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Comparing the impact of increasing condom use or HIV pre-exposure prophylaxis (PrEP) use among female sex workers

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ABSTRACT

In many settings, interventions targeting female sex workers (FSWs) could significantly reduce the overall transmission of HIV. To understand the role HIV pre-exposure prophylaxis (PrEP) could play in controlling HIV transmission amongst FSWs, it is important to understand how its impact compares with scaling-up condom use—one of the proven HIV prevention strategies for FSWs. It is important to remember that condoms also have other benefits such as reducing the incidence of sexually transmitted infections and preventing pregnancy. A dynamic deterministic model of HIV transmission amongst FSWs, their clients and other male partners (termed 'pimps') was used to compare the protection provided by PrEP for HIV-negative FSWs with FSWs increasing their condom use with clients and/or pimps. For different HIV prevalence scenarios, levels of pimp interaction, and baseline condom use, we estimated the coverage of PrEP that gives the same reduction in endemic FSW HIV prevalence or HIV infections averted as different increases in condom use. To achieve the same impact on FSW HIV prevalence as increasing condom use by 1%, the coverage of PrEP has to increase by >2%. The relative impact of PrEP increases for scenarios where pimps contribute to HIV transmission, but not greatly, and decreases with higher baseline condom use. In terms of HIV infections averted over 10 years, the relative impact of PrEP compared to condoms was reduced, with a >3% increase in PrEP coverage achieving the same impact as a 1% increase in condom use. Condom promotion interventions should remain the mainstay HIV prevention strategy for FSWs, with PrEP only being implemented once condom interventions have been maximised or to fill prevention gaps where condoms cannot be used.

1. Introduction

Oral pre-exposure prophylaxis (PrEP), which involves the use of antiretroviral agents by HIV uninfected individuals to reduce the risk of acquiring HIV, is a new HIV prevention measure being considered in affected regions (Baeten et al., 2013). There have been mixed findings from PrEP trials mostly due to different levels of adherence among targeted population groups (Amico and Stirratt, 2014), with two trials amongst African women showing no efficacy (Amico and Stirratt, 2014; Van Damme et al., 2012), and other trials demonstrating efficacy between 39% and 73% among heterosexuals (Baeten et al., 2012; Thigpen et al., 2012), 44–86% efficacy among men who have sex with men (Grant et al., 2010; Molina et al., 2015; McCormack, 2015) and 49% efficacy among injecting drug users (Choopanya et al., 2013). In these studies, higher PrEP efficacy was achieved amongst individuals with detectable drug levels (Amico and Stirratt, 2014). Although the findings (Baeten et al., 2012; Thigpen et al., 2012; Grant et al., 2010; Abdool Karim et al., 2010) clearly show the utility of PrEP in reducing the risk of acquiring HIV when used with high adherence (Grant et al., 2014), further studies are required to help design the best strategies of administration, and to determine cost-effectiveness in different risk groups and settings (Baeten et al., 2013; Alistar et al., 2014; Hellinger, 2013; Okwundu et al., 2012).

FSWs are a critical group for preventive interventions (Alary et al., 2013) because they contribute disproportionally to HIV transmission (Alary and Lowndes, 2004; Boily et al., 2002; Vickerman et al., 2010; Steen et al., 2014). PrEP use could be highly effective in this group because of their high HIV acquisition risk. For making decisions about prioritising interventions it is important to understand how the impact of PrEP compares with scaling up other prevention strategies such as condom use promotion, which

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can be increased to high levels amongst FSWs and clients (Behanzin et al., 2013; Pickles et al., 2013; Tran et al., 2006; Foss et al., 2007). Also, while both PrEP and condoms reduce the risk of HIV acquisition amongst susceptible FSWs, condoms also reduce the chance of transmission from infected FSWs. However, condoms are not used in all sexual partnerships, such as long-term partnerships where intimacy is important or partnerships where there is an imbalanced power relationship, and so sometimes can have limited effectiveness (Foss et al., 2007; Watts et al., 2010; Moreno et al., 2014). For FSWs, this includes relationships with men involved in the sex trade (Lowndes et al., 2000) who may have a higher HIV prevalence than the clients of FSWs and could be important for HIV transmission (Watts et al., 2010; Lowndes et al., 2000). We denote these men 'pimps'. PrEP could be important for protecting FSWs from these men.

The likely relative population effectiveness or impact of products can sometimes be simply compared by assessing their efficacy and likely consistency or coverage of use (Heise et al., 2011; Foss et al., 2003), but if one product only protects against transmission in one direction or the products are used by different population groups then it is hard to make product comparisons without assessing the population impact of both interventions (Foss et al., 2009). In this paper, we use a purposely simple model to get insights into the impact of targeting PrEP to FSWs in scenarios where pimps either do or do not contribute to HIV transmission. We compare the impact of PrEP to that of condoms to determine what PrEP coverage is equivalent to specific increases in the consistency of condom use. We consider the impact of PrEP and condoms within the FSW, client and pimp population groups with the main aim of the study being to use different quantifiable impact measures to compare the relative impact of PrEP to condoms. In so doing, we want to give insights into PrEP's relative importance for preventing HIV transmission amongst FSWs and guidance into when it may be more beneficial to introduce PrEP, or otherwise prioritise the scale-up of condom use amongst FSWs.

