Estimating the proportion of HIV transmissions from main sex partners among men who have sex with men in five US cities

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Background: HIV incidence in the United States among men who have sex with men (MSM) has been increasing since 2000, and MSM remain the most heavily impacted risk group in the US HIV epidemic.

Methods: We modeled HIV transmissions, using data from MSM in five US cities from the National HIV Behavioral Surveillance System, the HIVNET Vaccine Preparedness Study, and other published data. Annual HIV transmissions were estimated by partner type (main or casual) and by sex type (receptive anal intercourse, insertive anal intercourse, or oral sex).

Results: Sixty-eight percent [95% confidence interval (CI) 58–78) of HIV transmissions were from main sex partners because of a higher number of sex acts with main partners, more frequent receptive roles in anal sex with main partners, and lower condom use during anal sex with main partners. By sex type, 69% (95% CI 59–79) of infections were from receptive anal intercourse, 28% (95% CI 19–38) were from insertive anal intercourse, and 2% (95% CI 0–5) were from oral sex. The model-based estimated HIV incidence rate was 2.2% (95% CI 1.7–2.7) per year. Sensitivity analyses demonstrated estimates of transmission from main sex partners as low as 52% (95% CI 41–62) and as high as 74% (95% CI 68–80).

Conclusion: According to our model, most HIV transmissions among MSM in five US cities are from main sex partners. HIV prevention efforts should take into account the risks of HIV transmissions in male partnerships, and couples-based HIV prevention interventions for MSM should be given high priority in the US HIV prevention research portfolio.

AIDS 2009, **23**:000–000

Keywords: HIV, main sex partners, men who have sex with men, transmission risk

Introduction

Men who have sex with men (MSM) have been the predominantly affected risk group since the earliest days of the US HIV epidemic and continue to be the risk group most commonly diagnosed with HIV in the national HIV Surveillance System [1]. Recent data indicate that rates of reported HIV diagnoses have been increasing by over 8% annually since 2001, with the sharpest increases occurring among the youngest (aged 13–24 years) and oldest (aged ≥45 years) MSM and black MSM [2]. MSM are the only risk group with increasing HIV incidence since 2000 [3]. Recently, calls have emerged for a renewed focus on developing novel HIV prevention approaches for US MSM [4].

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Received: 23 October 2008; revised: 28 February 2009; accepted: 16 March 2009.

DOI:10.1097/QAD.0b013e32832baa34

An earlier report that most HIV infections among young MSM in the Netherlands are attributable to main sex partners [5], and a recent study [6] from Africa documenting that most HIV transmissions among male–female couples in Zambia and Rwanda are from cohabiting sex partners, led us to question the relative role of transmissions from main sex partners in the United States. We developed a model of HIV transmission based on survey data and HIV test results from respondents to Center for Disease Control and Prevention (CDC)'s National HIV Behavioral Surveillance System (NHBS) among MSM and other published and publicly available data [7,8].

Methods

Data sources

The primary data sources were a five-city subset of the NHBS data from the 2003 to 2005 cycle, which interviewed and conducted HIV testing among MSM recruited using venue–time–space sampling [9] in five US cities (Baltimore, Los Angeles County, Miami, New York, and San Francisco and the Greater Bay Area) [10,11], and the HIVNET Vaccine Preparedness Study (VPS), which collected data from MSM in six US metropolitan areas (Boston, Chicago, Denver, New York, San Francisco, and Seattle) from 1995 to 1997 (National Institute of Allergy and Infectious Diseases, National Institutes of Health, Department of Health and Human Services. Vaccine Preparedness Study, Uninfected Participant Cohort, FHCRC-HIVNET Statistical Center Version, March 2000). Because HIV testing was offered only during limited time periods in the five NHBS cities, not all men who completed the interview were offered HIV testing. During the period when HIV testing was offered, 2267 men completed the survey and 1777 (79% of these participants) agreed to be HIV tested. A total of 3617 MSM participated in the VPS study.

respondents were asked separately about last sex with both main and casual partners, when applicable. VPS data were used to approximate the number of sexual episodes per year for men with main and casual sex partners; because of the specific information available from VPS, we estimated sexual episodes per year in the following way. To estimate sexual episodes per year with main partners, we used data about number of oral or anal sex acts in the prior 6 months from the baseline interview and from 6, 12, and 18-month follow-up interviews for men who reported a single main partner. To estimate sexual episodes with causal partners, we used data from the same interview periods from men who had one or more casual partners, but not a main partner during the prior 6 months. Six-month estimates for episodes were annualized by multiplying by two.

