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Improving Estimation of HIV Viral Suppression in the United States: A Method to Adjust HIV Surveillance Estimates From the Medical Monitoring Project Using Cohort Data

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The US Centers for Disease Control and Prevention has estimated human immunodeficiency virus (HIV) viral suppression (VS) using 2 data sources. The National HIV Surveillance System estimate (50% of HIV-diagnosed persons in 2012) is derived from viral load reporting from a subset of jurisdictions that vary yearly. The Medical Monitoring Project (MMP) estimate (42% of HIV-diagnosed persons in 2012) is based on a sample of persons receiving HIV care during the first 4 months of each year. We developed the cohort-adjustment method to reconstruct VS estimates, accounting for persons receiving care later in the year. Using the HIV Outpatient Study cohort, we assessed timing of care receipt, demographics, and VS at last test (<200 vs. ≥200 copies/mL), standardizing MMP to HIV Outpatient Study data using multivariable regression models and yielding adjusted VS estimates. We estimated that 52% (95% CI: 48, 56) of HIV-diagnosed persons achieved VS in 2012. Differences from previously published estimates were due to: 1) 23% underestimation of persons receiving HIV care, and 2) lower VS rates among persons receiving care outside versus inside the 4-month MMP sampling period (79% vs. 88%). This methodology yielded VS estimates closer to the National HIV Surveillance System estimate than previously published. Use of more, geographically diverse cohort data may enable assessment of temporal trends.

cohort studies; HIV surveillance; indirect standardization; viral suppression

Abbreviations: CDC, Centers for Disease Control and Prevention; CI, confidence interval; HIV, human immunodeficiency virus; HOPS, HIV Outpatient Study; MMP, Medical Monitoring Project; NHSS, National HIV Surveillance System; SP, sampling period; VL, viral load; VS, viral suppression.

Antiretroviral therapy improves the health of persons living with human immunodeficiency virus (HIV) infection (1, 2), can substantially increase life expectancy (3), and greatly reduces the risk of transmitting HIV through suppression of viral replication (4). The prevalence of viral suppression (VS) among persons living with diagnosed HIV is one of the primary indicators used to demonstrate progress toward US HIV prevention and treatment goals and, as the endpoint of the HIV care continuum, also represents successful engagement in HIV care (5). Temporal trends in VS are requisite for understanding and predicting changes in HIV disease burden over time. However, 2 US Centers for Disease Control and Prevention (CDC) surveillance systems—the National HIV Surveillance System (NHSS) and the Medical Monitoring Project (MMP)—have historically yielded different VS estimates. For example, in 2012, according to MMP data, an estimated 41.7% of persons living with diagnosed HIV had VS (plasma HIV RNA viral load (VL) <200 copies/mL), compared with 50.1% of diagnosed persons from jurisdictions reporting viral load data to NHSS (6). Analytical methods are needed to increase understanding of these inconsistencies; in this work, we have described such a method.

It is important to understand how data limitations might bias VS estimates. NHSS is the flagship national HIV surveillance system and uses viral load laboratory results from diagnosed persons to estimate VS. However, not all jurisdictions meet reporting completeness standards in any given year, and the jurisdictions

that meet these standards vary year to year (28 states and the District of Columbia in 2009, 33 in 2012) (7). The number and geographic diversity of jurisdictions adequately reporting laboratory data have increased in recent years (7), but the year-to-year variability in which jurisdictions' data are included render NHSS data limited at this time for describing temporal trends. The MMP is a supplemental surveillance system, based on a complex sample of jurisdictions, producing nationally representative, cross-sectional estimates of behavioral and clinical characteristics of adults diagnosed with HIV in the United States, including the percent with VS (8). Before 2015, MMP estimates were based on a sample of adults receiving HIV clinical care during the first 4 months of a given year (8). MMP expanded in 2015 to sample all persons living with diagnosed HIV, including but not limited to those in care, but pre-2015 estimates excluded persons receiving care later in the year.

