New heterosexually transmitted HIV infections in married or cohabiting couples in urban Zambia and Rwanda: an analysis of survey and clinical data

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Summary

Background Sub-Saharan Africa has a high rate of HIV infection, most of which is attributable to heterosexual transmission. Few attempts have been made to assess the extent of HIV transmission within marriages, and HIV-prevention efforts remain focused on abstinence and non-marital sex. We aimed to estimate the proportion of heterosexual transmission of HIV which occurs within married or cohabiting couples in urban Zambia and Rwanda each year.

Methods We used population-based data from Demographic and Health Surveys (DHS) on heterosexual behaviour in Zambia in 2001–02 and in Rwanda in 2005. We also used data on the HIV serostatus of married or cohabiting couples and non-cohabiting couples that was collected through a voluntary counselling and testing service for urban couples in Lusaka, in Zambia, and Kigali, in Rwanda. We estimated the probability that an individual would acquire an incident HIV infection from a cohabiting or non-cohabiting sexual partner, and then the proportion of total heterosexual HIV transmission which occurs within married or cohabiting couples in these settings each year.

Findings We analysed DHS data from 1739 Zambian women, 540 Zambian men, 1176 Rwandan women, and 606 Rwandan men. Under our base model, we estimated that 55·1% to 92·7% of new heterosexually acquired HIV infections among adults in urban Zambia and Rwanda occurred within serodiscordant marital or cohabiting relationships, depending on the sex of the index partner and on location. Under our extended model, which incorporated the higher rates of reported condom use that we found with non-cohabiting partners, we estimated that 60·3% to 94·2% of new heterosexually acquired infections occurred within marriage or cohabitation. We estimated that an intervention for couples which reduced transmission in serodiscordant urban cohabiting couples from 20% to 7% every year could avert 35·7% to 60·3% of heterosexually transmitted HIV infections that would otherwise occur.

Interpretation Since most heterosexual HIV transmission for both men and women in urban Zambia and Rwanda takes place within marriage or cohabitation, voluntary counselling and testing for couples should be promoted, as should other evidence-based interventions that target heterosexual couples.

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Introduction

Evidence suggests that a woman's greatest risk of contracting HIV lies within a marital relationship.[1–12] Fewer attempts have been made to understand a man's risk within marriage;[2,12] but, in regions with generalised epidemics, high rates of serodiscordance among heterosexual couples in which the woman is HIV-positive suggest that a man's risk of marital HIV acquisition could also be substantial.[2,12,13]

Sub-Saharan Africa has the highest prevalence and incidence of HIV infection worldwide, mostly attributable to heterosexual transmission.[14] Various studies have noted a high prevalence of HIV serodiscordance among heterosexual couples in Africa;[15–17] population-based estimates of serodiscordance, from Demographic and Health Surveys (DHS), range from 2% (in Rwanda)[13] to 13% (in Zimbabwe[18] and Lesotho[19]). DHS data which show that between 45%[18] and 75%[20] of married

HIV-positive individuals have HIV-negative spouses affirm the importance of HIV-prevention efforts for couples.[18] Studies in Rwanda and Zambia with serodiscordant heterosexual couples showed that HIV transmission from HIV-positive to HIV-negative partners was 20–25% per year, irrespective of whether the man or woman was the positive partner.[21–23] This rate accords with a coital frequency of two to three times per week and a risk of transmission on the order of one in 500 for each contact.[23–25] Transmission in serodiscordant couples who have received joint voluntary counselling and testing ranges from 3% to 7% per year,[21,26,27] with higher rates reported in cohorts that include a mixture of couples who know their own serostatus or that of their partner and those who don't.[23,25,27] These data show that HIV-serodiscordant partnerships are a risky context for both women and men. These partnerships are also a potentially valuable context for preventive interventions.

We aimed to use both publicly available population-based data on sexual behaviour and service-based estimates of HIV serodiscordance to assess the proportion of heterosexually transmitted HIV infections in urban Zambia and urban Rwanda during a typical 12 month period which occur within the context of marital or cohabiting relationships. By quantifying the extent of HIV transmission among couples, we aimed to inform and perhaps to redirect the focus of HIV-intervention efforts, which have traditionally targeted individuals rather than couples.

Methods

Data sources

We used data collected by the Rwanda–Zambia HIV Research Group from July, 2003, to December, 2005, through voluntary counselling and testing services for couples in Kigali, Rwanda, and Lusaka, Zambia. Both partners were present at counselling sessions both before and after HIV tests, with simultaneous disclosure of

results, results-specific counselling, training in the use of condoms, and referrals as appropriate for follow-up care.[29] Data were available from 15 159 cohabiting couples and 8690 non-cohabiting couples in Kigali, and from 7027 cohabiting couples and 559 non-cohabiting couples in Lusaka. All these couples provided written joint informed consent.

