral therapy; HETs = sexually active heterosexuals; MSM = men who have sex with men; PrEP = pre-exposure prophylaxis; PWID = persons who inject drugs.

[a]Allocation to this intervention was limited by the maximum percentage of eligible persons who we assumed could be reached (in the limited-reach scenario) or by the maximum number of persons eligible (in the unlimited-reach scenario).

increase linkage to care after diagnosis (from 1.3% to 7.2%), interventions that support adherence to care and treatment to become virally suppressed (from 13.7% to 30.8%), and interventions that support adherence to care and treatment to remain virally suppressed (from 19.1% to 24.8%). A major decrease occurred in PrEP for high-risk MSM (from 46.0% to 0.0%).

In the unlimited-reach scenario, compared with the first 5-year time period, major increases in the allocation of prevention funding during the second 5-year time period included screening low-risk heterosexuals (from 0.0% to 48.8%) and SSPs (from 0.0% to 4.5%). Major decreases occurred in screening high-risk MSM (from 16.2% to 7.6%), interventions that increase linkage to care after diagnosis (from 7.2% to 0.1%),

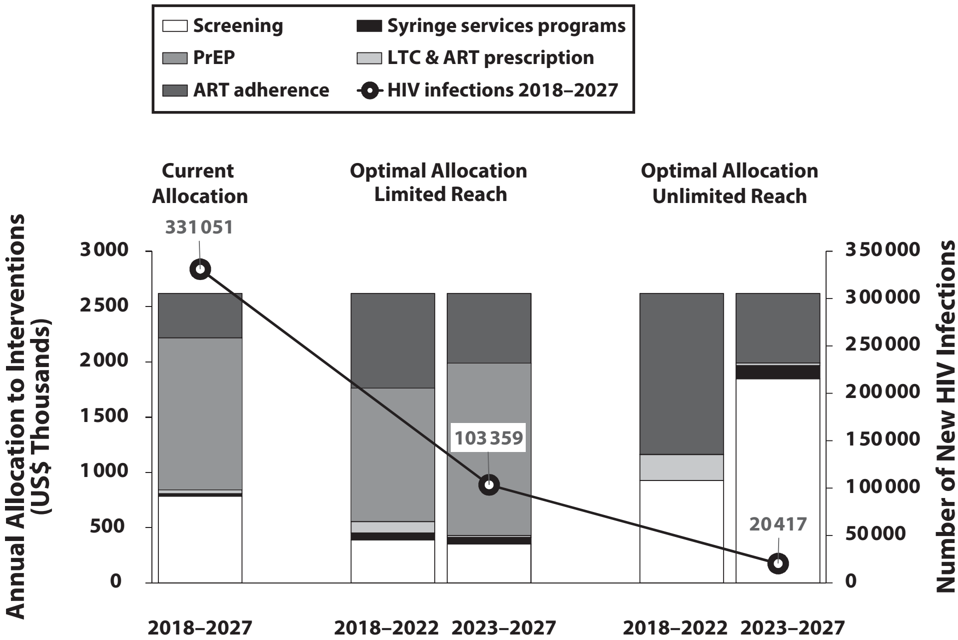


FIGURE 2— Annual Allocations to HIV Care–Continuum Interventions Under Current and Optimal Allocation Scenarios and Associated Cumulative Number of HIV Infections: United States, 2018–2027

Note. ART = antiretroviral therapy; LTC = linkage to care; MSM = men who have sex with men; PrEP = pre-exposure prophylaxis; PWID = persons who inject drugs. The same total prevention funding was applied in the 3 scenarios, but the allocations differed. Allocations to screening, PrEP, and interventions that increase linkage to care and support adherence to care and treatment represented allocations across subpopulations. Screening, for instance, included high- and low-risk MSM, high- and low-risk heterosexuals, and all PWID; PrEP included allocations to high-risk MSM, high-risk heterosexuals, and all PWID; linkage-to-care interventions influenced linkage at and after diagnosis; and interventions that support adherence to care and treatment included allocations to both achieve and maintain viral suppression. The dots on the solid black line indicate the 10-year cumulative incidence of HIV associated with a 10-year allocation of current funding and the 2 consecutive 5-year allocations under the 2 optimal distributions.

and interventions that support adherence to care and treatment to become virally suppressed (from 30.8% to 0.2%).