2. Methods

We use a mathematical model describing HIV transmission between FSWs, their clients and pimps to estimate the relative impact of PrEP and condom use by FSWs. The model structure, formulation details and analyses are described below.

2.1. Model formulation

The model stratifies the population into three classes, with y_0, y_1 and y_2 denoting the HIV prevalence amongst female sex workers (FSWs), their clients, and pimps, respectively. The corresponding population sizes are n_0, n_1 and n_2. Individuals are infected at rates $\lambda_0=\beta_0 c_0$, $\lambda_1=\beta_1 c_1$, $\lambda_2=\beta_1 c_2$ and $\lambda_3=\beta_0 c_3$ which are forces of infection of sex worker clients by FSWs, FSWs by clients, FSWs by pimps and pimps by FSWs, respectively. Here, β_0 and β_1 are probabilities of HIV transmission per sex act from infected females to males and vice-versa, respectively. The parameters c_0, c_1, c_2 and c_3 denote number of sex acts per month by each client with FSWs, by each FSW with clients, by each FSW with pimps and by each pimp with FSWs, respectively. For partnerships between pimps and FSWs, we define $c_2=c_2^* m$ and $c_3=c_3^* m$ where c_2^* and c_3^* are the number of pimp or FSW partners per month, respectively, and m is the number of sex acts between each pimp and FSW per month. To balance the total number of partnerships formed between clients and FSWs or pimps and FSWs we ensure that $c_0 n_0=c_1 n_1$ and $c_2^* n_1=c_3^* n_2$.

The rates of leaving being a FSW, client or pimp are given by α_0, α_1 and α_2 and the HIV-related death rate is denoted by η. For mathematical simplicity and tractability, the model does not incorporate anti-retroviral treatment or the initial acute phase of HIV. The model equations are included in the Supplementary methods and model schematic is in Fig. 1.

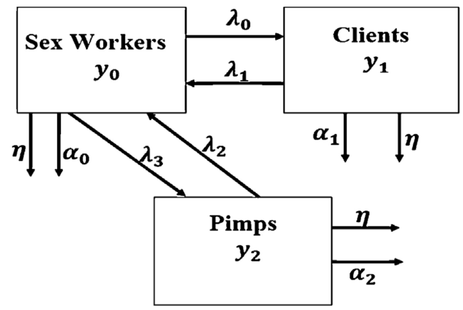

Fig. 1. HIV model schematic outlining the sexual behaviour structure. The arrows connecting compartments denote forces of HIV infection at rates λ_0, λ_1, λ_2 and λ_3 for clients by FSWs, FSWs by clients, FSWs by pimps and pimps by FSWs, respectively. The arrows out of the compartments denote rates of leaving being a FSW, client, pimp and HIV-related death given by α_0, α_1, α_2 and η, respectively.

Two versions of the model were developed with and without the pimp sub-group included. Within both models, condom and PrEP use are assumed to result in a reduced force of infection by factors $(1-ef_1)$, $(1-ef_2)$ and $\left(1-\gamma\theta\right)$, where e denotes efficacy of condom use, f_1 is the average consistency of condom use between clients and FSWs, f_2 is the consistency of condom use between pimps and FSWs (only relevant for model including pimps), θ is the efficacy of PrEP and γ is the proportion of HIV-negative FSWs that use PrEP adherently. It is assumed that both interventions are FSW-targeted, such that PrEP is only used by HIV-uninfected FSWs, and only reduces HIV transmission to these FSWs, whereas condoms are used by all FSWs at an average consistency dependent on whether the sexual partner is a pimp or a client and so also partially protects uninfected clients and pimps.

2.2. Model parameterization

The model is parameterized using data from different sources as in Table 1 and in Supplementary material. Point values are used for most parameters except for the probabilities of HIV transmission, which are varied to give different HIV prevalences or basic reproductive numbers, and the consistency of condom use and coverage of PrEP which are varied to make comparisons between different intervention scenarios. Of particular note amongst the other parameters are the number and frequency of pimp sexual partnerships and acts with FSWs, which have considerable uncertainty and so four scenarios were considered (Table 1). These pimp scenarios are: S1: pimps have sex with 8 FSWs per month and FSWs have 2 pimps per month with 2 sex acts with each per month; S2: pimps have sex with 4 FSWs per month and FSWs have 2 pimps per month with 2 sex acts with each per month; S3: pimps have sex with 4 FSWs per month and FSWs have 1 pimps per month with 1 sex acts with each per month; and S4: pimps have sex with 1 FSWs per month and FSWs have 1 pimps per month with 1 sex acts with each per month. For these scenarios, the consistency of condom use between pimps and FSWs is assumed to be a third of the consistency of use between clients and FSWs (Lowndes et al., 2002). Lastly, all baseline impact comparisons assume a condom efficacy of 85% (Pinkerton et al., 1998; Pinkerton and Abramson, 1997; Davis and Weller, 1999) and a PrEP efficacy of 70% (Baeten et al., 2012; Thigpen et al., 2012; Grant et al., 2010). A sensitivity analysis considered the effect of varying these and other parameter assumptions.