We obtained population-based sexual behavioural data from DHS surveys in Zambia (in 2001–02)[30] and Rwanda (in 2005).[13] Because data from the Rwanda–Zambia HIV Research Group were derived from major cities in each country, we limited our analysis of DHS data to records collected in urban areas. The DHS data covered heterosexual behaviour in the 12 months before the survey, and included the types and durations of relationships between the respondent and up to three of their most recent partners, and whether a condom was used at the most recent sexual intercourse.

Modelling analysis

For each individual within the DHS datasets who reported at least one sexual partner within the past 12 months, we estimated the probability that they had acquired an incident HIV infection during the past 12 months (1) from a cohabiting sexual partner; (2) from a non-cohabiting sexual partner; or (3) from any sexual partner (see webappendix). We then calculated the mean probability of any incident HIV infection from cohabiting, non-cohabiting, or any sexual partners and used these figures to estimate what proportion of incident heterosexually transmitted HIV infections were attributable to cohabiting relationships.

Our model used the assumptions that (1) all cohabiting serodiscordant sexual relationships have an equal probability of HIV transmission per unit of time; (2) all serodiscordant non-cohabiting sexual relationships have an equal probability of HIV transmission per unit of time; and (3) partners who are both HIV-negative are at no risk of infection from each other over the course of a year. Although the first two assumptions imply that these probabilities are constant over time, these assumptions are of course inaccurate at the individual level. Many variables—eg, coital frequency, co-infection with herpes simplex virus 2 (HSV-2) or other sexually transmitted infections, donor's viral load, or recipient's immune status—could cause the dyadic-level probability of HIV transmission to vary substantially. Our model, however, is based on aggregate population-level patterns of sexual partnerships—to produce estimates, it requires only the average transmission probability for each type of serodiscordant dyad at the population level.

We assigned estimated probabilities, pRD, of HIV serodiscordance for each person's relationships, whether cohabiting or not, on the basis of age-specific and sex-specific data for HIV serodiscordance within relationships derived from the Rwanda–Zambia HIV Research Group's data. The duration of each sexual

See **Online** for webappendix
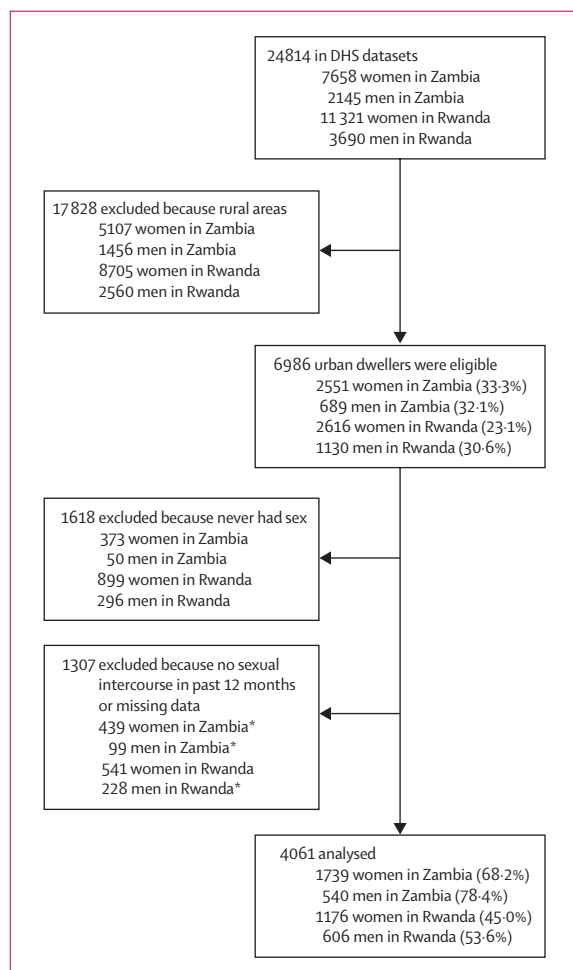
Figure: **Eligibility for analysis based on area of residence and sexual activity in the past year**

*Data on sexual activity in the past 12 months were missing for one participant.

relationship, t, was either 1 for relationships of 12 months or longer in duration, or was calculated as the proportion of a year since marriage or first sexual intercourse.