The optimal allocation in the unlimited-reach scenario was associated with a decrease in 10-year cumulative HIV incidence of 94%, from 331 051 cases to 20 417 cases (or 2000 cases per year on average) compared with the current scenario. At the end of the 10 years, nearly all infections (> 99.7%) were diagnosed; however, among low-risk heterosexuals, only 97% of infections were diagnosed. Nearly all persons with HIV (> 99.7%) were linked to care, prescribed ART, and virally suppressed.

DISCUSSION

Models, no matter the complexity or degree of validation, cannot fully represent the dynamics of HIV infection or capture the uncertainties inherent in HIV prevention program implementation. However, when tested carefully, modeling can provide insights into strategies more likely than others to achieve large reductions in HIV incidence. Our results suggest that the current estimated allocation of HIV prevention funds, if maintained over the next 10 years, is likely to be associated with stable incidence rates of approximately 33 100 cases a year. The current allocation spends a large proportion of prevention funding on testing low-risk heterosexuals and on PrEP for high-risk MSM. Although PrEP has been clinically proven to be highly efficacious in preventing acquisition of HIV among those susceptible,[14–16] models comparing interventions show that it is less effective in reducing new HIV cases nationally than ensuring that those already infected cannot transmit to others by achieving and maintaining viral suppression with effective ART.[9] Our analysis focused on the most efficient use of constant annual prevention funding to prevent new cases of HIV. Only after the most efficient interventions are funded are the remaining dollars shifted to less efficient interventions.

When compared with the current allocation, optimal allocations increased funding for screening populations at high risk of acquiring HIV and for interventions that move people along the HIV care continuum, especially those that support adherence to achieve and maintain viral suppression. The result was a surge in the percentage of persons with HIV whose infection was

TABLE 2— Outcomes Under the Current and Optimal HIV Prevention–Related Allocation Scenarios: United States, 2018–2027

Outcome	Current Allocation, No. Cases or % Distribution	Optimal Allocation With Limited Reach, No. Cases (% Difference vs Current Allocation) or % Distribution	Optimal Allocation With Unlimited Reach, No. Cases (% Difference vs Current Allocation) or % Distribution
10-year cumulative HIV incidence			
HETs	55 420	26 019 (−53)	6 746 (−88)
MSM	267 301	71 529 (−73)	11 262 (−96)
PWID	8 330	5 811 (−30)	2 409 (−71)
Total	331 051	103 359 (−69)	20 417 (−94)
Distribution of PWH along care continuum in 2027			
Diagnosed			
High-risk HETs	91	99	100
Low-risk HETs	82	85	97
High-risk MSM	88	99	100
Low-risk MSM	87	99	100
PWID	98	99	100
Linked to care	88	98	100
Prescribed ART	85	98	100
VLS among all PWH	51	86	100

Note. ART = antiretroviral therapy; HETs = sexually active heterosexuals; MSM = men who have sex with men; PWH = persons with HIV; PWID = persons who inject drugs; VLS = viral load suppression.

AJPH January 2021, Vol 111, No. 1

diagnosed and who were virally suppressed, and a sharp reduction in incidence over 10 years. The model reflects the clinical reality that when everyone infected is virally suppressed, transmission comes to a halt.[25]

We evaluated 2 optimization scenarios: a limited-reach scenario in which estimates of the maximum percentage of eligible persons who could be reached by each intervention reflected expanded efforts to serve such persons, and an idealistic, unlimited-reach scenario in which all eligible persons could be reached by each intervention. The largest reduction in HIV incidence over 10 years was observed in the ideal, unlimited-reach scenario that required nearly all persons infected with HIV to be diagnosed promptly and effectively treated to achieve and maintain viral suppression.

To more closely mimic how prevention programs are funded, we structured the model to allow for 2 consecutive 5-year allocations rather than a single 10-year allocation. In the limited-reach scenario, the optimal allocation for the first 5 years invested every dollar possible into screening all risk groups except low-risk heterosexuals, linking diagnosed persons to care and treatment, and supporting efforts to achieve and maintain viral suppression. Funding HIV screening and the HIV care–continuum interventions according to the optimal allocation, however, required only 51.6% of available prevention funds because of constraints on the number who could be reached. Sufficient funds thus were left over to allocate enough to support all persons eligible for SSPs. Even then, nearly half of all funds were unallocated, and most (46.0%) went to PrEP for high-risk MSM. In the unlimited-reach scenario, in which all eligible persons could be reached, the model increased allocations to HIV screening and to interventions that moved people along the care continuum, and these interventions absorbed all prevention funds, so that none were available for SSPs and PrEP.