We tested for differences in the distribution of demographic factors between NHBS respondents who were and were not tested for HIV and between NHBS respondents and VPS participants using χ^2 test. Published data were used to estimate per anal sex episode risk of HIV transmission [7,8]. Estimates of HIV transmission from the VPS data were updated, using the final study data from the VPS study; earlier estimates were published before the VPS data were finalized.

Modeling approach

To characterize new HIV infections, which would be expected to occur among a hypothetical cohort of 3652 HIV-negative MSM with the behavioral characteristics of the NHBS MSM respondents, we summed the estimated number of transmissions for each combination of partner type (main or casual), sex act (RAI, IAI, and oral sex), and reported partner serostatus (negative, positive, and unknown):

$$\text{Transmissions} = \sum_{\substack{i=\text{main, casual}\\ j=\text{neg, pos, unk}\\ k=\text{RAI, IAI, oralsex}}} N(i) \times S(i,j,k) \times U(i,j,k) \times H(i,j) \times R(k)$$

NHBS data were used to estimate numbers of MSM with main and casual partners in a year, average numbers of casual partners for men who had them, proportional distribution of partner serostatus, proportional distribution of sex episodes that involved receptive anal intercourse (RAI), insertive anal intercourse (IAI), or oral sex, proportion of anal intercourse that was unprotected by condoms, the prevalence of HIV by partner type (main versus casual), and the proportion of unrecognized HIV infection. Data on sex behaviors were from last sex;

where N is the number of men reporting having main or casual partners in the last year, S is the number of annual sex acts in the last year, U is the proportion of sex acts unprotected by condoms, H is the estimated true prevalence of HIV infection among partners, R is the per act risk of HIV transmission, i is the type of sex partner (main or casual), j is the reported partner HIV status (negative, positive, and unknown), and k is the type of sex act (receptive anal, insertive anal, and receptive oral)

Table 1. Input parameters and data sources used in a model of HIV transmissions among men who have sex with men, five US cities.

Variable	Data source	Comments
N (number of men)	NHBS	Number of men reported to be HIV negative or of unknown HIV status who provided complete information on their last main and casual (if applicable) partners. In our model, *N* represents a hypothetical cohort of HIV-negative MSM with the behavioral characteristics of the NHBS respondents.
S (number of sex acts)	VPS (number of acts/year with main and casual partners)	From VPS data, separate estimates were made for the number of sex acts (anal or oral) for men who had only a main partner, and men who had at least one casual partner.
	NHBS (number of casual partners/year; proportional distribution of sex acts among RAI, IAI, and oral sex by partner type and reported partner serostatus)	From NHBS, we calculated the number of casual partners separately for men who had main partners only, both main and casual partners, and casual partners only. Because NHBS defined a main sex partner as 'someone who you feel committed to above all others', we considered that men who reported more than one main sex partner per year must have had serial main partners, and considered all men who reported multiple main partners during the year as having one partner for the purposes of calculating total annual sex acts with main partners. We considered only receptive oral sex acts (the only oral sex associated with significant risk of HIV acquisition) to contribute to HIV transmission risk, and therefore multiplied the total number of estimated oral sex acts by 0.5. We used the proportional distribution of sex acts at last sex as a proxy for the population distribution of sex acts with a certain partner type of the model year [12].
U (proportion of sex acts unprotected by condoms)	NHBS	We calculated partner type-sex act-reported partner HIV status-specific rates of not using condoms. We included in this calculation an estimated number of sex acts reported to be protected by condoms but when condom failure occurred, using an estimate of condom failure (2.1%) during anal sex derived from analysis of VPS data [13]. Thus, the proportion of acts not protected by condoms is the sum of the proportion of acts in which no condom was used, and 2.1% of the proportion of acts in which a condom was used but presumed to have failed.
H (prevalence of HIV infection among partners)	NHBS five-city data [11]	We used data from NHBS respondents who were tested for HIV infection in the study to estimate true HIV prevalence and unrecognized HIV infection by partner type. This requires the assumption that NHBS respondents were also reflective of their own sex partners with respect to HIV prevalence and awareness of HIV serostatus (see Discussion). For partners who were reported to be HIV-positive, the prevalence of HIV infection was assumed to be 100%. For partners who were reported to have unknown HIV serostatus, the HIV prevalence was estimated to be the partner-type specific prevalence of HIV. For partners who were reported to be HIV-negative, the HIV prevalence was estimated to be the product of the partner-type-specific prevalence of HIV, and the partner-type specific proportion of HIV-infected men who reported being HIV-negative.
R (per act risk of HIV transmission)	Published data	Per-episode risks of HIV transmission were according to the method of Vittinghoff *et al.* [7], using final data from the study on which the original methods and estimates were reported.

IAI, insertive anal intercourse; MSM, men who have sex with men; NHBS, National HIV Behavioral Surveillance System; RAI, receptive anal intercourse; VPS, Vaccine Preparedness Study.

