Focusing strategies of condom use against HIV in different behavioural settings: an evaluation based on a simulation model*

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Using a sexually transmitted diseases simulation model (STDSIM), we made projections of HIV spread for four profiles of sexual behaviour reflecting patterns encountered across the developing world: 1) much commercial sex, no short relationships; 2) commercial sex, concurrent short relationships; 3) concurrent relationships, no commercial sex; 4) serial short relationships, some commercial sex. We studied the effects of increasing condom use in three target groups: commercial sex workers (CSWs); men engaging in commercial contacts and short relationships; and females in steady relationships. The projections indicated that the CSW and male strategies were more effective in reducing HIV incidence than the strategy focusing on females in steady relationships. In the long run, even the group of men and women with one recent partner were better protected against HIV infection by condom use in high-risk contacts than by condom use in steady relationships. Furthermore, the numbers of HIV cases prevented per condom used were 7 to 500 times higher for condoms used by CSWs or men engaging in short relationships and commercial sex than for ones used by females in steady relationships. The results indicated the merit of focusing on high-risk groups irrespective of the pattern of sexual behaviour, even in epidemics that had already spread throughout populations.

Keywords Condoms/utilization; HIV infections/transmission/prevention and control; Sex behavior; Prostitution; Risk factors; Men; Women; Forecasting/methods; Stochastic processes; Developing countries (*source: MeSH*).

Mots clés Condom/utilisation; HIV, Infection/transmission/prévention et contrôle; Comportement sexuel; Prostitution; Facteur risque; Hommes; Femmes; Prévision/méthodes; Processus stochastique; Pays en dévelopment (*source: INSERM*).

Palabras clave Condones/utilización; Infecciones por VIH/transmisión/prevención y control; Conducta sexual; Prostitución; Factores de riesgo; Hombres; Mujeres; Predicción/métodos; Procesos estocásticos; Países en desarrollo (*fuente: BIREME*).

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Introduction

HIV/AIDS continues to spread rapidly in many developing countries. In parts of southern Africa the prevalence of HIV in the general population exceeds 30%; high incidence rates have also been reported from parts of South-East Asia (*1*). In most countries in these regions, vaccination and affordable effective treatment are unlikely to be available for many years. Preventive measures are therefore the only realistic option for control. Over 90% of adult cases in developing countries are attributable to heterosexual activity (*2*) and it is therefore vital to prevent this mode of transmission. It is important to consider whether and to what extent special efforts should be made to reach specific groups in populations in order to develop strategies for the prevention of HIV.

Sexual behaviour patterns vary widely between countries (*3*) and there may be large differences in sexual norms and practices between different groups

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within countries. Mathematical models have shown that heterogeneity in sexual behaviour within a population (*4*, *5*) and the extent of concurrency in sexual relationships (*6*, *7*) are important determinants for the spread of HIV and other sexually transmitted diseases (STDs). Modelling exercises have also shown that interventions focused on groups at high risk of contracting and transmitting HIV are more effective and more cost-effective than interventions aimed at the general population (*2*, *5*, *8*, *9*). However, this finding has not been studied in more realistic behavioural settings.

In the present paper we discuss the value of focusing interventions on particular groups in a population in different behavioural settings with diverging HIV epidemics. We present model projections of the impact of three differently focused strategies of condom use, using a framework described earlier in a policy research report on AIDS (*10*). Using the sexually transmitted diseases simulation model STDSIM (*11*), we develop four profiles of sexual behaviour in order to study how differences in such behaviour affect the impact of prevention strategies on the spread of HIV. These profiles differ in the extent and distribution of sexual risk behaviour in the population, such as the presence and importance of commercial sex, the presence of short relationships and the occurrence of overlap in relationships. They are considered to be stylized patterns of behaviour encountered in various developing countries.

In this paper we are principally concerned with the impact of focusing intervention strategies in each of these behavioural profiles and with the resource requirements of different strategies.

An especially subtle aspect of interventions that focus on particular population subgroups, e.g. commercial sex workers (CSWs), is the indirect protective influence they can have on other segments of the population. The character of indirect effects can vary as a function of the prevailing behavioural pattern. By using a dynamic transmission model we can consider the benefits of interventions including indirect effects. Of particular interest is whether individuals with low-risk behaviour profit from interventions focused on high-risk groups, and if so, to what extent. We therefore study how particular groups within the population, differing in risk behaviour, benefit from differently focused condom interventions at different times after the start of an intervention. This gives an insight into the balance over time between the direct protection that condoms offer to their users and the indirect protection arising through a reduction in the prevalence of HIV in the population.

Methods

Simulation model

The STDSIM model (*11*) was used to project the effectiveness of different strategies of condom use. It simulates the transmission and natural history of HIV and four classic STDs, namely gonorrhoea, chlamydia, syphilis and chancroid. The integration of HIV/AIDS and other STDs into a single model is important because HIV transmission is facilitated if a partner carries another STD (*12*).

STDSIM is a dynamic stochastic mircrosimulation model which describes processes at the level of individuals. Microsimulation can account for complex interactions between a variety of factors affecting the effectiveness of health interventions in a population, as has been shown in its application to decision support in cancer screening (*13*) and river blindness control (*14*). Earlier studies used microsimulation to investigate the effectiveness of interventions for sexually transmitted diseases (*15–17*). However, the interaction between behavioural patterns and the effectiveness of interventions has not yet been studied with this type of model.

The four populations simulated in the present study differ only with regard to sexual behaviour. Identical assumptions were made on demography, the transmission and natural course of STDs and the effectiveness of health care. Only heterosexual transmission was considered.

General assumptions

The birth and death of hypothetical individuals determined the size and composition of the model population. We assumed a total fertility rate of 3.6 per woman, corresponding to the average total fertility rate in the developing world (*18*). Mortality in the absence of HIV was based on Coale & Demeny-West survival probabilities with a mean life expectancy of 62.5 for females and the accompanying survival probabilities for males (*19*). To start a simulation, these fertility and mortality rates were applied to an initial model population of 8000 individuals. The population size had grown to an average of about 20 000 at the moment of HIV introduction (year 0). We did not take migration into account.

Assumptions on the transmission, natural course and treatment of curable STDs were specified for each STD separately. For the complete set of assumptions with respect to the biology and management of the four included classic STDs, reference should be made to van Vliet et al (*20*). It was assumed that HIV infection lasted for eight years on average and that the patient then died (*21*). We modelled the time course of HIV transmission efficiency as a bathtub pattern (*22*). Transmission probabilities were 0.2% per unprotected contact from male to female and 0.1% from female to male during the long asymptomatic stage, and were 20 times higher during the first 10 weeks of infection and 5 times higher during the last symptomatic stage lasting 1 year. It was assumed that both susceptibility to and infectivity of HIV were increased fivefold per sexual contact by chlamydia and gonorrhoea and twenty-fivefold by chancroid and active syphilis.