In both the limited- and unlimited-reach scenarios, allocations in the second 5-year period served to shore up gains made in infections prevented during the first 5 years and to shift funds no longer required for screening, linkage, ART prescription, and achieving viral suppression into less cost-effective interventions. For instance, in the limited-reach scenario, even more funding was allocated to PrEP for high-risk MSM. In the unlimited-reach scenario, nearly half of all funds were allocated to screening low-risk heterosexuals, many of whom were unreachable in the limited-reach scenario.

Reductions in incidence over time resulted in reductions in annual HIV care and treatment costs, estimated at $35.2 billion per year on average from 2018 to 2027 in the current allocation scenario. In both the limited- and unlimited-reach scenarios, those costs rose above the average during the first 5 years to pay for the increased number of persons diagnosed and on ART and dropped below it during the final 5 years as the number of new HIV cases decreased. In the limited-reach scenario, they dropped 1.0% ($354 million/year) compared with current costs, and in the unlimited-reach scenario, they dropped 4.3% ($1.5 billion/year), indicating the large potential health care savings when HIV incidence drops.

Limitations

Our analysis has a number of potential limitations. We assumed that moving each PWH along each step of the care continuum required an average expenditure based on published cost data. However, for some people the move may have been costless, whereas for others it may have been more costly than we assumed. Because of lack of data, we did not increase intervention costs in either optimal allocation scenarios as higher percentages of eligible persons were reached or for subgroups that historically have been hard to reach. Better assessments of how intervention costs change for the hardest to reach will be important for understanding the full costs of HIV elimination in the United States.

We did not explicitly account for costs incurred as funds are transferred downstream from agencies to program providers, although these costs can be substantial. However, the Kaiser Family Foundation reported that the federal fiscal year 2018 request for domestic HIV prevention funds was $0.9 billion.[26] Considering that our estimated $2.6 billion prevention cost included $1.4 billion in funds for PrEP, typically incurred by the private sector, our public sector funding was approximately $1.2 billion. This amount is reasonably consistent with the Kaiser estimate, although we used very different methods to derive it. We were not able to include some interventions that have been implemented in local communities; we call for additional scientific research to demonstrate the efficacy of these interventions in preventing HIV.

Public Health Implications

In conclusion, optimizing the allocation of current societal investments in HIV prevention could achieve substantial reductions in new infections. Our results are consistent with and build on previous findings from models that optimized funding from the perspective of 1 or 2 government agencies. Given stable funding and the current effectiveness of intervention delivery, sizeable reductions in HIV incidence may be realized by focusing on screening persons at highest risk of HIV, linking the newly diagnosed to care, and supporting those in treatment to achieve and maintain viral suppression. Funds then could be spent on primary prevention programs including syringe services and PrEP for high-risk MSM.

Modeling an unlimited-reach scenario, in which all persons eligible for prevention and treatment can be reached, while aspirational, is instructive because it reinforces the idea that the path to HIV elimination, given current funding, is one that focuses primarily on prompt diagnosis with sustained treatment of those infected. Implementing optimal allocations will require careful planning so that implementation is done in accordance with community input and governing rules, laws, and ethics. Our results highlight which interventions to fund and how much to fund them to achieve maximum reductions in HIV transmission. However, models such as ours do not prescribe how best to deliver those interventions, especially for the hardest-to-reach populations. Determining best delivery strategies will be an important next step for program managers and implementation scientists. AJPH

ABOUT THE AUTHORS

Stephanie L. Sansom, Evin U. Jacobson, Ram K. Shrestha, Timothy A. Green, and David W. Purcell are with the Division of HIV/AIDS Prevention, Centers for Disease Control and Prevention (CDC), Atlanta, GA. Katherine A. Hicks and Justin Carrico are with RTI Health Solutions, Raleigh, NC.

CORRESPONDENCE

Correspondence should be sent to Stephanie L. Sansom, PhD, MPP, MPH, 1600 Clifton Road NE, US8-2, Atlanta, GA 30329 (e-mail: ssansombiz@gmail.com). Reprints can be ordered at http://www.ajph.org by clicking the "Reprints" link.

PUBLICATION INFORMATION

Full Citation: Sansom SL, Hicks KA, Carrico J, et al. Optimal allocation of societal HIV prevention resources to reduce HIV incidence in the united states. *Am J Public Health*. 2021;111(1):150–158.

Acceptance Date: September 4, 2020.

