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When Do Simpler Sexual Behavior Data Collection Techniques Suffice?:

An Analysis of Consequent Uncertainty in HIV Acquisition Risk Estimates

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Abstract

The "gold standard" for evaluating human immunodeficiency virus (HIV) prevention programs is a partner-by-partner sexual behavior assessment that elicits information about each sex partner and the activities engaged in with that partner. When collection of detailed partner-by-partner data is not feasible, aggregate data (e.g., total numbers of partners and acts of various types) must suffice. Lack of specificity in the primary data often translates into uncertainty in modeled outcomes, such as participants' risk of HIV acquisition. To our knowledge, no previous study has attempted to quantify this uncertainty. The results of the present analysis of the risk of HIV acquisition by men vacationing in Key West indicate that the use of aggregate rather than partner-by-partner data introduced relatively little uncertainty into the HIV risk estimates. Collection of aggregate data is a viable alternative to detailed partner-by-partner data, at least in some circumstances.

Keywords

HIV prevention; evaluation; modeling; sexual behavior

Extensive evaluations generally are best, the more detail the better (Rossi and Freeman 1993). In the realm of sexual behavior assessment, for example, the "gold standard" is a partner-by-partner assessment that elicits detailed information about each sex partner and the sexual activities engaged in with that partner (NIMH Multisite HIV Prevention Trial 1997; Pinkerton et al. 1998b). Unfortunately, feasibility issues sometimes arise which preclude collecting data with the specificity we might desire. An obvious example is street outreach activities—it quite simply is not possible to complete a detailed questionnaire or to conduct a comprehensive interview while standing on a street corner. Other public locations, including bars, beaches, airports, and so forth, introduce similar difficulties.

The need for detailed, ideally partner-by-partner, data is particularly acute when the data are used to model the adverse outcomes of risky sexual behaviors, such as HIV acquisition or transmission (Pinkerton et al. 1998a), which in turn form the basis of cost-effectiveness evaluations of sexual risk reduction interventions (Pinkerton and Holtgrave 1998). Lack of specificity in the data usually translates to uncertainty in modeled outcomes. This is especially true when sexual activity rates are very high, but less so when sexual activity is limited. For example, if a study participant reports just two acts of intercourse and two different partners (one HIV-positive and one HIV-negative), then the risk of HIV acquisition or transmission is uniquely determined. But if one of the two acts was unprotected and one was protected, then whether the unprotected sex act was with the HIV-positive partner or the HIV-negative partner greatly influences HIV risk. The situation becomes even more complicated as the number of sex act types (e.g., unprotected vs. protected; vaginal vs. anal) and sex partner types (e.g., HIV-positive vs. HIV-negative; casual vs. main) multiply and all possible permutations must be considered.

Again, lack of specificity in the primary data leads to uncertainty in secondary, model-based analyses, but how much uncertainty? To our knowledge, no previous study has attempted to quantify this uncertainty for any sexual behavior data set. It therefore is unknown whether simple assessment techniques (e.g., asking respondents the total number of times they had intercourse and the total number of partners) introduce overwhelming uncertainty—and consequently are of limited value for modeling studies that attempt to quantify the likelihood of HIV acquisition or transmission—or whether under certain circumstances, simpler assessments might suffice without sacrificing too much precision.

We addressed this important question using aggregate sex-partner and sex-act data collected from men who have sex with men (MSM) vacationing in Key West, Florida. For each study participant, data were available on the number of HIV-positive, HIV-negative, and HIV-status unknown partners, the number of partners who were Key West residents or other tourists, the number of acts of unprotected and condom-protected anal intercourse, and the number of insertive and receptive anal intercourse acts. However, the distribution of different types of acts among the different types of partners was not known, as it would have been had partner-by-partner data been collected. The objective of the present study was to quantify the uncertainty introduced into model-based estimates of the risk of HIV acquisition through the use of aggregate as opposed to partner-by-partner sexual behavior data. Based on the aggregate data, we previously estimated that approximately 0.51% of the MSM who visit Key West each year would acquire HIV during their vacation (Benotsch et al. 2006). Would substantively different findings have been obtained had partner-by-partner data been collected? To answer this question requires a method for "reconstructing" from the aggregate data the act-by-partner distributions that might have been ascertained in a partner-by-partner assessment. The task of reconstructing partner-by-partner data sets that potentially could have given rise to the aggregate data is an example of the more general challenge of inferring the entries in a contingency table from the marginal (row and column) totals. One approach that has been proposed in the literature (e.g., Cox and Plackett 1980), but which has not to our knowledge been applied to sexual behavior data, is to exhaustively enumerate all possible contingency table entries consistent with the observed marginals and then average them in some way.