The data sources and detailed information about model inputs are summarized in Table 1 ([7,11–13]). Total annual sex acts with main and casual partners were apportioned to one of nine categories [three levels of sex type (k) by three levels of partner's reported HIV status (j)]. Total numbers of sex acts with main and casual partners were multiplied, separately, by the proportion of sexual episodes that occurred with each stratum of sex type* reported partner HIV status. The result was an estimated annual number of RAI, IAI, and oral sex acts, by partner type and serostatus.

The total numbers of unprotected anal sex episodes were estimated by multiplying partner type–sex type–seroconcordance-specific condom usage rates (U) by the total number of sex acts (S) in the stratum. For oral sex, we assumed, on the basis of published literature, that the rates of condom use during oral sex were low enough to be negligible [14].

The number of unprotected sex acts with HIV-infected partners was estimated by multiplying the number of unprotected sex acts by the partner type–sex act-specific rates of HIV prevalence (*H*, as determined by HIV testing of respondents). The estimated new HIV infection was calculated by multiplying the total number of unprotected sex acts with infected partners by the per-act risk of HIV transmission for that act (*R*).

Thus, estimates of annual HIV infections were calculated and attributed to main or casual partners, RAI, IAI, or oral sex and perceived partner serostatus. The 95% confidence intervals (CIs) around the proportions were calculated using standard formulae, assuming a normal distribution. The annual HIV incidence rate was calculated by dividing the total number of predicted HIV transmissions by the total number of men, with 95% CIs.

We repeated the modeling process stratified by demographic variables when there were significant differences between the NHBS and VPS respondents (age, race, and education). The stratified models used stratum-specific estimates of partner numbers, distribution of sex acts, condom use rates, HIV prevalence, and undiagnosed HIV infection from NHBS data. We summed across strata to generate overall estimates from the stratified analysis. We tested for a trend in prevalence of transmission from main partners, from RAI, and from partners of unknown serostatus across age groups using the Cochran–Armitage test (SAS version 9.2; SAS Institute Inc., Cary, North Carolina, USA).

Sensitivity analyses

To determine how sensitive our model was to plausible changes in input parameters, we conducted sensitivity analyses (Table 2). We varied key input parameters to upper and lower 95% CIs and considered alternative data sources for estimates of annual sex episodes with main and casual partners. We constructed an overall scenario that favored transmission from casual partners, conducted an analysis restricted to the two cities (New York and San Francisco) where both NHBS and VPS data were collected, and constructed an analysis using only data from participants who were also HIV tested as part of the study. We also tested an alternate measure of seroprevalence by using direct estimates of seroprevalence in four groups (main and casual partners who reported being HIV-negative or HIV-unknown). Finally, we varied each individual variable according to an appropriate probability distribution and used Monte Carlo simulation (@RISK, Palisade Corporation, Ithaca New York, USA) to generate 95% CIs around the estimate of transmission from main partners and conducted a Monte Carlo simulation allowing all variables to vary according to their respective probability distributions.

To address the concern that the distribution of type of sex act might be correlated with frequency of sex (e.g., that men who reported higher numbers of sex acts might have a higher proportion of RAI), we used VPS data to model the relationship between number of annual sex acts and the proportion of sex which was RAI.

Results

A total of 3652 MSM respondents to the NHBS survey provided complete information on recent sex partners and were included in the analysis group. Men who provided complete information differed statistically from the 1777 NHBS respondents tested for HIV in the five cities by age group, educational attainment, and city of recruitment (Table 3), but the magnitude of the differences was small. Included NHBS respondents differed from MSM in the VPS study by age group, race, and educational attainment.

NHBS respondents reported information from most recent sex with a total of 2395 main sex partners and 2850 casual sex partners (Table 4). Forty-four percent of NHBS respondents reported both main and casual partners in the 12 months before interview. Main partners were significantly less likely to be of unknown HIV serostatus ($P < 0.0001$). Men were significantly less likely to use condoms with main partners (versus casual partners) for RAI and IAI with partners who were reported to be HIV negative (43 versus 73% for RAI, 43 versus 71% for IAI; $P < 0.0001$ for both comparisons) or with unknown serostatus (57 versus 76% for RAI, 59 versus 75% for IAI; $P < 0.0001$ for both comparisons); condom use was similar with main and casual HIV-positive partners ($P = 0.76$ and $P = 0.87$ for RAI and IAI, respectively). Men were more likely to have had RAI with their main partner (40%) than with their casual partner (26%) at last sex ($P < 0.0001$ by χ^2). Mean annual number of main partners was 1.5 for men with only main partners and 1.3 for men with both main and casual partners; 25% of men with only main partners and 10% of men with both main and casual partners reported more than one main partner. Among NHBS respondents, the proportion of men who had only main partners who were truly HIV-infected was 24% and of men who had any casual partner it was 26%; in the same groups, proportions of HIV-infected men who were unaware of their HIV infection were 43 and 49%, respectively. We estimated that NHBS respondents had 194 875 annual sex acts with main partners and 173 450 annual sex acts with casual partners.