Table 1
Model parameter values.

Parameter definition	Symbol	Baseline value or range [values used in sensitivity analysis]	References and notes
Population sizes			
Total client population size	n_1	$c_0 n_0/c_1$	Calculated to balance the number of commercial sex acts had by clients and FSW
Total FSW population	n_0	1000	Assumed FSW population size
Total pimp population	n_2	$c_0 n_0/c_0$	Calculated to balance the number of pimp sex acts had by FSW and pimps
HIV transmission and epidemiological parameters			
Probability of HIV transmission from females to males per sex act	β_0	0.0001–0.011	Boily et al. (2009). Varied to fit different HIV prevalence scenarios in the analysis
Probability of HIV transmission from males to females per sex act	β_1	$=\beta_0$	
HIV death rate per year	η	0.125	Morgan et al. (2000), WHO (2013), Alcabes et al. (1994)
Efficacy of condoms	e	85% [60,95%]	Lowndes et al. (2002), Pinkerton et al. (1998), Pinkerton and Abramson (1997), Hughes et al. (2012), Weller and Davis-Beaty (2002). We chose 85% as baseline value but varied it in sensitivity analysis
Efficacy of PrEP	θ	70% [45,95%]	Baeten et al. (2012), Thigpen et al. (2012). Estimates vary but we choose an efficacy of 70%
FSW behaviour parameters			
Rate at which FSWs have commercial sex with clients per month	c_1	50 [25,100]	Vickerman et al. (2010), Ramesh et al. (2008), FMOH (2007). Estimates vary, but chose 50 partners/month
Rate at which FSWs have sex acts with pimps per month–calculated as a product of the number of pimps have sex with per month $\left(c_2^*\right)$ and number of sex acts between each FSW and pimp per month (m)	$c_2^* \times m$	S1 and S2: $c_2^*=2$ and $m=2$ S3 and S4: $c_2^*=1$ and $m=1$	4 Scenarios considered based on previous modelling of HIV transmission amongst FSWs and pimps (Watts et al., 2010)
Consistency of condom use between clients and FSWs	f_1	0–100% variable	Considered different scenarios to compare impact with PrEP
Consistency of condom use between pimps and FSWs	f_2	$1/3f_1$ [$0.15f_1$, $0.6f_1$]	Condom use with pimps is assumed to be 1/3 of level of condom use with clients (Foss et al., 2009)–0.15 and 0.6 considered in sensitivity analysis
Proportion of FSW that use PrEP	γ	0–100% variable	Considered different scenarios to compare impact with condoms
Rate of leaving being a FSW per year	α_0	0.25 [0.125, 0.5]	Varies widely (Watts et al., 2010; Ramesh et al., 2008; FMoH, 2010; Jadhav et al., 2013). We use 0.25 per year as baseline value and vary in our sensitivity analysis
Client behaviour parameters			
Rate at which clients have commercial sex with FSW per month	c_0	5 [2.5, 10]	Varies widely (Vickerman et al., 2010; Moreno et al., 2014; Subramanian et al., 2008; Shaw et al., 2011). We use 5 partners/month as baseline value and vary in sensitivity analysis
Rate of leaving being a client per year	α_1	0.16 [0.08, 0.32]	Varies (Moreno et al., 2014; Shaw et al., 2011; Wilson et al., 1989). We use 0.16 as our baseline value and vary it in sensitivity analysis
Pimp behaviour parameters			
Rate at which pimps have sex with FSW per month–calculated as a product of the number of FSWs have sex with per month $\left(c_3^*\right)$ and number of sex acts between each FSW and pimp per month (m)	$c_3^* \times m$	S1: $c_3^*=8$ and $m=2$ S2: $c_3^*=4$ and $m=2$ S3: $c_3^*=4$ and $m=1$ S4: $c_3^*=1$ and $m=1$	Four scenarios considered based on previous modelling of HIV transmission amongst FSWs and pimps (Watts et al., 2010).
Rate of leaving being a pimp per year	α_2	S1–S4: 0.1	Based on Watts et al. (2010)

