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Do behavioural differences help to explain variations in HIV prevalence in adolescents in sub-Saharan Africa?

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Summary

OBJECTIVE To compare adolescent risk factors for HIV infection in two countries with high adolescent HIV prevalence and two lower prevalence countries with the aim of identifying risk factors that may help explain differences in adolescent HIV prevalence.
METHODS Data were available from two nationally representative surveys (South Africa, Zimbabwe), two behavioural intervention trials (Tanzania, Zimbabwe) and one population-based cohort (Uganda). Data on variables known or postulated to be risk factors for HIV infection were compared.
RESULTS Few risk behaviours were markedly more common in the high HIV prevalence populations. Risk factors more common in high HIV prevalence settings were genital ulcers and discharge, and women were more likely to report older male partners.
DISCUSSION Age mixing may be an important determinate of HIV prevalence in adolescents. Potential reasons for the general lack of association between other adolescent risk factors and adolescent HIV prevalence include adult HIV prevalence, misreported behaviour, different survey methods and other unmeasured adolescent behaviours. If adult factors dominate adolescent HIV risk, it would help explain the failure of behavioural interventions targeted at adolescents and suggests future interventions should include adults.

keywords HIV prevalence, adolescents, sexual behaviour, epidemiology, sub-Saharan Africa, age mixing

Introduction

Adolescents in sub-Saharan Africa, particularly women, carry a disproportionately large burden of HIV infection (UNAIDS 2006), and adolescent HIV prevalence differs markedly between regions (Buve *et al.* 2002). Differences in adolescent risk factors could help explain the observed heterogeneity in HIV prevalence. To date, behavioural interventions designed to reduce HIV/STI risk in adolescents have led to reported risk reductions but have failed to show an impact on HIV incidence (Jemmott & Jemmott 2000; Johnson *et al.* 2003; Gallant & Maticka-Tyndale 2004; Robin *et al.* 2004; Ross *et al.* 2007).

Many behavioural and biological factors have been suggested to be associated with HIV infection in adolescents. Younger age at sexual debut and having older partners increase HIV risk (Kelly *et al.* 2003; Pettifor *et al.* 2004; Hallett *et al.* 2007a,b), as does marriage, especially in women (Glynn *et al.* 2001; Clark 2004; Clark *et al.* 2006). Concurrency of partnerships is important in facilitating STI transmission in adolescents (Rosenberg *et al.* 1999). Biological factors that could increase adolescent risk of HIV infection include STI cofactors (Dickerson *et al.* 1996; Auvert *et al.* 2001; Gray *et al.* 2001), particularly primary HSV-2 infection (Benedetti *et al.* 1999; Reynolds *et al.* 2003; Freeman *et al.* 2006) and male circumcision (Halperin & Bailey 1999). Variation in these and other risk factors could, in part, explain differences in HIV prevalence across countries. But other studies have failed to find these risks factors to be associated with increased risk of HIV (Auvert *et al.* 2001, Bongaarts 2007, Huang *et al.* 2002); therefore, the relationship between these individual-level risk factors and risk of HIV infection in adolescent is equivocal. There is little evidence linking these risk factors at the population level to HIV prevalence (Buve *et al.* 2001a, Gregson *et al.* 2009), and community-level factors may also be important. For example, HIV prevalence in adults varies greatly across sub-Saharan Africa, and therefore, the same risk behaviour in adolescents is likely to lead to a higher probability of HIV infection in high prevalence areas than in lower prevalence areas.

Previous studies have failed to find associations between behavioural risks factors and HIV prevalence, but these have tended to be comparisons among adults only (Boerma *et al.* 2003, Ferry *et al.* 2001; Wellings *et al.* 2006), or among adolescents from a single population or country or focus on a single risk factor (Gregson *et al.* 2002, Hartell 2005, Katz & Low-Beer 2008, Konde-Lule *et al.* 1997, Marston *et al.* 2009, McGrath *et al.* 2009, Pettifor *et al.* 2005; Rosenberg *et al.* 1999, Todd *et al.* 2004, Zaba *et al.* 2004). This study takes the novel approach of comparing risk factors in adolescents to try to explain differences in adolescent HIV prevalence among adolescents in these populations. Data on five adolescent populations in two high and two lower HIV prevalence countries were compared to investigate to what extent differences in reported sexual behaviours, STI symptoms and male circumcision could help explain differing HIV prevalences.

Methods

Data

Five datasets were selected for inclusion in this comparison. These datasets were selected because they contained data on the required indicators, the indicators were comparable across sites, the dataset sample sizes were large, the data were collected in similar years and because of the unrestricted permission to analyse these datasets available to the study investigators. Other datasets, primarily Demographic and Health Surveys (DHS) datasets, were considered for inclusion, but excluded from the main analysis (Online Supplementary Material Table S4) because of the smaller sample sizes of adolescents and differences in the denominators for the required indicators between DHS surveys.