Most transmissions (68%) were estimated to be from main partners in the primary analysis and in models stratified by age, race, and educational attainment (Fig. 1a). There was a significant trend in proportion of transmissions from main partners across age groups by Cochran–Armitage test (two-tailed $P = 0.002$, Fig. 1a). There was no trend in proportion of transmissions from RAI or from partners of unknown serostatus across age groups. By sex type, most

Table 2. Sensitivity analyses of a model to estimate HIV transmissions among men who have sex with men, five US cities.

	Base case		Sensitivity analysis		
Parameter	Source	Estimate	Source	Estimate/range	% Transmissions from main partners (95% CI)
Number of sex episodes/year	Vaccine Preparedness Study	Main, 80.7/year; casual, 4.0/year	VPS	95% CI on estimates:	
				Main, 76.2–85.1	67 (58–77), 70 (61–79)
				Monte Carlo simulation on annual sex episodes with main partners[a]	68 (46–85)
				Casual, 3.0–4.9	74 (65–83), 64 (54–73)
				Monte Carlo simulation on annual sex episodes with casual partners[b]	71 (47–85)
			National Survey of Health and Social Life[c]	Main, 60.4/year; casual: 4.3/year	66 (54–73)
			General Social Survey[d]	Main, 48.2/year; casual: 4.2/year	62 (54–70)
Per episode risk of HIV transmission	Method of Vittinghoff *et al.* [7] with final study data	URA, 0.65%; UIA, 0.16%; OS, 0.013%	Vargehese *et al.* [8]	RR of transmission: oral sex = 1, UIA = 13, UAI = 100	74 (68–80)
Proportion of partners with HIV infection	NHBS (five cities)	Main 24%	NHBS (five cities)	95% CI on proportions:	
		Casual 26%		Main 20, 29%	65 (55–75), 72 (63–80)
		Main partner reported to be negative 10%		Monte Carlo simulation on proportion of main partners with HIV infection[c]	71 (70–72)
		Main partner reported to be unknown 24%		Casual 26%, 30%	70 (61–79), 67 (58–76)
		Casual partner reported to negative 13%		Monte Carlo simulation on proportion of casual partners with HIV infection[c]	71 (69–73)
		Casual partner reported to unknown 26%		Direct measures of prevalence in main and casual partners from NHBS	66 (56–76)
Proportion of partners with unrecognized HIV infection	NHBS (five cities)	Main 43%	NHBS (five cities)	95% CI on proportions:	
		Casual 49%		Main 31%, 52%	65 (55–75), 71 (62–80)
				Monte Carlo simulation on proportion of HIV-infected main partners with unrecognized infection[e]	71 (68–73)
				Casual 44%, 54%	69 (60–78), 68 (59–77)
				Monte Carlo simulation on proportion of HIV-infected casual partners with unrecognized infection[e]	71 (71, 71)
Aggregate scenario favoring transmission by casual partners	–	–	NHBS, VPS, Vittinghoff *et al.* [7]	Lower CI for estimates of sex frequency with main partners (76.2), upper CI for sex frequency with casual partners (4.9), lower CI for HIV prevalence among main partners (20%), upper CI for HIV prevalence among casual partners (30%), lower CI for undiagnosed prevalence among main partners (31%), upper CI for undiagnosed prevalence among casual partners (54%)	52 (41–62)
Restricted analysis to two cities that collected data in both studies	–	–	NHBS, VPS, Vittinghoff *et al.* [7]	New York and San Francisco only	69 (53–85)
Restricted analysis to only respondents who were HIV tested in the study	–	–	NHBS, VPS, Vittinghoff *et al.* [7]		72 (57–87)
Monte Carlo simulation varying all factors according to their respective probability distribution	–	–	NHBS, VPS, Vittinghoff *et al.* [7]		67 (29–92)

CI, confidence interval; NHBS, National HIV Behavioral Surveillance; UIA, unprotected insertive anal intercourse; URA, unprotected receptive anal intercourse; VPS, Vaccine Preparedness Study.
[a]Negative binomial distribution.
[b]Inverse Gaussian distribution.
[c]National Health and Social Life Survey; 1992 [United States] [computer file]. ICPSR version, Chicago, Illinois: University of Chicago and National Opinion Research Center [producer]; 1995. Ann Arbor, Michigan: Inter-university Consortium for Political and Social Research [distributor]; 1995.
[d]General social surveys, 1972–2006: cumulative codebook. Principal investigator, James A. Davis, Director and Co-principal investigator, Tom W. Smith. – Chicago: National Opinion Research Center; 2007. 2552 pp., 28 cm. – (National Data Program for the Social Sciences Series, no. 18).
[e]Normal distribution.

