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HIV Risk in Relation to Marriage in Areas With High Prevalence of HIV Infection

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Summary: In sub-Saharan Africa, the prevalence of HIV infection among young women is much higher than that among young men. Many women enter marriage HIV-infected, suggesting that men may be predominantly infected by their wives. Using data from cross-sectional surveys in Kisumu, Kenya, and Ndola, Zambia, in 1997, the prevalence of HIV infection at marriage was estimated from age at marriage and age- and sex-specific prevalence of HIV infection among unmarried individuals. Using a deterministic model, this prevalence was compared with measured concordance of HIV infection among recently married couples to estimate transmission probabilities within marriage and extramarital incidence of HIV infection. Over a wide range of assumptions, we estimated that at least one quarter of cases of HIV infection in recently married men were acquired from extramarital partnerships, and for both men and women, less than one half of cases of HIV infection were acquired from their spouse. In these sites, many infections in married men, even in those with HIV-infected wives, may be acquired from outside the marriage. **Key Words:** HIV, risk factors, Africa, marriage, heterosexual transmission

In many areas of Africa, the prevalence of HIV infection among women is high within the first few years of sexual activity, whereas that among men rises more slowly.[1–4] Since sexual activity usually starts before marriage, many women enter marriage already infected with HIV. At marriage, men are usually older than women. A substantial proportion of them may also already be HIV-infected, but the proportion is probably lower than that of the women. It has therefore been postulated that men in such populations are predominantly infected by their wives (and then go on to infect younger unmarried women).

If women are more likely than men to be HIV-infected at the time of marriage and male-to-female transmission is at least as efficient as female-to-male transmission,[5–8] if not more so,[9–13] then it would be expected that the proportion of HIV-positive men who have HIV-positive wives ("proportion concordant positive") would be higher than the proportion of HIV-positive women who have HIV-positive husbands. In a number of studies, however, the proportion concordant positive is very similar for men and women.[5,10,13] This could be explained by new HIV infections in men from outside the marriage.

We analyzed data from two cities with stable high prevalence of HIV infection (Kisumu, Kenya, and Ndola, Zambia) from the Multicentre Study on Factors Determining Differences in HIV Spread between African Cities to estimate the proportion of HIV infection occurring before or after marriage for men and women and the proportion acquired from their spouse.

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METHODS

Households were selected by two-stage cluster sampling based on census lists, aiming for a sample of about 1000 men and 1000 women in each city.[14] Within each household, all individuals aged 15–49 years who had slept the previous night in the house were eligible for inclusion. Some married couples (defined as "married" or "living as married") were thus included. Those individuals who consented to take part in the study were interviewed and were asked to give a blood sample for testing for HIV infection, syphilis, and infection with *Herpes simplex* virus 2. All information was collected confidentially and independently for husband and wife.

For husband and wife couples within the data, the proportions concordant and discordant for HIV infection overall and within 5 years of their first marriage were calculated. For the latter, couples were included only if both partners dated the marriage as occurring within the last 5 years and if the marriages were monogamous.

The prevalence of HIV infection among married individuals and the proportions of couples concordant and discordant for HIV infection must depend on the prevalence of HIV infection among males and females at the time of marriage, the transmission (male-to-female and female-to-male) probabilities of HIV within marriage, and the incidence of new HIV infections brought into partnerships by males and females.

In this cross-sectional survey, we could not measure the prevalence of HIV infection at the time of marriage directly. We therefore estimated it from the age at marriage of those couples who were married for the first time within the 5 years before the survey and the age- and sex-specific prevalence of HIV infection among unmarried people seen in the survey. For women, we included those who were not yet sexually active in estimating the prevalence of HIV infection, but this strategy was not used for men, since few men in these populations were virgins at marriage.[15] For the older age groups (30 years and older for men and women in Kisumu and women in Ndola, and 35 years and older for men in Ndola), those who were married were included to obtain estimates, as the numbers of older unmarried individuals were very small. Since there were very few individuals marrying for the first time in these age groups, this had little influence on the results. In the population surveys, not all spouses of married individuals were interviewed, and there may have been different sampling biases for men and women. The results were therefore cross-checked by repeating the estimates using the reported age of the spouse at marriage for both men and women and by restricting the analysis to the couples for whom we had information for both partners.