Thus, to assess the uncertainty in HIV-acquisition risk estimates associated with the use of aggregate rather than partner-by-partner data collection techniques, we developed a computer program to exhaustively enumerate all possible partner-type by act-type combinations and to estimate the HIV risk associated with each such combination. The exhaustive enumeration allowed us to determine the minimum and maximum possible risk for each participant, providing lower and upper bounds on the uncertainty in our estimates versus the risk estimates that would have been obtained based on a partner-by-partner sexual behavior assessment. The results of the exhaustive enumeration also were compared for consistency to a simulation model of HIV transmission that probabilistically assigned partner types and act types on a "micro" level, as contrasted with the "macro" level assignment of the exhaustive enumeration technique. The results of this study have important implications for the cost-benefit trade-off of detailed versus simplified assessments of sexual behavior as they relate to HIV risk.

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Method

Description of Data Set

Data for this analysis were collected as part of a larger study that examined sexual risk among MSM vacationing in Key West, Florida (Benotsch et al. 2006). Participants were recruited at gay bars and guest houses and at a street booth near several gay-oriented businesses. A total of 247 MSM completed the anonymous questionnaire, which assessed the following sexual behaviors: (a) the number of HIV-positive sex partners, the number of HIV-negative or HIV-status unknown partners from Key West, and the number of HIV-negative or HIV-status unknown non-Key West, tourist partners (denoted m(1), m(2), and m(3), respectively); and (b) the number of acts of unprotected receptive anal intercourse, condom-protected receptive anal intercourse, unprotected insertive anal intercourse, and condom-protected insertive anal intercourse (n(1), n(2), n(3), and n(4), respectively).

The present study focuses on the subset of MSM who met the inclusion criteria of the main study, reported sexual activity with other men while on vacation in Key West, and who self-identified as HIV-negative or who did not know their HIV serostatus. Two men were excluded because they did not provide sexual partner information and one was excluded because the number of possible partner-act distributions (see below) was too large to be efficiently analyzed by the computer program. The final sample for the present study consisted of 92 sexually-active, at-risk MSM.

Partner-Act Distributions

Using the notation introduced above, the total number of sex partners is m = m(1) + m(2) + m(3) and the total number of acts of intercourse is n = n(1) + n(2) + n(3) + n(4). The key unknown for the present analysis is the exact distribution of the 4 different types of sex acts among the 3 different types of sex partners. We therefore considered all possible *valid* partner-act distributions. Specifically, we developed a computer program to generate all possible combinations of partner type variables (Key West resident or nonresident; positive, negative, or unknown HIV-status) and possible distributions across partners of the four types of anal intercourse (unprotected or condom-protected, insertive or receptive) based on each participant's self-reported sexual behavior. The computer program first generated potential *act distributions* and then potential *partner-act distributions*.

An *act distribution for partner k* is an ordered 4-tuple, d_k = <n(1,k), n(2,k), n(3,k), n(4,k)>, that specifies the number of each type of sex act with partner k. A potential act distribution d_k is considered valid if and only if the total number of acts with partner k, n(1,k) + n(2,k) + n(3,k) + n(4,k), is greater than or equal to 1. The HIV acquisition risk associated with act distribution d_k is

$$P(d_k) = \pi_k \left[1 - (1-\alpha_1)^{n(1,k)} (1-\alpha_2)^{n(2,k)} (1-\alpha_3)^{n(3,k)} (1-\alpha_4)^{n(4,k)} \right],$$

where π_k is the likelihood that the partner is infected with HIV and the α_i values are the per-act transmission probabilities associated with the 4 types of sex acts (Pinkerton and Abramson 1993, 1998).