2.3. Summary of model analysis

Model analyses were carried out for the scenario without pimps followed by the scenario with pimps, and made comparisons of the relative impact of condoms and PrEP using analytical and numerical approaches. Using the model without pimps, we began by comparing the impact on the number of secondary infections over the infectious period (R_0 amongst the FSWs and clients) and endemic FSW HIV prevalence of different consistencies of condom use and coverage levels of PrEP when each intervention is introduced in to a population at endemic prevalence. With and without pimps, we then assessed the relative impact of PrEP by estimating the average increase in the consistency of condom use that gives the same impact as a unit increase in PrEP coverage (further details in Supplementary materials). For comparison, impact was either assessed in terms of reductions in the endemic FSW HIV prevalence or number of HIV infections averted amongst all modelled groups over 10 years. This analysis was undertaken for different endemic FSW HIV prevalences and baseline levels of condom use to see their effect on the model projections.

3. Results

3.1. Analysis of the model without pimps

3.1.1. Performance of PrEP with no condom use at baseline

Supplementary Fig. S1 shows a roughly linear relationship exists between the coverage of PrEP (γ) and consistency of condom use (f_1) that achieves the same impact in reducing the basic reproductive number (R_0) for the transmission of HIV between FSWs and clients. Note that R_0 estimated here only quantifies transmission

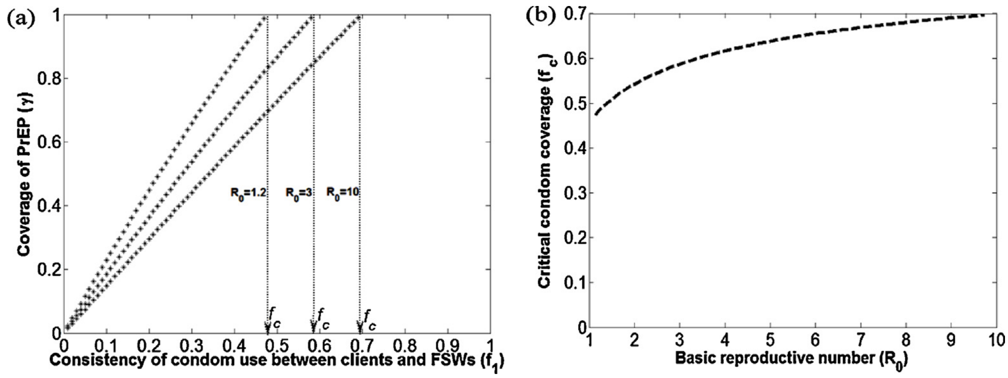

Fig. 2. Shows the relationship between the coverage of PrEP use (γ) and consistency of condom use (f_1) required to achieve the same impact in reducing FSW HIV prevalence at endemic equilibrium while assuming no condom or PrEP use at baseline. We vary the transmission probabilities to give different R_0 values of 1.2, 3 and 10 which correspond to endemic HIV prevalence of 21%, 69% and 90%, respectively, using other parameters values given in Table 1. Consistency of condom use and coverage of PrEP use are varied in the range 0–100%.

between FSWs and clients, and does not take into transmission in the wider population. This relationship is independent of R_0, and suggests that approximately twice the coverage of PrEP is required to achieve the same impact as a specific consistency of condom use.

Fig. 2 illustrates that a similar linear relationship exists between the coverage of PrEP (γ) and consistency of condom use (f_1) when we consider the impact on decreasing FSW HIV prevalence (projections against time are in the Supplementary material), but the relationship is now dependent on R_0, with the factor difference decreasing for settings with greater HIV transmission. This suggests that the relative impact of PrEP compared to condoms becomes greater for higher levels of HIV transmission. For example, for FSW and client HIV epidemics with a basic reproductive number of 1.2, 3 and 10 (FSW HIV prevalence 21%, 69% and 90%, respectively), the impact of 100% coverage of PrEP use in reducing FSW HIV prevalence is equivalent to the impact of condom use increasing from 0 to 47, 58 or 70% consistency, respectively.

For a range of epidemic scenarios, Fig. 3(a) presents the relative impact of PrEP (non-pimp scenario) compared to condoms for decreasing FSW HIV prevalence, as given by the average relative increase in consistency of condom use (f_1) required to achieve the same impact on FSW HIV prevalence as a unit increase in PrEP coverage (γ) amongst HIV negative FSWs. Fig. 3(a) (non-pimp model) shows that although the relative impact of PrEP increases as HIV prevalence increases, a unit increase in the consistency of condom use generally results in approximately double the impact of a unit increase in PrEP coverage except at very high FSW HIV prevalence (>65%).

When impact is assessed in terms of HIV infections averted (over 10 years) instead of decreases in FSW HIV prevalence, Fig. 3(b) shows that the relative impact of PrEP (non-pimp scenario) (average relative increase in consistency of condom use (f_1) required to achieve the same impact as a unit increase in PrEP coverage (γ)) is generally lower than for the impact on FSW HIV prevalence and now decreases as FSW HIV prevalence increases, although improves slightly over longer time frames (Supplementary Fig. S3). For example, at low FSW prevalence (10%), the consistency of condom use needs to increase by 0.4 unit to achieve the same impact over 10 years as a unit increase in PrEP coverage, whereas at high HIV prevalence (65%) this ratio reduces to about 0.25.