Detailed data collection methods for each study have been presented elsewhere (Pettifor *et al.* 2005; , Nunn *et al.* 1994; Hayes *et al.* 2005; Cowan *et al.* 2002; F. M. Cowan *et al.* in preparation). South African data were obtained from a nationally representative household survey conducted in 2003 (Pettifor *et al.* 2005). Ugandan data were from the general population cohort (GPC), an annual population-based survey of Kyamulibwe area within Masaka district (1990-present) (Nunn *et al.* 1994). Unless otherwise stated, data from 1999 were used to maximise comparability with the other datasets. Tanzanian data were from a community-randomised trial of a school-based behavioural intervention in Mwanza Region. Baseline and follow-up data were collected in 1998–1999 and 2001–2002, respectively (Hayes *et al.* 2005). The baseline data were used in this analysis to maximise comparability with the other datasets, except for data on age of partners that were only available from the follow-up survey. Two sources of data on Zimbabwean youth were available. The first source was the nationally representative Young Adult Survey (YAS) from 2001 to 2002 (Macro International 2004). The second source was the 'Regai Dzive Shiri' (RDS) project, a community-randomised trial of a behavioural intervention, conducted in three rural provinces (Cowan *et al.* 2002). Data were collected in a population-based follow-up survey in 2007 (F. M. Cowan *et al.* in preparation), and data from both intervention and control arms were pooled for this analysis. Two survey methods were used to reduce misreporting (Online Supplementary Material Methods S1). The numbers of survey respondents eligible for this analysis from each study are shown in Online Supplementary Material Table S1.

Data on age of sexual debut, ever had sex, marital status, lifetime number of partners, partners in the past year, age of partners, condom use, self-reported genital ulcer disease (GUD) and discharge, forced and anal sex were compared. Data on male circumcision were available from four of the studies. HIV infection status was available from all populations. Full details of the HIV tests used in the studies are given in the Online Supplementary Material Methods S2.

Statistical methods

For comparison of summary measures, data were adjusted for survey design and age-standardised. Two of the studies over-sampled clusters within the target population, and therefore, data were re-weighted so that the results were nationally representative. Data were age-standardised to account for differences in age distribution in the samples. The results were adjusted using a standard population categorised by single year of age. The standard population was calculated by averaging the four national census populations obtained from the UN Website (UN 2003) (Online Supplementary Material Table S2).

Data were categorised into two age groups to aid comparison as the studies covered differing age ranges. For 15- to 18-year-olds, data were available from South Africa, Tanzania, Uganda and the YAS in Zimbabwe. For 19- to 22-year-olds, data were available from South Africa, Uganda and both surveys in Zimbabwe.

For each survey, the question *'have you ever had sex'* was used to improve the internal consistency and comparability of the data between studies. For example, if an individual reported that they had not had sex, but in subsequent questions reported having two previous partners, the number of partners was recoded to zero. This method was selected because it could be replicated on all datasets.

Median age of first sex was derived from reported age at first sex using Kaplan–Meier estimation. Observations on those who had not had sex were censored at their current age. Survival functions were smoothed by adding a uniform random number between 0 and 1 to reported ages, 50 simulations were performed for each site.

Data were available on the reported age of partners from South Africa and both Zimbabwean studies. An 'age difference' variable was created based on the respondent's most recent partnership, calculated as the respondent's age minus the partner's age at that point in time. A negative age difference means the partner was older than the respondent. In Tanzania, respondents were asked whether their partners were *'older'*, *'younger'* or the *'same age'* than themselves during the follow-up survey (age range 16–20). Data were available over the same age range from South Africa and YAS in Zimbabwe. RDS data only included 18- to 22-year-olds and thus were dropped from this analysis. To allow comparison, the continuous age difference data from South Africa and Zimbabwe were recoded into the categories by assuming '*same age*' was defined as within 1 year of the respondent's age (i.e. age difference = −1,0,+1). We also explored sensitivity to this assumption by reanalysing our data assuming '*same age*' was defined as within 2 or 3 years of the respondent's age (Online Supplementary Material Methods S1).

A statistical test was not used to determine whether there were significant differences between studies. Because of large sample sizes, many small differences would be statistically significant. This analysis aimed to identify any relatively large differences between high and low prevalence populations that could be sources of heterogeneity in HIV prevalence.

Validity of reported sexual behaviour was investigated using biological markers for sexual activity, pregnancy, HSV-2 and HIV infection (Online Supplementary Material Methods S3).

Results

HIV prevalence

Tables 1 and 2 show HIV prevalence in adolescents aged 15–18 and 19–22, respectively and the best available data on adult HIV prevalence in each of the populations. Prevalence data were not available for 23+-year-olds in all five populations, and therefore, HIV prevalence in 15- to 49-year-olds is shown. Figure 1 shows HIV prevalence by age and gender in each study. HIV prevalence in 15- to 49-year-olds was much higher in South Africa and Zimbabwe than in Tanzania and Uganda. HIV prevalence was higher in women than men across all studies and ages. The female-to-male ratio of adolescent HIV prevalence tended to be lower in higher prevalence populations. The very high female-to-male ratios observed in adolescents were not maintained in 15- to 49-year-olds because this wider age range included the peak HIV prevalence age among men, resulting in more similar prevalences by gender.

