ORIGINAL RESEARCH ARTICLE

Modelling the impact of HIV prevention and treatment for men who have sex with men on HIV epidemic trajectories in low- and middle-income countries

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Summary: Little is known about the impact of combination HIV prevention interventions for men who have sex with men (MSM) and the impacts on the wider epidemics. Modelling analyses of MSM-specific interventions across varied HIV epidemics may inform evidence-based responses. The Goals model was adapted to project the impacts of providing HIV interventions for MSM and access to expanded coverage of antiretroviral therapy (ART) for adults to measure the effects on the MSM and adult epidemics in Peru, Ukraine, Kenya and Thailand. Positive impacts were observed in all four countries. Across epidemics, 14–25% of infections among MSM may be averted between 2012 and 2016 when MSM interventions are brought to scale and MSM have equal access to expanded ART for adults. Among adults, MSM interventions may avert up to 4000 new infections, in addition to the benefits associated with increased ART. Greatest impacts from expanded interventions were observed in countries where same sex transmission contributes significantly to the HIV epidemic. While significant benefits are observed among the adult and MSM populations with expansion of ART, consideration should be given to the synergies of combining ART expansion with targeted interventions to reach hidden, high-risk populations for HIV testing and counselling and linkages to care.

Keywords: HIV, AIDS, homosexuality, MSM, HIV infection, Goals model, transmission, prevention

INTRODUCTION

The HIV epidemics among men who have sex with men (MSM) have received growing attention from researchers and medical communities, donors and political stakeholders. Baral and colleagues' systematic review of HIV prevalence data reported by low- and middle-income countries (LMICs) from 2000 to 2006 demonstrated a markedly higher risk for HIV among MSM when compared with the general population, with a pooled odds ratio (OR) of 19.3 (95% confidence interval [CI] 18.8 to 19.8) across all countries when comparing MSM to all reproductive age adult males. HIV risks were 33 times greater for MSM in the Americas (OR 33.3, 95% CI 32.3 to 34.2), 19 times greater for MSM in Asia (OR 18.7, 95% CI 17.7 to 19.7) and four times for MSM in Africa (OR 3.8, 95% CI 3.3 to 4.3) compared with other men.[1] Responses have varied across countries; ranging from countries where stakeholders have actively sought to understand and increase prevention strategies to respond to the epidemic among MSM compared to other countries where

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response is challenged by a lack of data and/or sociopolitical issues that inhibit care seeking. Same-sex behaviour among men remains criminalized in over 30 LMICs globally, including approximately half of the countries in Africa, and is punishable by death in at least four countries.[2] Stigma in countries where same sex practices have been decriminalized still inhibits MSM from seeking HIV-related care or prevention services. These barriers compromise and limit understanding of HIV epidemics among MSM and, hence, of the wider populations with which they interact.

We recently reported on emerging MSM epidemics, developing a method to classify HIV epidemic scenarios among MSM and to incorporate the concepts of concentrated or generalized epidemics in a more distinctive approach that is inclusive of MSM and other at-risk groups.[3] These scenarios situate MSM transmission within wider epidemic contexts. Based on a systematic review of the existing data we found that HIV epidemics in LMICs could be described with four country scenarios: (1) the predominant mode of transmission of HIV cases is related to MSM anal sex transmission; (2) HIV transmission among MSM occurs in the context of injecting drug use (IDU) epidemics; (3) HIV transmission among MSM occurs in the context of widespread and generalized HIV transmission among heterosexuals; and (4) MSM, heterosexual and

parenteral modes of transmission all contribute to HIV spread.[3] These epidemic scenarios allow for more nuanced understandings of the interplay of transmission related to MSM and the other components of the HIV epidemics that exist at population levels. Acknowledging, for example, that some MSM may also inject drugs or that in many epidemic contexts a majority of MSM may be married to women and acquisition and transmission risks, therefore, exist for both MSM and women.

Evidence-based responses to prevent HIV transmission among MSM require an understanding of the impacts of interventions available for MSM. Through clinical and outreach services, interventions can be provided to MSM for individual prevention of HIV transmission and acquisition. Limited data on population-level impacts with HIV endpoints exist for these interventions for MSM. Mathematical models can fill this gap to inform national and local programming by estimating the impacts of alternative combinations of interventions. We used the Goals model to assess the impact of combinations of HIV prevention interventions and antiretroviral therapy (ART) treatment access and uptake for MSM on overall country-level HIV epidemic scenarios, through 2016, represented by Peru, Ukraine, Kenya and Thailand.