Estimates of the prevalence of HIV infection at the time of marriage were compared with data for the recently married couples to estimate transmission probabilities within marriage and the extramarital incidence of HIV infection after marriage using a spreadsheet deterministic model. Using a starting population of 1000 couples with the prevalence of HIV infection at the time of marriage as estimated from the data, we examined the effect of altering transmission probabilities within marriage and the rate of extramarital incident infections on the prevalence and concordance of HIV infection. Since the observed outcomes—which the model was trying to match—came from couples marrying within the last 5 years, within-marriage transmission probabilities and extramarital incidence used in the model refer to this period (average: 2.6 years in Kisumu and 2.7 years in Ndola) not per year.

Initially, a range of within-marriage transmission probabilities (from 0.1 to 0.8) and extramarital incidence (from 0 to 20%) were examined, both manually and by minimizing the sum of squares of the differences between the calculated outcomes (prevalence and concordance of HIV infection) and those observed. It was assumed that female-to-male HIV transmission is less efficient than or equally efficient as male-to-female transmission and that female incidence of HIV infection from outside the marriage is less than or equal to male incidence of HIV infection from outside the marriage (Fig. 1). It assumed that the HIV status of the husband and wife before marriage was independent of each other and that any HIV transmission from a spouse infected before marriage occurred before any HIV infection from outside the marriage. (This simplifying assumption will increase the transmission risk within marriage compared with acquisition of HIV infection from outside marriage.) From these results, the proportions of HIV infection attributable to acquisition before marriage, transmission from the spouse, and extramarital acquisition were calculated.

Several studies have found higher male-to-female than female-to-male transmission probabilities for HIV infection,[9–13] although others have found similar rates.[5–8] Most information comes from studies of discordant couples, which may be biased since any early transmission will prevent the couple from being identified as discordant.[9] Where the prevalence of HIV infection among the population is high, those with extramarital partnerships (mainly men) have a high risk of acquiring HIV infection. Similar overall incidence of HIV infection among men and women in discordant couples in these areas may reflect different transmission probabilities between spouses combined with different rates of extramarital infections. Our analyses of young unmarried individuals in Kisumu and Ndola suggest that the per partnership transmission probability of HIV from men to women is much higher than that from women to men.[15] Further analyses therefore restricted the model by setting the male-to-female transmission probability to be at least twice that of the female-to-male transmission probability.[10]

Initial results from the model gave unrealistically high estimates for male incidence of HIV infection from outside the marriage, especially in Kisumu. The model was therefore restricted to a maximum extramarital incidence of HIV infection of 10% (over the average 2.6 years of the marriage).

RESULTS

Prevalence of HIV Infection Before and After Marriage

The estimated prevalence of HIV infection at the time of marriage was much higher among women than among men in both sites (Table 1). Results from the individual responses are shown: results based on the reported age of the spouse or for the couples were very similar. Within 1 year of marriage, the prevalence of HIV infection had risen considerably from that estimated at the time of marriage (Table 1).

Concordance of HIV Infection Within Marriage

Data were available for 204 couples in Kisumu and 249 in Ndola. Of these couples, 67 and 65, respectively, were married for the first time within the previous 5 years and were in monogamous marriages (Table 2). The proportion concordant positive was higher in Ndola than in Kisumu (Table 3), and this difference was significant for men ($P = 0.04$) but not for women ($P = 0.2$).

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Summary of assumptions used in the model

"Basic Model"

The HIV prevalence of those about to be married is the same as HIV prevalence in those of the same age and sex who are unmarried

The HIV prevalence at the time of marriage estimated for the whole population is appropriate for those identified as couples in the data.

The HIV status of husband and wife at the time of marriage is independent

HIV transmission within marriage from those infected before marriage occurs before any HIV transmission from extra-marital partners.

The probability of transmission of HIV to the spouse following marriage from those infected before marriage is the same as that after incident infection acquired from outside the marriage

Within marriage male-to-female transmission ≥ female-to-male transmission

Transmission probability within marriage is between 0.1 and 0.8 over the period studied

Male incidence from outside marriage ≥ female incidence from outside marriage

Incidence rates from outside marriage are between 0 and 20% over the period studied

Incidence rates from outside marriage are the same irrespective of the HIV status of the partner

The point estimates of HIV prevalence and concordance from the small numbers of couples were good approximations of the true prevalence and concordance.