Behavioural and biological variables

Tables 1 and 2 also show data from the five populations on adolescent behaviours among 15- to 18-and 19- to 22-year-olds, respectively. The median age of sexual debut did not vary in line with HIV prevalence, with Zimbabwean adolescents reporting the highest age of first sex and Tanzanian men reporting the lowest (Table 1). Among 19- to 22-year-olds, Zimbabwean adolescents had the highest median age of debut. The median age of debut was higher in the later RDS study than in the YAS, suggesting an increase in debut age over time, consistent with the findings of other studies (Gregson *et al.* 2006; Hallett *et al.* 2007b). Kaplan–Meier plots of age of first sex for each site by gender are shown in Online Supplementary Material Figure S1. At all ages, a lower proportion of Zimbabweans reported ever having had sex than South Africans or Ugandans. The proportion reporting sexual debut ≤15-years-old was highest in Tanzanian men (45%). The lowest proportions were reported in the YAS study in Zimbabwe (13.3% of men and 10.1% of women aged 15–18), with even lower proportions reported in the later RDS study (2.4% of men and 2.7% of women). In all studies, the proportions reporting early sexual debut were higher in the 15- to 18 year age group than in 19- to 22-year-olds. This suggests that either there has been an increase in early sexual debut in all populations or younger individuals are more likely to recall, or truthfully report, early debut.

There were no clear differences in the proportion reporting having had sex by age between high and lower prevalence populations (Online Supplementary Material Figure S2). Tanzanian males reported the highest proportion having had sex among 15- to 18-year-olds (53.3%) despite having the lowest HIV prevalence (0.04%). The lowest proportions of having had sex were reported in Zimbabwe in both populations and age ranges. The proportion ever-married was highest in 19- to 22-year-old women from Zimbabwean (YAS: 52.7%, RDS: 57.7%) and Ugandan women (51%). The proportions

Table 1 Demographic, behavioural and epidemiological, age-standardised characteristics of 15- to 18-year-olds from South Africa, Tanzania, Uganda and Zimbabwe YAS. HIV prevalence of 15- to 49-year-olds data sources: South Africa – 2002 HSRC Study of HIV/AIDS (HSRC 2002). Uganda – from general population cohort 1999, Tanzania –, demographic surveillance study of Kisesa ward of Mwanza district (Mwaluko *et al.* 2003) Zimbabwe YAS – national estimate from ANC data from 2001 survey recalculated in UNAIDS report 2008 (UNAIDS 2008)

	South Africa		Tanzania (baseline)		Uganda		Zimbabwe (YAS)	
	Male	Female	Male	Female	Male	Female	Male	Female
HIV prevalence in 15- to 49-year-olds %	12.8	17.7	6.7	9.5	7.3	10.4	26.0	
Prevalence ratio (female/male)	1.4	1.4	1.4	1.5				
Epidemic trend	Peaking		Stable		Stable after falling		Falling	
Adolescent data								
Number	2885	3011	3213	2082	393	375	1653	1682
HIV prevalence %	2.5	6.0	0.04	0.2	0.3	1.3	1.9	9
Prevalence ratio (female/male)	2.4	6.0	4.9	4.8				
Median age of debut	17.5	17.7	16.5	17.8	17.3	17.8	18.1	17.9
% had sex ≤15 years old	24.2	20.0	45.0	19.0	23.7	24.8	13.3	10.1
% ever had sex	42.5	41.0	53.3	34.0	38.2	44.8	25.4	27.5
% ever married	0.15	0.8	–	–	1.1	21.7	0.3	15.9
% multiple partners last year*	14.0	6.1	15.7	7.7	16.1	5.8	4.9	1.7
Partners last year(%)								
0	10.3	3.8	20.5	4.7	4.3	2.7	6.4	2.3
1	18.2	31.1	17.2	21.7	17.8	36.4	13.7	23.1
2	8.3	5.1	7.5	6.3	10.1	5.2	2.7	0.9
3–4	4.7	0.9	6.4	1.1	4.5	0.6	1.9	0.5
≥5	1.0	0.1	1.8	0.2	1.5	0.0	0.3	0.2
Not had sex	57.6	59.0	46.7	66.0	61.8	55.2	74.6	72.5
Lifetime partners (%)								
1	15.9	24.1	14.2	17.1	9.6	21.9	14.1	22.5
2	7.8	9.1	11.6	12.5	10.5	16.5	4.8	3.6
3–4	8.8	6.5	16.4	3.2	11.1	5.2	3.6	0.9
≥5	9.9	1.3	10.9	1.1	5.6	0.8	2.4	0.4
Not had sex	57.6	59.0	46.7	66.0	61.8	55.2	74.6	72.5
Mean age difference†								
At first sex	0.3	−2.8	–	–	–	–	0.2	−5.6
At last sex	0.5	−3.8					−0.1	−4.6
% Age difference ≥ 10								
At first sex	0.2	1.6	–	–	–	–	0.2	10.7
At last sex	0.03	6.5					1.4	8.3
Condom at last sex‡	55	61.5	3.8	5.4	23.4	20.5	51.3	13.9
% males circumcised	28.2	13.5	28.3§	–				
% ever had genital ulcer disease‡	4.9¶	6.8¶	–	–	0.8**	4.2**	2.8	4.2
% ever had genital discharge‡	8.3¶	19.4¶	–	–	0.8**	6.0**	5.0	13.5
% ever forced to have sex	1.5	12.7	–	7.2	–	–	1.2	3.2
% ever had anal sex	1.5	1.4	–	–	–	–	–	–

*Having more than one partner in the last year, denominator all individuals.
†Age difference = age of individual – age of partner.
‡Denominator those reporting they had ever had sex.
§Data from 2002–2003 survey.
¶Only in the past 12 months.
**Data from 2001–2002 survey.
YAS, Young Adult Survey.

ever-married were much lower in South Africa than the other populations, as has been reported elsewhere (Hunter 2005; Hosegood *et al.* 2007).