When MMP was designed in 2005, sampling during the first 4 months of a given year captured an estimated 88% of all persons attending HIV clinical care during the year (9) while expediting data collection. However, HIV clinical care guidelines and practices have changed considerably since. Antiretroviral therapy initiation is now recommended at the time of HIV diagnosis, so fewer care visits may be needed to monitor patients' immune function prior to treatment initiation, and for many patients, less-frequent clinical care may be needed to monitor health status when taking highly effective and safe antiretroviral therapy regimens (10). As patients tended to have less-frequent HIV care visits over the last decade, they may have been less likely to be captured by MMP's sampling period (SP) and thus not represented in a given year's VS estimate. If, as suggested by previous research, frequency of clinical care is associated with VS (11, 12), resulting VS estimates may be compromised by selection bias.

Both MMP and NHSS are improving as sources of VS data, but there is an interim need for VS estimates that are nationally representative and can be compared over time. To achieve this for MMP, we developed an analytical method to assess and correct for selection biases by reconstructing the population of persons with VS by standardizing MMP data to HIV clinical cohort data. Using data from the HIV Outpatient Study (HOPS), we assessed our method's potential to measure the extent to which less-frequent care attendance during the first 4 months of the year may have affected national VS estimates derived from MMP.

METHODS

Cohort-adjustment method

The cohort-adjustment method uses principles of indirect standardization (13) and synthetic estimation (14) to estimate the proportion of individuals receiving HIV medical care during the year who would not have been sampled by MMP. In indirect standardization, one projects onto the target population an estimated outcome, measured on a reference population, according to the demographic composition of the target population. Synthetic estimation is a related technique in which one uses a statistical model derived from a reference population to project an outcome onto the target population. The method then estimates VS for this unsampled group using stratum-specific suppression prevalences based on MMP estimates, in combination with the relative probability of VS given care attendance based on an external reference cohort of persons receiving care for HIV infection throughout the year.

Equations 1 and 2 (described in Web Appendix 1, available at https://academic.oup.com/aje) estimate, respectively, $\hat{T}_{\tilde{S}_i}$ and $\hat{V}_{\tilde{S}_i}$, the number receiving HIV medical care and the number with VS at the most recent test, exclusively outside of the MMP SP. These equations can be expressed in terms of 4 primary model parameters, A–D; A) estimated number receiving HIV medical care during the MMP SP, in the United States; B) estimated odds of care receipt exclusively outside of the SP, among those receiving care during the year; C) estimated proportion with VS (viral load <200 copies/mL) at the most recent test, among people receiving care during the SP, in the United States; D) estimated prevalence ratio for VS at the most recent test, comparing persons receiving care exclusively outside of the MMP SP versus persons receiving at least some care during the MMP SP. When multiplied, parameters A and B yield the number of persons receiving HIV care but missed by MMP sampling ($\hat{T}_{\tilde{S}_i}$), which, further multiplied by C and D, yields the number of such persons who have VS ($\hat{V}_{\tilde{S}_i}$).

Parameters A and C are respectively estimated as weighted totals and proportions, with their standard errors, from the MMP sample (15). Parameters B and D may be estimated via stratified analyses or logistic regression using reference-cohort participants receiving any care during the calendar year. For example, in the application using the HOPS described below, parameters B and D were estimated from 2 logistic regression models, which respectively modeled care attendance during the SP and VS conditional on attendance during the SP. Both models had terms for known confounders (sex, age) and their product terms, equivalent to a fully stratified contingency analysis (16). The second model additionally had main and product terms for care attendance during the SP. Point estimates and standard errors were estimated for the odds (parameter B) and prevalence ratios (parameter D) at each linear combination of covariate values, using unconditional maximum likelihood and predicted marginals methods (17).