Data from Zambia and Rwanda suggest that for partners in a serodiscordant couple who are unaware of their HIV serostatus, transmission is 20–25% per year.[19,20] We set the probability of HIV transmission within a cohabiting sexual relationship over 12 months, a, as 0·20 for cohabiting couples in our base models, and tested variations from 0·01 to 0·99 to assess the sensitivity of our model to this probability. For our base models, we assumed that the probability of HIV transmission within a non-cohabiting sexual relationship per unit time, b, would be equal to the probability in a cohabiting sexual relationship over 12 months. However, we also tested the effects of varying the ratio of a to b, so that cohabitation was associated with either a higher or lower risk of HIV transmission per unit of time than was non-cohabitation.

We next estimated the effect of reported condom use on HIV transmission. Since the only available indicator of condom use at the relationship level was condom use at last sex, we could not assess whether this represented consistent or correct condom use or what level of protection resulted. We therefore estimated the probability, c, that reported condom use at most recent sexual intercourse with a given partner represented a level of condom use sufficient to prevent transmission of HIV that would otherwise occur, to range from 0·25 to 0·85, or 0·50 for the base models.

To estimate the potential effect of an effective intervention for couples on overall heterosexual HIV incidence, we ran hypothetical cases with probabilities of 0·03 and 0·07 for cohabiting couples (0·20 for non-cohabiting couples) to represent the annual transmission rate in serodiscordant couples who receive voluntary counselling, testing, and on-going support from existing services in Kigali and Lusaka.[21,26]

Additional sensitivity analyses

Unlike a, b, and c, the probability of HIV serodiscordance and the numbers and types of sexual partners used in our models were based on empirical data. However, since all data sources have inherent limitations, we investigated how varying values from the data would affect the models. To estimate the potential effect of different rates of serodiscordance, we multiplied the assigned serodis-cordance probabilities by values ranging from 0·5 to 2·0. To assess the potential effect of under-reporting or over-reporting of sexual partners, we added two partner-multi-plication factors to the models, one for cohabiting partners, and one for non-cohabiting partners. These increased or decreased the number of reported partners for each individual in each category by the assigned factor while maintaining reported patterns of relationship duration and condom use at most recent sexual intercourse.

	Zambia		Rwanda	
	Women (N=1739)	Men (N=540)	Women (N=1176)	Men (N=606)
Area of residence				
Lusaka or Kigali	540 (31·1%)	162 (30·0%)	450 (38·3%)	268 (44·2%)
Other urban	1199 (68·9%)	378 (70·0%)	726 (61·7%)	338 (55·8%)
Age (years)				
15–19	248 (14·3%)	55 (10·2%)	43 (3·7%)	13 (2·1%)
20–29	831 (47·8%)	201 (37·2%)	519 (44·1%)	171 (28·2%)
30–39	438 (25·2%)	165 (30·6%)	420 (35·7%)	209 (34·5%)
40–49	222 (12·8%)	74 (13·7%)	194 (16·5%)	147 (24·3%)
≥50	··	45 (8·3%)	··	66 (10·9%)
Current marital status				
Never married	244 (14·0%)	154 (28·5%)	116 (9·9%)	117 (19·3%)
Married	1307 (75·2%)	342 (63·3%)	615 (52·3%)	321 (53·0%)
Living together	17 (1·0%)	5 (0·9%)	363 (30·9%)	148 (24·4%)
Widowed	51 (2·9%)	5 (0·9%)	14 (1·2%)	5 (0·8%)
Divorced	79 (4·5%)	16 (3·0%)	5 (0·4%)	5 (0·8%)
Not living together	41 (2·4%)	18 (3·3%)	63 (3·5%)	10 (1·7%)
Number of spousal or cohabiting sex partners in past 12 months				
0	351 (20·2%)	195 (36·1%)	179 (15·2%)	157 (25·9%)
1	1385 (79·6%)	337 (62·4%)	995 (84·6%)	446 (73·6%)
2	2 (0·1%)	8 (1·5%)	2 (0·2%)	3 (0·5%)
3	1 (0·1%)	··	··	··
Number of non-cohabiting sex partners in past 12 months				
0	1363 (78·4%)	265 (49·1%)	993 (84·4%)	440 (72·6%)
1	341 (19·6%)	192 (35·6%)	172 (14·6%)	154 (25·4%)
2	32 (1·8%)	56 (10·4%)	11 (0·9%)	12 (2·0%)
3	3 (0·2%)	7 (1·3%)	··	··
≥4	··	20 (3·7%)	··	··
Condom use at most recent sexual intercourse				
With any cohabiting partner	129* (9·3%)	39‡ (11·3%)	52¶ (5·2%)	26** (5·8%)
With any non-cohabiting partner	179† (47·6%)	162§ (63·5%)	64‖ (35·0%)	96†† (57·8%)

Data are number (%), and are from Demographic and Health Surveys in Zambia in 2001–02[30] and Rwanda in 2005.[13] *N=1388. †N=376. ‡N=345. §N=255. ¶N=997. ‖N=183. **N=449. ††N=166.

