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Infections Prevented by Increasing HIV Serostatus Awareness in the United States, 2001 to 2004

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Abstract

Background: Persons living with HIV (PLWH) who are aware of their HIV status are more likely than serostatus-unaware PLWH to take precautions to prevent HIV transmission to their partners. The estimates of the Centers for Disease Control and Prevention (CDC) indicate that the proportion of PLWH who were aware of their serostatus increased between 2001 and 2004. The epidemiologic consequences of this increase in serostatus awareness are unknown.

Methods: We developed a basic model of the US HIV epidemic from 2001 to 2004. Using this model, we calculated the number of incident infections that would have occurred in 2002 to 2004 had the proportion of PLWH who were aware of their serostatus remained at its 2001 level rather than increasing between 2001 and 2004. We then compared this incidence estimate with the CDC's estimated total of 120,000 incident infections in 2002 to 2004 to determine the number of infections prevented by the increase in serostatus awareness.

Results: The increase from 2001 to 2004 in the proportion of PLWH who were aware of their serostatus can be credited with preventing nearly 6000 incident HIV infections in the 3-year period from 2002 to 2004. Sensitivity analyses indicated a plausible range of 4000 to 8700 prevented infections.

Conclusion: This analysis demonstrates the important epidemiologic benefits of increasing the proportion of PLWH who are aware of their HIV status.

Keywords

HIV; incident infections; mathematic model; serostatus awareness

Increasing the proportion of persons living with HIV (PLWH) who are aware of their HIV-positive serostatus is a key objective of the Centers for Disease Control and Prevention's (CDC's) "serostatus approach to fighting the epidemic," which was initiated in 2001.¹ HIV-infected persons who are aware of their serostatus are less likely to engage in transmission risk behaviors than are HIV-infected persons who are unaware of their serostatus² and, consequently, are less likely to infect at-risk sex partners.³ Moreover, infected persons who are aware of their HIV status can benefit from the availability of highly effective antiretroviral therapies and opportunistic infection prophylaxis, which can increase the length and quality of

their lives.⁴ Effective antiretroviral therapy also decreases viral load, which, in turn, reduces the likelihood of HIV transmission.⁵

The CDC estimates indicate that the number of PLWH who were unaware of their serostatus decreased between 2001 and 2004 despite an overall increase in the number of PLWH in the United States.^{6,7} The proportion of PLWH who were aware of their HIV status increased from approximately 70.5% at the start of 2001⁶ to approximately 74.2% at the start of 2004.⁷ According to CDC estimates, the number of incident infections remained constant at 40,000 new infections per year during this period.⁴

The failure of HIV prevention initiatives to reduce HIV incidence to lower than the 40,000 plateau is disappointing, but considering the counterfactual of increasing incidence as the number of PLWH increased, the steady incidence of recent years could instead be viewed as an indicator of successful prevention efforts.⁸ We demonstrate here that the increase in serostatus awareness between 2001 and 2004 can be credited, in part, with maintaining incidence at 40,000 new infections per year.

The present analysis addresses the following questions. First, what would the incidence in 2004 have been had the proportion of PLWH who were aware of their HIV status remained constant at the 2001 level rather than increasing between 2001 and 2004? Second, how many incident infections were prevented from 2002 to 2004 as a consequence of the increase in serostatus awareness?

METHODS

We used methods developed by CDC analysts to model the growth of the HIV epidemic between 2001 and 2005.^{6,7} Let $N(t)$ denote the number of PLWH at the start of year t . The increase in prevalent infections from 2001 and 2005 was modeled using the following equation:

$$N(t+1) = N(t) + I(t) - D(t) \quad [1]$$

where $I(t)$ and $D(t)$ are the numbers of incident infections and deaths among persons with AIDS during year t .

For the present analysis, it is useful to distinguish between incident infections attributable to the transmission risk behaviors of serostatus-aware and serostatus-unaware PLWH. Let $x(t)$ denote the proportion of PLWH who were aware of their HIV status at time t . The number of serostatus-aware PLWH equals $x(t) \cdot N(t)$, and the number of serostatus-unaware PLWH equals $(1 - x(t)) \cdot N(t)$. The incidence in year t equals the sum of the numbers of infections transmitted by these 2 groups:

$$\begin{aligned} I(t) &= \gamma_A \cdot x(t) \cdot N(t) + \gamma_U \cdot (1 - x(t)) \cdot N(t) \\ &= (\gamma_U - (\gamma_U - \gamma_A) \cdot x(t)) \cdot N(t) \end{aligned} \quad [2]$$

where γ_A and γ_U are the annual HIV transmission rates for serostatus-aware and -unaware PLWH, respectively. (The HIV transmission rate for a particular group of PLWH is defined as the average [fractional] number of new infections per PLWH per year⁹). Consistent with previous analyses,^{3,10} our model assumed that γ_A and γ_U were constant between 2001 and 2004.