METHODS

Modification of Goals

The Goals model was adapted and used to estimate HIV incidence, with and without one or more interventions delivered at different levels of coverage. The Goals model (Spectrum software, Futures Institute, Glastonbury, CT, USA) is a deterministic model that uses data in three main areas to project new HIV infections: demography, sexual behaviour and HIV/sexually transmitted infection (STI) epidemiology.[4] Prior to this effort, Goals considered five different risk groups in the general population: MSM, IDU, high-risk heterosexuals, medium-risk heterosexuals and low-risk heterosexuals. Recognizing that risk may vary among MSM as well, we adapted the Goals model within the Spectrum software to allow for the input of epidemiological data relating to four MSM risk categories (Table 1). The MSM risk categories were defined as high-risk MSM or male sex workers, medium risk or MSM with more than one sex partner in last 12 months, low-risk MSM or men with 0–1 male sex partner in last 12 months (stable relationship) and MSM IDU or MSM who also inject drugs. Further details of the Goals model are available in the appendix or the Goals manual.[5]

The Goals model was further adapted to include selected MSM-specific interventions with evidence for efficacy. These included promotion and distribution of condoms with water-based lubricants; community-level behavioural change interventions which include HIV counselling and testing (selected over individual level behavioural change as a recent Cochrane review showed higher efficacy of community over individual level interventions for MSM[6]); and earlier initiation of ART (Table 1).[7,8]

Selection of countries and inputs for Goals

Four countries with HIV prevalence and transmission risk data for MSM were selected, each representing an epidemic scenario. MSM specific data for each country were collected through a

Table 1 Major updates to the Goals model and rationale	
Addition of MSM risk categories	Based on literature reviews followed by expert and community group review and consensus • *High-risk MSM*: male sex workers • *Medium risk*: MSM with more than one sex partner in last 12 months • *Low-risk MSM*: men with 0–1 male sex partner in last 12 months (stable relationship) • *MSM-IDU*: MSM who also inject drugs
Addition of MSM-specific interventions and impacts	Based on systematic review of literature and analysis for interventions impacts • *Individual level* with promotion and distribution of condoms and water-based lubricants (acknowledging that water-based lubricants must be provided with condoms to maintain condom efficacy) • *Community-level behavioural change* interventions based on evidence of higher efficacy of community over individual level interventions for MSM[1]
Epidemiological inputs: infectiousness when on ART	Based on the most recent finding reported by Eshleman and colleagues who reported an 86% reduction in HIV transmission after ARV treatment was initiated in discordant couples

MSM = men who have sex with men; ARV = antiretroviral

systematic review (methods previously published in Beyrer *et al.*[3]) and augmented by communications with country experts and review of gray literature and country reports. Key data used to parameterize the Goals model are presented in Table 2 and described briefly below. Once parameterized, the Goals models were calibrated to the median UNAIDS estimations for the prevalence of HIV infection among the adult population and fit to within 95% CIs around the recent projected UNAIDS estimates (unpublished). The HIV prevalence trends among MSM that were estimated by the models were cross-checked against surveillance or other published estimates of HIV prevalence among MSM in each country.[9–19]

Scenario 1 countries, where MSM transmission predominantly contributes to the HIV epidemic, were represented by Peru. General population prevalence data and projected ART coverage estimates were available from DemProj and AIM of the Spectrum suite, as well as behavioural inputs, and intervention coverage among the general population. Personal communication with research experts from Peru (Konda and Caceres CC, personal communication) provided data specific to the MSM population, and a 2009 paper by Aldridge and colleagues,[20] who conducted similar modelling work using an Excel version of the Goals model, was used to supplement any missing information and confirm inputs.

Scenario 2 countries, where HIV transmission among MSM occurs in the context of IDU epidemics, were represented by Ukraine. General population data and ART-projected coverage were populated using data available in DemProj and AIM of the Spectrum suite and further updated with UNAIDS and Alliance reports;[12,21,22] HIV and STI prevalence of HIV among IDU and MSM and behavioural data were derived from UNGASS reports[21] and published papers; and[9,10,23] data from Russia were used as a proxy for behavioural and epidemiological data specific to the MSM IDU category.[24–30]

Table 2 Epidemiological assumptions and behavioural inputs and sources per MSM risk category for each country model

	Ukraine				Kenya				Peru				Thailand			
	Low	Med	High	MSM-IDU	Low	Med	High	MSM-IDU	Low	Med	High	MSM-IDU	Low	Med	High	MSM-IDU
Proportion of adult male population																
Value in model (%)	0.41	1.40	0.55	0.15	0.53	2.01	0.42	0.4	0.62	1.86	0.91	N/A	0.68	1.78	0.59	0.35
Reference(s) for estimates	2,3	2,3	3,4	3,5	3,6	3,6,7	3,8	3,8	3,9	3,9	3,9	3,9	3,10	3,10	3,11	3,12
HIV Prevalence among MSM																
Value in model (%)	N/D	10.6*	16.0	43.0	N/D	24.8	16.7	N/D	20.2	23	25.2	N/A	N/D	19.2	15.6	31.8
Reference(s)		5,13	14	15		16	7,16		9	9	9			10	10	12
Ulcerative STI prevalence among MSM																
Value in model (%)	10.5†	10.5	12.0	10.5†		31.8	19.7	N/D	7.0	15.0	20.0	N/A	7.0	7.0	7.0	7.0
Reference(s)	17	17	14	17	16	16	16		9	9	9		18	18	18	18
Percent married																
Value in model (%)	10.3	10.3	10.3	10.3	0	12.4	4.5	N/D	1.6	9.5	9.5	N/A	14.1	14.1	14.1	24.2
Reference(s)	2	2	2	2	16	16	16		9	9	9		19	19	19	19
Consistent condom use (adjustment factor – 33% for use at last contact)																
Value in model (%)	25.0	27.1	26.5	27.1	25.0	38.6	32.1	N/D	16.0	28.0	42.0	N/A	15.0	45.0	80.0	45.0
Reference(s)	2	2	2	2	7,16	7,16	7,16		9	9	9		19	10,19	19,20	12
Mean sexual partners per year																
Value in model	1	4	12	4†	1	3	20	N/D	1	3	20	N/A	1	4.7	28	15
Reference(s)	t	2	21	2	t	16	16		9	9	9		t	22	22	19