Table 1: Demographic characteristics and sexual behaviour over the past year among urban women and men

This research was approved by the University of Zambia Research Ethics Committee, the National Ethics Committee of Rwanda and the Emory University Institutional Review Board.

Role of the funding source

Results

In the DHS data for urban Zambia, 1739 (68·2%) women and 540 (78·4%) men reported sexual activity in the past 12 months, whereas in urban Rwanda, 1176 (45·0%) women and 606 (53·6%) men reported sexual activity in the past year (figure). The difference

in sexual activity in the two areas is probably associated with the older average age of first sexual intercourse in Rwanda.[13,30,31]

Overall, 1388 (79·8%) of the sexually active Zambian women, 345 (63·9%) of the Zambian men, 997 (84·8%) of Rwandan women, and 449 (74·1%) of Rwandan men reported sex with at least one marital or cohabiting partner during the past 12 months, whereas 376 (21·6%) Zambian women, 275 (50·9%) Zambian men, 183 (15·6%) Rwandan women, and 166 (27·4%) Rwandan men reported sex with a non-cohabiting partner during the past 12 months (table 1). 25 (1·4%) Zambian women, 80 (14·8%) Zambian men, 4 (0·3%) Rwanda women, and 9 (1·5%) Rwandan men reported both cohabiting and non-cohabiting sex partners during the past 12 months. Self-reported condom use at most recent sexual activity was more common for non-cohabiting relationships than for cohabiting couples in both Zambia and Rwanda (p<0·0001, table 1).

We assigned the probability that a reported sexual relationship would involve serodiscordance on the basis of the Rwanda–Zambia HIV Research Group data on the prevalence of serodiscordance by sex, age, and cohabitation status for Lusaka and Kigali (table 2).

In model 1, we assumed that 20% of serodiscordant relationships result in HIV transmission in each 12 month interval. In model 2, we added a parameter for reported condom use at most recent sexual intercourse. Model 1 predicts that 55·1% to 92·7% of new HIV infections among sexually active adults, and 84·1% to

	Zambia		Rwanda	
	Cohabiting couple	Non-cohabiting couple	Cohabiting couple	Non-cohabiting couple
HIV-negative men with HIV-positive female partners				
Man's age (years)				
16–19	0/7 (0%)	2/20 (10·0%)	4/31 (12·9%)	12/423 (2·8%)
20–29	185/1943 (9·5%)	47/292 (16·1%)	337/5335 (6·3%)	407/5850 (7·0%)
30–39	297/3117 (9·5%)	30/372 (8·1%)	342/5142 (6·7%)	179/1620 (11·0%)
≥40	180/1960 (9·2%)	8/74 (10·8%)	309/4651 (6·6%)	103/795 (13·0%)
Total	662/7027 (9·4%)	87/558 (15·6%)	992/15159 (6·5%)	701/8690 (8·1%)
HIV-negative women with HIV-positive male partners				
Woman's age (years)				
16–17	5/84 (6·0%)	3/48 (6·3%)	3/64 (4·7%)	2/409 (0·5%)
18–24	170/2126 (8·0%)	30/269 (11·2%)	243/5074 (4·8%)	176/5440 (3·2%)
25–29	145/1845 (7·9%)	15/118 (12·7%)	220/3822 (5·8%)	63/1535 (4·1%)
30–34	106/1337 (7·9%)	6/55 (10·9%)	174/2660 (6·5%)	37/681 (5·4%)
≥35	129/1631 (7·9%)	9/69 (13·0%)	240/3539 (6·8%)	49/618 (7·9%)
Total	555/7023 (7·9%)	63/559 (11·3%)	880/15159 (5·8%)	327/8683 (3·8%)

Data are number (%), and are derived from voluntary counselling and testing for couples services run by the Rwanda–Zambia HIV Research Group. Data on age were missing for some people.