In general, men reported larger proportion of multiple partners (>1 partner in the last year) than women in all studies. Similar proportions of 15- to 18-year-olds reported

Table 2 Demographic, behavioural and epidemiological, age-standardised characteristics of 19- to 22-year-olds from South Africa, Uganda and Zimbabwe (RDS and YAS). HIV prevalence of 15- to 49-year-olds data sources: South Africa – 2002 HSRC Study of HIV/AIDS (HSRC 2002). Uganda – from the general population cohort in 1999, Zimbabwe RDS – average HIV prevalence in the 3 regions in the study Zimbabwe (2006) YAS – national estimate from ANC data from 2001 survey recalculated in UNAIDS report 2008 (UNAIDS 2008)

	South Africa		Uganda		Zimbabwe (RDS)		Zimbabwe (YAS)	
	Male	Female	Male	Female	Male	Female	Male	Female
HIV prevalence in 15- to 49-year-olds %	12.8	17.7	7.3	10.4	14.3	20.3	26.0	
Prevalence ratio (female/male)	1.4	1.4	1.4	1.5				
Epidemic trend	Peaking		Stable after falling		Falling		Falling	
Adolescent data								
Number	2,141	2,428	256	272	1,327	1,637	1,282	1,426
HIV prevalence %	5.0	20.3	0.7	4.9	1.9	10.6	6.3	21.9
Prevalence ratio (female/male)	4.1	6.6	5.7	3.5				
Median age of debut	17.8	18.4	17.6	17.2	20.9	20.3	19.5	18.9
% had sex ≤15 years old	20.1	11.7	23.1	29.6	2.4	2.7	11.2	10.2
% ever had sex	86.1	83.7	84.2	90.1	55.1	66.7	66.5	73.3
% ever married	0.9	3.9	14.8	51.0	11.0	57.7	8.3	52.7
% multiple partners in the past year*	30.6	8.1	31.8	4.9	16.4	3.4	19.6	2.9
Partners last year (%)								
0	17.4	12.5	11.8	8.2	13.3	9.5	13.4	9.2
1	35.6	65.5	40.7	76.8	23.1	52.7	31.6	61.0
2	16.7	7.3	20.1	4.6	9.7	2.4	9.9	2.5
3–4	11.5	0.7	8.5	0.3	4.5	0.8	8.0	0.3
≥5	2.4	0.1	3.2	0.0	2.2	0.2	1.7	0.1
Not had sex	16.4	13.9	15.8	9.9	47.2	34.4	33.5	26.7
Lifetime partners (%)								
1	17.4	38.5	16.2	38.4	16.6	50.9	23.8	53.3
2	14.6	21.3	14.8	23.0	15.0	9.7	14.1	13.7
3–4	22.2	18.7	41.4	22.9	12.3	3.4	11.1	5.0
≥5	29.0	7.4	1.1	0.3	8.8	1.3	14.7	0.7
Not had sex	16.4	13.9	15.8	9.9	47.3	34.6	33.5	26.7
Mean age difference†								
At first sex	1.1	−3.2	–	–	0.4	−6.8	1.3	−5.8
At last sex	1.1	−4.6			1.6	−5.1	1.7	−5.7
% Age difference ≥ 10								
At first sex	0.04	2.6	–	–	1.3	23.5	0.1	13.2
At last sex	0.8	8.3			3.1	16.7	0.3	11.7
Condom at last sex‡	57.2	44.3	34.7	11.4	30.0	10.5	60.9	16.2
% males circumcised	37.6	27.9§	17.8	–				
% ever had genital ulcer disease‡	5.3¶	6.2¶	3.2**	4.9**	5.4	5.5	3.3	3.6
% ever had genital discharge‡	7.5¶	16.0¶	2.6**	9.9**	8.5	12.4	4.7	6.7
% ever forced to have sex	1.9	8.7	–	–	6.5	22.2	1.4	8.5
% ever had anal sex	5.1	4.9	–	–	6.1	11.6	–	–

*Having more than one partner in the last year, denominator all individuals.
†Age difference = age of individual – age of partner.
‡Denominator those reporting they had ever had sex.
§Data from 2002–2003 survey.
¶Only in the past 12 months.
**Data from 2001–2002 survey.
RDS, Regai Dzive Shiri; YAS, Young Adult Survey.

multiple partners in South Africa, Tanzania and Uganda. A similar proportion of 19- to 22-year-old South African and Ugandan men reported multiple partners. Nearly, twice as many South African women aged 19–22 reported multiple partners as females from all other sites. A smaller proportion of Zimbabwean adolescents reported multiple