These quantities $\hat{T}_{\tilde{S}_i}$ and $\hat{V}_{\tilde{S}_i}$ are then combined with MMP-based weighted estimates via addition within strata, to yield analogous quantities $\hat{T}_{\tilde{S}\cup S}$ and $\hat{V}_{\tilde{S}\cup S}$, representing adjusted estimators of the total number receiving HIV medical care and number with VS at the most recent test, in the United States, for the whole calendar year (equations 3 and 4, Web Appendix 1). These quantities are used to construct common HIV-epidemic indicators, such as the proportion of persons living with an HIV diagnosis who have VS ($\hat{p}\,(U|\tilde{S}\cup S)$; equation 5, Web Appendix 1).

Illustration of the cohort-adjustment method

We illustrate our approach in Web Figure 1, with the problem demonstrated in Web Figure 1A. Suppose the true size of the US population of persons receiving HIV care during the calendar year was 30, 20 (67%) of whom were male and 10 female (33%). VS varied by sex, such that 70% of men and 80% of women had suppression, thus yielding 73% overall. Based on selection during the MMP SP, 70% of all people receiving care were represented, such that the MMP weighted estimate is that 21 persons received care. Compared to the underlying in-care population, women were more likely to be represented in the MMP sample, and VS among those represented was higher, with an overall estimate of 81% VS. Thus the MMP sampling methodology both

undercounts the number of persons receiving HIV care and introduces selection bias to the extent that care attendance during the SP is associated with the likelihood of VS, as well as with factors associated with VS (e.g., sex). These sources of bias distort estimates of VS, when considered among those receiving HIV care and among all those with an HIV diagnosis.

Web Figure 1B illustrates using the cohort-adjustment method to correct for these biases. An external, reference cohort is used to estimate the odds of care receipt exclusively outside of the SP for men (0.538) and women (0.250). These odds are multiplied by the MMP population estimates to yield an estimated 7 unsampled men and 2 women (those missed by MMP). Next, prevalence ratios for VS, comparing those receiving care exclusively outside of the SP versus those receiving at least some care during the SP, are computed among men (0.743) and women (0.571) in the reference cohort. These are multiplied by the unsampled population sizes and VS estimates from MMP to yield the unsampled population's estimated numbers suppressed (4 men, 1 woman). With the entire true population accounted for, the unbiased estimates of VS can be found.

Application of the cohort-adjustment method to the US care continuum, 2012

We applied the cohort-adjustment method to 3 CDC HIV-related data sources to adjust the MMP-based VS estimates for 2012. The data sources and approaches taken are described below.

Medical Monitoring Project, 2012. During 2012, MMP employed a 3-stage, complex sampling design in which US states and territories were sampled, followed by facilities providing outpatient HIV clinical care in those jurisdictions, and then adults (ages ≥18 years) seen for HIV care at those facilities during January through April of a given year (18). Demographic factors and HIV clinical outcomes, including VS at the most recent observation (visit or lab value), were collected from June 2012 to May 2013 using face-to-face or telephone interviews and medical record abstractions. All sampled states and territories participated in MMP. The 2012 facility response rate was 85%, and the patient response rate was 53%. Data were weighted to account for unequal probabilities of selection and both facility and patient nonresponse. Weighted estimates of parameters A and C and their standard errors, double-stratified by sex and age category (in years: 18–24, 25–34, 35–44, 45–54, ≥55), contributed to the analysis, extending previously reported single-stratified national weighted estimates for 2012 (6).