Occasional sexual contacts with infected persons from outside the simulated population introduced additional STD infections at a constant rate. In profiles that included commercial sex, HIV was introduced by one CSW in year 0; in the profile without commercial sex, HIV was introduced in 10 sexually active males and 10 sexually active females.

Assumptions on sexual behaviour

In the STDSIM model, men and women are linked by sexual relationships that form a dynamic network through which STDs are transmitted. Three types of relationships were modelled, which, in principle, can overlap with each other:

- steady relationships (marriages) with a fixed yearly divorce probability of 1%, such that most would last until the death of one of the partners;
- short relationships with an average duration of 0.2 years;
- commercial contacts between male clients and female CSWs.

The formation of relationships is simulated using the concepts of availability for and selection of new partners, i.e. supply and demand respectively. It follows age preference matrices guiding the search for new partners from the same or adjacent age groups. The frequency of intercourse was set at 1.5 times per week per relationship for both steady and short relationships (*23*), and was independent of the number of ongoing relationships.

Heterogeneity in sexual behaviour was incorporated in three different ways. First, the simulated population was heterogeneous in the number, type and overlap of sexual relationships. Individuals differed in their tendency to initiate new relationships, whether steady or short, depending on their sex, age, personal inclination and the existence of steady or short relationships. Second, the frequency of one-off contacts with female CSWs varied between males. This personal frequency depended on marital status, but was otherwise assumed constant throughout a man's sexual life. In all profiles, the males who engaged in commercial sex were evenly divided between a class with one visit to a CSW per year and a class with six visits per year. Third, the age at which sexual activity began varied between individuals and between the sexes.

More details on the modelling of sexual behaviour are given elsewhere by Korenromp et al. (*24*).

Using this framework, we constructed the following stylized profiles of sexual behaviour:

1) much commercial sex, no short relationships;
2) commercial sex, concurrent short relationships;
3) concurrent relationships, no commercial sex;
4) serial short relationships, some commercial sex.

Table 1 indicates the risk behaviours occurring in each profile, depending on individuals' current involvement in a steady relationship or steady relationships.

Profiles 1, 2 and 3 could be thought of as simplified representations of sexual behaviour in South-East Asian countries (*3*, *25*), cities in sub-Saharan Africa (*3*, *25–27*) and rural sub-Saharan Africa (*3*, *25*, *28*) respectively. Profile 4 involves low risk and is added for purposes of comparison.

Fig. 1 shows age-specific and sex-specific numbers of partners during one year for the four different profiles as calculated by the model. These outcomes relate to a situation before HIV introduction. HIV induces selective mortality among persons who have the highest sexual activity, and this changes sexual behaviour patterns in a population.

In Profile 1 the number of sex partners is strongly asymmetric between males and females. Except for CSWs, women have sex only in steady relationships. All single males and 40% of married males engage in commercial sex. Especially among males aged 20–24 years, all of whom have initiated sexual activity but are often not yet in a steady relationship, visits to CSWs result in high numbers of recent partners.

In Profile 2, both men and women who are not in a steady relationship engage in possibly overlapping short relationships. Moreover, 40% of men have sex with CSWs. Overlap in sexual relationships and high rates of partner change result in large numbers of partners in young males and females. Most older females have entered into monogamous steady relationships, as evidenced by a majority having one recent partner. In contrast, males in steady relationships continue with commercial sex and short relationships, and consequently they still have large numbers of partners.

In Profile 3, sexual behaviour is relatively symmetrical between the sexes: both women and men can have multiple concurrent relationships, even while engaged in a steady relationship. Full symmetry is not accomplished because women in relationships are usually younger than their partners. Despite the absence of commercial sex, the proportion with more than one partner in the last year is rather high because of overlapping relationships.

In Profile 4 all persons are serially monogamous, apart from 40% of young males who have commercial sex contacts while single or engaged in short relationships. Because of high promiscuity among the young, the termination of relationships is followed almost immediately by the commencement of new ones. Consequently, numbers of recent partners are high for persons who have initiated sexual activity but are not yet in a steady relationship. Only men who are not in a steady relationship practise commercial sex. Consequently, both men and women of older ages, who are often in a steady relationship, mostly have one recent partner.

The proportion of females aged 15–49 years who are active as CSWs at a given time follows the male demand for commercial sex, so that CSWs have an average of 10 contacts a week. The proportion of females practising commercial sex is highest in profile 1, at approximately 0.3%, followed by profile 2 at

approximately 0.2%, and profile 4 at 0.05%; no commercial sex takes place in profile 3.

The correspondence between model profiles and geographical regions is parallelled by similarities in numbers and age/sex patterns in respect of non-regular partners. This can be seen by comparing Fig. 1 with outcomes of behavioural and health surveys in the general population (*3*, *24*).

Baseline projections

We made projections of HIV spread for a period of 30 years since the moment of introduction of HIV into the population in year 0. For each profile, we averaged the results of 150 simulations of a population of, on average, around 20 000 hypothetical individuals in year 0, in order to reduce stochastic fluctuations in simulation outcomes.

For the baseline projections without intervention we assumed that 20% of CSWs used condoms in all commercial contacts and that 5% of men used condoms consistently in all short relationships and commercial contacts. It was considered that a condom was used in a commercial contact if there was consistent use of condoms by either or both partners, i.e. CSW and client. Furthermore, we assumed that no condoms were used in steady relationships.

The failure rate of condoms through breakage or incorrect use was set at 5%, implying that 95% of contacts involving the use of condoms were protected against the transmission of HIV and STDs.

Table 1. **Risk behaviour in model profiles of sexual behaviour with reference to current involvement in steady relationships (unmarried vs married)**

Profile	Male				Female	
	Visiting CSWs		Short relationships		Short relationships	
	Unmarried	Married	Unmarried	Married	Unmarried	Married
1	+	+	–	–	–	–
2	+	+	+	+	+	–
3	–	–	+	+	+	+
4	+	–	+[a]	–	+[a]	–