Marks et al³ and Holtgrave and Pinkerton¹⁰ estimate that γ_U is 3.5 to 3.7 times larger than γ_A . Exact values of γ_A and γ_U (or the ratio γ_U/γ_A) are not needed for the present analyses, which assume only that $\gamma_A < \gamma_U$ and, consequently, that increasing the proportion of PLWH who are aware of their HIV status decreases overall incidence.

If, contrary to the available evidence,^{6,7} the proportion of PLWH who were aware of their HIV status had not increased from 2001 to 2004 but instead had remained at 2001 levels (ie, $x(t) = x(2001)$ for $t = 2001$ to 2004), then $I(t) = (\gamma_U - (\gamma_U - \gamma_A) \cdot x(2001)) \cdot N(t)$ for all years t . This would imply that $I(t)/N(t)$ is a constant equal to $\gamma_U - (\gamma_U - \gamma_A) \cdot x(2001)$ and, in particular, that $I(t)/N(t) = I(2001)/N(2001)$ for all years t . Therefore, in this counterfactual scenario,

$$I(t) = I(2001) / N(2001) \cdot N(t) \quad [3]$$

The total number of incidence infections between 2002 and 2004 then would equal the following:

$$I_{\text{Total}} = I(2001) / N(2001) \cdot \sum_{t=2002..2004} N(t) \quad [4]$$

This total can be compared with the CDC's estimate of 120,000 incident infections in this period (40,000 per year) to determine the number of infections prevented by the increase in the serostatus awareness from 2001 to 2004.

Importantly, the total number of incident infections in the counterfactual model, I_{Total} , depends only on the number of PLWH and the incidence in 2001 [$N(2001)$ and $I(2001)$, respectively] and on the number of deaths in 2001 to 2003. Specifically, because $I(t) = I(2001)/N(2001) \cdot N(t)$ in the counterfactual model,

$$N(t+1) = (1 + I(2001) / N(2001)) \cdot N(t) - D(t) \quad [5]$$

Equations 3 and 5 completely determine the counterfactual model.

In the base-case analysis, $N(2001)$ and $I(2001)$ were set to 950,000⁶ and 40,000,⁴ respectively. $D(t)$ values were drawn from the 2005 CDC HIV/AIDS Surveillance Report.¹¹ The total number of incident infections in the counterfactual scenario, I_{Total} , was calculated using Equation 4. Equation 5 was used to model the progression of the epidemic in the counterfactual scenario, and Equation 1 was used for the “factual” model, which assumed an annual incidence of 40,000 new infections between 2001 and 2004.⁴

RESULTS

In the base-case model, the number of PLWH increased from 950,000 at the start of 2001 to 1,041,522 at the start of 2005, as shown in Table 1. There were 160,000 incident infections and 68,478 deaths among persons with AIDS between 2001 and 2004.

If the proportion of PLWH who were aware of their HIV status had not increased from 2001 to 2004, the incidence of infection would have increased to 43,029 during 2004 and the total number of PLWH would have grown to 1,047,514 at the start of 2005. A total of 5992 additional incident infections would have occurred in 2002 to 2004. Thus, the increase in serostatus awareness between 2001 and 2004 can be credited with preventing nearly 6000 incident infections in the 3-year period from 2002 to 2004.

The base-case findings were not especially sensitive to the number of PLWH at the start of 2001, assuming a constant incidence of 40,000 new infections during 2001 to 2004. As indicated in Table 2, the number of infections prevented by the increase in serostatus awareness ranged from 5407 to 6719 when the number of people living with HIV at the start of 2001 was varied from 850,000 to 1,050,000, with larger values of $N(2001)$ associated with smaller numbers of prevented infections.

Additional sensitivity analyses were conducted to examine how the results might have changed if the incidence were 10% larger or smaller than the base-case value of 40,000 new infections per year. If the annual incidence during 2001 to 2004 were 36,000, 4445 infections would have been prevented by the increase in serostatus awareness, whereas if the incidence equaled 44,000

infections per year, 7756 new infections would have been prevented (these results assume that there were 950,000 PLWH at the start of 2001; see Table 2). Overall, the number of prevented infections ranged from a minimum of 4012 to a maximum of 8700 across various combinations of $N(2001)$ (850,000 to 1,050,000) and annual incidence values (36,000 to 44,000).

Consistent with CDC modeling techniques,^{6,7} the base-case model considered only deaths among persons with AIDS when updating the number of PLWH (Equations 1 and 4). We conducted a final sensitivity analysis that assumed an average 2% annual mortality rate for all PLWH.¹² This increased the number of deaths in 2001 to 2003 by 14.2%, to 58,252. The estimated number of infections prevented by the increase in serostatus awareness from 2001 to 2004 was reduced from 5992 to 5384 when deaths among all persons with HIV were included in the model.