Table 2: **Prevalence of serodiscordance among cohabiting and non-cohabiting couples in Lusaka and Kigali by sex of at-risk partner and age**

	Zambia						Rwanda					
	Women			Men			Women			Men		
	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only
Probability of any infection	0·01588	0·01554	0·00240	0·02179	0·02233	0·02082	0·01106	0·01208	0·00538	0·01049	0·01327	0·00254
Probability of infection from marriage or cohabitation	0·01222	0·01533	··	0·01200	0·01879	··	0·01023	0·01206	··	0·00972	0·01312	··
Probability of infection from non-cohabiting partnership	0·00365	0·00021	0·00240	0·00983	0·00361	0·02082	0·00083	0·00002	0·00538	0·00077	0·00015	0·00254
Estimated proportion infected through marriage or cohabitation	77·0%	98·6%	0%	55·1%	84·1%	0%	92·5%	99·8%	0%	92·7%	98·9%	0%
Probability of any infection if transmission through cohabitation was reduced from 20% to 3%	0·00548	0·00251	0·00240	0·01162	0·00642	0·02082	0·00237	0·00183	0·00538	0·00222	0·00211	0·00254
Proportion of infections potentially averted	65·5%	83·8%	··	46·7%	71·3%	··	78·6%	84·9%	··	78·8%	84·1%	··
Probability of any infection if transmission through cohabitation was reduced from 20% to 7%	0·00793	0·00557	0·00240	0·01401	0·01016	0·02082	0·00441	0·00424	0·00538	0·00417	0·00474	0·00254
Proportion of infections potentially averted	50·1%	64·1%	··	35·7%	54·5%	··	60·1%	64·9%	··	60·3%	64·3%	··

Data are mean probabilities, from models based on Demographic and Health Surveys in Zambia in 2001–02[30] and Rwanda in 2005.[13]

Table 3: **Estimated mean probability of incident HIV infection resulting from marriage or cohabitation and from non-cohabiting sexual partners, based only on population-based data on self-reported sexual partnerships, assuming 20% annual transmission within serodiscordant couples (model 1)**

	Zambia						Rwanda					
	Women			Men			Women			Men		
	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only	All sexually active	Any spouse or cohabiting partners	Non-cohabiting partners only
Probability of any infection	0·01449	0·01478	0·00240	0·01886	0·02039	0·01613	0·01065	0·01176	0·00450	0·01002	0·01284	0·00196
Probability of infection from marriage or cohabitation	0·01166	0·01461	..	0·01136	0·01779	..	0·00996	0·01174	..	0·00944	0·01274	..
Probability of infection from non-cohabiting partnership	0·00284	0·00018	0·00240	0·00752	0·00265	0·01613	0·00070	0·00002	0·00450	0·00058	0·00010	0·00196
Estimated proportion infected through marriage or cohabitation	80·4%	98·8%	0%	60·3%	87·2%	0%	93·5%	99·9%	0%	94·2%	99·3%	0%
Probability of any infection if transmission through cohabitation was reduced from 20% to 3%	0·00467	0·00247	0·00240	0·00932	0·00546	0·01613	0·00223	0·00182	0·00450	0·00204	0·00206	0·00196
Proportion of infections potentially averted	67·8%	83·3%	..	50·6%	73·2%	..	79·1%	84·5%	..	79·7%	83·9%	..
Probability of any infection if transmission through cohabitation was reduced from 20% to 7%	0·00712	0·00554	0·0024	0·01171	0·00921	0·01613	0·00427	0·00423	0·00450	0·00398	0·00469	0·00196
Proportion of infections potentially averted	50·9%	62·5%	..	37·9%	54·8%	..	59·9%	64·0%	..	60·3%	63·5%	..

Data are mean probabilities, are from models based on Demographic and Health Surveys in Zambia in 2001–02[30] and Rwanda in 2005.[13]

Table 4: **Estimated mean probability of incident HIV infection resulting from marriage or cohabitation and from non-cohabiting sexual partners, accounting for reported condom use at most recent sexual intercourse with each partner, if condom use reduces transmission risk by 50% (model 2)**

99·8% of infections among married or cohabiting adults, occur within serodiscordant marital or cohabiting relationships, depending on sex of the index partner and residential area (table 3).

Model 2, which accounts for higher rates of reported condom use with non-cohabiting partners, predicts that 60·3% to 94·2% of new HIV infections among sexually active adults, and 87·2% to 99·9% of infections among married or cohabiting adults, are attributable to transmission within marital or cohabiting relationships (table 4).

Model 1 predicts that an intervention for couples which could reduce transmission in urban cohabiting couples from 20% to 7% every year could avert 35·7% to 60·3% of heterosexually transmitted infections that would otherwise occur, whereas an intervention that could reduce such transmission from 20% to 3% could avert 46·7% to 78·8% of infections. Model 2, which includes condom use and therefore attributes a lower proportion of infection to non-cohabiting relationships, predicts that reducing annual transmission in urban cohabiting couples from 20% to 7% could prevent 37·9% to 60·3% of new heterosexual infections, whereas reducing transmission from 20% to 3% would prevent 50·6% to 79·7% of new infections (table 4).