Table 3. Characteristics of men who have sex with men and studies in datasets used to model HIV transmissions in five US cities.

Characteristic	NHBS respondents, *n* (%)	NHBS respondents who were tested for HIV as part of NHBS, *n* (%)	Vaccine Preparedness Study, *n* (%)
Total	3652	1777[a]	3617
Age group (years)[b,c,d,e]			
18–24	759 (21)	415 (23)	593 (16)
25–29	727 (20)	314 (17)	841 (23)
30–39	1289 (35)	593 (33)	1381 (38)
≥40	877 (24)	455 (26)	802 (22)
Race/ethnicity[c,d,e,g]			
White, non-Hispanic	1384 (38)	619 (35)	2549 (71)
Black, non-Hispanic	612 (17)	443 (25)	339 (9)
Hispanic	1121 (31)	470 (26)	551 (15)
Other races[f]	535 (14)	245 (14)	176 (5)
Educational attainment[c,d,e,h]			
Less than high school	219 (6)	166 (9)	191 (5)
High school or GED	613 (17)	391 (22)	448 (12)
More than high school	2818 (77)	1219 (69)	2978 (82)
City of recruitment[c]			
Baltimore	421 (12)	470 (26)	–
Boston		–	322 (9)
Chicago		–	594 (16)
Denver		–	676 (18)
Los Angeles County[i]	1132 (31)	378 (21)	–
Miami[i]	624 (17)	232 (13)	–
New York City	385 (11)	336 (19)	659 (18)
San Francisco[i,j]	1090 (30)	361 (20)	788 (22)
Seattle	–	–	578 (16)

GED, General Education Diploma; NHBS, National HIV Behavioral Surveillance.
[a]Data include 10 respondents whose data were not finalized at the time of the earlier published analysis of HIV testing [11].
[b]Age groups for VPS study were 18–25, 26–30, 31–40, and at least 41 years of age.
[c]$P < 0.05$ by χ^2 comparing NHBS respondents to NHBS HIV testers.
[d]$P < 0.05$ by χ^2 comparing NHBS respondents to VPS respondents.
[e]$P < 0.05$ by χ^2 comparing NHBS HIV testers to VPS respondents.
[f]Includes Asian/Pacific Islander, American Indian/Alaskan Native, men reporting multiple races, and men who refused to provide race information.
[g]Two VPS respondents had missing race.
[h]Two NHBS respondents had missing information on educational attainment.
[i]Surveys were completed for 6 months when testing was not available, so nontesters represent a combination of respondents who were not offered testing, and respondents who declined testing. In other NHBS cities, nontesters represent those who declined testing.
[j]For NHBS, includes the Greater Bay Area.

Table 4. Number and percentage of participants who reported being HIV negative or reported not knowing their HIV status who had unprotected anal sex during their most recent sexual encounter with a casual or main partner, by partner's HIV serostatus (National HIV Behavioral Surveillance System, men who have sex with men, five US Cities, November 2003–April 2005).

	Insertive				Receptive				
	Anal sex		Unprotected anal sex		Anal sex		Unprotected anal sex		
Partner's reported HIV status	No.	(%)[a]	No.	(%)[b]	No.	(%)[a]	No.	(%)[b]	Total
Main partner									
HIV negative	1005	(75)	574	(57)	710	(74)	408	(57)	
HIV positive	69	(5)	29	(42)	50	(5)	10	(20)	
Unknown	263	(20)	107	(41)	196	(21)	84	(43)	
Total	1337		710		956		502[c]		2395[d]
Casual partner									
HIV negative	446	(38)	128	(29)	296	(39)	79	(27)	
HIV positive	42	(4)	17	(40)	18	(2)	3	(17)	
Unknown	686	(58)	170	(25)	441	(58)	105	(24)	
Total	1174		315[e]		755		187[f]		2850

[a]Percentages are column percents (i.e. add to 100% within main and casual partners).
[b]Percentages are row percents (i.e. the percentage of the total number of anal sex acts that were not protected by condoms).
[c]Two men had missing data on condom use.
[d]The number of sex acts is greater than the number of sex partners because some men reported having both insertive and receptive anal sex at last sex.
[e]One man had missing data on condom use.
[f]Three men had missing data on condom use.