HIV Outpatient Study, 2012. The reference cohort for this analysis was HOPS, a prospective, observational cohort study of HIV-infected adults (ages ≥18 years) seen at HIV specialty clinics since 1993 (19). The 9 clinics participating in HOPS in 2012, and included in this analysis, are public, private, and university-based sites and are located in Tampa, Florida; Washington, DC; Denver, Colorado (3 sites); Chicago, Illinois (2 sites); Stony Brook, New York; and Philadelphia, Pennsylvania. In addition to baseline demographic characteristics, participants' clinical (diagnoses and treatments) and laboratory (including HIV VLs and CD4+ cell counts) data are abstracted from medical records for each visit. We included HOPS participants aged ≥18 years and actively providing data to HOPS as of January 1, 2012; having ≥1 clinical encounter during 2012; and alive as of December 31, 2012. Participants were classified as attending care exclusively outside the MMP SP or not, and as having VS (VL <200 copies/mL) at the most recent observation or not. Parameters B and D were estimated from logistic regression models that controlled for sex and categorized age (in years: 18–24, 25–34, 35–44, ≥55), as described above.

National HIV Surveillance System, 2012. The NHSS receives confidential, notifiable HIV diagnoses from all US states and territories (20). NHSS-reported persons living with an HIV diagnosis in the 50 US states, the District of Columbia, and Puerto Rico in 2012, matching the 2012 MMP sampling frame, were used as denominators for VS estimates (D, equation 5) (6). In 2012, NHSS received viral load laboratory reports for persons living with an HIV diagnosis, enabling previously reported calculations of the proportion of diagnosed persons with VS, in 28 jurisdictions (6).

We used estimates of the above parameters and the cohort-adjustment method to estimate the national adjusted total number receiving HIV medical care ($\hat{T}_{\tilde{S}\cup S}$), total with VS ($\hat{V}_{\tilde{S}\cup S}$), and proportion with VS ($\hat{p}\,(U|\tilde{S}\cup S)$). Point estimates and 95% confidence intervals for $\hat{T}_{\tilde{S}\cup S}$, $\hat{V}_{\tilde{S}\cup S}$, and $\hat{p}\,(U|\tilde{S}\cup S)$ were obtained from the 2.5th, 50th, and 97.5th percentiles of a Monte Carlo bootstrap simulation. To do so, across 100,000 simulations, we jointly sampled normal distributions for parameters A–D, defined by their point estimates as means and standard errors as standard deviations, and we subsequently recomputed and derived distributions for these outcome statistics. These were estimated both overall and for one-way stratifications of sex and age category. These were compared with previously published contemporaneous estimates based on MMP only and NHSS. These comparisons were descriptive, rather than inferential, because the 2 MMP-based estimates are for the same underlying population, and sampling variability estimates are not provided for NHSS results.

RESULTS

Consistent with earlier reports (6), based on a sample of 4,901 MMP participants, in 2012 an estimated 476,366 persons with an HIV diagnosis received HIV care during the SP of January–April, of whom 77% (95% confidence interval (CI): 75, 79) had VS at the most recent test, with men (80%, 95% CI: 78, 82) more likely than women to have suppression (71%, 95% CI: 67, 74, Table 1).

Among 3,170 HOPS participants with ≥1 visit or CD4+ or viral load measurement during 2012, 79% (95% CI: 77, 80) received HIV care during the SP (Table 2). Within sex-age strata, odds of receiving care exclusively outside of this period, indicative of less-frequent care receipt, were generally lower for men and declined with age. Among 2,990 patients with a viral load measurement, those receiving care exclusively outside of the SP were less likely to have VS (79% vs. 88%), and this finding was consistent within all sex-age strata (Table 3).

These results were then combined to yield overall and one-way estimates of VS in the United States. Based on the cohort-adjustment method, among 882,993 persons with an HIV diagnosis in the United States, an estimated 611,803 (69% of diagnosed) received HIV medical care, an increase of 28% from the original weighted estimate of 476,366 (54% of diagnosed) using MMP only (data not shown in table). Of those diagnosed, the method yielded an estimated 460,505 (52%, 95% CI: 48, 56;

Table 1. Medical Care Related to Human Immunodeficiency Virus During the Medical Monitoring Project Sampling Period and Viral Suppression at the Most Recent Test, Medical Monitoring Project, United States, 2012