No deaths occurred over the period of the study

Further assumptions for later models - ***"Restricted Model"***:

Within marriage male-to-female transmission ≥ 2 x female-to-male transmission

Maximum HIV incidence from outside marriage is 10% over the period studied

FIGURE 1. Summary of assumptions used in the model.

HIV Transmission Within Marriage and Extramarital Incidence of HIV Infection

To estimate transmission probabilities within marriage and extramarital incidence after marriage, it was initially assumed that the prevalence of HIV infection at marriage was 26% and 14% for females and males, respectively, in Kisumu and 21% and 13%, respectively, in Ndola (Table 1). In Ndola, the proportion concordant positive was high. Within-marriage transmission rates estimated by the model were therefore high. In the basic model, the results were closely approximated by a within-marriage male-to-female transmission rate of 67%, female-to-male transmission rate of 52%, male extramarital incidence of 12%, and female extramarital incidence of 0.3% (Table 4). Restricting the male extramarital incidence to ≤10% and the ratio of male-to-female/female-to-male transmission within marriage to ≥2 (the restricted model) gave estimates of within-marriage male-to-female transmission rate of 76%, female-to-male transmission rate of 38%, male extramarital incidence of 10%, and female extramarital incidence of 0. This model underestimated the male prevalence of HIV infection and therefore fitted less well.

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TABLE 1. *Prevalence of HIV infection by duration of marriage and estimated prevalence of HIV infection at the time of marriage: Kisumu, Kenya, and Ndola, Zambia, 1997*

	Kisumu		Ndola	
	Males	Females	Males	Females
Estimated % HIV-positive at time of marriage*	13.8 (n = 125)	25.7 (n = 236)	13.2 (n = 111)	20.9 (n = 202)
% HIV-positive among those marrying in last 1 year	21.6 (8/37)	48.2 (40/83)	19.4 (6/31)	31.3 (20/64)
% HIV-positive among those marrying in last 5 years	30.4 (38/125)	39.8 (94/236)	36.9 (41/111)	42.1 (85/202)
% HIV-positive among those marrying in last 5 years and in current, monogamous marriages	30.4 (35/115)	35.3 (61/173)	36.3 (33/91)	40.5 (66/163)

* Based on the prevalence of HIV infection among unmarried individuals with an age structure similar to the age structure of the study population at the time that they got married. See text for details.

In Kisumu, the proportion concordant positive was lower, implying low transmission rates within marriage. However, the prevalence of HIV infection was high compared with the estimated premarriage prevalence of HIV infection, especially among men. Using these estimates of premarriage prevalence, the observed pattern of concordance and prevalence among the couples could only be matched by high rates of incident HIV infections among men from outside the marriage. In the basic model, the best fit was obtained with male-to-female and female-to-male within-marriage transmission rates of 19%, male extramarital incidence of 18%, and female extramarital incidence of 0. Restricting male extramarital incidence worsened the fit of the model, as the male prevalence of HIV infection was then underestimated among all groups. Increasing within-marriage male-to-female transmission relative to female-to-male transmission also worsened the fit and required a higher male extramarital incidence to improve the results. In the restricted model, the best fit was obtained with within-marriage male-to-female transmission rate of 27%, female-to-male transmission rate of 14%, male extramarital incidence of 10%, and female extramarital incidence of 0: this underestimated the male prevalence of HIV infection.