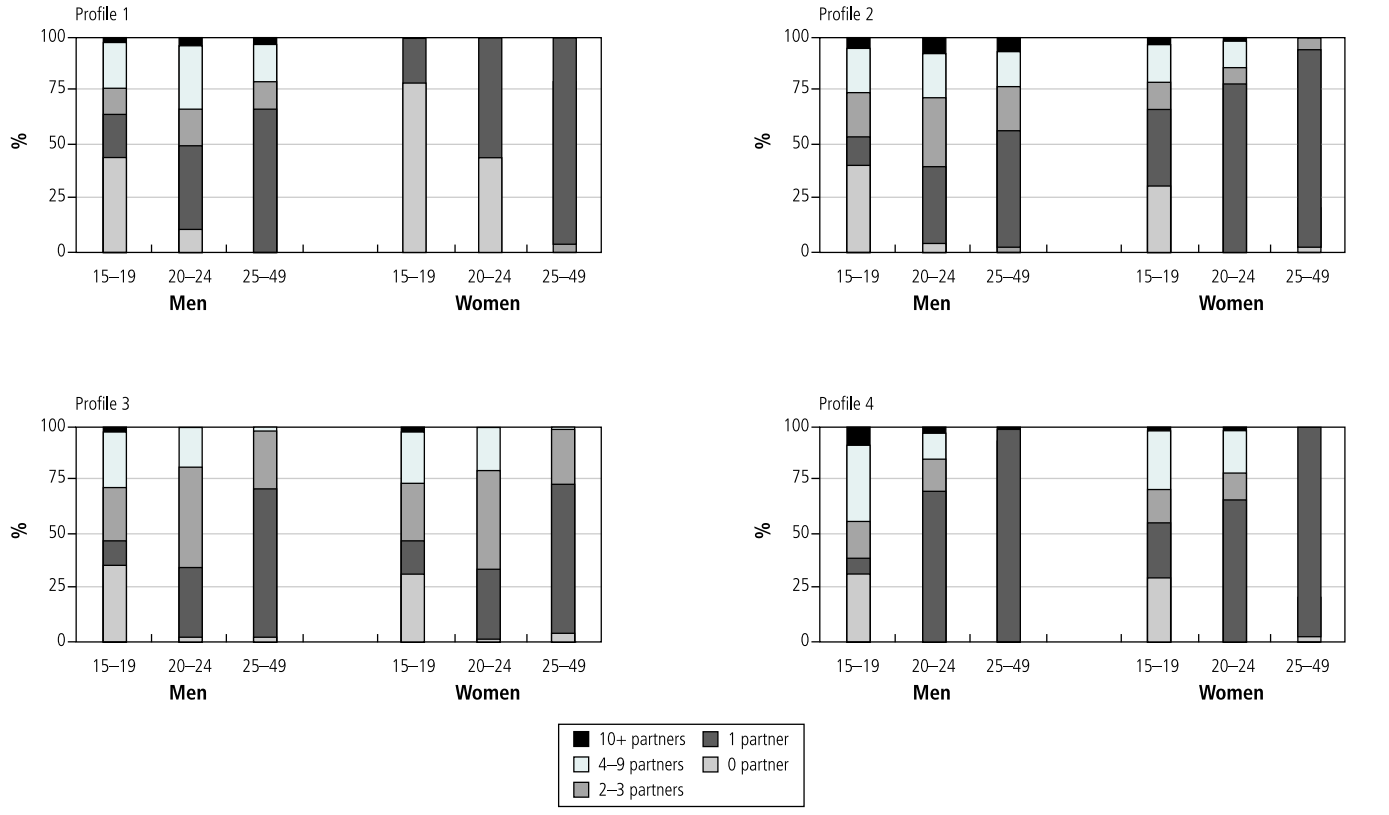
[a] Serial monogamy.

Prevention strategies

We considered the effects on HIV spread of three strategies of condom use which focus on different groups in the population.

- *CSW strategy*: increases the proportion of CSWs consistently using condoms in their commercial contacts.
- *Male strategy*: increases the proportion of men consistently using condoms in commercial contacts and short relationships.

Fig. 1. **Age-specific and sex-specific distribution of number of sexual partners in previous year, for STDSIM profiles 1, 2, 3 and 4** (see Table 1)



Note. Because differences in numbers of partners are small for age groups older than 25 years, ages 25–49 years are combined.

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- *Family planning strategy*: increases the proportion of women under 50 years of age who consistently use condoms in steady relationships.

We considered a range of coverage levels for each strategy. It was assumed that these were attained immediately on implementation, 15 years after HIV introduction, and that they led to sustained changes until the end of the simulation period.

The epidemiological effects of the prevention strategies are presented as reductions in HIV incidence in the general adult population aged 15–49 years over a period of 15 years. Averages and standard errors of the reduction in HIV incidence were calculated from the reductions in individual simulation runs.

All interventions begin from the same base, meaning that the simulated population was captured in year 15 for each of the 150 runs, and then allowed to continue with no intervention or one of the three prevention strategies in place. As we aimed to evaluate the impact of interventions on HIV epidemics that had taken off, we excluded runs with HIV prevalence in the adult population below 0.5% in the starting year of interventions. This criterion resulted in the exclusion of two runs for profile 1, four for profile 3, and nineteen for profile 4.

Effects in different groups

We evaluated the effects of the three strategies on HIV incidence in specific groups in the population. A 50% increase in condom use in each target group considered was assumed, i.e. from 20% to 70% for CSWs, from 5% to 55% for males engaging in short and commercial relationships, and from 0% to 50% for females in steady relationships.

The effects were evaluated for:

- males with one partner in the previous year;
- males with two or more partners in the previous year;
- females with one partner in the previous year;
- females with two or more partners in the previous year.

We evaluated the effects on yearly HIV incidence the first year after implementation and in the last year of the evaluation period. In this way we studied the balance over time between the direct protection that condoms offer to their users and the indirect protection arising through a reduction in prevalence in the population. It is worth observing that these groups are dynamic: a person with one partner in a given year may have no partner or more than one partner in a subsequent year.

Effectiveness per condom used

In order to study the effectiveness of prevention strategies in relation to the number of condoms used, we calculated the numbers of new HIV infections and condoms used for simulations with and without an intervention in place. For each strategy the yearly differences in numbers of HIV infections and in numbers of condoms used were added over an evaluation period of 15 years. The cumulative number of HIV cases prevented was then divided by the cumulative incremental number of condoms used. Standard errors were calculated from the results of individual simulation runs, weighted by the cumulative incremental numbers of condoms used per simulation run.

Our estimates of effectiveness per condom used are conservative because we did not control for possible indirect effects after the evaluation period.

Results

Baseline projections

Fig. 2 shows the simulated course of the HIV epidemic over time for the four profiles. It can be seen that different profiles of sexual behaviour induce completely different courses of the epidemic.

In profile 1, the epidemic evolves rapidly after introduction because of the pivotal role of commercial sex in the spread of HIV. After year 10 the prevalence of HIV begins to decline slightly. Risk behaviour is concentrated in men engaging in commercial sex, who are relatively likely to contract HIV and die from AIDS early in the epidemic. This process of selective mortality reduces the actual percentage of males engaging in commercial sex. Around year 20, an equilibrium in HIV prevalence is established, during which the inflow of young males at risk is counterbalanced by the outflow of persons due to HIV-related death.