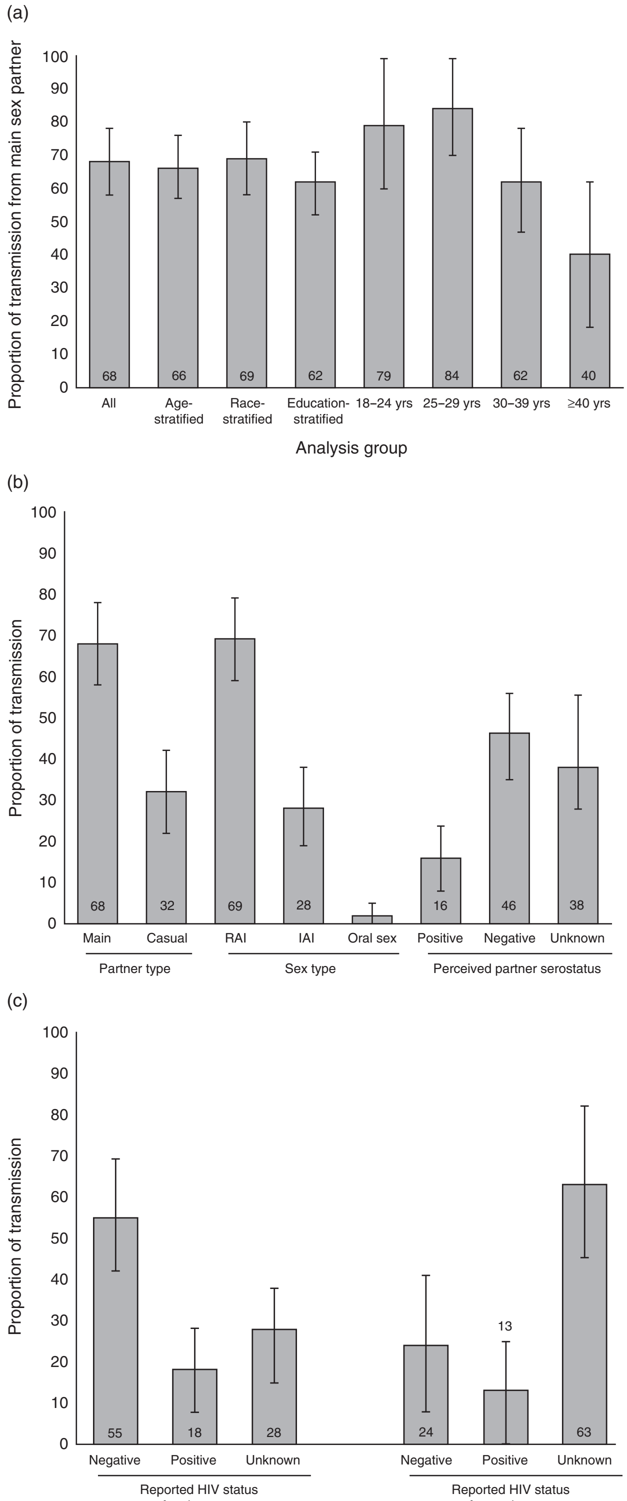

Fig. 1. Proportions of HIV transmissions by partner type, sex type, and perceived partner serostatus (a), proportion of HIV transmissions from main sex partners overall, in stratified analyses, and by age (b), and proportion of transmissions by reported HIV serostatus of partner and partner type (c) among men who have sex with men in five US cities, 2003–2005. RAI, receptive anal intercourse; IAI, insertive anal intercourse.

transmissions were estimated to arise from RAI; among all men, most transmissions were estimated to arise from partners believed to be HIV-negative (Fig. 1b). Among transmissions from main partners, most were from partners reported to be HIV negative; among transmissions from casual partners, most were from partners of unknown HIV status (Fig. 1c).

The predicted annual HIV incidence for the overall analysis was 2.2% (CI 1.7–2.7%). In sensitivity analyses (Table 2), the highest and lowest estimates of the proportion of HIV transmissions from main partners were 74 and 52%, respectively.

In addressing our concern that the distribution of type of sex act might be correlated with frequency of sex, we found that among VPS respondents, frequency of sex was significantly ($P < 0.0001$) but not meaningfully associated with proportion of sex acts, which were RAI. Only 1% in the variability of proportion of sex acts, which were RAI was explained by frequency of sex ($r^2 = 0.01$).