Sensitivity analyses showed that our models were robust across a wide range of values for our assigned constants, a, b, and c (table 5). Varying the overall rate of transmission per year yields no change in results as long as the rate in cohabiting couples, a, is set equal to the rate in non-cohabiting couples, b. When a was equal to b, the model yielded essentially identical results for all values of a and b ranging from 0·01 to 0·99. Varying the ratio of a to b (assuming that the 12 month incidence rate is not equal in cohabiting and non-cohabiting sexual partnerships), does produce different estimates. Holding self-reported condom use constant as per the DHS data, if we assume that the average risk of transmission in a serodiscordant cohabiting couple is higher than that of a non-cohabiting couple (as might result, for example, from greater coital frequency), the proportion of transmission attributable to cohabiting couples increases. If incidence in non-cohabiting relationships is assumed to be higher than that in cohabiting relationships (for example because of a higher prevalence of other sexually transmitted infections, resulting in higher risk of transmission for each exposure) the fraction attributable to cohabiting relationships decreases.

Varying the estimated level of protection represented by self-reported condom use at most recent sexual intercourse,

Probability of HIV transmission within married or cohabiting couples per unit time	Probability of HIV transmission within non-cohabiting couples per unit time	Protection from condom use at most recent sexual intercourse	Zambia				Rwanda			
			Women		Men		Women		Men	
			All sexually active	Married or cohabiting	All sexually active	Married or cohabiting	All sexually active	Married or cohabiting	All sexually active	Married or cohabiting
0·10	0·10	0·50	80·5%	98·8%	60·3%	87·2%	93·5%	99·9%	94·3%	99·3%
0·30	0·30	0·50	80·4%	98·8%	60·2%	87·2%	93·4%	99·9%	94·2%	99·3%
0·20	0·10	0·50	89·2%	99·4%	75·3%	93·2%	96·6%	99·9%	97·1%	99·6%
0·20	0·15	0·50	84·6%	99·1%	67·0%	90·1%	95·0%	99·9%	95·6%	99·4%
0·20	0·30	0·50	73·1%	98·2%	50·2%	81·9%	90·4%	99·8%	91·5%	98·9%
0·20	0·40	0·50	67·1%	97·6%	42·9%	77·0%	87·6%	99·7%	89·0%	98·5%
0·20	0·20	0·25	78·7%	98·7%	57·5%	85·6%	92·9%	99·9%	93·4%	99·1%
0·20	0·20	0·50	80·4%	98·8%	60·3%	87·2%	93·5%	99·9%	94·2%	99·3%
0·20	0·20	0·75	82·4%	98·9%	63·5%	89·0%	93·5%	99·9%	95·0%	99·4%
0·20	0·20	0·85	83·2%	98·9%	64·9%	89·7%	94·2%	99·9%	95·4%	99·5%

Table 5: Sensitivity analysis of the mean probability of incident HIV infection within marriage or cohabitation in urban Zambia and Rwanda, with changing assumptions about transmission of HIV per unit time and protection from condom use

Multiplication factors for prevalence (pRD) of serodiscordance in married or cohabiting couples	Multiplication factors for prevalence (pRD) of serodiscordance in non-cohabiting couples	Multiplication factors for number of married or cohabiting sexual partners	Multiplication factors for number of non-cohabiting sexual partners	Zambia				Rwanda			
				Women		Men		Women		Men	
				All sexually active	Married or cohabiting	All sexually active	Married or cohabiting	All sexually active	Married or cohabiting	All sexually active	Married or cohabiting
0·5	1			67·4%	97·7%	44·9%	78·5%	87·7%	99·7%	89·2%	98·5%
2	1			89·2%	99·4%	76·6%	93·8%	96·6%	99·9%	97·1%	99·6%
1	0·5			89·2%	99·4%	76·4%	93·6%	96·6%	99·9%	97·1%	99·6%
1	2			67·4%	97·7%	45·3%	78·7%	87·7%	99·7%	89·2%	98·5%
0·5	2			50·9%	95·4%	29·3%	64·7%	78·1%	99·5%	80·5%	97·1%
2	0·5			94·3%	99·7%	86·7%	96·8%	98·3%	100·0%	98·5%	99·8%
		0·5	1	67·4%	97·6%	43·2%	77·3%	87·7%	99·7%	74·7%	96·0%
		2	1	89·1%	99·4%	75·1%	93·2%	96·6%	99·9%	92·2%	99·0%
		1	0·5	89·1%	99·4%	75·0%	93·1%	96·6%	99·9%	92·1%	99·0%
		1	2	67·5%	97·7%	43·8%	77·6%	87·8%	99·7%	74·8%	96·0%
		1	3	58·3%	96·6%	34·8%	70·2%	82·8%	99·6%	66·6%	94·2%
		1	5	46·1%	94·6%	25·1%	59·3%	74·4%	99·4%	77·1%	96·5%