DOI: https://doi.org/10.2105/AJPH.2020.305965

CONTRIBUTORS

S. L. Sansom conceptualized the analysis; oversaw the model design and parameterization; reviewed and refined model results, tables, and figures; and drafted and edited the article. K. A. Hicks and J. Carrico developed the model design and parameterization; coded and ran the model; produced results, tables, and figures; drafted the technical appendix; and reviewed and edited the article. E. U. Jacobson reviewed model inputs and coding, reviewed tables and figures, and edited the article and technical appendix. R. K. Shrestha developed intervention costs based on published literature and independent calculations, reviewed figures and tables, and edited the article and technical

appendix. T. A. Green and D. W. Purcell reviewed the conceptual framework and results; reviewed and edited tables, figures, and the article; and provided insights on policy and programmatic implications of the results.

ACKNOWLEDGMENTS

All funding for this project came from the CDC.

The authors gratefully acknowledge the contributions of Paul Farnham, PhD, Jennifer Kates, PhD, John Brooks, MD, and Nidhi Khurana, PhD, for reviews of the article and helpful comments.

Note. The findings and conclusions are those of the authors and do not necessarily represent the views of the CDC.

CONFLICTS OF INTEREST

None of the authors have potential or actual conflicts of interest.

HUMAN PARTICIPANT PROTECTION

Institutional review board approval was not needed for this analysis because it was based on published data.