Discussion

Our finding that most HIV transmissions among this group of urban MSM arose from sex with main partners was driven by several factors. First, men have more sex with their main partners than with their casual partners each year, over 10% more by our estimates. Second, men were 14% more likely to have RAI, which carries a higher per-act risk of HIV transmission, with their main partners than with their casual partners. Third, men in our study, and others [15–19], were less likely to use condoms for anal sex with their main partners; partner serostatus–sex type-specific rates of sex not protected by condoms were 16–31% higher with main partners than casual partners in our data. Taken together, these factors result in more episodes of unprotected anal sex, especially RAI, with main partners than with casual partners. Although prevalence of HIV infection and of undiagnosed HIV infection were marginally lower in main than casual partners in our model (Table 2), these differences were too small to overcome the larger differences favoring more unprotected RAI acts with main partners.

Our finding of a decreasing trend by age in transmission from main partners is driven by higher proportions of undiagnosed HIV infection in younger men; a previous analysis [10] of NHBS data showed that the prevalence of undiagnosed HIV was as high as 79% among younger MSM. There may be differences in how younger men define main partners or differences in the length of relationships with main partners. It is likely that, for many older men, main partners may have been established for many years. Given the frequency of HIV testing among MSM [10], a main partner of long duration is less likely to have unrecognized HIV infection, and the risk of acquiring HIV from that partner would be lower.

Two other findings bear special attention. First, transmissions from IAI represented 28% of estimated infections; the ratio of RAI to IAI transmissions in our model (about 2.5) is lower than would be predicted only on the basis of the relative transmission efficiencies of RAI versus IAI (about 4.0). The difference is explained in the model by lower condom use for IAI than RAI, especially with HIV-positive partners (Table 3). Strategic positioning may play an important role in transmission dynamics, and prevention counselors should continue to emphasize that the risk of IAI, although lower than the risk of acquisition from RAI, is still an important concern for MSM. Second, among main partners, transmissions mostly arise from partners believed to be negative (partners with unrecognized infection), whereas among casual partners, most transmissions arise from partners of unknown serostatus. Assumptions about serostatus in main partnerships may be especially problematic with respect to decisions about condom use within main partnerships.

Our data are subject to several limitations. First, our model synthesizes data collected in different cities during different time periods. However, in analyses stratified by race and limited to the two cities where both studies collected data, our main conclusion was unchanged. Because data were collected differently in NHBS and VPS, there was some misalignment of our definitions of main and casual partners: VPS did not allow estimation of annual sexual episodes separately for sex with main and casual partners for men who had both types of partners.

Second, data on HIV prevalence and unrecognized HIV infection are an important component of the model. It is possible that proportion of men with unrecognized HIV may be erroneously high because men who know they are HIV-infected may have reported in the interview that they were HIV negative [11]. We estimated the true prevalence of HIV infection and the prevalence of unrecognized HIV infection among partners of our modeled cohort by assuming that the NHBS respondents were themselves reflective of the true HIV prevalence and prevalence of unrecognized HIV infection in their sex partners. This assumption could be problematic if venue-attending men often had male sex partners who did not attend venues and would not have been eligible for recruitment. The use of age-specific and race-specific estimates of HIV prevalence and undiagnosed prevalence require the assumption that most partnerships are similar with respect to age and race. If this assumption were violated, it would be more likely to affect the race- and age-specific estimates; the overall estimates would still be valid as long as the types of sex partners our respondents sought attended venues and were eligible for sampling in the NHBS study.

Third, our model does not account for some other, important aspects that impact HIV transmission among MSM. For example, infection with sexually transmitted diseases (STDs) increases the per-act risk of HIV transmission and acquisition [20]; STD infections have increased among MSM in the United States in recent years [21,22]. Our model did not account for the impact of STDs on HIV transmission risk. The VPS data used to estimate HIV transmission risks were collected before the broad availability of HAART; HAART prescription, when associated with suppression of viral load, is expected to substantially reduce the per-episode risk of HIV transmission [23]. Also, we did not account for varying infectivity of HIV-infected persons in different stages of HIV disease (acute infection versus latent period), for certain harm-reduction practices such as premature withdrawal, or for the potential impact of circumcision [24] on HIV transmission rates.

Our modeling approach did not allow us to censor men at the time of infection; therefore, our model may have overestimated transmissions. Because the likelihood and magnitude of this issue would be related to number of sex acts, it would tend to differentially overestimate transmissions from main partners. Our assumption that men reporting more than one male sex partner per year contributed the same number of transmissions as men reporting one male partner may also be problematic. Men who have serial main partners may actually be at greater risk of HIV infection, so our assumption may lead to an underestimate of transmissions in main partners.