A *partner-act distribution* is an ordered m-tuple, D = <d_1, d_2, … , d_m>, that specifies the act distribution for each of the m partners. A potential partner-act distribution D is considered valid if and only if each d_k is a valid act distribution and the total number of each of the 4 types of acts within the distribution equals the overall total number of acts of that type for the participant —that is, for act type j (j = 1 to 4), n(j) = n(j,1) + n(j,2) + … + n(j,m). The risk of HIV acquisition associated with partner-act distribution D is

$$P(D) = 1 - (1 - P(d_1))\,(1 - P(d_2)) \ldots (1 - P(d_m)).$$

Minimum and maximum risk estimates, P_{min} and P_{max}, were obtained for each participant from the exhaustive enumeration of possible partner-act distributions. The participant's true risk of HIV acquisition necessarily lies between the minimum and maximum values, P_{min} and P_{max}. Moreover, the risk estimate that would have been obtained had partner-by-partner data been available also must lie between P_{min} and P_{max}. Thus, the width of the interval between P_{min} and P_{max} provides a measure of the potential uncertainty in the estimated risk.

If the participant has only m = 1 partner, or if the number of acts equals the number of partners (n = m) and all sex acts are of the same type, then a unique partner-act distribution is obtained, which implies that $P_{min} = P_{max}$. The simplest example in which there is not a unique partner-act distribution occurs when there are 2 partners (partner #1 and partner #2), 1 sex act of type A, and 1 act of type B. Different distributions are obtained depending on whether the type A sex act is with partner #1 or partner #2. Notice, however, that if partner #1 and partner #2 are of the same partner type, then the 2 possible distributions produce identical risk estimates. Thus it is possible to have $P_{min} = P_{max}$ even though there is not a unique distribution.

Modeling HIV Risk

We estimated each participant's risk of acquiring HIV using two different modeling strategies. In the *exhaustive enumeration* approach we generated all possible valid partner-act distributions, $D_1, D_2, \ldots, D_M$, for each participant and then used the mean as his overall risk estimate: $P_{exhaust} = (P(D_1) + P(D_2) + \ldots + P(D_M))/M$, where M is the number of possible distributions for that participant. In the *random generation* strategy we randomly generated N = 10,000 valid partner-act distributions for each participant and then took the mean, $P_{random} = (P(D_1) + P(D_2) + \ldots + P(D_N))/N$. For either of these modeling approaches, the resulting HIV acquisition probability must lie between P_{min} and P_{max} since each $P(D_i)$ does. Because each possible partner-act distribution had an equal likelihood of being randomly generated, we expected that these 2 modeling strategies would produce similar results.

Supplementary Analyses

The main analysis assumed that each possible partner-act distribution was equally plausible. However, MSM may be more likely to use condoms or to assume the insertive role in anal intercourse with higher-risk partners (Parsons et al. 2005; Van de Ven et al. 2002). This “strategic risk management”—which would be captured in a partner-by-partner assessment but which is lost in aggregate assessments—could lower these men's risk of HIV acquisition. The highest-risk partners in our study were those “known” to be HIV-positive, followed by Key West partners, and finally, other tourist partners. To account for the possibility of “strategic risk management” and to illustrate the flexibility of the exhaustive enumeration and simulation modeling approaches, we conducted special analyses in which the space of valid partner-act distributions was constrained to include only: (a) those distributions in which condom-protected acts were preferentially assigned to higher-risk partners; and (b) distributions in which insertive sex acts were preferentially assigned to higher-risk partners.

Parameter Values

The following per-act transmission probabilities were used in the analysis: $\alpha_1 = 0.0006$ (unprotected insertive anal intercourse), $\alpha_2 = 0.02$ (unprotected receptive), $\alpha_3 = 0.00006$ (condom-protected insertive), and $\alpha_4 = 0.0002$ (condom-protected receptive) (Katz and Gerberding 1997); the last two probability values assume that condoms are 90% effective in preventing HIV transmission (Pinkerton and Abramson 1997). The estimated probability that a partner was infected depended on the partner type. For HIV-positive partners π_k was set to 1. For HIV-negative and unknown-status partners π_k was set to either the estimated prevalence of HIV infection among MSM in Key West (31.4%; Holmberg 1996) or among MSM in the 96 largest US metropolitan statistical areas (18.3%; Holmberg 1996), depending on whether or not the partner was from Key West. To compensate for the fact that most men completed the survey in the middle of their vacation rather than at the end, before calculating the risk of HIV acquisition, the numbers of intercourse acts were multiplied by d_1/d_2, where d_1 is the number of days the participant reported having been in Key West and d_2 is the number of days he expected to stay.