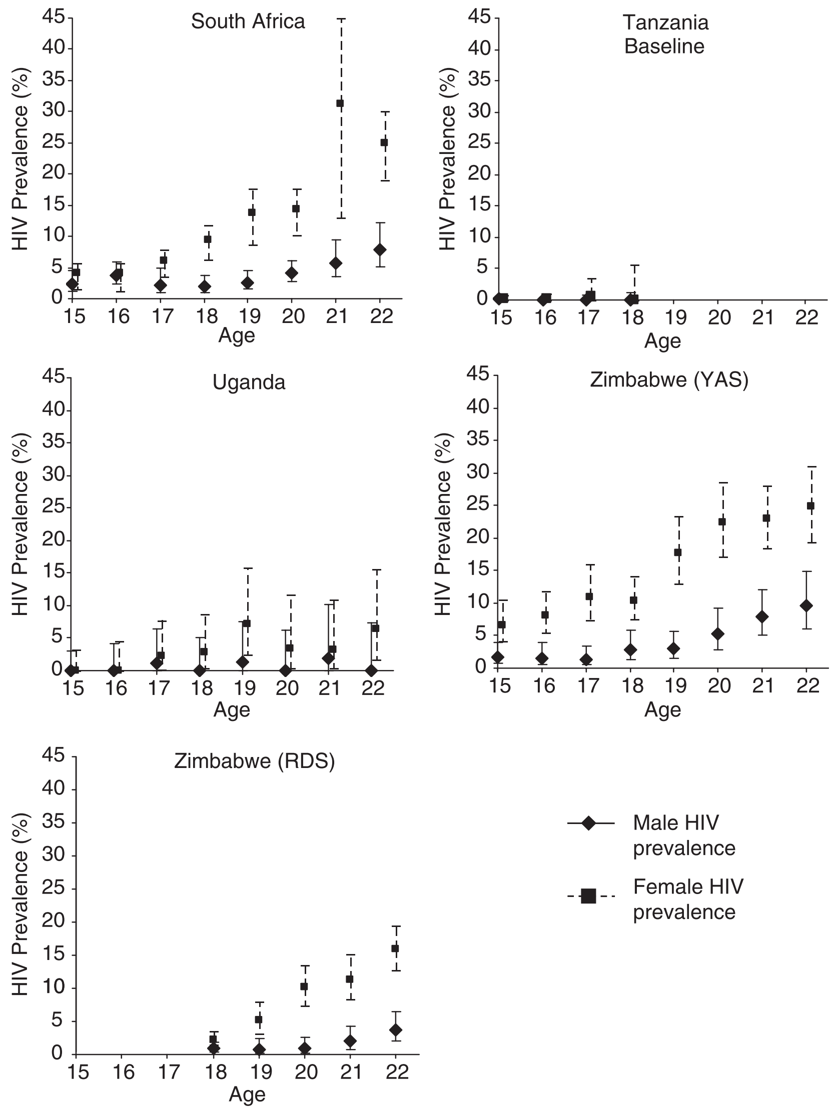


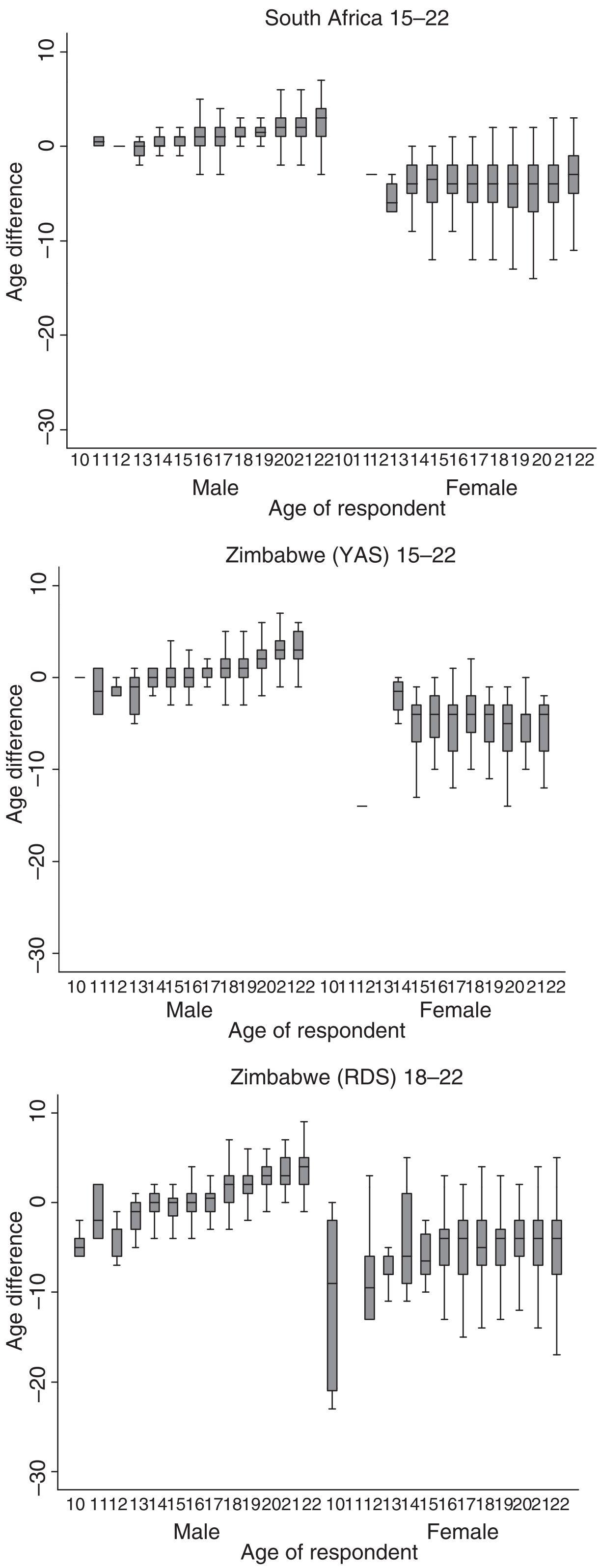
Figure 1 HIV prevalence by age and sex in each population (95% confidence intervals).

partners than adolescents in other studies. Overall, reported numbers of partners, either over the last year or lifetime, were not consistently higher in high prevalence populations.