TABLE 2. *Characteristics of couples who where married within the 5 years preceding the survey and were in monogamous marriages: Kisumu, Kenya, and Ndola, Zambia, 1997*

	Kisumu (67 couples)		Ndola (65 couples)	
	Males	Females	Males	Females
Mean age (y)	27	21	27	21
Premarital partner(s), N (%)				
0	2 (3)	5 (7)	5 (8)	14 (22)
1–2	17 (25)	44 (66)	27 (42)	43 (66)
3–10	38 (57)	18 (27)	30 (46)	8 (12)
>10	10 (15)	0 (0)	3 (5)	0 (0)
"Virgin" at marriage,* N (%)	3 (4)	8 (12)	5 (8)	18 (28)
Mean duration between sexual debut and marriage (y)	7.9	2.7	6.5	2.2
Extra marital partner(s), N (%)				
0	37 (55)	63 (94)	42 (65)	58 (91)
1–2	17 (25)	4 (6)	16 (25)	6 (9)
3–10	12 (18)	0 (0)	4 (6)	0 (0)
>10	1 (1)	0 (0)	3 (5)	0 (0)
Extra marital partner(s), in previous 12 mo, N (%)				
0	47 (70)	64 (96)	52 (80)	65 (100)
1	13 (19)	2 (3)	6 (9)	0 (0)
2–3	7 (10)	1 (1)	7 (11)	0 (0)
Syphilis, N (%)	3 (5)	2 (3)	11 (17)	7 (11)
HSV-2 infection, N (%)	28 (47)	34 (52)	30 (48)	35 (55)
Circumcised, N (%)	20 (30)		2 (3)	

* Virginity at marriage was not recorded directly, and those persons who had sexual intercourse with their future spouse may not have counted them as premarital partners. "Virgins" at marriage were thus defined as those with either no premarital partners or those with one premarital partner if the age at onset of sexual activity was the same as the age at marriage. However, in each site, 1 man and 1 woman thus defined as a virgin at marriage were HIV-positive with an HIV-negative spouse, and 3 of the 4 denied any extramarital partners.

HSV-2, herpes simplex virus 2.

When the male extramarital incidence of HIV infection after marriage is restricted to a maximum of 10% (equivalent to 4% per year), the estimated prevalence of HIV infection among men in Kisumu is consistently less than that seen among the married couples. The only way to increase the male prevalence of HIV infection to improve the fit of the model (without worsening the fit for concordance and for women) is to increase the premarriage estimates for men. The estimates used are based on the age-specific prevalence of HIV infection among unmarried individuals. They will underestimate the true prevalence of HIV infection at marriage if those who married younger had higher-risk sexual behavior than did those marrying later. The full data set was examined to see if this was the case.

For men in Kisumu, there was no association between age at marriage and having had many premarital sexual partners in a crude analysis or adjusting only for current age (eg, those marrying younger were as likely to have had at least 3 or 10 premarital partners as those marrying older, suggesting higher rates of partner change for those marrying younger). After adjusting for time between onset of sexual activity and marriage, those men marrying older were less likely to have had many partners.

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TABLE 3. *HIV status of individuals by HIV status of their spouses: Kisumu, Kenya, and Ndola, Zambia, 1997*

	Overall		First 5 y, monogamous marriages	
	Kisumu	Ndola	Kisumu	Ndola
Male HIV-positive/female HIV-positive (N)	40	62	10	17
Male HIV-positive/female HIV-negative (N)	26	26	12	4
Male HIV-negative/female HIV-positive (N)	22	18	9	5
Male HIV-negative/female HIV-negative (N)	116	143	36	39
Overall female HIV-positive (%)	30.4	32.1	28.4	33.9
Overall male HIV-positive (%)	32.4	35.3	32.8	32.3
% concordant if male HIV-positive	60.6	70.5	45.5	81.0
% concordant if female HIV-positive	64.5	77.5	52.6	77.3
% discordant if male HIV-negative	15.9	11.2	20.0	11.4
% discordant if female HIV-negative	18.3	15.4	25.0	9.3

Compared with men marrying later, the adjusted odds ratio for having had at least 3 premarital partners among those marrying at younger than 25 years of age was 1.9 (95% CI, 1.1–3.3), and that for having had at least 10 partners was 2.7 (95% CI, 1.5–5.1). No such association was seen for women in Kisumu (adjusted odds ratio for at least 3 premarital partners comparing women marrying younger than 20 years of age with women marrying later was 1.3 [95% CI, 0.82–2.0). In Ndola, similar results were found for men (adjusted odds ratio [95% CI]: 2.8 [1.7–4.6] and 2.5 [1.1–5.6] for having had ≥3 and ≥10 partners, respectively). For women in Ndola, the risk of having had at least 3 premarital partners was higher for those marrying younger than 20 years of age than for those marrying later (adjusted odds ratio [95% CI], 2.7 [1.2–5.8]).