In profile 2 the epidemic evolves rapidly after introduction. In year 10 the prevalence level is already 20%, after which it continues to increase at a slower rate. At the beginning of the epidemic, as in profile 1, most infections can be attributed to commercial sex. In later stages, however, non-commercial short relationships are the source of a large part of HIV infection and the virus spreads to the whole population.

In profile 3 the epidemic evolves slowly after introduction since there is no commercial sex to fuel it. However, the prevalence of HIV continues to grow steadily, reaching over 30% at the end of the simulation period because of the high level of concurrent relationships.

In profile 4 the epidemic evolves slowly to a prevalence level of 9% in year 30. In the initial phase, however, HIV spreads more rapidly than in profile 3 because of the occurrence of commercial sex. The absence of concurrent non-commercial relationships in profile 4 precludes an eventually widespread epidemic.

Prevention strategies

Fig. 3 shows the simulated impact on cumulative HIV incidence over 15 years of the three strategies of condom use for all profiles; the 90% confidence intervals around the mean effects are scarcely visible because the standard errors are so small.

In profiles 2, 3 and 4 the strategy of male condom use in both short and commercial relationships reduces HIV incidence most for each coverage level. Increased condom use by CSWs is as effective as increased use by males only in profile 1, where commercial sex is the only type of sex outside steady relationships.

The absolute reduction of HIV incidence varies between the profiles for all alternative condom strategies. Where 100% condom use is practised by males in short relationships and commercial contacts, HIV incidence is reduced by between 75% (profile 4) and 85% (profile 1), while the effectiveness of a 100% family planning strategy varies between 35% (profile 4) and 55% (profile 3). The variation in effectiveness between profiles is highest for condom use in commercial sex: 100% condom use in commercial contacts lowers the incidence of HIV by between 45% (profile 2) and 80% (profile 1).

In general there is an almost linear relationship between coverage level and reduction in HIV incidence. Only for the male strategy does the incremental effectiveness decrease at high coverage levels in profiles 2, 3 and 4.

Effects of prevention strategies on different population groups

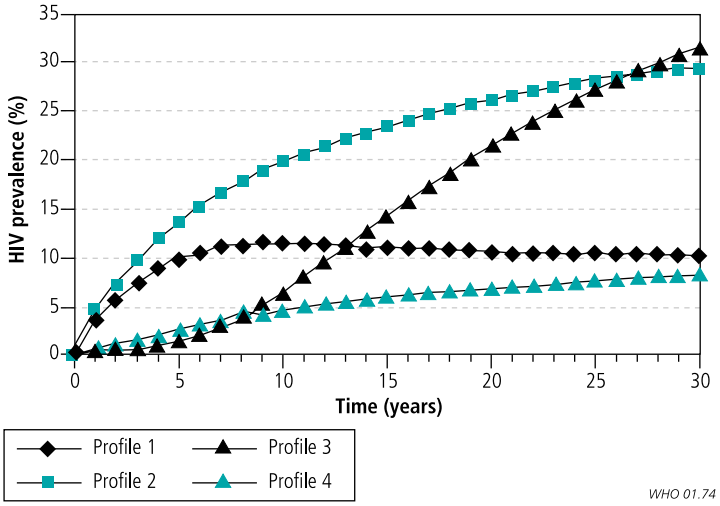
Figs. 4a and 4b show how the different condom strategies affect yearly HIV incidence in four groups of the population aged 15–49 years during the first year after implementation and the last year of the evaluation period respectively.

In the first year, in all profiles, both males and females with one partner in the previous year benefit most from an increase of condom use in steady relationships. Among these population groups the effect of the strategies of condom use by CSWs and males varies remarkably between the four profiles considered. For instance, in profile 4 the effect of both strategies is only marginal (<5% reduction) among men and women with one partner, whereas in the other profiles it is more pronounced.

Among males and females with two or more partners the reduction in HIV incidence in the first year is highest for the strategy of male condom use except in profile 1, where an increase in condom use among CSWs is more effective. Among males with two or more partners the short-term reduction in HIV incidence is smallest for the family planning strategy in all profiles. Among females with two or more partners the effectiveness of this strategy is also low, although, in profiles 1 and 2, differently focused strategies, i.e. on males in profile 1 and on CSWs in profile 2, have a comparable low effectiveness.

Comparing the long-term impact on HIV incidence (Fig. 4b) with the short-term impact (Fig. 4a), we see remarkable shifts in the relative effectiveness of the different strategies in all profiles, especially among males and females with one partner, among whom the family planning strategy is no longer the most effective one in the last year of the simulation period.

Fig. 2. **Baseline projections of HIV prevalence in adult population (15–49 years) for four sexual behaviour profiles** (see Table 1)