DISCUSSION

Our analyses indicate that the increase in serostatus awareness between 2001 and 2004 can be credited with preventing nearly 6000 incident HIV infections during the 3-year period from 2002 to 2004. These prevented infections are associated with a savings of more than \$5 billion in averted lifetime economic productivity losses and HIV/AIDS-related medical care costs.¹³ Additionally, of course, each infection that is prevented in the present averts new infections in the future.

The results were not especially sensitive to differing assumptions about the number of PLWH at the start of 2001. They were somewhat more sensitive to the assumption that the annual incidence of HIV has remained constant at 40,000 new infections per year. A plausible range of 4000 to 8700 prevented infections was obtained across a broad spectrum of potential values of the initial number of PLWH and the annual incidence. Including deaths among all persons with HIV rather than just persons with AIDS did not substantially affect the estimated number of prevented infections.

Importantly, the analyses did not require specific assumptions regarding the magnitude of the increase in serostatus awareness between 2001 and 2004 or estimates of the transmission rates for serostatus-aware and -unaware PLWH. Simply stated, the results indicate that if there were 950,000 PLWH at the start of 2001 and the incidence of infection during 2001 equaled 40,000, 125,992 infections would have occurred in 2002 to 2004 if the proportion of PLWH who were aware of their serostatus had remained at its 2001 level. Compared with the CDC's estimate of 120,000 incident infections in 2002 to 2004, 5992 infections were prevented as a consequence of the increase in serostatus awareness.

Several limitations of this analysis should be noted. First, data for the epidemiologic model were derived from CDC estimates and, as such, are subject to the same limitations as those estimates. Of particular note, the CDC's estimate of 40,000 new infections per year was based on "informal methods"¹⁴ rather than on demonstrably sound empiric data or careful modeling. Second, in accordance with Marks et al³ and Holtgrave and Pinkerton,¹⁰ our model assumed that the annual transmission rates for serostatus-aware and -unaware PLWH have remained constant in recent years and that the transmission rate was the same for persons living with AIDS and for other persons who were aware of their HIV status. Persons with AIDS might be more likely than others to transmit HIV because of increased infectiousness in late-stage disease¹⁵ or less likely because of reductions in HIV transmission risk activities with deteriorating health. Likewise, the annual transmission rates did not distinguish between sexually transmitted HIV and HIV transmitted through the sharing of drug injection equipment. Third, our mathematic analysis cannot determine why serostatus awareness rates increased from 2001 to 2004. Overall increases in testing rates and increased use of testing services by

at-risk subgroups may have contributed to the reported increase in serostatus awareness.¹⁶ Our analyses suggest that the increase in serostatus awareness helped to maintain HIV incidence at a relatively stable level between 2002 and 2004, but other prevention initiatives likely helped as well.

In summary, one can argue that the incidence of HIV in the United States remains unacceptably high and that this indicates a failure of HIV prevention efforts. The first assertion may be true, but the second fails to consider the counterfactual. The present analysis indicates that had serostatus awareness levels remained constant from 2001 to 2004, the incidence of HIV would have increased to more than 43,000 infections in 2004 and nearly 6000 additional infections would have occurred in the 3-year period from 2002 to 2004. Although additional prevention activities are needed to reduce HIV incidence to lower than current levels, the successes of past prevention efforts should not be overlooked.

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TABLE 1

Factual and Counterfactual Models of the US HIV Epidemic, 2001 to 2005

Year	Factual Model [*]			Counterfactual Model ^{†‡}			Excess Infections [§]
	Total PLWH [‡]	Incident Infections	AIDS Deaths	Total PLWH	Incident Infections	AIDS Deaths	
2001	950,000	40,000	16,980	950,000	40,000	16,980	0
2002	973,020	40,000	16,641	973,020	40,969	16,641	969
2003	996,379	40,000	17,404	997,348	41,994	17,404	1994
2004	1,018,975	40,000	17,453	1,021,938	43,029	17,453	3029
2005	1,041,522			1,047,514			

^{*} Factual model assumes 40,000 incident infections per year.

^{†‡} Counterfactual model assumes that the proportion of PLWH who were aware of their HIV status did not change between 2001 and 2004; incidence was calculated as described in text.

[‡] PLWH at start of year.

[§] Difference in number of incident infections predicted by factual and counterfactual models.

TABLE 2

Sensitivity Analysis Results: Infections Prevented by Increased Serostatus Awareness, 2002 to 2004

Annual Incidence, 2001 to 2004			
PLWH 2001 *	36,000	40,000	44,000
850,000	4983	6719	8700
950,000	4445	5992 [†]	7756
1,050,000	4012	5407	6997

* PLWH at start of the year 2001.

[†] Result of base-case analysis.