Therefore, there is some evidence that for men in Kisumu and men and women in Ndola those marrying younger had higher-risk behavior than did their peers. Furthermore, in Kisumu, the prevalence of HIV infection among recently married men with HIV-negative wives was 25% (Table 3). If the prevalence of HIV infection at marriage were 14%, this would imply >11% incidence from outside marriage (since some of the men with initially noninfected wives would have transmitted HIV to their wives and so would not be included in this group). In contrast, in Ndola the prevalence of HIV infection among those persons with HIV-negative spouses was lower than the estimated prevalence of HIV infection at the time of marriage for both men and women, suggesting that these prevalence estimates at marriage may not have been too low (although this result also follows from a high transmission rate within marriage).

Increasing prevalence of HIV infection at marriage for men improves the fit of the restricted model in Kisumu, since it increases the estimates of the prevalence of HIV infection among men (Table 4). As male prevalence of HIV infection at marriage increases, the estimates of within-marriage transmission probability decrease slightly. In Ndola, the effect of increasing the premarriage prevalence of HIV infection for both men and women was examined. This tended to overestimate the prevalence of HIV infection for women. Increasing the male prevalence alone improved the fit of the restricted model. In Ndola, the estimates of within-marriage transmission probability remained high in all models. It is unlikely that the true prevalence of HIV infection among men at the time of marriage was higher than 22% in Kisumu or 19% in Ndola, since these were the prevalence levels measured within 1 year of marriage (Table 1). With high premarital prevalence of HIV infection among men, the effects of restricting the extramarital incidence of HIV infection among men to 5% were explored (Table 4).

Implications for the Proportion of HIV Infections Acquired Within Marriage

The proportion of HIV infection attributable to transmission from the spouse in the different scenarios is shown in Table 4. Even with a much wider range of assumptions for within-marriage transmission probabilities and extramarital incidence than those shown, the estimated proportion of infections attributable to transmission from the spouse was almost always <50% for both men and women. In the fitted models, at least one quarter of HIV-positive men was estimated to have been infected from extramarital partnerships. When the male incidence of HIV infection from outside the marriage was restricted to 5%, these infections accounted for about 15% of HIV infection in men in both sites (Table 4).

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TABLE 4. *Results of simulations of prevalence of HIV infection among couples*

	Starting population (% HIV-positive)		Within-marriage transmission probability		Extramarital HIV incidence over 2.6 y		Outcome (% HIV-positive)		% concordant if		% discordant if		Least squares fit*	% infection acquired from different sources					
									Male HIV-positive	Female HIV-positive	Male HIV-negative	Female HIV-negative		Premarriage		From spouse		Extramarital	
	Female	Male	Male to Female	Female to Male	Male	Female	Female	Male						Female	Male	Female	Male	Female	Male
Kisumu																			
Measured results							28	33	46	53	20	25							
Basic model	26	14	0.19	0.19	0.18	0.0	30	33	47	51	22	26	0.0011	86	42	14	13	0	45
Male → female ≥ female → male, incidence ≤10%	26	14	0.22	0.22	0.1	0.0	30	27	51	47	22	19	0.0148	88	52	12	18	0	30
Male → female ≥2× female → male, incidence ≤10%	26	14	0.27	0.14	0.1	0.0	31	25	52	43	23	18	0.0259	85	55	15	12	0	33
	26	16	0.26	0.13	0.1	0.0	31	27	51	45	23	19	0.0177	85	59	15	11	0	30
	26	18	0.26	0.13	0.1	0.0	31	29	50	46	23	21	0.0114	84	63	16	10	0	28
	26	20	0.25	0.13	0.1	0.0	31	30	49	47	24	23	0.0069	83	66	17	9	0	26
	26	22	0.24	0.12	0.1	0.0	31	32	48	49	24	24	0.0042	83	69	17	8	0	24
Male → female ≥2× female → male, incidence ≤5%	26	14	0.29	0.14	0.05	0.0	30	21	55	39	23	14	0.0537	87	66	13	15	0	19
	26	20	0.27	0.13	0.05	0.0	31	27	51	44	23	19	0.0194	85	75	15	10	0	15
Ndola																			
Measured results							34	32	81	77	11	9							
Basic model	21	13	0.67	0.53	0.12	0.003	34	32	81	77	11	9	≪0.001	62	40	37	30	1	30
Male → female ≥ female → male, incidence ≤10%	21	13	0.63	0.58	0.1	0.03	34	32	81	77	11	9	≪0.001	62	40	32	36	7	24
Male → female ≥2× female → male, incidence ≤10%	21	13	0.76	0.38	0.1	0.0	34	28	85	70	14	6	0.0107	62	47	38	25	0	29
	21	15	0.75	0.37	0.1	0.0	35	30	84	71	14	7	0.0069	60	51	40	23	0	27
	21	17	0.74	0.37	0.1	0.0	36	31	83	72	14	8	0.0045	59	55	41	21	0	25
	21	19	0.73	0.37	0.1	0.0	37	33	82	74	14	9	0.0033	57	58	43	19	0	23
Male → female ≥2× female → male, incidence ≤5%	21	13	0.79	0.40	0.05	0.0	32	24	88	67	14	4	0.0258	66	54	34	30	0	16
	21	17	0.76	0.38	0.05	0.0	34	27	86	70	14	6	0.0121	62	62	38	24	0	14