Male circumcision was relatively rare in these populations compared to many sub-Saharan African populations (Halperin & Bailey 1999). Tanzanian men had the lowest prevalence of circumcision, followed by Zimbabwean men, with South Africa and Uganda having the highest prevalence. Therefore, male circumcision does not help explain the observed differences in adolescent HIV prevalence in these populations.

Condom use at last sex was more common in higher HIV prevalence populations, especially in men; although South African women aged 15–18 reported the highest levels of condom use (61.5%). Tanzanian adolescents rarely reported condom use at last sex (15- to 18-year-olds: men = 3.8%; women = 5.4%). Therefore, differences in condom use cannot explain differences in HIV prevalence and may be most plausibly explained by differential risk perception.

Self-reported GUD and discharge rates in those reporting ever had sex tended to be higher in the high HIV prevalence populations, especially South Africa, than in lower HIV



prevalence populations. However, the proportion reporting GUD in the Zimbabwe YAS survey did not follow this pattern, perhaps reflecting the timing of the study in comparison with the RDS. Rates of reporting genital discharge were markedly higher in high prevalence women (15- to 18-year-olds: 19.4% in South Africa, 13.5% in Zimbabwe YAS *vs.* 6% in Uganda 19- to 22-year-olds: 18.5% in South Africa, 15.9% in Zimbabwe RDS *vs.* 9.9% in Uganda). These biological variables are markers for STIs that are known risk factors for HIV, and variation of these in adolescent populations could help explain heterogeneity in HIV prevalence.

Data on forced sex were difficult to compare because of inconsistent survey questions (Online Supplementary Material Methods S1). Data suggest that forced sex was relatively common in women in South Africa (15- to 18-year-olds 12.7%) and Zimbabwe (RDS 19- to 22-year-olds 22.2%). In Tanzania, a lower HIV prevalence population, forced sex was less common (15- to 18-year-olds 7.2%). Data were not available on anal sex from either of the low prevalence populations. These limitations mean we cannot fully determine whether heterogeneity in reported forced sex or anal sex may have contributed to differing HIV prevalence, but these data suggest they could have a role.

Figure 2 shows the reported age difference between partners by age for South Africa and both populations in Zimbabwe. Men aged 15–18 tended to report that their partners were the same age or slightly older. Older men (19- to 22-year-olds) tended to form partnerships with younger women, and this age difference increased with increasing male age. Women consistently reported older partners, and the age difference remained fairly constant with increasing female age. The variance in reported age difference was greater in women than men at all ages, suggesting young women form partnerships with a wider age range of men than young men form with women. This trend was consistently observed in these three high HIV prevalence populations and another population in Zimbabwe (Gregson *et al.* 2002).

Figure 3 shows the proportion of most recent partnerships formed by 16- to 20-year-olds with partners who were older, younger or the same age, by respondent age and gender. The pattern of male age mixing was similar in all studies, with the proportion reporting

Figure 2 Age difference between partners, by age at partnership and gender. The box-plot shows the 25th and 75th percentiles with the central line representing the median, and the whiskers show the range within which 95% of the data lie. Age difference = age of individual – age of partner.