Sex and Age Group, years	Persons Receiving Care			Viral Suppression at Most Recent Test, Among Those Receiving Care[a]			
	No.	Weighted No.[b]	95% CI	Weighted No.	95% CI	Weighted %[c]	95% CI
Male	3,625	354,773	296,647, 412,899	282,168	234,575, 329,761	79.5	77.5, 81.6
18–24	112	11,331	7,572, 15,090	7,302	5,077, 9,527	64.4	56.2, 72.7
25–34	423	41,970	34,050, 49,890	29,503	23,129, 35,877	70.3	65.7, 74.8
35–44	717	72,094	57,770, 86,418	55,028	44,081, 65,975	76.3	72.9, 79.7
45–54	1,393	132,582	111,336, 153,828	107,624	90,456, 124,792	81.2	78.8, 83.6
≥55	980	96,796	78,950, 114,642	82,711	65,737, 99,685	85.4	82.4, 88.5
Female	1,274	121,428	104,251, 138,605	86,004	74,271, 97,737	70.8	67.4, 74.2
18–24	32	3,373	1,935, 4,811	2,045	979, 3,111	60.6	43.4, 77.9
25–34	156	16,441	13,089, 19,793	10,795	8,457, 13,133	65.7	58.8, 72.5
35–44	298	26,339	21,841, 30,837	18,216	15,084, 21,348	69.2	64.5, 73.8
45–54	475	45,576	37,185, 53,967	31,714	25,522, 37,906	69.6	63.7, 75.4
≥55	313	29,700	24,239, 35,161	23,234	19,206, 27,262	78.2	73.3, 83.1
Overall[d]	4,901	476,366	411,617, 541,115	368,338	316,592, 420,084	77.3	75.4, 79.2

Abbreviations: CI, confidence interval; HIV, human immunodeficiency virus.

[a] Viral suppression defined as viral load <200 copies/mL.

[b] Model parameter A (estimated number receiving HIV medical care during the Medical Monitoring Project sampling period) for cohort-adjustment method.

[c] Model parameter C (estimated proportion with viral suppression (viral load <200 copies/mL) at the most recent test, among people receiving care during the sampling period) for cohort-adjustment method.

[d] Overall total differs from the sum of the presented strata because of intersex persons.

Table 2. Receipt of Medical Care Related to Human Immunodeficiency Virus[a] During the Medical Monitoring Project Sampling Period[b] Among All Patients Receiving Such Care, Human Immunodeficiency Virus Outpatient Study, United States, 2012

Sex and Age Group, years	Total No. of Patients	Received Care During Sampling Period		Did Not Receive Care During Sampling Period		Estimated Odds of Not Receiving Care During Sampling Period[c]	
		No.	%	No.	%	Odds	95% CI
Male	2,452	1,906	77.7	546	22.3		
18–24	29	20	69.0	9	31.0	0.45	0.20, 0.99
25–34	208	152	73.1	56	26.9	0.37	0.27, 0.50
35–44	430	332	77.2	98	22.8	0.30	0.24, 0.37
45–54	967	743	76.8	224	23.2	0.30	0.26, 0.35
≥55	818	659	80.6	159	19.4	0.24	0.20, 0.29
Female	718	585	81.5	133	18.5		
18–24	15	9	60.0	6	40.0	0.67	0.24, 1.87
25–34	68	55	80.9	13	19.1	0.24	0.13, 0.43
35–44	172	128	74.4	44	25.6	0.34	0.24, 0.48
45–54	270	234	86.7	36	13.3	0.15	0.11, 0.22
≥55	193	159	82.4	34	17.6	0.21	0.15, 0.31
Overall	3,170	2,491	78.6	679	21.4		

Abbreviations: CI, confidence interval; HIV, human immunodeficiency virus.

[a] HIV-related medical care receipt defined as attending a clinical care visit or receipt of an HIV viral load or CD4 test.