* Smaller values imply a closer fit.

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DISCUSSION

In both Kisumu and Ndola, the prevalence of HIV infection among women was high within a few years of onset of sexual activity. As a result, despite the age gap at marriage and the young age at marriage for women, almost twice as many women as men were estimated to be HIV-infected at the time of their first marriage. The proportion of HIV-positive individuals with HIV-positive spouses was found to be similar for men and women within each site, as has been found elsewhere.[5,10]

The higher prevalence of HIV infection among women than among men before marriage, together with the likely higher rate of male-to-female than female-to-male transmission within marriage, and the concordance seen imply high rates of incident HIV infection from outside marriage among men. Even allowing for some underestimation of the prevalence of HIV infection among men at the time of marriage, most HIV infections in individuals within the first 5 years of marriage were found to have occurred from outside the marriage. In women, most of these occurred premaritally. In men, at least one quarter of HIV infections appear to have occurred since the marriage, from outside the marriage.

The basic model gave high estimates for the extramarital incidence of HIV infection among men. We artificially restricted this figure to 10%, or ~4% per year. This is still high, although there is evidence of a high incidence of HIV infection among these populations. Among men in Kisumu, the prevalence of HIV infection increased from 0 for those younger than 17 years to 2.7% for those aged 17 to 18 years and to 27.3% for those aged 25 to 26 years. Assuming low mortality before this age, this gives an approximate incidence of HIV infection of at least 3% per year, although some of this will have been from spouses. Among the unmarried men, the prevalence of HIV infection increased from 0 for those younger than 17 years to 2.8% for 17- to 18-year-olds and 12.1% for 23- to 24-year-olds, giving an approximate incidence of 1.6% per year. Equivalent estimates in Ndola were 1.5% and 1.2% per year, respectively.

The possibility of a high extramarital incidence of HIV infection even within 5 years of marriage is supported by behavioral data from this same study, which showed high rates of extramarital partners both among the identified couples (Table 2) and overall. Among recently married individuals in the whole data set, 44% of men and 5% of women in Kisumu and 37% of men and 8% of women in Ndola declared at least one extramarital partner. The proportion of men with more than one partner in the last 12 months (ie, at least two nonmarital partners for never married men or at least one for married men) was similar for never married men and those who were married within the last 5 years: 35% versus 31% in Kisumu and 28% versus 24% in Ndola, respectively. Among those with nonmarital partners, the recently married men were more likely than the never married men to have partners with a high risk of HIV infection: their partners were older, more likely to be married (in Kisumu only), and more likely to fit a definition of commercial sex work (depending on exchange of money and multiple partners). Recently married men were also much more likely than were never married men to have sexually transmitted infections.