3.1.2. *Performance of PrEP with varying condom use at baseline*

Previous projections assumed no condom or PrEP use at baseline. However, condoms are widely used by FSWs and so PrEP will likely be introduced in settings with a pre-existing level of condom use. Fig. 4 presents the average increase in condom use (f_1) required to achieve the same impact as a unit increase in PrEP coverage (γ) on reducing endemic FSW HIV prevalence or averting HIV infections (over 10 years) for different baseline levels of condom use and FSW HIV prevalence. For both impact measures, the projections suggest that the relative impact of PrEP compared to condoms diminishes at higher baseline levels of condom use. For

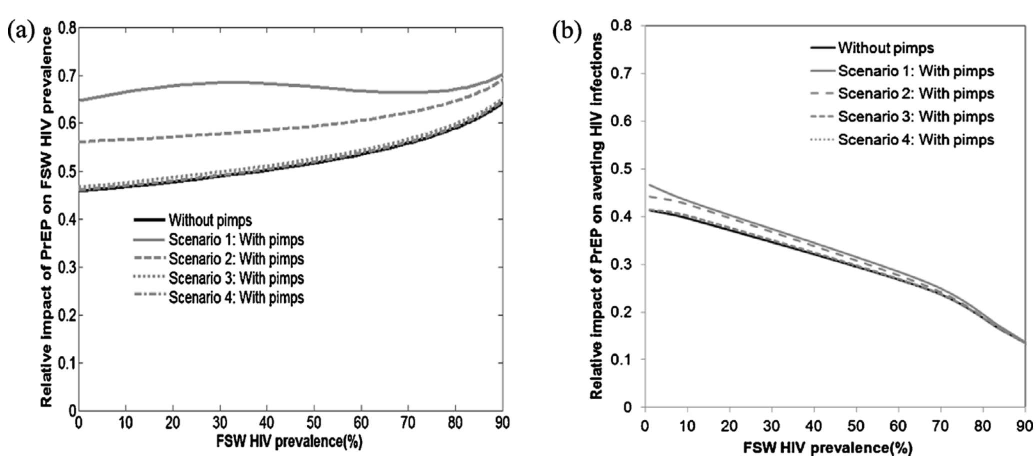

Fig. 3. The relative impact of PrEP compared to condoms for decreasing the endemic FSW HIV prevalence (a) or averting HIV infections (b) after 10 years for different baseline FSW HIV prevalences, *with no condom or PrEP use at baseline*. The relative impact of PrEP is defined as the average increase in condom consistency that is required to have the same impact in decreasing FSW HIV prevalence or averting HIV infections as a unit increase in coverage of PrEP amongst HIV negative FSWs. Each figure considers the results for the model with no pimps and the model with pimps for four different pimp scenarios described in Section 2.

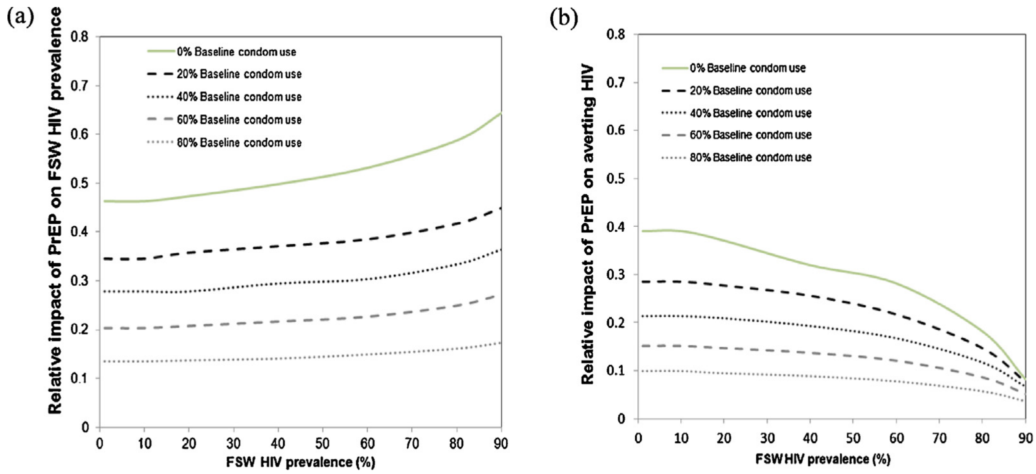

Fig. 4. Relative impact of PrEP (average increase in condom consistency required to have the same impact as a unit increase in coverage of PrEP amongst HIV negative FSWs) for different baseline levels of condom use and FSW HIV prevalence, for scenario without pimps. Impact is either assessed in terms of decreases in FSW HIV prevalence (a) or number of HIV infections averted over 10 years (b). These were estimated using parameter values in Table 1.

example, in terms of decreasing HIV prevalence in FSWs, condom consistency would only have to increase by 0.3% or 0.15% to match the impact of a unit increase in PrEP coverage at a baseline condom use of 40% or 80%, respectively. As before, PrEP seems less effective at averting HIV infections than reducing FSW HIV prevalence and this becomes more pronounced at higher HIV prevalence.