REFERENCES

1. Antiretroviral Therapy Cohort Collaboration. Survival of HIV-positive patients starting antiretroviral therapy between 1996 and 2013: a collaborative analysis of cohort studies. *Lancet HIV*. 2017;4(8):e349–e356. https://doi.org/10.1016/S2352-3018(17)30066-8
2. Farnham PG, Gopalappa C, Sansom SL, et al. Updates of lifetime costs of care and quality-of-life estimates for HIV-infected persons in the United States: late versus early diagnosis and entry into care. *J Acquir Immune Defic Syndr*. 2013;64(2):183–189. https://doi.org/10.1097/QAI.0b013e3182973966
3. Centers for Disease Control and Prevention. Estimated HIV incidence and prevalence in the United States, 2010–2016. HIV Surveillance Supplemental Report. 2019;24(1). Available at: http://www.cdc.gov/hiv/library/reports/hiv-surveillance.html. Accessed July 11, 2019.
4. Hall HI, Song R, Rhodes P, et al.; HIV Incidence Surveillance Group. Estimation of HIV incidence in the United States. *JAMA*. 2008;300(5):520–529. https://doi.org/10.1001/jama.300.5.520
5. Centers for Disease Control and Prevention. Monitoring selected national HIV prevention and care objectives by using HIV surveillance data—United States and 6 dependent areas, 2017. HIV Surveillance Supplemental Report. 2019;24(3). Available at: https://www.cdc.gov/hiv/pdf/library/reports/surveillance/cdc-hiv-surveillance-supplemental-report-vol-24-3.pdf. Accessed December 30, 2019.
6. 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. https://doi.org/10.1001/jama.2019.1343
7. Lasry A, Sansom SL, Hicks KA, Uzunangelov V. Allocating HIV prevention funds in the United States: recommendations from an optimization model. *PLoS One*. 2012;7(6):e37545. https://doi.org/10.1371/journal.pone.0037545
8. Yaylali E, Farnham PG, Cohen S, Purcell DW, Hauck H, Sansom SL. Optimal allocation of HIV prevention funds for state health departments. *PLoS One*. 2018;13(5):e0197421. https://doi.org/10.1371/journal.pone.0197421
9. Khurana N, Yaylali E, Farnham PG, et al. Impact of improved HIV care and treatment on PrEP effectiveness in the United States, 2016–2020. *J Acquir Immune Defic Syndr*. 2018;78(4):399–405. https://doi.org/10.1097/QAI.0000000000001707
10. Bavinton BR, Pinto AN, Phanuphak N, et al.; Opposites Attract Study Group. Viral suppression and HIV transmission in serodiscordant male couples: an international, prospective, observational, cohort study. *Lancet HIV*. 2018;5(8):e438–e447. https://doi.org/10.1016/S2352-3018(18)30132-2
11. Cohen MS, Chen YQ, McCauley M, et al.; HPTN 052 Study Team. Antiretroviral therapy for the prevention of HIV-1 transmission. *N Engl J Med*. 2016;375(9):830–839. https://doi.org/10.1056/NEJMoa1600693
12. Rodger AJ, Cambiano V, Bruun T, et al.; PARTNER Study Group. Risk of HIV transmission through condomless sex in serodifferent gay couples with the HIV-positive partner taking suppressive antiretroviral therapy (PARTNER): final results of a multicentre, prospective, observational study. *Lancet*. 2019;393(10189):2428–2438. https://doi.org/10.1016/S0140-6736(19)30418-0
13. Rodger AJ, Cambiano V, Bruun T, et al.; PARTNER Study Group. Sexual activity without condoms and risk of HIV transmission in serodifferent couples when the HIV-positive partner is using suppressive antiretroviral therapy. *JAMA*. 2016;316(2):171–181. https://doi.org/10.1001/jama.2016.5148
14. Baeten JM, Donnell D, Ndase P, et al.; Partners PrEP Study Team. Antiretroviral prophylaxis for HIV prevention in heterosexual men and women. *N Engl J Med*. 2012;367(5):399–410. https://doi.org/10.1056/NEJMoa1108524
15. Grant RM, Lama JR, Anderson PL, et al.; iPrEx Study Team. Preexposure chemoprophylaxis for HIV prevention in men who have sex with men. *N Engl J Med*. 2010;363(27):2587–2599. https://doi.org/10.1056/NEJMoa1011205
16. Thigpen MC, Kebaabetswe PM, Paxton LA, et al.; TDF2 Study Group. Antiretroviral preexposure prophylaxis for heterosexual HIV transmission in Botswana. *N Engl J Med*. 2012;367(5):423–434. https://doi.org/10.1056/NEJMoa1110711
17. Adams M, An Q, Broz D, Burnett J, Wejnert C, Paz-Bailey G; NHBS Study Group. Distributive syringe sharing and use of syringe services programs (SSPs) among persons who inject drugs. *AIDS Behav*. 2019;23(12):3306–3314. https://doi.org/10.1007/s10461-019-02615-4
18. Aspinall EJ, Nambiar D, Goldberg DJ, et al. Are needle and syringe programmes associated with a reduction in HIV transmission among people who inject drugs: a systematic review and meta-analysis. *Int J Epidemiol*. 2014;43(1):235–248. https://doi.org/10.1093/ije/dyt243
19. Des Jarlais DC, Nugent A, Solberg A, Feelemyer J, Mermin J, Holtzman D. Syringe service programs for persons who inject drugs in urban, suburban, and rural areas—United States, 2013. *MMWR Morb Mortal Wkly Rep*. 2015;64(48):1337–1341. https://doi.org/10.15585/mmwr.mm6448a3
20. US Department of Veterans Affairs. Pharmaceutical prices. Federal supply schedule, Office of Procurement, Acquisition and Logistics (OPAL). 2018. Available at: https://www.va.gov/opal/nac/fss/pharmPrices.asp. Accessed July 18, 2019.
21. Desai K, Sansom SL, Ackers ML, et al. Modeling the impact of HIV chemoprophylaxis strategies among men who have sex with men in the United States: HIV infections prevented and cost-effectiveness. *AIDS*. 2008;22(14):1829–1839. https://doi.org/10.1097/QAD.0b013e32830e00f5
22. Sullivan PS, Giler RM, Mouhanna F, et al. Trends in the use of oral emtricitabine/tenofovir disoproxil fumarate for pre-exposure prophylaxis against HIV infection, United States, 2012–2017. *Ann Epidemiol*. 2018;28(12):833–840. https://doi.org/10.1016/j.annepidem.2018.06.009
23. Centers for Disease Control and Prevention. HIV infection, risk, prevention, and testing behaviors among persons who inject drugs—National HIV Behavioral Surveillance: injection drug use, 20 US Cities, 2015. *HIV Surveillance Special Report*. May 2018;18. Available at: http://www.cdc.gov/hiv/library/reports/hiv-surveillance.html. Accessed January 7, 2019.
24. Nguyen TQ, Weir BW, Des Jarlais DC, Pinkerton SD, Holtgrave DR. Syringe exchange in the United States: a national level economic evaluation of hypothetical increases in investment. *AIDS Behav*. 2014;18(11):2144–2155. https://doi.org/10.1007/s10461-014-0789-9
25. Centers for Disease Control and Prevention. HIV treatment as prevention. 2019. Available at: https://www.cdc.gov/hiv/risk/art/index.html. Accessed July 18, 2019.
26. Henry J. Kaiser Family Foundation. US federal funding for HIV/AIDS: trends over time. 2019. Available at: http://files.kff.org/attachment/Fact-Sheet-US-Federal-Funding-for-HIVAIDS-Trends-Over-Time. Accessed July 12, 2019.