MSM = men who have sex with men; STI = sexually transmitted infection
*Pooled HIV prevalence used for all risk groups in the absence of group-specific data
†Medium-risk group estimates used as a proxy when low or MSM-IDU data are unavailable; t number of partners by definition of low risk group; N/D = no data; N/A = not applicable

Table 3 Country intervention coverage: baseline 2011 coverage levels and expansion scenarios used for projections

Country of interest	Outreach for MSM			Condoms and lubricants for MSM			ART for all adults who meet criteria	
	Status quo	Scenario 1 +20% of status quo	Scenario 2 +40% of status quo	Status quo	Scenario 1 +20% of status quo	Scenario 2 +40% of status quo	Status quo (2011)	Expanded (2016)
Peru	21%[23]	41%	61%	45%[23]	65%	85%	43%	57%
Ukraine	33%[5]	53%	73%	40%[5]	60%	80%	12%	24%
Kenya	15%[7]	35%	55%	5%[16]	25%	45%	63%	85%
Thailand	20%[24]	40%	60%	20%[24]	40%	60%	53%	59%

MSM = men who have sex with men; ART = antiretroviral therapy

Scenario 3 countries, where HIV transmission among MSM occurs in the context of well-established HIV transmission among heterosexuals, were represented by Kenya. General prevalence data and ART-projected coverage were provided from DemProj and AIM of the Spectrum suite, population prevalence of MSM were calculated using data from peer-reviewed publications;[15,31] prevalence of HIV and STI and MSM behavioural data were provided by experts from the Kenya Medical Research Institute (KEMRI, unpublished); and coverage of MSM specific interventions were obtained from UNGASS/MoH reports.[13,32,33]

Scenario 4 countries, where both sexual and parenteral modes of transmission contribute significantly to HIV transmission, were represented by Thailand. General population data, including incidence and prevalence trends and national projections for ART coverage, were populated using data available in DemProj and AIM of the Spectrum suite. IDU and MSM epidemiological and behavioural data were collected with assistance from the Bangkok MSM Cohort research experts from data published in the Asian Epidemic Model[34] and other publications from the CDC, the Thai Red Cross, Thailand's Ministry of Public Health and other regional experts.[11,18,19,35–38] Intervention coverage estimates were obtained from UNGASS/MoH reports[39] and expert opinion.

For all country models, we updated infectiousness when on ART with the finding reported by Eshleman *et al.*[8] that demonstrated reduction in HIV transmission after ART treatment was initiated in discordant couples. Given the importance of recent findings from the HPTN 052 study, we modelled the impact of earlier initiation of treatment among all adults in need of ART, according to the recent change in standards.[40] These models utilized an initiation of ART at a CD4 count of 350 cells/mm^3 and the demonstrated effectiveness value of 88.6% reduction in risk associated with ART at this initiation.[8] For this study, we used a slightly conservative estimate of 87% (0.13 reduction in transmission when on ART).

The behavioural intervention impact matrix used in the Goals model records the impact of exposure to a prevention intervention on the reduction in non-use of condoms and the reduction in number of partners per risk group (See Goals Description, Appendix, for further details).[4] Because two new MSM interventions were added, the impacts of exposure to MSM prevention interventions were derived through the systematic review of HIV prevention interventions for MSM.[3,41] The results of these reviews were then used to develop summary estimates of the reductions of condom non-use (unprotected anal intercourse) and reduction in number of partners, stratified for each MSM risk group (Table 3). These estimates provided the data for the impacts of the MSM specific interventions.

Estimating the fraction of HIV transmission attributable to MSM

To understand how MSM transmission is situated within each country's epidemic, we estimated the total fraction of new HIV-positive cases attributable to same sex behaviour of MSM. This was estimated through a calculation nested within the overall Goals model analysis of each of the case countries. The baseline number of new HIV infections was estimated using the 'current intervention scenario' of each country, in which no additional coverage of existing or new interventions is added to what is currently in place in 2011. Coverage levels from 2011 were selected as most data and reports were available from this year and provided the most coverage information for all four selected countries. The number of new HIV infections attributable to MSM is then calculated as a residual by subtracting the number of new HIV infections *not* attributable to MSM from the total number of new HIV infections. To estimate the number of new HIV infections *not* attributable to MSM, the HIV transmission probability for MSM was assumed to be zero, and the number of new HIV infections was then calculated. The numerator was calculated as the number of new HIV cases not attributed to MSM subtracted from the total number of new HIV cases; the denominator was the number of total new HIV cases. The percentage is presented for year 2016 for each case country to understand how the epidemic would progress without further expansion of intervention coverage.