[b] Medical Monitoring Project sampling period defined as January through April of 2012.

[c] Model parameter B (estimated odds of care receipt exclusively outside of the sampling period, among those receiving care during the year) for cohort-adjustment method.

Table 3. Viral Suppression at Most Recent Test, According to Receipt of Medical Care Related to Human Immunodeficiency Virus[a] During the Medical Monitoring Project Sampling Period[b], Human Immunodeficiency Virus Outpatient Study, United States, 2012

Sex and Age Group, years	Participants Receiving Care During Sampling Period			Participants Not Receiving Care During Sampling Period			Estimated Prevalence Ratio for Viral Suppression[c]	
	No. With Viral Suppression	Total[d]	% With Viral Suppression	No. With Viral Suppression	Total[d]	% With Viral Suppression	Estimated PR	95% CI
Male	1,604	1,799	89.2	413	508	81.3		
18–24	14	20	70.0	3	9	33.3	0.48	0.18, 1.25
25–34	110	146	75.3	29	53	54.7	0.73	0.56, 0.94
35–44	284	318	89.3	67	93	72.0	0.81	0.71, 0.92
45–54	618	695	88.9	182	204	89.2	1.00	0.95, 1.06
≥55	578	620	93.2	132	149	88.6	0.95	0.89, 1.01
Female	463	561	82.5	82	122	67.2		
18–24	5	9	55.6	2	4	50.0	0.90	0.29, 2.82
25–34	33	53	62.3	5	10	50.0	0.80	0.42, 1.55
35–44	96	121	79.3	25	42	59.5	0.75	0.58, 0.98
45–54	184	222	82.9	26	34	76.5	0.92	0.76, 1.12
≥55	145	156	93.0	24	32	75.0	0.81	0.66, 0.99
Overall	2,067	2,360	87.6	495	630	78.6		

Abbreviations: CI, confidence interval; HIV, human immunodeficiency virus; PR, prevalence ratio.

[a] HIV-related medical care receipt defined as attending a clinical care visit or receipt of an HIV viral load or CD4 test.

[b] Medical Monitoring Project sampling period defined as January through April 2012.

[c] Model parameter D (estimated prevalence ratio for viral suppression at the most recent test, comparing persons receiving care exclusively outside of the Medical Monitoring Project sampling period versus persons receiving at least some care during the Medical Monitoring Project sampling period) for cohort-adjustment method.

[d] Number with viral suppression (<200 copies/mL) at last test, divided by total persons.

Table 4) persons with VS. This was over 10 percentage points higher than the original weighted estimate of 42% for MMP only, but it was only 2.1 percentage points higher than the estimate based on NHHS data from a 28-jurisdiction subset of the United States.

When stratified by sex, VS estimates were similarly close between the cohort-adjustment method and NHSS-data–based estimates, with values 2.9 percentage points higher and 0.4 percentage points lower using the cohort-adjustment method, respectively, for men and women, compared with analogous differences of 11.3 and 8.0 percentage points between the cohort-adjustment method and the original MMP-only estimate. By age, stratum-specific differences between the cohort-adjustment method and NHSS-data estimates ranged from 7 percentage points lower proportion with suppression for those aged 35–44 years to 15 percentage points higher for those ≥55 years of age. When compared with the MMP-only estimates, the cohort-adjustment method yielded consistently higher estimates (range, 8–12 percentage points higher).

DISCUSSION

These findings quantify a segment of the underlying population of persons in HIV care that was unrepresented in national VS estimates derived from 2012 MMP data and suggest that this bias partially accounts for differences between previously published estimates from MMP and NHSS data. Although VS was lower among those not represented, the enumeration and inclusion of this group increased overall estimates of suppression among those diagnosed. As demonstrated here and previously (21), 23% of persons receiving HIV care in HOPS during 2012 were not seen during the MMP SP, compared with an estimated 12% in 2003 (9).The analytical method described here allows reconstruction of that missing segment of the population using clinical cohort data, using a variation on indirect standardization. Reconstructing the population in this way can facilitate improved estimation of VS among persons living with diagnosed HIV. The percentage of persons seen exclusively outside the MMP SP and who had VS in HOPS may not be nationally representative, but this method can also be used with larger and more diverse clinical cohorts to inform national estimates.