HIV Acquisition by MSM Vacationing in Key West

Previously, our research team used a Bernoullian model of HIV transmission similar to the one described above to estimated HIV acquisition risk for MSM vacationing in Key West (Benotsch et al. 2006). Then, to estimate the annual number of MSM who would acquire HIV while vacationing in Key West, we multiplied the HIV risk estimates by the number of MSM who visit Key West each year (100,000) and the proportions of these men who are sexually active while on vacation (48.2%) and HIV-negative (81.7%). We followed the same procedure here. Thus, the estimate of the number of vacationing MSM who acquire HIV in Key West presented below is not novel. We included it to illustrate how uncertainty in the HIV risk estimates translates into potential error in a tangible and meaningful result. Importantly, the present analysis estimated risk using exhaustive enumeration and random generation to simulate the possible partner-act distributions that could have been obtained through a partner-by-partner sexual behavior assessment, whereas Benotsch et al. simply assumed that each participant's sex acts were evenly disturbed among his sex partners. Consequently, Benotsch et al. were unable to quantify the uncertainty in their results. In addition to generating estimates of this uncertainty, the present approach also serves as a check on the findings of Benotsch et al. Specifically, the results of the exhaustive enumeration and random generation models were compared to those reported by Benotsch et al. to determine whether the choice of modeling strategies affected the findings.

Results

Most of the 92 sexually active men included in the study sample were white (88.0%), self-identified as gay (94.6%), and knew their HIV status (82.6%). The mean age was 37.4 years old, with a range of 23 to 60. The men reported an average of 1.84 sex partners (range = 1 to 8), most of whom (61.5%) were other tourists. Only 3 men had sex with a partner known to be HIV-positive. The average numbers of insertive and receptive anal intercourse acts were 1.45 and 1.26, respectively. Condoms were used for 49% of intercourse occasions, irrespective of the type of anal intercourse. On average, the men had been in Key West 4.5 days at the time of the interview and expected to stay an average of 7.3 days.

Participants demonstrated several distinct sexual behavior patterns. Five (5.4%) engaged in a single act of intercourse, 47 (23.9%) had only one sex partner, and 16 (17.4%) had only one sex act per partner and only one type of sex act. Thus, a unique partner-act distribution was obtained for 68 (73.9%) of the 92 men in the study. Seven of the remaining men (7.6% of the study sample) had multiple types of sex acts but only one type of sex partner; for these men there were multiple possible partner-act distributions but the minimum risk equaled the maximum risk. The minimum and maximum risk estimates were unequal for the remaining 17 men (18.5% of the study sample), who averaged 9.2 valid partner-act distributions (range 2 to 55).

For the overall sample of 95 men both the exhaustive enumeration and random generation models produced a mean HIV acquisition risk estimate of 0.0051, which was approximately midway between the minimum and maximum possible risk values (0.0050 and 0.0052, respectively). Thus, these modeling strategies could have underestimated or overestimated the true risk of HIV acquisition by as much as 2.6%. This 2.6% estimate of uncertainty represents an upper bound on the percentage by which the risk estimates—which were based on aggregate sex partner and sex act data—could have differed from the estimates obtained from a detailed partner-by-partner sexual behavior assessment.

Using the minimum and maximum risk estimates, between 195.9 and 206.4 of the estimated 100,000 MSM who visit Key West each year would be expected to acquire HIV. The exhaustive enumeration and random generation modeling strategies produced nearly identical estimates of 201.0 and 201.1 acquired infections, respectively. Again, the potential error in the estimates obtained from the exhaustive enumeration and random generation models was no greater than 2.6%.

The uncertainty in the estimated number of vacationing men who would acquire HIV was due solely to the sexual behaviors of the 17 men (18.5% of the study sample) who had multiple types of sex partners and multiple types of sex with those partners, or who had multiple sex partners and at least 2 more sex acts than sex partners (e.g., 4 sex acts with 2 partners). The exhaustive enumeration and random generation models estimated that 0.51% of these men would acquire HIV. The results of the constraint analyses indicate that “only” 0.46% of these men would be expected to acquire HIV if they preferentially used condoms with higher-risk partners and 0.48% would acquire infection if insertive sex was preferred with higher-risk partners. The minimum and maximum risk estimates for these 17 men were 0.44% and 0.58%, respectively. Thus, the model-based results could have underestimated these men's true risk by as much as 16.1% or overestimated it by as much as 12.7%. A partner-by-partner analysis would have generated more precise estimates. However, as noted above, the overall estimate of the total number of vacationing men who would be expected to acquire HIV would have been similar (±2.6%) if partner-by-partner data had been used rather than aggregate data.