Projections of MSM intervention scenarios

The impact of MSM focused interventions on the HIV epidemic can be assessed by varying levels of intervention coverage among MSM and coverage of ART among the adult population, including and assuming equitable distribution to MSM in need of treatment. Estimated coverage levels of each intervention modelled are detailed in Table 3. The modelled scenarios include (1) Status quo: current coverage of MSM-specific prevention interventions are maintained from 2011 to 2016 while all other interventions remain constant. (2) Scenario 1: all MSM interventions increase from current, 2011 levels incrementally to reach an additional 20% by 2016 (coverage changes from 2012 to 2016), while all interventions are held constant from 2011 levels. (3) Scenario 2: MSM interventions increase from current, 2011 levels incrementally to reach an additional 40% by 2016 (coverage changes from 2012 to 2016), while all interventions are held constant from 2011 levels.

All three scenarios were analysed with ART coverage of the adult population held constant from 2011 levels forward. The

Table 4   Transmission impacts of MSM-specific interventions on condom use and number of partners per MSM risk categories: results of a systematic review for inputs to the Goals impact matrix

	Reduction in condom non-use			Reduction in number of partners		
	High-risk MSM	Medium-risk MSM	Low-risk MSM	High-risk MSM	Medium-risk MSM	Low-risk MSM
Intervention	% reduction (range)	% reduction (range)	% reduction (range)	% reduction (range)	% reduction (range)	% reduction (range)
Community-based outreach	−19.6 (−8.1 to −29.9)	−19.6 (−8.1 to −29.9)	−19.6 (−8.1 to −29.9)	−19.0 (−0.7 to −25.0)	−19.0 (−0.7 to −25.0)	−19.0 (−0.7 to −25.0)
Individual with condoms and lubricants	−22.8 (−0.6 to −26.0)	−17.4 (−2.0 to −58.8)	−6.9 (−4.0 to −9.0)	−18.3 (−1.1 to −25.0)	−0.8 (0 to −3.8)	0.0 0.0

MSM = men who have sex with men
Source: Systematic review of HIV prevention interventions for MSM[20]

scenarios were then replicated with the planned expansion of ART among the adult population. These scenarios assume that the increase in ART coverage among adults applies to MSM as well as other adult risk groups, and also assumes a supportive environment in which MSM interventions are fully provided and HIV-positive MSM have full access to HIV counselling and testing and ART. We investigate the impacts of increased coverage of MSM interventions and ART expansion among adults on new infections among the MSM population from 2012 to 2016. We investigate the combined impacts and the impacts that are attributable to the increased coverage of the MSM interventions. We also investigate the impacts on the new infections among the adult population that are attributable to expansion of the MSM interventions, in the environments of either maintained or expanded ART.

Sensitivity analyses were conducted to assess the uncertainty surrounding the impact coefficients for the disaggregated MSM groups. These analyses were performed using upper and lower bounds of impacts of optimal intervention scenario for MSM-specific interventions (Table 4) and sensitivity analyses were conducted for second scenario that included ART coverage among the adult population. The results are presented as the percent reduction in new infections among MSM, compared with the status quo estimates without expansion of ART.

RESULTS

The proportion of new HIV cases attributed to male anal sex transmission from 2012 through 2016 varies across the four countries when coverage levels were held constant (data not displayed). Figure 1 shows the fraction of new HIV cases attributed to MSM by 2016. Ongoing MSM incidence would contribute to 8% of new infections in Kenya, to a high of 96.3% of new infections in Peru, by 2016. The attributable fraction of transmission related to MSM is increasing in Peru and, to a lesser degree, in Thailand. The prevalence of HIV among IDUs and sex workers in Thailand and Ukraine may account for a significant proportion of the remaining 53% and 80% of HIV that is attributed to other modes of transmission, respectively. Finally, the attributable fraction of HIV infections related to MSM may be increasing in Kenya. Estimating these proportions allows us to account for behaviour and transmission between MSM and bridging with other populations (e.g. MSM who inject drugs and female sex partners of bisexual men).

Figures 2–5 display the modelled impact of the interventions on new infections among MSM. Figure 6 displays the sensitivity analysis around the maximal intervention – increasing
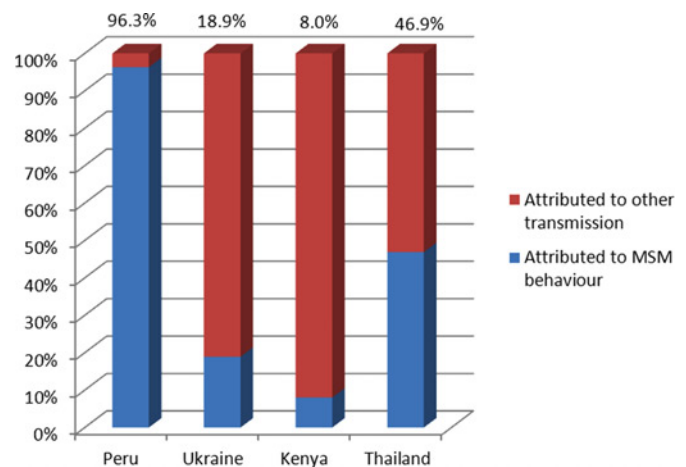