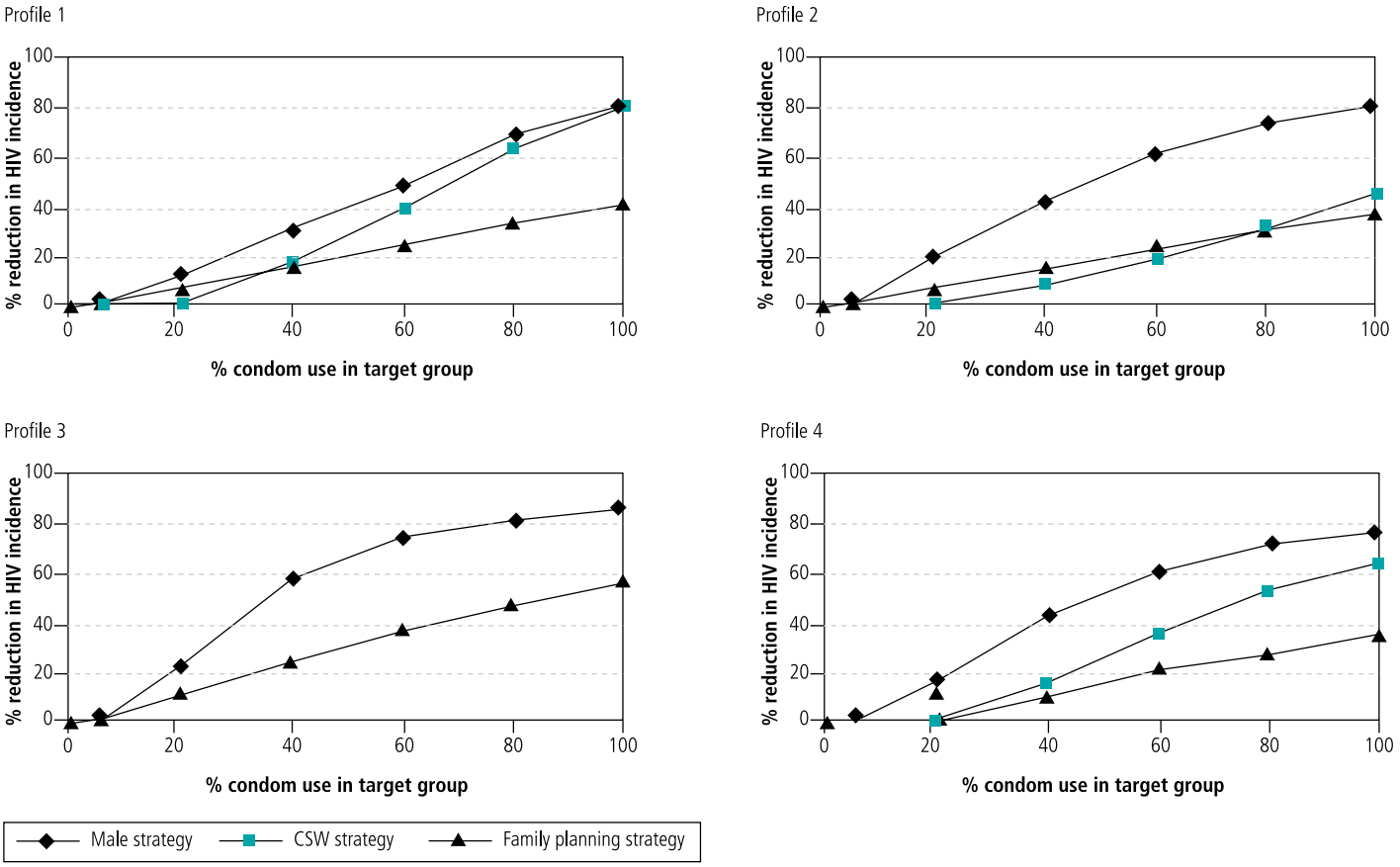
In profiles 2, 3 and 4 the increase in condom use by males in short relationships and commercial contacts is best able to bring down HIV incidence in the last year of the simulation period in all groups in the population, including females and males with one partner in the previous year. In profile 1 the increase in condom use among CSWs is most successful in reducing HIV incidence in the whole population. In this profile, the alternative strategies lead to an *increase* in HIV incidence in females, mostly CSWs, with two or more partners in year 15. By reducing overall HIV prevalence in the general population these strategies increase the number of females who in year 15 are still uninfected and at risk for HIV infection once they begin commercial sex activities.

Effectiveness per condom used

Fig. 5 shows the projected effectiveness per condom used of the three condom strategies for different coverage levels, and the 90% confidence intervals around the means (note logarithmic scale). At all coverage levels the number of HIV cases averted per condom is low for condoms used in steady relationships in comparison with the two other strategies of condom use. Considering all combinations of coverage levels, the effectiveness per condom used by CSWs and males in their short relationships and commercial contacts is, respectively, 75 (profile 2) to 500 (profile 4) and 7 (profile 3) to 100 (profile 1) times higher than that for condoms used in steady relationships.

For profile 2 and, especially, profile 4, the effectiveness per condom is higher for increased condom use among CSWs than for condom use among males at all coverage levels. In profile 1, in which no casual sex other than commercial sex is assumed, the effects of the strategies of condom use by males and CSWs are comparable at the different coverage levels.

Fig. 3. **Projected impact of three condom strategies on cumulative HIV incidence in adult population (15–49 years) at different coverage levels for profiles 1, 2, 3 and 4** (see Table 1)



Note 1. Condom use strategies initiated 15 years after HIV introduction.

Note 2. Effect on cumulative HIV incidence is calculated over a period of 15 years.

Note 3. In profile 3, where no commercial sex is assumed, the CSW strategy is not considered.

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For all profiles, STDSIM projects a reduction in the effectiveness of the strategy of condom use by males at high coverage levels. The maximum saturation effect occurs in profile 3, where the number of HIV cases prevented per 1000 condoms used falls from 12 at 20% coverage to 8 at 100% coverage. The effectiveness per condom of the family planning strategy is relatively stable for all profiles. In profile 4, saturation effects result in a slightly lower effectiveness per condom used by CSWs for higher coverage levels than for low coverage levels. In contrast, in profile 2 there is a slight increase in the number of HIV cases prevented per condom for higher coverage levels.