Neither NHBS nor VPS collected data on duration of partnerships. If most HIV transmissions occur from main sex partners, then substantial rates of main partner change would be prerequisite to sustaining onward HIV transmission among MSM. In our study, a substantial proportion of men with main partners reported more than one main partner in the previous 12 months. Previous studies [25,26] in cross-sectional groups of MSM have documented mean duration of current primary relationships of 17 and 40 months. For men who have main partnerships of longer duration, the risk of HIV transmission from main partners would likely decrease over time. The frequency of sex within main partnerships declines over time in relationship [27]. Also, it is likely that the longer relationships (especially monogamous relationships) last, the more likely it is that both partners would have accurate knowledge of HIV serostatus. Of note, structural interventions to promote stability of relationships between men have been suggested as an approach to addressing the HIV epidemic in MSM [4]; if such approaches are implemented and are successful in promoting stability, longer duration of primary relationships may be an important mediator in reducing HIV incidence and would be expected to decrease the proportion of infections attributed to main partners in our model.

Our data are not generalizable to all MSM in the United States. Both source studies recruited sexually active MSM in urban areas; our findings do not apply to MSM in more rural areas. If MSM in our hypothetical cohort migrated to areas of varying HIV prevalence or undiagnosed HIV infection, our model would likely misrepresent incidence. Although diverse venues such as retail establishments and social organizations were included in the NHBS sampling frame [9], most NHBS participants were recruited from bars or dance clubs [10]. It is likely that MSM who do not attend NHBS venues, or who attend such venues infrequently, have patterns of behavioral risk that are different from those recruited to NHBS.

Despite these limitations, we believe that our model is a reasonable one. Our model estimated an annual HIV incidence of 2.2% (CI 1.7–2.7%). A meta-analysis [28] of published estimates of HIV incidence from 1995 to 2005 reported a weighted mean incidence of 2.3% (CI 2.0–2.65%) for MSM recruited in community settings. The median transmission rate derived from the serologic algorithm for HIV seroconversion (STARHS) from the same respondents in the five NHBS cities who were included in our analysis was 2.3% (range by city, 1.2–8.0%) [11]. The comparability of our estimates of HIV incidence derived by modeling and other estimates of HIV incidence derived using biological markers of recent infection suggests that our model makes reasonable assumptions.

Our data suggest that existing HIV prevention interventions should address issues related to risk within male partnerships and issues of testing and disclosure, and interventions that focus on MSM couples should also be considered. To date, most HIV prevention interventions tested in MSM (80%) have been group level interventions [29]. Many of our estimated transmissions arose in partnerships, which were believed by the participants to be seronegative concordant relationships. It is clear that men, whether they believe themselves to be HIV negative or know that they are HIV positive, do communicate a negative serostatus to sex partners [30,31]. Couples who believe themselves to be concordant seronegative may also benefit from improved knowledge of serostatus and risk reduction strategies. Also, the current MSM cycle of the NHBS system is interviewing MSM in 21 US cities during 2008; in the 2008 cycle, all men were offered HIV testing, and data on concurrency and duration of sexual partnerships were collected. This analysis should be repeated with data from this broader group of cities, to determine whether our finding is robust over time and in a more heterogeneous group of US cities.

A recent commentary [32] on HIV prevention noted that, 'for too long, AIDS activists, academics, and national and international institutions have given insufficient emphasis to aligning prevention priorities with epidemic transmission dynamics'. Such is the case with available HIV prevention interventions for MSM in the United States. Although over 50% of new US HIV infections are among MSM, only eight of 36 (22%) HIV-prevention interventions designated as 'best-evidence' prevention interventions by the CDC have been tested with MSM [33]. New HIV prevention interventions for US MSM are needed and should be responsive to the current behavioral risk patterns and transmission characteristics of the US MSM epidemic. Our data suggest that the development and testing of HIV prevention interventions for MSM couples, a historically understudied area of HIV prevention, may be important as we approach the fourth decade of the US HIV epidemic.

Acknowledgements

The authors express thanks to the Principal Investigators of the NHBS surveillance sites for the MSM data collection, who participated in the protocol development, oversaw the collection and local management of behavioral and HIV testing data, and provided critical review of the manuscript: Baltimore, Colin Flynn; Los Angeles County, Trista Bingham; Miami, Marlene LaLota; New York, Alan Neaigus; San Francisco and the Greater Bay Area, H. Fisher Raymond.

The authors express thanks to Dr Eric Vittinghoff, who provided updated estimates of HIV transmission risk for use in the model and thoughtful critique of the manuscript.

P.S. conceived the analysis, conducted the statistical analyses, and drafted the manuscript. L.S. participated in the development of the analysis plan, assisted in preparation of the manuscript, and provided perspective on how local data collection practices may have affected variable quality. S.B. provided critical input into the specifications of the model, coordinated updating of the HIV transmission risks, and provided critical input on the manuscript. T.S. conceived the analysis with P.S., participated in the development of the analysis plan, and provided critical input on the manuscript. All authors reviewed and provided substantial input to revisions of the manuscript.

The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the Centers for Disease Control and Prevention.

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