Figure 1   Attributable fraction of new HIV infections from MSM behaviour in selected countries by 2016. MSM = men who have sex with men

coverage of MSM interventions by 40% by 2016 and allowing equal access to expanded ART for MSM – compared with a status quo scenario in which there is no increase in coverage of MSM interventions or ART. The error bars display the high and low values of the sensitivity analysis of the impact matrix. Tables 5–8 depict the numbers of new HIV infections among adults for each country stratified by intervention combination without and with ART expansion among the adult populations.

Projections from Peru show that much higher coverage of interventions for MSM will be needed to change the trajectory of the HIV epidemic among MSM in Peru, if ART is maintained at current coverage levels (Figure 2). Increasing MSM-specific interventions and providing HIV-positive MSM equal access to and treatment with ART may also lead to a 15% reduction in new infections (4600 averted) among MSM. Beyond ART, MSM interventions may avert 2600–2800 infections between 2012 and 2016, almost a 10% reduction in new infections among MSM. The expansion of MSM-specific interventions with and without additional expansion of ART for adults, may also contribute an additional 2700–2900 infections averted among the adult population (a reduction of 7%) within the five-year time span (Table 5).

In Ukraine, increasing coverage of MSM-specific interventions demonstrates an impact on the HIV epidemic among the general population in later years and may avert between
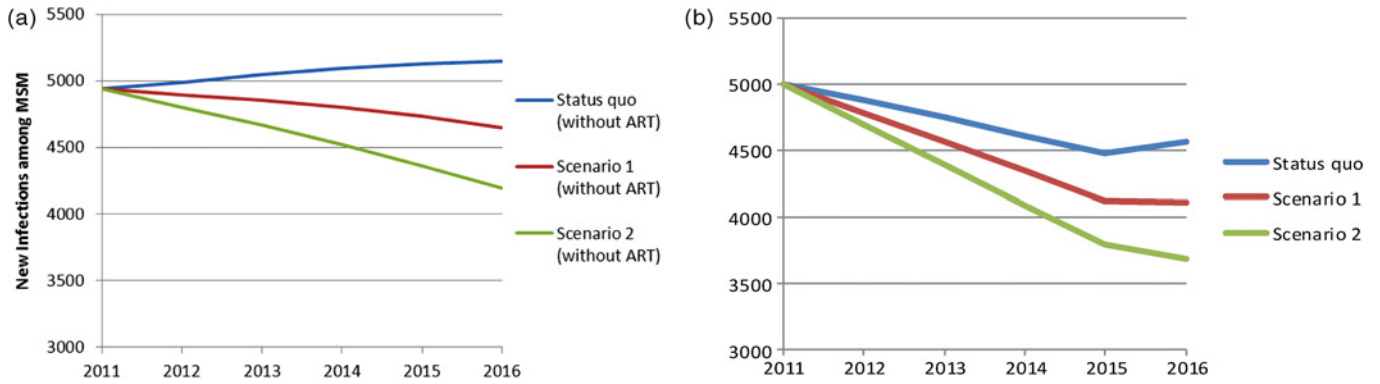
Figure 2 Trajectories of the estimated number of new HIV infections among MSM in Peru with implementation of three intervention scenarios for MSM without (a) and with ART expansion among the adult population (b) (2011–2016). *y*-Axes do not start at zero new infections for the purpose of ensuring differences in new infections are visible over time. MSM = men who have sex with men; ART = antiretroviral therapy
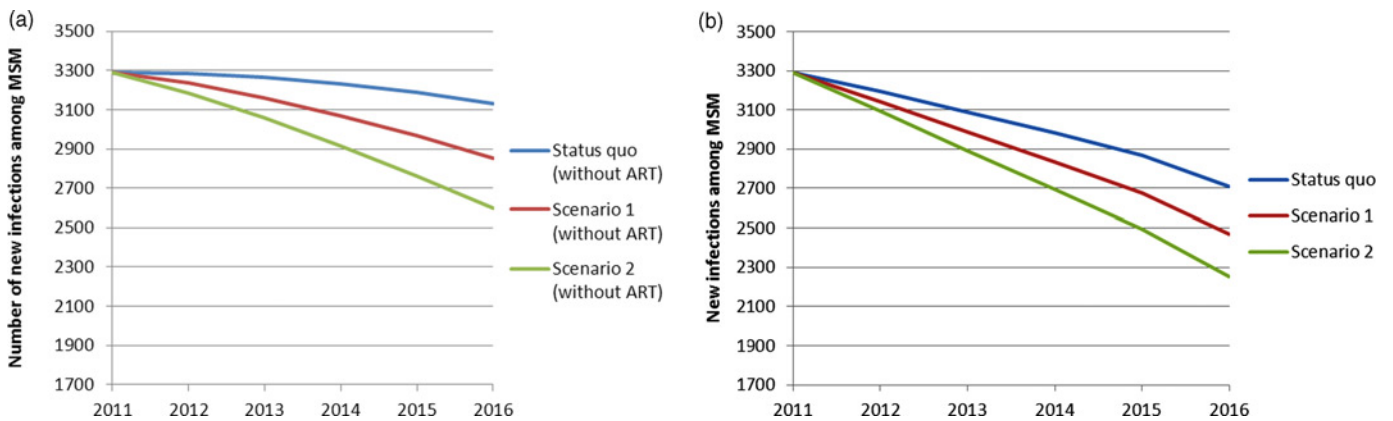