High extramarital incidence of HIV infection among married men is therefore plausible, although the estimated rates seem very high. Restricting the model to a maximum extramarital incidence of 5% gave a poor fit in both sites unless the premarital prevalence of HIV infection among men was increased (Table 4). In Kisumu, the estimated extramarital incidence of HIV infection among men from outside marriage was not much lower than the estimated incidence due to transmission from an HIV-positive wife. It is possible that the rates calculated within marriage are too low. However, studies of initially discordant couples in Masaka, Uganda,[10] and Mwanza, Tanzania,[13] gave estimates of 10% male-to-female transmission and 5% female-to-male transmission per year, which translate as 24% and 12.5%, respectively, over 2.6 years and so are very similar to those estimated in the restricted model for Kisumu. The calculated male-to-female transmission rates within marriage were low compared with the high premarriage incidence of HIV infection, which can be inferred from the high prevalence of HIV infection among women at a young age. However, since the per-sex-act transmission probability is not constant, varying for example with viral load and coinfection with other sexually transmitted infections,[7,16] the risk from multiple partners is much higher than that from the same number of sex acts with the same partner.[9] It is also possible that younger individuals are more susceptible to HIV infection.[8] The estimates for within-marriage transmission rates in Ndola were much higher. This could be chance, but different transmission rates are possible: in Kisumu, circumcision was much more common and syphilis was much less common than in Ndola (Table 2). The prevalence of *Herpes simplex* virus 2 infection was similar in both sites.

The conclusions on the relative importance of different sources of HIV infection were robust to a wide range of different values for within-marriage transmission probabilities and estimates of extramarital incidence. However, the model contains various assumptions that may influence the results.

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The model assumes independence in the HIV status of future husbands and wives before marriage, which is unlikely to be true. Lack of independence (assuming like with like) would increase the concordance. It may provide part of the explanation for the higher concordance in Ndola than in Kisumu, since many more women in Ndola than in Kisumu were virgins at marriage and the average time between onset of sexual activity and marriage was shorter in Ndola than in Kisumu (Table 2). Excluding couples in whom the women had no declared premarital partners had little effect on the concordance results. Introducing nonindependence into the model for Kisumu would lead to even lower estimates of transmission probabilities within marriage.

The model assumes that the transmission probability of HIV from a spouse infected before marriage is the same as that from a spouse newly infected extramaritally. Transmission probabilities are likely to be higher soon after acquiring infection (therefore high for the extramarital infections) and in the late stages of disease (therefore high later in marriage). In Ndola, the transmission probabilities were high anyway; therefore, this is unlikely to have much influence on the results. In Kisumu, increasing the probability of transmission following extramarital infections implies improbably low transmission rates from premarital infections to achieve the concordance seen.

If one member of a married couple has died, the couple will not be included in the concordance data. Since HIV-positive individuals are most likely to die, particularly those infected several years before the marriage (predominantly women) and since transmission rates may be higher in the late stages of disease, this could lead to underestimation of the concordance. Higher concordance might therefore be expected within 1 year of marriage (allowing less time for deaths to occur), although this might be balanced by the shorter period for transmission between spouses. There were too few couples in either site to examine this directly. In Kisumu, the higher prevalence of HIV infection among women marrying within the previous year than among those marrying within the previous 5 years (Table 1) is consistent with some deaths occurring soon after marriage.

However, death in the women is unlikely to be a major factor for explaining the results. Using the restricted model for Kisumu, when 20% of women infected before marriage are assumed to have died so that neither they nor their partners are included in the analysis, the model estimates for within-marriage transmission probabilities and extramarital incidence are similar to those without including the deaths. With higher death rates, the estimate of extramarital incidence of HIV infection among women starts to rise. If deaths occur preferentially in those persons who transmit HIV, the true within-marriage transmission rates might be higher. As an extreme, when all the women who were infected before marriage and transmitted HIV to their husbands are assumed to have died (so that these couples are not included in the analysis) and none of the other women (or men) are assumed to have died, the restricted model predicts within-marriage male-to-female and female-to-male transmission probabilities of 35% and 18%, respectively, with a male extramarital incidence of HIV infection of 10%.

The results depend on the prevalence of HIV infection among men and women at marriage, and this may have been initially underestimated, at least among men. The fit of the restricted model was improved in both sites by increasing the prevalence of HIV infection among men before marriage. These changes had little effect on estimates of within-marriage transmission probabilities. With a much higher premarriage prevalence of HIV infection than originally estimated, it was possible to get a reasonable fit to the model with an incidence of HIV infection from outside marriage of 5% (Table 4).