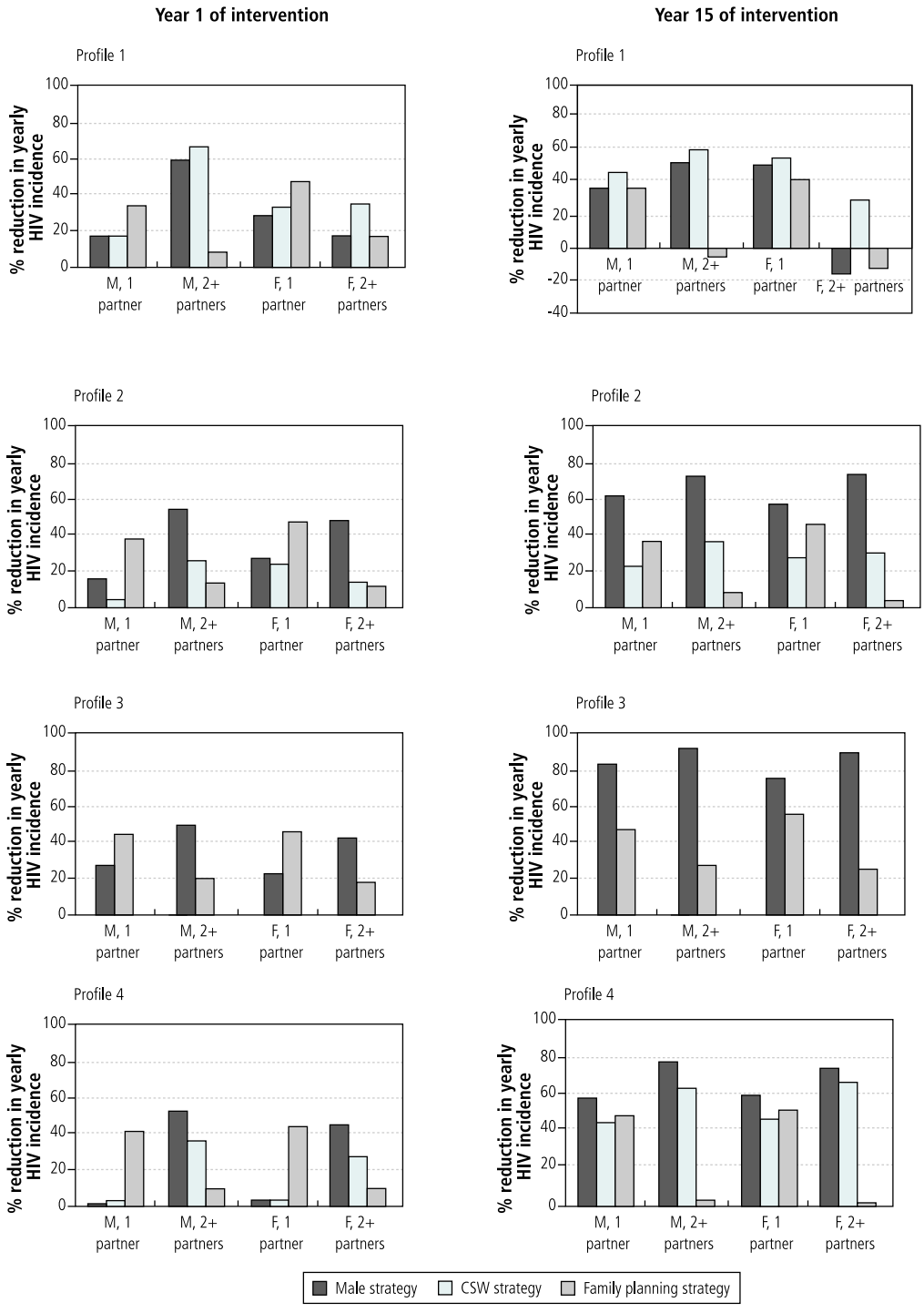
Discussion

Courses of HIV epidemic

We have studied the impact of differently focused condom interventions on HIV in stylized profiles of sexual behaviour, indicative of behaviour patterns in different parts in the developing world. Different patterns of sexual behaviour result in divergent courses of the HIV epidemic (Fig. 1). While drastic and successful interventions in an early phase of the epidemic in Thailand (*29*) precluded a comparison of its natural pattern of HIV spread with profile 1, the prevalences of HIV in populations in several sub-Saharan subregions (*1*) resemble those projected for profiles 2 and 3, describing widespread risk behaviour.

As for other infectious diseases, the course of the HIV epidemic is determined by a balance between an increase in the size of the group of infected persons and a decrease in the size of the group of susceptible persons, respectively increasing and decreasing the risk of new infections. In settings where risk behaviour is dispersed over the population, as in profile 3, the increase in numbers of infected persons predominates and saturation effects are small. The prevalence of HIV therefore continues to increase to high levels. On the other hand, where risk behaviour is concentrated, as in profile 1, an increase in the overall prevalence of HIV in the general population has a limited impact on the incidence of HIV. Saturation effects play a major role once the epidemic has taken off, resulting in the

Fig. 4. **Projected impact of three condom strategies on yearly HIV incidence in different groups in adult population (15–49 years) for four sexual behaviour profiles** (see Table 1)**, in first year and fifteenth year of strategy implementation**



Note 1. For all strategies it was assumed that condom use increased by 50% (5% to 55% in male strategy; 20% to 70% in CSW strategy; 0% to 50% in family planning strategy).
Note 2. Strategies initiated 15 years after HIV introduction.

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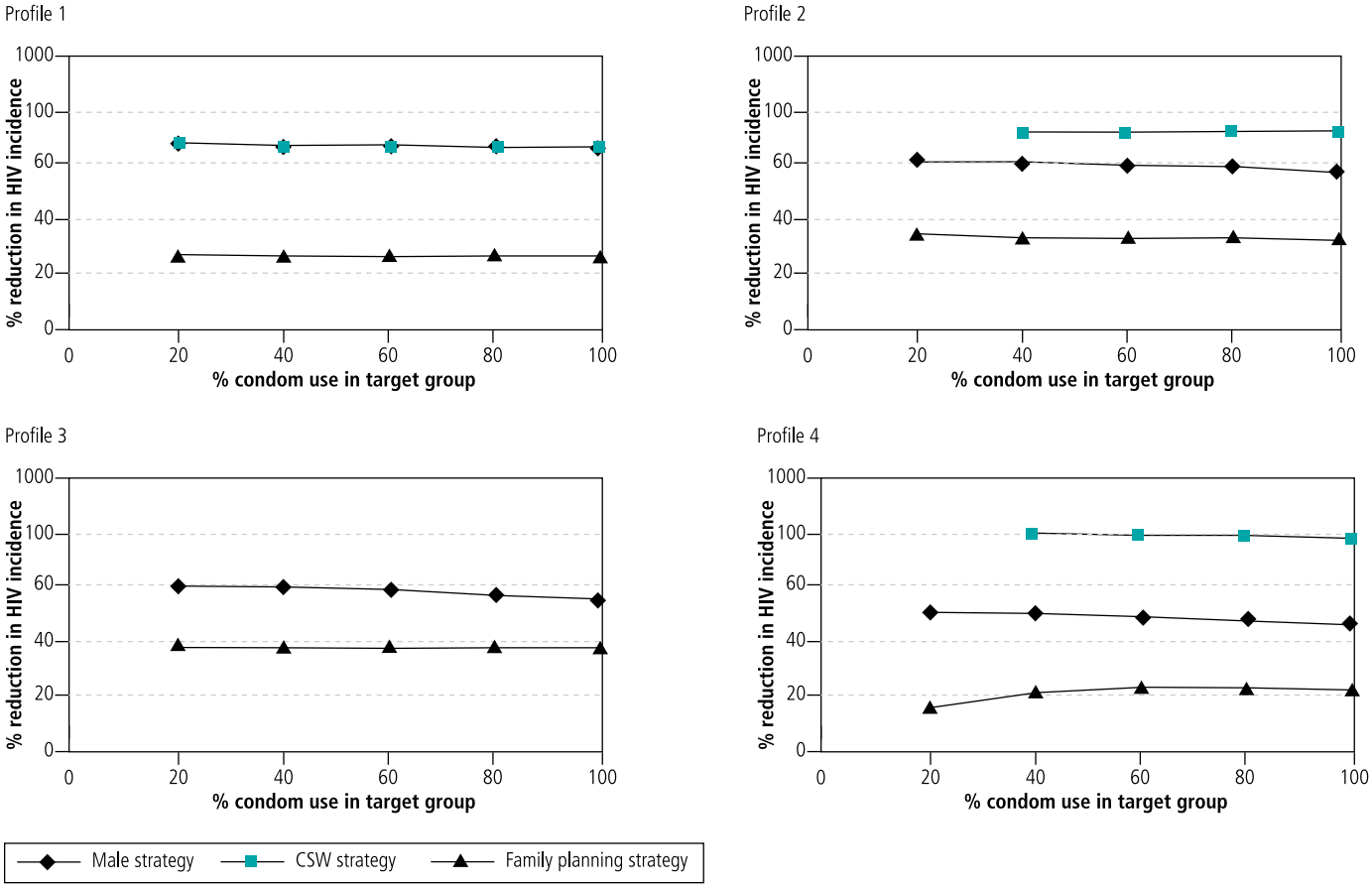
prevalence of HIV rising steeply at first and then stabilizing or even falling.