Figure 3 Trajectories of the estimated number of new HIV infections in Ukraine with implementation of three intervention scenarios for MSM without (a) and with ART expansion among the adult population (b) (2011–2016). *y*-Axes do not start at zero new infections for the purpose of ensuring differences in new infections are visible over time. MSM = men who have sex with men; ART = antiretroviral therapy
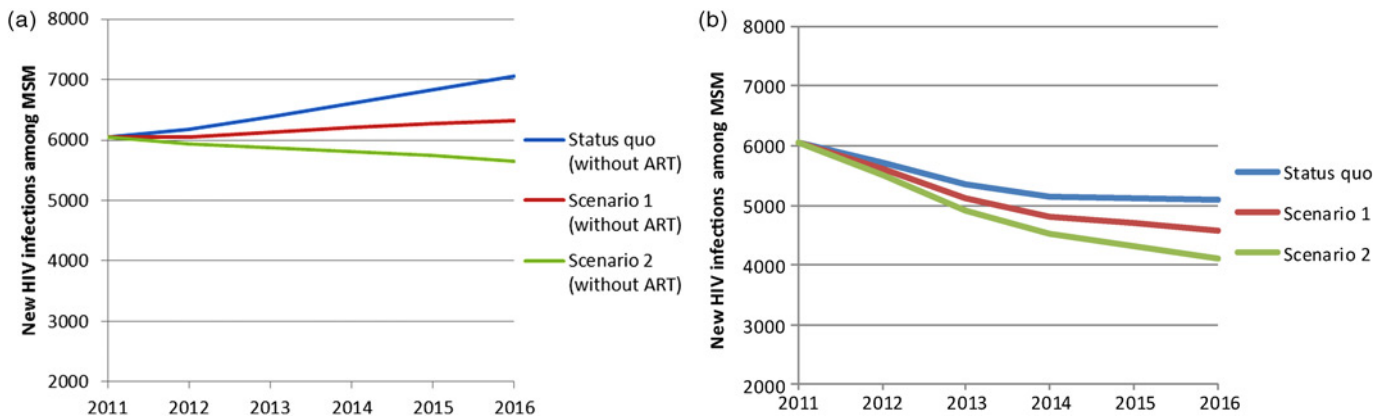

Figure 4 Trajectories of the estimated number of new HIV infections in Kenya with implementation of three intervention scenarios for MSM without (a) and with ART expansion among the adult population (b) (2011–2016). *y*-Axes do not start at zero new infections for the purpose of ensuring differences in new infections are visible over time. MSM = men who have sex with men; ART = antiretroviral therapy

1800 and 2000 new adult infections between 2012 and 2016, a 1% reduction in addition to the benefits observed with expansion of ART (Table 6). Among MSM, there is general decline in new infections; this decline is augmented by the expansion of ART and further enhanced through scale-up of