It was assumed that these estimates of the premarriage prevalence of HIV infection from the whole data set were applicable to the married couples seen, but couples who are both found and agree to take part in the study are likely to differ from others. The couples included account for 39%–40% of the women and 58%–71% of the men in the whole data set who were recently married and had results of HIV testing available. Compared with all recently married individuals, the prevalence of HIV infection among individuals seen in couples was slightly lower (Tables 1 and 3), but there was little difference in age, partnership histories, onset of sexual activity, sexually transmitted infections, or circumcision.

All the calculations were based on point estimates of the results for <70 couples in each site. If the "true" concordance were higher than that measured and/or the overall prevalence of HIV infection were lower, this would suggest higher within-marriage transmission probabilities and a lower incidence of HIV infection from outside marriage. Nevertheless, in both sites, despite very different levels of concordance and therefore different estimated within-marriage transmission probabilities, we still estimated that among HIV-infected individuals within the first 5 years of marriage most HIV infections were not acquired from their spouse (at least during the marriage) and that there are high rates of new infections brought into marriages by men. These

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conclusions are supported by the behavioral data but do not rely on them, as they are entirely based on the measured prevalence of HIV infection and reported age and age at marriage.

Although marriage is a risk factor for HIV infection in areas where the prevalence of HIV infection among the general population is very high, a substantial proportion of HIV infections among men, even those with an HIV-infected wife, may be acquired from outside the marriage. This may help to explain the apparent discrepancies in male-to-female and female-to-male transmission probabilities in studies of discordant couples.

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APPENDIX: DESCRIPTION OF MODEL

Let x = proportion of women HIV-positive at time of marriage

Let y = proportion of men HIV-positive at time of marriage

Assuming nonassortative mixing, the proportion of couples who are both HIV-positive at marriage = xy

Of 1000 couples at the time of marriage:

The number both positive ($f_{pos}m_{pos[start]}$) = $1000xy$

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The number female positive, male negative ($f_{pos}m_{neg[start]}$) = 1000x − 1000xy

The number male positive, female negative ($f_{neg}m_{pos[start]}$) = 1000y − 1000xy

The number both negative ($f_{neg}m_{neg[start]}$) = 1000 − (1000xy) − (1000x − 1000xy) − (1000y − 1000xy)

Assume that transmission within marriage occurs with a transmission probability of

a for male to female transmission

b for female to male transmission

The distribution of HIV within the couples changes so that

$f_{pos}m_{pos[after\ transmission]} = f_{pos}m_{pos[start]} + b(f_{pos}m_{neg[start]}) + a(m_{pos}f_{neg[start]})$

$f_{pos}m_{neg[after\ transmission]} = f_{pos}m_{neg[start]} - b(f_{pos}m_{neg[start]})$

etc.

Assume that there is extramarital incidence over the period of the study of

i for men

j for women

Assume that the transmission probabilities for newly infected couples are a and b as above, then the new distribution of HIV within the couples becomes

$f_{pos}m_{pos[after\ incidence]} = f_{pos}m_{pos[after\ transmission]} + i(f_{pos}m_{neg[after\ transmission]}) + j(f_{neg}m_{pos[after\ transmission]}) + ia(f_{neg}m_{neg[start]}) + jb(f_{neg}m_{neg[start]})$

$f_{pos}m_{neg[after\ incidence]} = f_{pos}m_{neg[after\ transmission]} - i(f_{pos}m_{neg[after\ transmission]}) + j(1 - b)(f_{neg}m_{neg[start]})$

etc.

From these results six proportions are calculated:

$f_{pos}/1000$

$m_{pos}/1000$

$f_{pos}m_{pos}$/all m_{pos}

$f_{pos}m_{pos}$/all f_{pos}

$f_{pos}m_{neg}$/all m_{neg}

$f_{neg}m_{pos}$/all f_{neg}

These are compared with the equivalent proportions measured in the data set as the sum of squares of the differences. Smaller values imply a better fit. This value is minimized by altering a, b, i, and j and later the starting prevalences of HIV infection, as discussed in the text.

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