3.2. Analysis of the model with pimps

When the effect of pimps is included into the model, then Fig. 3 shows that the relative impact of PrEP compared to condoms, either in terms of impact on FSW HIV prevalence or HIV infections averted, can increase noticeably but only when pimps play an important role in HIV transmission (i.e. have more FSW partners and sex acts per month as in Scenarios 1 and 2—Supplementary Figs. S5–S8), with the effect on FSW HIV prevalence being more pronounced. This is also the case for different baseline levels of condom use. Interestingly, PrEP seems to result in the same reduction in FSW HIV prevalence and percentage of HIV infections averted (Supplementary Fig. S4) irrespective of whether pimps contribute to HIV transmission or not, whereas the impact of condoms reduces as pimps contribute more to transmission. This is because condoms do not protect the FSWs from pimps, whereas PrEP protects the FSW from both their clients and pimps.

3.3. Sensitivity analysis

We carried out a univariate sensitivity analysis to investigate the effect of altering different model parameters on the relative impact of PrEP compared to condoms for the scenario with 40% HIV prevalence (FMoH, 2007) and 60% condom use at baseline. Only the scenario with pimps (S1) was considered and the parameter variations considered are shown in Table 1 and Fig. 5. For each parameter change, the model was refit to the baseline 40% HIV prevalence. The results (Fig. 5) suggest that changes in number of clients per FSW or vice versa, overall leaving rates, and level of condom use between FSWs and pimps will only affect the relative impact of PrEP by less than 25%. This effect is lessened for the model without pimps (Supplementary Fig. S9). However, uncertainty in the efficacy of condoms or PrEP can substantially affect the projected relative impact of PrEP by up to a half if the efficacy of condoms is 60% instead of 85% or the efficacy of PrEP is 45% or 95% instead of 70% (depending on the adherence patterns of FSWs).

4. Discussion

Mathematical modelling was used to compare the HIV impact of PrEP and condom use among FSWs and clients. The model analyses suggest that increasing PrEP use amongst FSWs is unlikely to result in the same population level impact as increasing condom use. To achieve the same decrease in FSW HIV prevalence, the increase in PrEP coverage has to be roughly double the overall increase in consistency of condom use if there is no PrEP or condom use at baseline, and this becomes much greater if there is moderate to high condom use at baseline (over four times if baseline condom use is over 50%) or impact is assessed in terms of HIV infections averted (roughly three times if no condom use at baseline and over five times if 50% condom use at baseline). Since condom use between FSWs and their clients can be increased to high levels (Behanzin et al., 2013; Foss et al., 2007; Lowndes et al., 2010; Rojanapithayakorn and Hanenberg, 1996), these results highlight that in pursuing a combination of HIV prevention programmes, intervention efforts should prioritise maximising condom use before introducing PrEP because greater population level impact is likely to be achieved. It is also crucial that funds should not be channelled away from existing condom use interventions to fund PrEP strategies because any reduction in condom use is likely to offset the beneficial impact of PrEP (Foss et al., 2003).

A possible important use for PrEP is protecting FSWs against HIV transmission from 'other' male sexual partners that they have difficulty using condoms with. These male partners (termed 'pimps' in our model) could include boyfriends of FSWs or other individuals involved in the sex industry (Watts et al., 2010; Lowndes et al., 2000). When the model considered the importance of PrEP for scenarios where these 'other' male sexual partners play an important role in transmitting HIV, the modelling suggested the importance of PrEP is heightened because it affords FSWs protection in all their sexual partnerships, whereas condoms do not. However, the effect was not great, with a 1% increase in condom use between clients and FSWs being equivalent to at least a 1.5% increase in PrEP coverage except at very high FSW HIV prevalences (>80%). The importance of FSW's 'other' male sexual partners for driving HIV transmission amongst FSW populations in different settings is poorly understood, with just a few settings documenting their behaviour and HIV transmission risk (Watts et al., 2010). Further work is needed to characterise their importance for HIV transmission before accurate predictions can be made of the degree to which these other male partners could increase the importance of PrEP.