Table 6: Sensitivity analysis of mean probability of incident HIV infection within marriage or cohabitation in urban Zambia and Rwanda, with varying estimates of potential error in the data sources used to estimate serodiscordance and numbers of sexual partners

c, changes the estimated proportion of infection associated with cohabitation as a function of the disparity between condom use in cohabiting versus non-cohabiting relationships (table 5). Overall, the assumption that reported condom use at most recent sexual intercourse represents higher levels of protection attributes a higher proportion of infection to cohabiting couples because of the lower rates of condom use reported in cohabiting relationships.

In the most extreme case of our serodiscordance sensitivity analysis (table 6), in which we assume serodiscordance in cohabiting couples to be overestimated by 100% and serodiscordance in non-cohabiting couples to be underestimated by 100%, we still predict that more than half of new heterosexually transmitted HIV infections originate in marriage or cohabitation in Rwanda and among Zambian women, whereas 29% of new infections in Zambian men are acquired in marital or cohabiting relationships.

A simulated three-fold increase in the reported number of non-cohabiting partners similarly predicts that more than half of all new HIV infections are attributable to marriage or cohabitation, except among Zambian men. A simulated five-fold increase in non-cohabiting partners yields an overall estimate of nearly three-quarters of new

HIV infections in Rwanda still attributable to marriage or cohabitation, whereas 25% of new infections among Zambian men and 46% among Zambian women remain so attributable.

Discussion

HIV prevalence in urban areas of Zambia in 2001 was 19·2% in men aged 15–59 and 26·3% in women aged 15–49.[30] In 2005, urban HIV prevalence in Rwanda was 5·8% in men and 8·6% in women.[13] Our most conservative model (model 1), predicted that most heterosexual HIV infections in both men and women in urban Zambia and Rwanda every year are probably transmitted within marriage. Our sensitivity analyses affirm the robustness of our key finding that most new heterosexually transmitted HIV infections in urban Zambia and Rwanda are acquired within marriage or cohabitation, and strengthen the assertion that marriage and cohabitation should be a key focus for HIV-prevention efforts.

Cultural contexts support men's extramarital sexual activities and prevent women from practising HIV prevention within their relationships, which increases their risk of HIV infection in marriage.[3–6,8] Our analysis suggests that marriage also poses a risk of HIV infection for men. This finding accords with data from our services in both Lusaka and Kigali that provide voluntary counselling and testing for couples. These data show that serodiscordance in which the female partner is HIV-positive is more frequently recorded than serodiscordance in which the male partner is HIV-positive (table 2). The risks of HIV infection within marriage are the product of premarital and extramarital sexual activity. Given that women are generally infected at younger ages than men,[14] women are probably more likely than men to enter marriage already infected.[1]

Our estimates differ as expected from those of Glynn and colleagues[2] for a similar city in Zambia, in which they retrospectively estimated the likely origin of infection for each HIV-positive member of 65 couples. This method necessarily yields more than 50% of infections acquired outside the union, since at least one partner in a marriage must have acquired the infection from a non-spouse. Our approach uses population-based data on patterns of sexual partnership to estimate the proportion of new infections that would be acquired from cohabiting and non-cohabiting partners over a 1 year period. Although both models have merits, ours focuses attention on the proportion of heterosexual HIV infections that could be prevented, given the high proportion of the urban African population that is married or cohabiting and the high prevalence of marital serodiscordance.

To reduce HIV transmission, couples need to know their joint serostatus and have access to information which enables them to reduce the risk of infection both within and outside the union. This is especially important for women, who might not have the cultural freedom to negotiate condom use and sexual activity within a union.[3–6,8] Most HIV services in Africa currently deal with clients as individuals. However, since most pregnant women, patients on antiretroviral therapy, and attendees at voluntary counselling and testing clinics are in marital or cohabiting partnerships, this represents a missed opportunity.