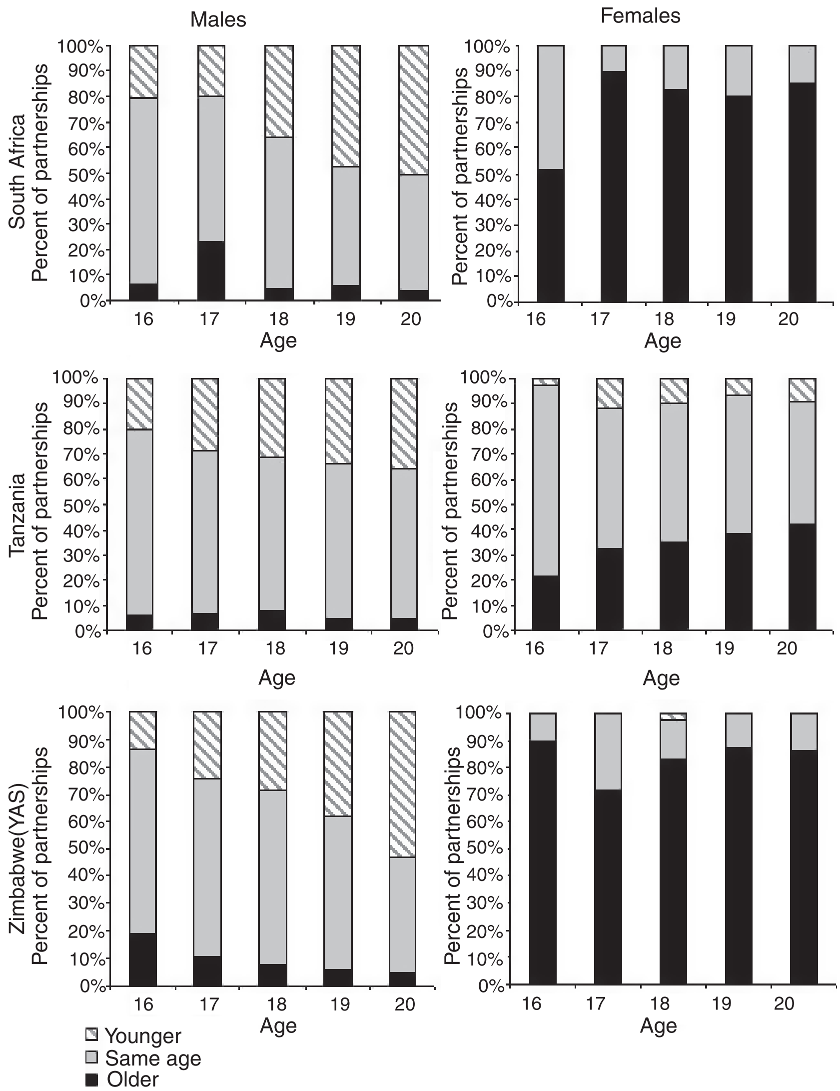


Figure 3 The proportion of most recent partnerships formed by 16- to 20-year-olds reported to have been with older, younger or same-aged individuals by respondent age and gender. Same age is defined as an age difference of −1, 0 or +1 years.

partners younger than themselves increasing with male age. However, women in Tanzania reported a much higher proportion of partners that were the same age than in the high prevalence studies, where a greater proportion reported having older partners. This finding was robust to increasing the age range that was defined 'same age' to ±2 years or ±3 years (Online Supplementary Material Figures S3 and S4).

The proportion of individuals likely to have misreported having not had sex differed between populations (Online Supplementary Material Results S4 and Table S3). Misreporting was more common in higher prevalence populations, and this may be a true difference or because of differences in study design, survey methodology, data-cleaning methods (Gregson *et al.* 2004) or differing social acceptability.

Discussion

This study compared adolescent sexual behaviour and other factors from five populations within four sub-Saharan African countries with markedly differing HIV epidemics with the aim of identifying patterns that may help to explain differences in adolescent HIV prevalence. In general, the adolescent behaviours assumed *a priori* to be higher risk were not found to be more common in populations with higher HIV prevalence. In some cases, risk behaviours were much more prevalent in lower prevalence studies. For example, the lowest levels of having had sex, oldest age of debut and the lowest proportion of multiple partners were reported in Zimbabwe, although that country had the highest HIV prevalence. Tanzanian men reported some of the highest risk behaviours but had the lowest HIV prevalence. The risk factors that were more common in high HIV prevalence settings were reported GUD and genital discharge, and women reporting more male partners older than themselves. HIV prevalence in the general adult population was also markedly higher in populations with higher adolescent HIV prevalence.

Higher adult HIV prevalence and a tendency to form partnerships with older partners will increase the probability that adolescents form partnerships with HIV-infected individuals. Once in a partnership with an HIV-infected individual, the higher rates of adolescent STI cofactors would increase the probability of HIV acquisition (Rottingen *et al.* 2001). These factors would lead to high rates of HIV infection in adolescents and may, in part, explain the higher HIV prevalence in South Africa and Zimbabwe compared to Tanzania and Uganda. If our finding of a smaller age difference between partners and Tanzanian women was not because of selection bias, our study would provide support for the hypothesis that age mixing may play a role in determining HIV prevalence in adolescents, particularly in young women (Gregson *et al.* 2002).

Differences in the local epidemic must be considered when interpreting these results as current HIV prevalence is in part a reflection of past behaviour, however less so in adolescents than adults. Zimbabwe and Uganda have experienced a decline in prevalence (Whitworth *et al.* 2002, Gregson *et al.* 2006, Mahomva *et al.* 2006). The decline in Uganda has been attributed to behaviour change along with epidemic stage (Hallett *et al.* 2006, Kilian *et al.* 1999). There is evidence that the decline in Zimbabwe was associated with a change in behaviour, especially the age of sexual debut (Gregson *et al.* 2006; Hallett *et al.* 2007b). In this analysis, the more recent RDS study reports a higher median age of sexual debut than in the earlier YAS study and around a five-fold lower proportion reporting early sexual debut. In the later study, HIV prevalence was over 50% lower in women and around 70% lower in men, and prevalence of GUD and discharge was substantially lower. Therefore, the results of our analysis support the hypothesis that behaviour change has occurred in Zimbabwe, leading to reductions in HIV prevalence.

The comparison of data across these five populations was limited by differences between the study designs. Two of the studies were intervention trials, and therefore, participants may differ from population-based cohorts. All data on Tanzanian adolescents, apart from age differences, were from the baseline analysis of a school-based intervention trial. If sexual behaviour of adolescents attending school is lower risk than that of out-of-school adolescents, the observed difference between Tanzanian adolescents and adolescents in the other studies may not represent a true difference. Specifically, there may be bias against sexually active women who may have left school because they are pregnant or to marry. However, few studies have looked at the relationship between school attendance and sexual behaviour, and their findings are equivocal (Gregson *et al.* 2001; Glynn *et al.* 2004; Hargreaves *et al.* 2008), and except for smaller age difference between partners, Tanzanian youth reported some of the riskiest sexual behaviours, and therefore, we believe the differing study designs are unlikely to weaken our conclusions.

Our study made use of more detailed adolescent behaviour data than was typically available from DHS. Where comparison was possible, the results of the DHS analyses were consistent with our findings (Online Supplementary Material Table S4). Zimbabwean adolescents reported the highest median debut age. Tanzanian men reported the youngest debut age, highest proportion reporting sex under the age of 15 and highest proportion with multiple partners.