NHSS data are used to monitor VS for the National HIV/AIDS Strategy (5) and are becoming more robust each year. The number of jurisdictions adequately reporting laboratory results (including viral load and CD4+ cell counts) to NHSS for persons living with HIV has been increasing (7), and this number is expected to continue to increase over time. The primary advantage of using the laboratory data is that they are reported for everyone who receives viral load testing in a particular jurisdiction. Until the laboratory data are nationally representative, however, valid estimation methods are needed for temporally comparable VS estimates, both to provide parameters for HIV prevention models and for baseline estimates against which more complete NHSS data can be

Table 4. Viral Suppression Among Persons Living With a Human Immunodeficiency Virus Diagnosis, United States, 2012[a]

Demographic Group	Persons Living With an HIV Diagnosis[b]	MMP: Cohort-Adjustment Method Using HOPS			HIV Surveillance Supplemental Report 20(2)			
					MMP: Unadjusted[c]			NHSS[d]
		Persons With Viral Suppression			Persons With Viral Suppression			Persons With Viral Suppression
		No.	%	95% CI	No.	%	95% CI	%
Sex								
Male	664,893	356,867	53.7	48.5, 59.0	282,168	42.4	35.3, 49.6	50.8
Female	218,100	103,336	47.4	42.3, 53.1	86,004	39.4	34.1, 44.8	47.8
Age group, years								
18–24	35,904	12,547	34.9	23.7, 54.5	9,348	26.0	19.7, 32.4	38.0[e]
25–34	124,568	50,489	40.5	33.7, 48.2	40,298	32.4	26.0, 38.7	43.5
35–44	219,620	91,212	41.5	34.8, 48.6	73,244	33.4	28.4, 38.3	48.6
45–54	315,658	176,561	55.9	48.2, 63.8	139,421	44.2	37.8, 50.5	53.0
≥55	187,243	129,009	68.9	58.1, 79.9	106,027	56.6	47.2, 66.1	53.9
Overall[f]	882,993	460,505	52.2	48.0, 56.3	368,338	41.7	35.9, 47.6	50.1

Abbreviations: CI, confidence interval; HIV, human immunodeficiency virus; MMP, Medical Monitoring Project; NHSS, National HIV Surveillance System.
[a] Cohort-adjustment method results compared with previous MMP and NHSS results.
[b] Includes United States and Puerto Rico for 2012, as reported in Surveillance Supplemental Report 20(2) (6).
[c] Based on viral suppression results found in both Table 1 and Surveillance Supplemental Report 20(2) (6), divided by diagnoses found in Surveillance Supplemental Report 20(2) (6).
[d] Estimated based on 27 states and the District of Columbia providing laboratory data to the Centers for Disease Control and Prevention.
[e] Source report defines age group as 13–24 years.
[f] Totals may differ from the sum of the presented strata because of intersex persons and additionally for the estimates based on the cohort-adjustment method, because stratum estimates are based on a probabilistic simulation.

compared. The method presented here, in combination with geographically diverse clinical cohort data, can provide such estimates.

The CDC has estimated the percentage of persons with VS in the United States using different methods and data sources, which have evolved over time. Before MMP or NHSS laboratory data were available for this purpose, methods relied on meta-analyzed results from clinical studies (22). Continual examination and improvement of estimation methods and data sources is important, because, as shown here, surveillance estimates are influenced by variables apart from real change in burden of disease or other outcomes—in this case changing patterns of HIV care receipt, which inadvertently reduced MMP's sampling fraction over time.