Discussion

In some situations, collecting detailed partner-by-partner sexual behavior information may be impractical. Although aggregate sex partner and sex act data are sufficient to characterize overall levels of sexual risk (e.g., mean number of partners or mean percentage of condom use), the use of aggregate data introduces uncertainty into estimates of the risk of HIV acquisition which, in turn, can lead to uncertainty or error in the results of cost-effectiveness analyses of HIV prevention interventions or other applications that utilize model-based risk estimates.

The present analysis indicates that, for the Key West MSM tourist data, relatively little uncertainty was introduced into the risk estimates as a consequence of the use of aggregate rather than partner-by-partner data. Had partner-by-partner data been collected, the estimated number of MSM tourists who acquired HIV while vacationing in Key West would have been between 196 and 206 rather than the estimated value of 201 obtained using the aggregate sexual behavior data. This difference represents a relative error (uncertainty) of no more than 2.6%.

Probabilistic models often are used to estimate health related outcomes, such as the acquisition of HIV or another sexually transmitted infection, or the number of life years saved by a pharmacological intervention. The choice of a specific model can introduce “model-level uncertainty” into the analyses (Manning, Fryback, and Weinstein 1996). However, this important source of potential error seldom is addressed in published studies, which typically rely on a single model. The present analysis provides an indication of the relative importance of model-level uncertainty for the Key West tourist data. The exhaustive enumeration and random generation models produced nearly the same estimate of the number of MSM who acquire HIV while vacationing in Key West as did the simpler model used by Benotsch et al. (2006) (201.0 vs. 200.5, respectively). This very slight difference indicates that model-level uncertainty was not a significant source of error.

There are, of course, other sources of uncertainty in the survey data and the HIV risk estimates. The survey required participants to retrospectively recall their sexual behaviors while vacationing in Key West. Self-report sexual behavior data generally are fairly reliable, especially over relatively short recall periods (Holtgrave and Pinkerton 2000), which minimize mnemonic errors (in the present study the mean recall period was the previous 4.5 days). Socially desirable responding might have caused some participants to mischaracterize a sexual encounter (e.g., by reporting unprotected sexual activity as condom-protected) or to intentionally omit sexual encounters, and thereby could have led to an underestimation of participants' true risk for HIV acquisition. However, socially desirable responding would be expected to arise more-or-less equally during aggregate or partner-by-partner sexual behavior assessments, and therefore would not be expected to substantively impact the present comparison of these two data collection methods. Uncertainty in the precise values of epidemiological parameters in the HIV transmission model (e.g., per act transmission probability, prevalence values) also could affect the risk estimates. Depending on the “true” values of these parameters, the uncertainty introduced into the risk estimates through the use of aggregate rather than partner-by-partner data collection techniques could be either larger or smaller than the uncertainty estimates reported here.

The results of this analysis support the collection of aggregate data as a viable alternative to detailed partner-by-partner data, at least in some circumstances. Aggregate data are easier and less expensive to collect than are partner-by-partner data, and place fewer demands on study participants. Prospective study participants may be more willing to volunteer for a 10-minute survey than a more comprehensive survey that takes twice as long. In short, aggregate data collection may be the preferred option even when conditions would otherwise permit a more detailed assessment.

Notably, the men in the Key West study reported relatively few sex partners or sex acts (1.84 and 2.71, respectively, on average). Greater uncertainty would be obtained for data sets with higher sexual activity levels. In the present study uncertainty was present for only 17 of the 92 men included in the analyses. For these 17 men, the use of aggregate rather than partner-by-partner data could have resulted in an error of up to 16.1%. Thus, the choice of assessment strategy should take into account the anticipated sexual activity level of study participants, which in turn depends on the time period over which sexual behaviors are assessed. For studies in which sexual activity rates are likely to be relatively low, the results of the present analysis suggest that aggregate data collection may be an attractive alternative to the collection of detailed partner-by-partner sexual behavior information.

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Biographies

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John Mikytuck is a freelance writer and graduate student at Columbia University. He has worked in HIV/AIDS prevention since 1991, most recently as the Director of Education at AIDS Help in Key West, Florida. He was the recipient of two New York City Community Trust Grants and partnered with David Nimmons, Gay Men's Health Crisis, and Dr. Barbara Warren, New York LGBT Community Center, to produce END AIDS, a series of HIV prevention Public Service Announcements distributed nationally. Mr. Mikytuck was a member of Florida's HIV Prevention Planning Group, and the co-chair of the Florida Key's HIV/AIDS Community Planning Partnership.

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