MSM interventions (Figure 3). MSM interventions, with and without ART expansion, may lead to a cumulative 1400–1600 infections averted among MSM or a reduction of 8% within five years beyond benefits provided by ART. The combined effect of increasing MSM interventions and allowing equal
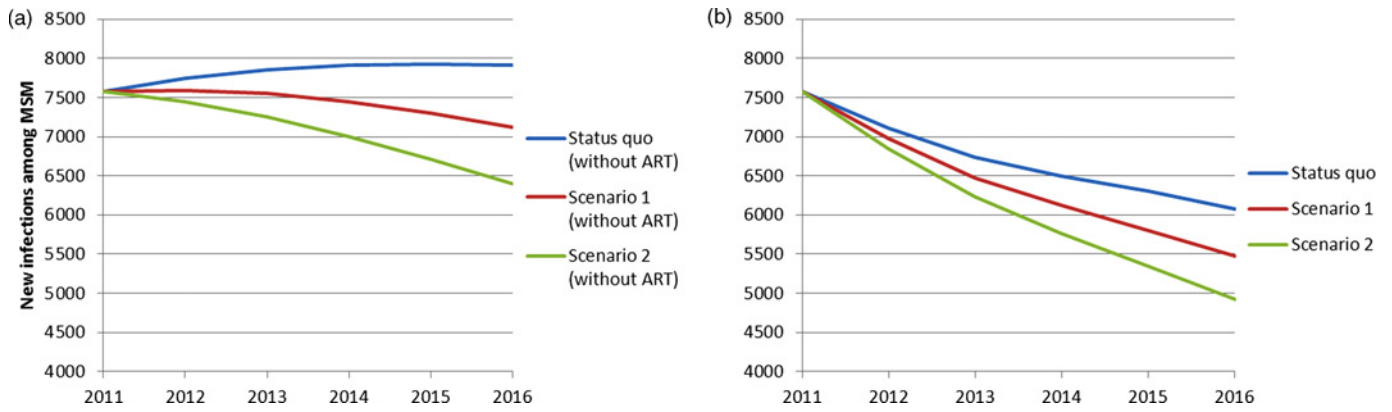
Figure 5 Trajectories of the estimated number of new HIV infections in Thailand implementation of three intervention scenarios for MSM without (a) and with ART expansion among the adult population (b) (2011–2016). y-Axes do not start at zero new infections for the purpose of ensuring differences in new infections are visible over time. MSM = men who have sex with men; ART = antiretroviral therapy
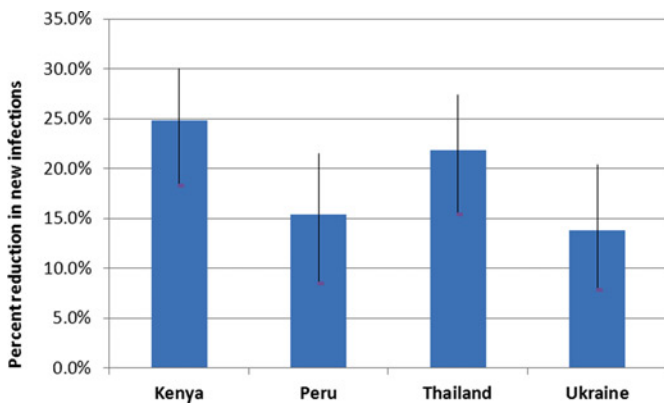

Figure 6 Sensitivity analysis of reduction in new infections among MSM with increased coverage of interventions for MSM and equal access to expanded ART, 2012–2016. MSM = men who have sex with men; ART = antiretroviral therapy

among the MSM population (Figure 4) and, in combination with the MSM interventions may result in a 25% reduction in new infections among MSM, or almost 10,000 infections averted within five years. MSM specific interventions may avert 3000 new MSM infections (9% reduction) over the five-year period, in addition to the benefits provided by ART. Almost 4000 new infections may be averted if ART does not increase beyond current coverage levels (10% reduction in new infections). MSM-specific interventions positively impact the general population in Kenya and, while relative impact may be modest, the numbers of infections averted are considerable averting almost 3300 new adult infections when ART is expanded and more (almost 4400) when ART coverage is maintained at 2011 levels (a reduction of approximately 1% of new infections) (Table 7).

The epidemic projections of new infections in Thailand show an increase over time, particularly when MSM-specific interventions and ART coverage is maintained at 2011 levels. Like Peru, the increase in coverage of MSM-specific interventions could change the trajectory of the epidemic among MSM by 2016 compared (Figure 5). Among MSM, approximately 3600–4500 infections may be averted, a 9–10% reduction in new infections, by MSM interventions when they are scaled-up without and with expansion of ART coverage among adults. The combined impact of ART expansion and MSM interventions may result in a cumulative 10,300 infections averted, or a 22% reduction in new infections among MSM from 2012 to 2016. Among adults, in addition to the benefits observed with

access to expanded ART may lead to a 14% reduction in new infections, or 2700 infections averted, among MSM within five years.

There has been a great expansion of ART among the adult population in Kenya and this expanded coverage is planned to continue into the future and, thus far, has provided obvious impact for the adult and MSM populations. The expansion of ART among adults also shows demonstrable impacts

Table 5 Projected estimates of the number of new adult HIV infections in Peru with implementation of three intervention scenarios for MSM (2011–2016)

	Status quo	Scenario 1	Scenario 2	Status quo	Scenario 1	Scenario 2
	(without expansion of ART)			(with expansion of ART)		
2011	6583	6583	6583	6666	6666	6666
2012	6636	6542	6450	6494	6402	6312
2013	6710	6517	6329	6310	6126	5948
2014	6764	6469	6187	6122	5849	5589
2015	6798	6400	6026	5934	5573	5236
2016	6816	6313	5850	6038	5572	5146
Cumulative	40,307	38,824	37,425	37,564	36,188	34,897
% reduction	(ref)	3.7	7.2	(ref)	3.7	7.1
Infections averted		1483	2882		1376	2667

MSM = men who have sex with men

Table 6 Projected estimates of the number of new adult HIV infections in Ukraine with implementation of three intervention scenarios for MSM (2011–2016)

	Status quo	Scenario 1	Scenario 2	Status quo	Scenario 1	Scenario 2
	(without expansion of ART)			(with expansion of ART)		
2011	45,589	45,589	45,589	45,589	45,589	45,589
2012	45,914	45,841	45,769	44,544	44,474	44,404
2013	46,001	45,859	45,720	43,530	43,395	43,264
2014	45,873	45,666	45,467	42,553	42,361	42,176
2015	45,596	45,328	45,075	41,513	41,269	41,039
2016	45,211	44,886	44,584	39,841	39,555	39,289
Cumulative	**274,184**	**273,169**	**272,204**	**257,570**	**256,643**	**255,761**
% reduction	**(ref)**	**0.4**	**0.7**	**(ref)**	**0.4**	**0.7**
Infections averted		**1015**	**1980**		**927**	**1809**