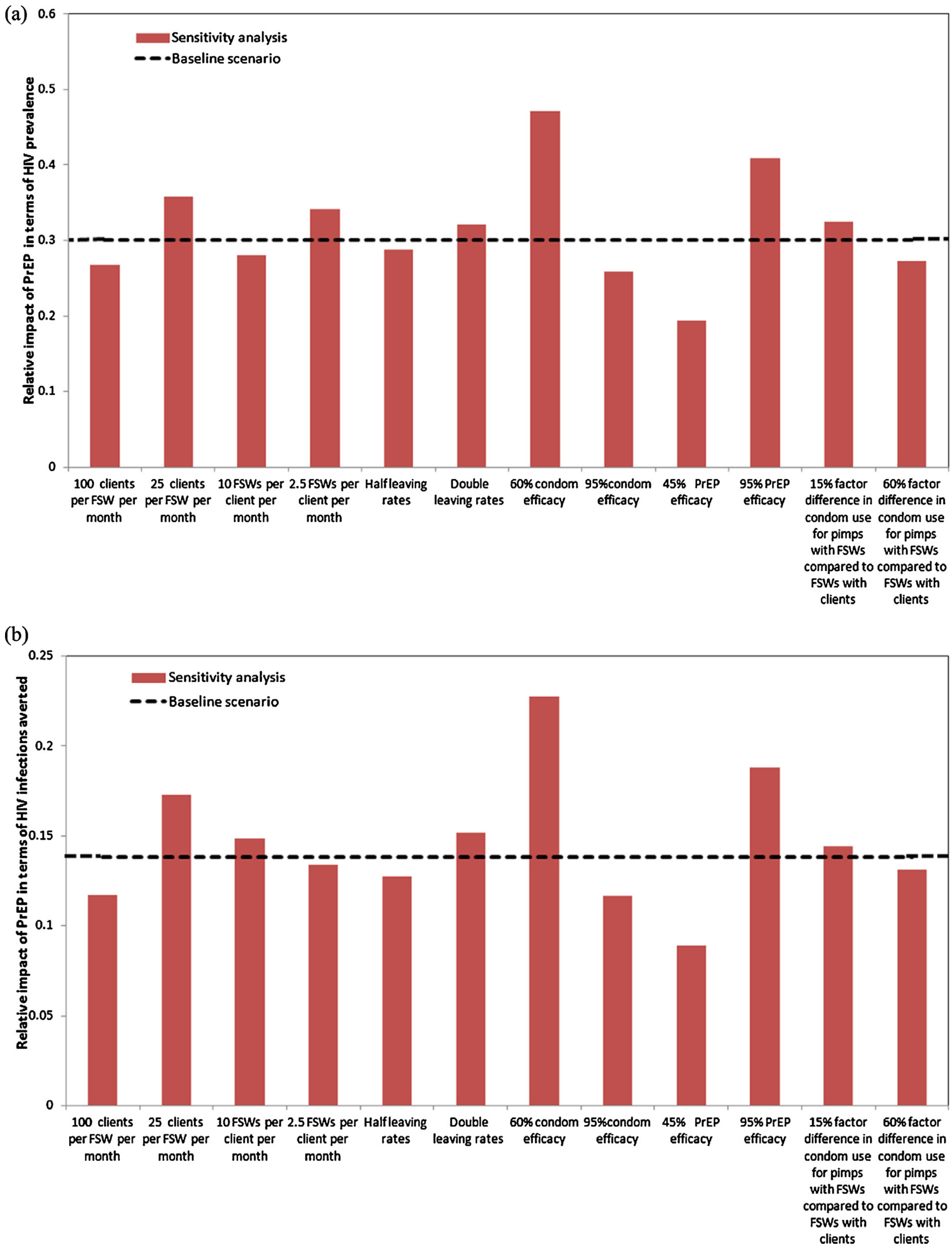

Fig. 5. Sensitivity analysis on how the relative impact of PrEP changes for specific changes in model parameters. The relative impact of PrEP is defined as the average increase in condom consistency that is required to have the same impact in either decreasing FSW HIV prevalence (a) or averting HIV infections over 10 years (b) as a unit increase in coverage of PrEP amongst HIV negative FSWs. All projections are compared against a baseline impact scenario (shown as black dashed line) that assumes 40% HIV prevalence amongst FSWs, 60% condom use between FSWs and clients and incorporates pimp scenario S1 (pimps have sex with 8 FSWs per month and FSWs have 2 pimps per month with 2 sex acts with each per month). The parameter value variations considered are shown in the figure with the baseline values being: number of clients per FSW $c_1 = 50$ per month; number of FSWs per client $c_2 = 5$ per month; yearly leaving rates for FSWs (α_0), clients (α_1), pimps (α_2) being 0.25, 0.16 and 0.1, respectively; condom efficacy $e = 85\%$; PrEP efficacy $\theta = 70\%$; and factor difference in condom consistency between pimps and FSWs compared to between clients and FSWs $f_2 = 33\%$.