Previous studies have shown that interventions aimed at couples have encouraged uptake of antiretroviral treatment and HIV testing.[32–35] We suggest that a gender-sensitive approach to HIV services and prevention for couples should be expanded to the general population, with HIV services aimed at both couples and individuals. Voluntary counselling and testing for couples and behavioural-change interventions aimed at couples have been shown to reduce HIV transmission among serodiscordant couples.[21,36–38]

Our most conservative estimate in this analysis (model 1) suggests that voluntary counselling and testing for couples, which reduced the incidence of HIV among serodiscordant urban cohabiting couples from 20% to 7% per year (as reported by our clinics in Lusaka[26]), could prevent 35·7% to 60·3% of heterosexual infections in this population. Reducing transmission within couples in urban Rwanda would yield a greater proportionate reduction in HIV, since more infection is attributable to marriage, and incidence of HIV infection after voluntary counselling and testing for couples in Rwandan serodiscordant couples is closer to 3%.[21] However, focusing on couples in Zambia could potentially prevent a greater overall number of infections, given the relatively higher HIV prevalence and incidence in that country.

Our method can be easily replicated. The DHS data are publicly available for 33 sub-Saharan African countries. AIDS Indicator Surveys and other nationally representative population-based behavioural surveys that include HIV serostatus, some of which have more detail on sexual behaviour, are becoming available in sub-Saharan Africa. However, our analysis is made possible by data on HIV serodiscordance within couples from two ongoing cohort studies of services that provide voluntary counselling and testing for couples in the capital cities of Rwanda and Zambia. Although recent DHS included HIV testing, which allowed serodiscordance within couples to be estimated, this was restricted to cohabiting couples. We therefore advocate collection of representative data on the prevalence of serodiscordance in all couples, and of linked data on sexual behaviour in all types of couples (to the extent that this is ethically and logistically possible) to understand better the effects of HIV transmission and prevention for couples.

We assumed that partners who are both HIV-negative are at zero risk of HIV infection from each other over the course of a year. However, a partner who is HIV-negative at the beginning of a year could potentially acquire HIV from an external relationship and then transmit it to

their HIV-negative partner; indeed, such newly acquired infections would probably be associated with extremely high viral load and therefore higher than usual risk of transmission.[23] Without linked data on the sexual behaviour of sexual partners, these probabilities are difficult to estimate. The very low number of people who reported both cohabiting and non-cohabiting partners and the relatively low number of people who reported multiple partners mean that this should have had little effect on our estimates, although we have probably slightly underestimated the proportion of married or cohabiting adults who acquire HIV within marriage.

Our estimates of HIV serodiscordance are taken from clinic-based populations at research sites in Rwanda and Zambia; although a previous analysis showed similar demographic and socioeconomic profiles between these populations and nationally representative samples,[31] these populations are urban and thus likely to yield higher levels of discordance than national populations.

Our estimate that 20% of HIV-serodiscordant partnerships will result in infection every year in the absence of intervention is taken from estimates of older studies in Rwanda[21] and Zambia.[22] Although these estimates are somewhat dated, more recent studies of serodiscordant couples in these and other settings have the methodological limitation of including participants who were aware of either their own or their partner's HIV serostatus, or both, during follow-up.

The DHS data used for sexual behaviour are based on self-report, and collected in the context of a broader household-based survey. They contain no information on same-sex sexual behaviour or risks for iatrogenic HIV acquisition. They also probably contain biased reporting of stigmatised sexual behaviour, such as under-reporting of partner numbers and over-reporting of condom use, especially for non-marital partners. These biases could yield overestimates of the proportion of heterosexual transmission that is attributable to cohabiting relationships. However, the DHS data used represent the only population-based data on sexual behaviour that are currently publicly available for these countries.

We strongly encourage other investigators to replicate our methods in other settings with other primary data sources, and to test values for model parameters that are appropriate for other countries and contexts. Thus can we collectively refine estimates of the proportion of HIV infection which takes place within marriage and continue the much needed discussion about the role of marital partners in HIV transmission and the benefit of targeted interventions.

We estimate that most heterosexual HIV transmission in urban Zambia and Rwanda takes place within married and cohabiting couples. Traditional reliance on promoting abstinence overall and fidelity for couples without accompanying HIV testing is inadequate in these settings without a focus on HIV-prevention services for couples. Voluntary counselling and testing for couples is an evidence-based intervention that has been proven to reduce heterosexual transmission within serodiscordant couples in these countries. If we assume an incidence of 20% among serodiscordant couples per year in the absence of intervention, we estimate that effective scale-up of programmes for voluntary counselling and testing of couples in urban Zambia and urban Rwanda has the potential to reduce heterosexual HIV transmission by 35–80%. We therefore call for increased promotion of voluntary counselling and testing for couples and for development and assessment of other interventions for couples that are both culturally and gender sensitive.

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