It is especially noteworthy that an epidemic that begins slowly may result in extremely high HIV prevalence levels, as shown in profile 3. A low prevalence of HIV gives no guarantee that an epidemic will be self-limiting in a given population.

Impact of prevention strategies in different settings

Projections showed that the strategy of increasing condom use among women in steady relationships is the least effective in reducing the incidence of HIV in all four profiles and for all coverage levels (Fig. 3). In profile 4, where serial monogamy in non-commercial

Fig. 5. **Number of HIV cases prevented per 1000 condoms used for different coverage levels in three condom strategies**



Note 1. A period of 15 years is considered for both the number of HIV cases prevented and the number of condoms used.

Note 2. Because the baseline assumption on condom use among CSWs is 20% (against 5% for males and 0% for females in steady relationships), the line for the CSW strategy starts at a coverage level of 40%.

Note 3. In profile 1 there is an overlap between the CSW and male strategies in respect of effectiveness.

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relationships is assumed, the effect of this strategy is particularly small, as it can only prevent HIV transmission in one relationship at a time. In profile 3, on the other hand, the impact is relatively large. The frequent overlap in relationships in this profile ensures that condom use in a specific steady relationship has relatively large indirect effects on transmission in other relationships.

These results are in line with earlier ones based on more stylized models stressing the importance of reaching high-risk groups, also termed the core, in STD prevention (*2*, *5*, *8*, *9*).

The results were obtained on the assumption that a proportion of a given population group uses condoms consistently. Similar levels of condom use could also be reached if a larger part of the population used condoms inconsistently. In that case the benefits of condom use in steady relationships would be even lower. Because of the large number of contacts per relationship, inconsistent condom use delays but does not prevent HIV transmission in discordant couples.

In practice it is likely that the achievable level of behavioural change differs between target groups in the population. Studies in a variety of developing countries show that levels of condom use of up to 70–90% can be reached among CSWs following intensive information, education and communication campaigns (*29*–*32*). Lower levels of condom use have been reported in other types of contact. Repeated surveys of sexual behaviour in the United Republic of Tanzania and Uganda have shown 20–40% increases in condom use with non-regular partners, reaching levels of 27% and 66% respectively (*33*, *34*). Demography and health surveys in various developing countries show that between 1% and 4% of women use condoms as a family planning tool (*35*). In Uganda, a population-based sexual behaviour survey has shown an increase to 11% in condom use among spouses (*34*).

Considering, on the basis of these studies, condom use levels of 80%, 50% and 20% as reasonable targets for CSWs, males engaging in commercial contacts and short relationships, and

females in steady relationships, respectively, the relative effectiveness of the family planning strategy lags even further behind the other strategies. The male strategy is the most effective one in reducing the incidence of HIV in profiles 2 and 3, and the CSW strategy gives the best results in profiles 1 and 4 (Fig. 3), reflecting the fact that the majority of infections can be related to commercial sex in profiles 1 and 4 and to non-commercial sex in profiles 2 and 3.

Until now the impact of condom interventions on the prevalence and incidence of HIV and STD in populations has not been studied in community-based trials in developing countries (*36*). It is therefore difficult to validate model predictions of the effectiveness of prevention strategies for different profiles. However, our projections of large effects of condom use among CSWs in settings like profile 1 bear a marked a resemblance to what has been observed in Thailand, where the programme of enforcing 100% condom use in commercial sex has resulted in a marked decrease in HIV prevalence among military conscripts (*37*, *38*).

Impact of prevention strategies in different population groups

In order to examine how different sexual behaviour groups within a population benefit from differently focused interventions, we evaluated the reduction in HIV incidence among males and females with either one or more than one partner in the preceding year, resulting from an increase in condom use in each target group.

In the first year after the implementation of strategies, males and females with one recent partner benefit most from an increase of condom use in steady relationships because they are concentrated in such relationships. Consistent condom use in these relationships directly reduces their risk of infection.

However, when considering HIV incidence in the fifteenth year of implementation, i.e. the last year of the simulation period, the use of condoms in commercial contacts and short relationships becomes the most effective strategy for the group of females and males with one recent partner. This arises because the large effects of the CSW and male strategies on incidence and prevalence in a population (Fig. 2) indirectly reduce the risk of HIV infection in steady relationships. In the long run these indirect effects on the population prevalence of condom use in risky contacts are larger than the direct effects of condom use in steady relationships, so that low-risk groups benefit most from strategies aimed at high-risk contacts.

This does not imply that the use of condoms among low-risk groups is ineffective. Indeed, the direct protection given by condom use in low-risk contacts is considerable. The majority of males and females with one recent partner who consistently use condoms in their steady relationships *themselves* are protected from HIV because condom failure is low. However, because of the limited indirect effects, *the group* of males and females with one recent partner *as a whole* benefits more from strategies targeting high-risk groups. Furthermore, increased awareness and acceptability of condom use in all segments of the general population may form an essential basis for more focused efforts directed at high-risk groups.

In both the short run and the long run, males and females with more than one recent partner benefit most from the strategy of condom use by males in profiles 2, 3 and 4. This strategy increases condom use in both commercial contacts and short relationships, which are clearly more risky than contacts in steady relationships. In profile 1, males and females with more than one recent partner gain more from an increase in condom use by CSWs than from an increase in condom use by males, even though, in the absence of short relationships, both these strategies only increase condom use in commercial contacts. However, the difference between these strategies is that, in the former, CSWs use condoms consistently, whereas in the latter males do so. It appears that consistent use among some CSWs is more effective in reducing the incidence of HIV than inconsistent use among all of them.

Resource requirements

For priority setting, both the health effects and the resource requirements of intervention strategies should be considered. For all the profiles the effect on HIV incidence per condom used is much higher in the CSW and male strategies than in that focusing on females in steady relationships (Fig. 5). Furthermore, the effect per condom used is lower in the male strategy than in the CSW strategy in profiles 2 and 4. This result is robust for changes in the assumptions on coverage (Fig. 5). In the male strategy, condoms are used in both commercial contacts and short relationships. A condom used in a short relationship apparently prevents fewer HIV cases than one used in a commercial contact.

At higher coverage levels the strategy of condom use by males shows a decline in the number of HIV cases prevented per condom used (profiles 2, 3 and 4; Fig. 5). This parallels the decrease in the incremental effect on cumulative HIV incidence shown in Fig. 3. The explanation for these findings is that the reduction in HIV prevalence induced by increased condom use lowers the risk of HIV transmission per contact. The marginal benefits of additional condom use therefore decrease. Such saturation effects can, in general, be expected to increase as the effect on HIV prevalence increases.