Several factors contribute to condoms having a greater impact than PrEP. First, we assume that condoms have a greater efficacy per sex act than PrEP. Studies have estimated that PrEP efficacy amongst high adherers (with detectable drug in the blood) could be as high as 90% (Grant et al., 2010; Baeten et al., 2012), comparable to the effectiveness of condoms when used correctly (80–95%) (Pinkerton et al., 1998; Davis and Weller, 1999). The lower estimate (70%) used here reflects adherence levels seen in trials. It is unknown how high PrEP adherence will be amongst FSWs, with our sensitivity analysis emphasising this could have a large effect on our projections. Demonstration projects are currently underway in various settings to assess the degree to which FSWs may use and adhere to PrEP (WHO, 2015). Second, condoms offer two-way protection, of clients as well as FSWs, whereas PrEP protects only the FSWs taking it, with our modelling showing this is the main cause for the higher overall impact achieved with condoms. Although PrEP could be given to clients, this is unlikely in practise due to the difficulty in reaching this group with interventions. Lastly, condoms are used by all FSWs whereas PrEP is only used by those who are HIV negative. This makes direct comparisons between consistency of condom use and PrEP coverage difficult, particularly for high HIV prevalence settings. When the coverage of PrEP is adjusted to reflect its average coverage of use over all FSWs then a unit increase in PrEP coverage can become more 'effective' than a unit increase in condom use at high HIV prevalence. However, the costs of each intervention are likely to be very different (Creese et al., 2002; Vassall et al., 2014; Mitchell et al., 2015), with the restriction of PrEP to HIV-negative FSWs limiting its potential coverage and impact.

While all of our analyses suggested that condom use would have greater impact than PrEP, the magnitude of the difference varied considerably depending on the impact measure used, with a greater difference occurring when impact was measured in terms of infections averted rather than reduction in prevalence. This increased difference in impact for infections averted is due to the inclusion of HIV infections averted amongst clients which PrEP achieves indirectly but condoms achieve directly, whereas PrEP has a direct impact on reducing FSW HIV prevalence as do condoms, but condoms also achieve added indirect impact through protecting clients. Although prevalence is easier to measure in epidemiological studies and needs to be reduced to low levels to ultimately control an HIV epidemic, infections averted gives a better indication of intervention impact and cost-effectiveness, as prevalence is also affected by other factors such as population turnover and factors influencing survival.

Our model considered an average consistency of condom use by all FSWs with their commercial clients. The reason we did not consider a coverage of condom use is because most FSWs use condoms to some degree. Despite this, it has been documented that some FSWs find it more difficult to use condoms irrespective of how well condoms are promoted and distributed (Reza-Paul et al., 2008; Ramesh et al., 2010; Gangopadhyay et al., 2005; Kilmarx et al., 1999; Bui et al., 2013; Bharat et al., 2013). If PrEP could be targeted to these FSWs then it could be an important adjunct to existing interventions for further decreasing HIV transmission. Ongoing PrEP studies are considering the impact of such selective targeting (Eisingerich et al., 2012; Ye et al., 2014).

Our modelling analysis had a number of other limitations, partly due to the simplifying assumptions made to enable general comparisons of the impact of the two intervention strategies. First, the model did not include different stages of HIV infection (with varying infectiousness), or anti-retroviral treatment, which has become a cornerstone of HIV prevention programmes. While each of these is important for estimating the impact of interventions, they are not expected to have a large effect on the comparison of impact between PrEP and condom use made in this paper. Second, the model did not include behavioural heterogeneity amongst FSWs, which could affect intervention impact. This could further reduce the impact of PrEP because it only protects HIV negative FSWs which are likely to be lower risk. Third, the development of resistant strains following PrEP use was not considered which could also compromise the effectiveness of PrEP (Dimitrov et al., 2013). Lastly, we only compared the relative impact of these interventions, whereas in reality decisions on whether to scale up an intervention should also consider the cost-effectiveness of each strategy (Alistar et al., 2014; Walensky et al., 2012; Hallett et al., 2011; Nichols et al., 2014; Kessler et al., 2014).

In conclusion, our modelling analyses emphasise that PrEP could be an effective HIV prevention tool for FSWs, but is unlikely to achieve the same population level impact as existing condom use promotion interventions among FSWs (Pickles et al., 2013; Williams et al., 2014). This highlights these interventions should remain the mainstay HIV prevention strategy for FSWs (Alary et al., 2013), with PrEP only being implemented once condom promotion interventions have been maximised or to fill prevention gaps where high condom use cannot be achieved. This could include scenarios where other male sexual partners play an important role in HIV transmission but are reluctant to use condoms. An improved understanding of the role of these men in HIV transmission amongst FSWs is needed before recommendations can be made about scaling up PrEP in such settings.

Competing financial interests

The authors declare that they have no competing financial interests.

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Author contributions

Dr Mukandavire and Prof. Vickerman constructed the model and developed the initial analysis plan. All author input into the analyses and wrote the paper.

Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:10.1016/j.epidem.2015.10.002.

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