In line with previous studies (Allen *et al.* 2003; Plummer *et al.* 2004), we found evidence of misreporting of risk behaviours (Online Supplementary Material Results S4) and these varied by study. Risk behaviours may have been under-estimated in the higher HIV prevalence populations, and this may explain, in part, why risk behaviours did not appear to be higher risk in the HIV prevalence populations.

Sexual contact between young women and older men has been shown to be a risk factor for young women in both empirical (Gregson *et al.* 2002, Kelly *et al.* 2003) and modelling studies (Hallett *et al.* 2007a). Age difference, however, has not previously been shown to vary in line with adolescent HIV prevalence. Two studies compared age differences across Africa, but both studied all-adults rather than adolescents, and their results were equivocal (Ferry *et al.* 2001; Wellings *et al.* 2006). A study of sexual behaviour in 15- to 49-year-olds in two high and two low HIV prevalence cities in Africa reported mean age difference between partners (Ferry *et al.* 2001). The age difference between marital partners was larger in the two high prevalence cities than in the two low prevalence cities, but this finding was reversed in non-marital partners. In a global comparison of sexual behaviours, mean age difference between spouses of 15- to 49-year-olds differed between geographical areas and was larger in Africa than the rest of the world (Wellings *et al.* 2006). Age difference between spouses within Africa was not associated with overall HIV prevalence. Our study may therefore offer a new and important insight into the patterns of age mixing among adolescents across southern and eastern Africa.

A modelling study has suggested that an intervention that reduced the proportion of 'cross-generational sex' partnerships with individuals 10 or more years older from 20% to 5% of partnerships would reduce HIV prevalence in female adolescents from 10% to 4.5–7% but would not have a large population level effect (Hallett *et al.* 2007a). In our empirical comparison, we found a much lower proportion of reported partnerships with individuals 10 or more years older, especially at younger ages (Tables 1 and 2), and therefore, modelling work is required to explore the impact of interventions that reduce the overall difference in age in all partnerships, rather just in partnerships with very large age differences.

Our study highlights some of the difficulties in comparing behavioural studies. There were difficulties in identifying comparable survey questions across studies. Unlike the DHS surveys and the four-cities study (Buve *et al.* 2001a,b), the surveys used here were not designed to be compared. Therefore, it was not possible to compare all the aspects of sexual behaviour that may be important such as concurrency. Increased consideration of cross-study comparability when designing behavioural surveys would greatly enhance the utility of these data for comparative research.

The lack of association between reported sexual behaviours and HIV prevalence has been noted in other studies comparing African cohorts (Boerma *et al.* 2003, Ferry *et al.* 2001, Marston *et al.* 2009, Todd *et al.* 2009). Reasons for this lack of association may include the large level of misreporting that sexual behaviour is subject to (Buve *et al.* 2001b), specifically because of differing levels of social desirability bias. It may also be that commonly used indicators of sexual risk taking do not reveal the true risk factors for individuals. For example, risk activity within a partnership, such as concurrency (Morris & Kretzschmar 1997,), rather than quantity of partners may be important for transmission. Averaged measures of behaviour may also fail to capture periods of high risk behaviour (Todd *et al.* 2009). This is a problem when trying to understand the epidemic, such as surveillance studies using sexual behaviour indicators (Zaba *et al.* 2005) and interpreting intervention trials. Despite this, analysing reported behaviour is still important for retrospective analysis and understanding success in reducing the spread of HIV (Garnett *et al.* 2006, Gregson *et al.* 2009). For adolescents, adult HIV prevalence and risk behaviours may be a dominant influence on adolescents and determine heterogeneity in prevalence. If adult factors have a dominant influence on adolescent HIV risk, it would help to explain the failure of behavioural interventions that primarily targeted adolescents (Jemmott & Jemmott 2000; Johnson *et al.* 2003; Gallant & Maticka-Tyndale 2004; Robin *et al.* 2004; Ross *et al.* 2007) and suggests future interventions should include adults.

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Supporting Information

Additional Supporting Information may be found in the online version of this article:

Methods S1. Data analysis.

Methods S2. Biological tests.

Methods S3. Biological markers of sexual behaviour.

Results S4. Validity of reported behaviour.

Figure S1. Kaplan–Meier plots of reported age of first sex by gender in each study.

Figure S2. Proportion reporting ever had sex by age and gender in each study.

Figure S3. Sensitivity of age mixing patterns in South Africa to different definitions of 'same' age, A and B using the original definition of 1 year older or younger, C and D, using 2 years older or younger, E and F using 3 years older or younger.

Figure S4. Sensitivity of age mixing patterns in Zimbabwe to different definitions of 'same' age, A and B using the original definition of 1 year older or younger, C and D, using 2 years older or younger, E and F using 3 years older or younger.

Table S1. Number of individuals eligible for this analysis in each study by age and gender for 15–18 year olds (A) and 19–22 year olds (B).

Table S2. Standard populations used in the analysis. A separate standard is used for each age range and gender (15–18, 19–22 and 16–20 years).

Table S3. Analysis of biological markers of sexual activity to determine levels of behavioural misreporting, in Tanzania (age range 16–20) and Zimbabwe RDS (age range 19–22). The proportion of individuals that report they have never had sex that were found to be HSV-2 positive or had ever been pregnant.

Table S4. Available weighted behavioural variables for 15–24 year olds extracted from The HIV/AIDS Survey Indicator Database (MEASURE DHS) with weighted denominators.

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