In contrast, the number of HIV cases prevented per condom *increases* slightly for higher levels of condom use among CSWs in profile 2. At high coverage there is a reduction in the risk of HIV infection for both clients and CSWs.

Prevention strategies can also be expected to reach persons outside the target group, something that was not taken into account in the simulations. For instance, when promoting condom use as a

family planning tool, distributed condoms may not only be used in steady relationships, as assumed in the projections, but also in more risky extramarital contacts. Moreover, the acceptance of condoms might be increased by such a strategy, as condoms are no longer only associated with STDs and illicit sexual encounters. In particular, the consistent use of condoms in semicasual relationships might be encouraged by a perception that condoms are not only good for STD/HIV prevention but also for pregnancy prevention.

Such spillover effects contribute to the overall effectiveness of condom use in the population. At the same time they decrease the effectiveness per condom used of prevention strategies focused on high-risk groups, while increasing that of strategies aimed at low-risk groups. However, this is not likely to alter the ranking of strategies in terms of effectiveness per condom, given the large differences between them.

In our analysis we related the effects to the numbers of condoms used but did not include cost calculations. The costs of condom strategies vary widely with the specific setting and the target group (*39*). The cost of distributed condoms was shown to range from US$ 0.02 to $ 0.30 in ten social marketing programmes directed at the general population, while that of condoms used in high-risk groups ranged from $ 0.10 to $ 0.70 in three programmes (*10*). Furthermore, one has to bear in mind that the marginal costs of strategies vary with the coverage level. On the one hand, economies of scale can reduce marginal costs when coverage increases. However, the cost of reaching additional cases may increase considerably after a certain point, because, for instance, of difficulties in identifying targeted individuals, increased resistance to participation in an intervention programme, and geographical barriers.

Because of differences in cost per condom distributed, the differences between strategies directed at high-risk groups and those aimed at low-risk groups can be expected to be smaller in effects per dollar than in effects per condom. However, the differences in effects are unlikely to be outweighed by differences in costs, considering the large differences in the numbers of HIV cases prevented by the family planning strategy on the one hand and the male and CSW strategies on the other, namely 7 to 100 times and 75 to 500 times, respectively.

Conclusions

In line with earlier modelling results (*2*, *5*, *8*, *9*), the consistency of results across profiles and the large size of the differences in effectiveness between differently focused strategies illustrate the efficiency of HIV prevention strategies directed at high-risk groups for diverse patterns of sexual behaviour. This is true even in epidemics that have already spread throughout populations. In the long run, moreover, groups at low risk benefit most from condom programmes directed at high-risk contacts.

Programmes aimed at the general population become increasingly important as the prevalence of HIV rises. However, such programmes should not detract from efforts to reach the groups at greatest risk. Indeed, one of the threats to effective HIV prevention in generalized epidemics is a tendency to divert resources from focused cost-effective interventions to general population interventions with lower cost-effectiveness. Ideally, the creation of awareness and acceptability of condom use in the general population should form the basis for extra efforts directed at high-risk groups. ■

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Résumé

Cibler les stratégies d'utilisation du préservatif dans la lutte contre le VIH en fonction des schémas de comportement sexuel : évaluation fondée sur un modèle de simulation

En utilisant le modèle de simulation pour les maladies sexuellement transmissibles, nous avons réalisé des projections de la propagation du VIH pour quatre grands schémas de comportement sexuel correspondant aux situations rencontrées dans les pays en développement : 1) beaucoup de rapports sexuels rémunérés, pas de relations de courte durée ; 2) rapports sexuels rémunérés plus relations de courte durée ; 3) plusieurs relations sexuelles simultanées, pas de rapports sexuels rémunérés ; 4) succession de relations sexuelles de courte durée, quelques rapports rémunérés. Nous avons étudié les effets du développement de l'usage des préservatifs dans trois groupes cibles : les professionnels du sexe ; les hommes ayant à la fois des rapports sexuels rémunérés et des relations de courte durée, et les femmes ayant des relations stables. Les projections ont indiqué que les stratégies ciblées sur les professionnels du sexe et sur les sujets masculins avaient été plus efficaces en termes de réduction de l'incidence du VIH que celle axée sur les femmes ayant des relations stables. A long terme, même dans le groupe d'hommes et de femmes ayant un partenaire sexuel récent, la protection contre l'infection à VIH conférée par l'utilisation du préservatif était meilleure chez les personnes ayant des contacts à haut risque que chez celles ayant des relations stables. En outre, le nombre de cas d'infection par le VIH évités par l'usage du préservatif était de 7 à 500 fois plus élevé chez les professionnels du sexe ou chez les hommes ayant des

relations de brève durée et des rapports sexuels rémunérés que chez les femmes entretenant des relations stables. Ces résultats font ressortir l'intérêt de se focaliser sur les groupes à haut risque quels que soient leurs schémas de comportement sexuel, même lorsque l'épidémie touche l'ensemble de la population.

Resumen

Focalización de las estrategias de uso del preservativo contra el VIH en distintas formas de comportamiento: evaluación basada en un modelo de simulación

Usando el modelo de simulación de las enfermedades de transmisión sexual (STDSIM), realizamos una serie de proyecciones de la propagación del VIH para cuatro perfiles de comportamiento sexual que describen la situación en el mundo en desarrollo: 1) comercio sexual intenso, sin relaciones de corta duración; 2) comercio sexual, relaciones cortas simultáneas; 3) relaciones simultáneas, sin comercio sexual, y 4) relaciones cortas consecutivas, cierto comercio sexual. Estudiamos los efectos del aumento del uso del preservativo en tres grupos destinatarios: profesionales del sexo; hombres que practicaban el comercio sexual y tenían relaciones cortas; y mujeres que mantenían relaciones estables. Las proyecciones mostraron que las estrategias centradas en los profesionales del sexo y en los hombres reducían con más eficacia la incidencia de infección por el VIH que la estrategia centrada en las mujeres que mantenían relaciones estables. A largo plazo, incluso el grupo de hombres y mujeres con una pareja reciente gozaron de mayor protección usando el preservativo en los contactos de alto riesgo que usándolo en relaciones estables. Además, el número de casos de infección por el VIH evitados por preservativo utilizado fue entre siete y 500 veces mayor para los profesionales del sexo o los hombres que mantenían relaciones cortas o practicaban el comercio sexual que para las mujeres con relaciones estables. Los resultados muestran los beneficios que se derivan de centrar las actividades en grupos de alto riesgo con diversas pautas de comportamiento sexual, incluso cuando la epidemia ha afectado a una vasta proporción de la población.

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