Research studies and surveillance systems have traditionally served distinct roles in informing HIV prevention and treatment, but findings can be used jointly to improve national HIV care and treatment estimates. Importantly, combining assets from individual data sources for robust estimation of a population-level clinical care indicator can be extended to other clinical indicators within and apart from HIV. The cohort-adjustment method could be used to estimate the percentage of persons living with HIV who are prescribed antiretroviral therapy, for example, but could also be used to combine multiple data sources for estimates of controlled hypertension or diabetes. Care continuums have emerged as important models for depicting multiple stages of care (e.g., people with an illness, people receiving care specific to that illness, and people with treatment success) for a variety of diseases (23, 24).

In addition to improving the accuracy of care-engagement estimates, the cohort-adjustment method may reduce bias in assessing trends in VS over time. In the HOPS, 88% of patients seen during the MMP SP had VS compared with 79% of those seen exclusively outside the SP. If the HOPS findings hold nationally (i.e., patients receiving care less frequently are less likely over time to be captured by a fixed 4-month SP, and frequency of care receipt is associated with VS), the association between calendar time and VS would be subject to selection bias. The use of more geographically diverse clinical cohort data, such as those in the North American AIDS Cohort Collaboration on Research and Design (NA-ACCORD), over multiple years will determine to what extent selection bias in VS estimates derived from MMP data is addressed.

MMP expanded in 2015 to include sampling of all persons living with diagnosed HIV from the NHSS. The post-2015 sampling frame is therefore the register of persons diagnosed with HIV as reported to the national case surveillance system. As such, the 4-month SP is no longer used, and HIV care and treatment outcomes will be estimated for all diagnosed persons going forward. Use of this cohort-adjustment method will improve comparability of VS estimates derived from pre-2015 MMP data to those from post-2015 data. Quantifying bias that may have been introduced by the SP will thus help to distinguish temporal trends in treatment outcomes like VS from bias and facilitate bridging of pre- and post-2015 data.

The approach taken in this paper is subject to limitations. First, although the cohort-adjustment method facilitates correction of previously published surveillance data, in adjusting such data one is limited in confounding control by how many factors by which the data can be stably stratified. The recommended maximum simultaneous number of stratification factors for MMP data is 2. However, the method described can be extended to incorporate additional control factors, through fitting participant-level weighted regression models of the source surveillance system and predicting probabilities of the outcome for strata of interest, rather than using stratified summaries. Second, while VS estimates from the cohort-adjustment method lie outside the confidence intervals for the original MMP-only estimate, statistical inferential methods cannot be used to compare the adjusted and unadjusted estimates because they both contain the same underlying MMP participants. Third, the response rate among persons sampled for MMP is lower than optimal, but nonresponse bias in estimates is minimized using known information about nonrespondents. Characteristics of more than 90% of the MMP sample (i.e., sex, age, race, length of time since HIV diagnosis) is available from HIV case surveillance and is routinely used to adjust weighted estimates for characteristics associated with nonresponse. Last, limitations exist in the use of HOPS as a reference cohort. The 9 HOPS clinics are largely in urban centers and may not be representative of all persons receiving HIV care. These possible differences and those due to mortality in the cohort have been described (21, 25). Viral load results were unavailable for 6% of HOPS participants in care, and available VL were assumed representative of the full sample receiving care (i.e., VL missing at random). It is possible that persons in care but without VL results have different levels of VS.

Viral suppression is an important indicator of how much progress is still needed to improve the health of persons living with HIV and reduce new infections. The cohort-adjustment method facilitates robust estimation of VS over time through data triangulation and combining the strengths of multiple data sources. Limited public health resources necessitate development of creative methods to overcome methodological shortcomings of existing data sources, and we have provided a relatively simple method that can be expanded to fit other applications. This method will be used in combination with a larger, more diverse cohort data set from North American AIDS Cohort Collaboration on Research and Design to revise annual MMP-derived VS estimates.

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