MSM = men who have sex with men

Table 7 Projected estimates of the number of new adult HIV infections in Kenya with implementation of three intervention scenarios for MSM (2011–2016)

	Status quo	Scenario 1	Scenario 2	Status quo	Scenario 1	Scenario 2
	(without expansion of ART)			(with expansion of ART)		
2011	102,756	102,756	102,756	102,756	102,756	102,756
2012	103,347	103,213	103,081	92,435	92,312	92,191
2013	105,643	105,357	105,082	81,619	81,384	81,157
2014	108,160	107,715	107,294	75,500	75,159	74,839
2015	110,685	110,074	109,508	74,216	73,762	73,344
2016	113,120	112,337	111,630	72,504	71,939	71,432
Cumulative	**643,711**	**641,452**	**639,351**	**499,030**	**497,312**	**495,719**
% reduction	**(ref)**	**0.4**	**0.7**	**(ref)**	**0.3**	**0.7**
Infections averted		**2259**	**4360**		**1718**	**3311**

MSM = men who have sex with men

Table 8 Projected estimates of the number of new adult HIV infections in Thailand with implementation of three intervention scenarios for MSM (2011–2016)

	Status quo	Scenario 1	Scenario 2	Status quo	Scenario 1	Scenario 2
	(without expansion of ART)			(with expansion of ART)		
2011	25,636	25,636	25,636	25,636	25,636	25,636
2012	25,342	25,178	25,016	22,653	22,503	22,356
2013	24,735	24,397	24,070	20,384	20,098	19,821
2014	23,927	23,416	22,929	18,816	18,400	18,004
2015	23,014	22,331	21,692	17,522	16,980	16,475
2016	22,063	21,208	20,425	16,255	15,595	14,993
Cumulative	**144,717**	**142,166**	**139,768**	**121,266**	**119,212**	**117,285**
% reduction	**(ref)**	**1.8**	**3.4**	**(ref)**	**1.7**	**3.3**
Infections averted		**2551**	**4949**		**2054**	**3981**

MSM = men who have sex with men; ART = antiretroviral therapy

the expansion of ART, almost 4000–5000 new infections may be averted (3% reduction) within five years when MSM interventions are scaled up (Table 8).

DISCUSSION

These modelling projections show the combined benefit for MSM of providing equal access to ART as it expands according to national strategies and increasing coverage of targeted MSM interventions. The greatest impacts among MSM that are associated with the combined access to ART and expanded MSM interventions are observed in Kenya and Thailand, likely a result of greater coverage of ART. The projections also demonstrate additional impact of MSM interventions among both the

MSM and the general populations when such interventions are applied within epidemic scenarios. Greatest impacts of these MSM interventions on the adult epidemics are observed among countries such as Peru and Thailand, where the attributable fraction of HIV transmission is predominantly related to male same sex behaviour. While the percent reductions may appear to be low, likely due to the short five-year time frame of the projections, the absolute numbers of infections averted are significant and are likely to continue increasing as the interventions continue in the future.

The attributable fraction can be used to allocate HIV prevention resources and target programmes on the basis of the contribution of risk groups to local HIV incidence; however, it is important that these estimates be examined in relation to all

other risk groups contributing to the total number of HIV. Countries that have actively sought to understand the epidemic and prevent transmission among MSM within the overall epidemic scenario, such as Thailand and Peru, demonstrate benefits for MSM and the general population.[42] Even in countries where positive social changes are observed, research suggests that national health strategies need to follow and provide appropriate resources for prevention among MSM. Caceres' work in Peru, for example, shows that despite evidence that HIV transmission occurs predominantly among MSM, the majority of funding has been allocated to prevention for other vulnerable populations among which the prevalence of HIV is lower than that observed among MSM.[32,42]

Though Kenya has a generalized epidemic, the estimated proportion attributable to MSM suggests that HIV infection among MSM in Kenya is emerging as a significant contributor. Sanders *et al.*[15] recently reported an HIV prevalence of 43.0% among exclusive MSM and 12.3% among men who have sex with men and women, highlighted the vulnerability of these populations. It is important to note that the projections in this study also rely on available epidemiological and behavioural data of MSM; in a stigmatizing environment that currently exists for MSM in Africa, data are particularly difficult to obtain and, thus, these projections may underestimate the attributable fraction and the potential impacts of HIV interventions for MSM. Addressing this HIV epidemic among MSM at an early stage may contribute to reductions in incidence for this particularly hidden group.

The role of injecting drug use in the HIV epidemic cannot be ignored, and IDU may face both parenteral and sexual risk exposures. Ukraine, with an estimated HIV prevalence of 1.1% among the adult population (2010), now has the greatest prevalence of HIV in Eastern Europe Central Asia[43] and effective strategies for HIV prevention among the general population and at-risk groups are needed. Strathdee *et al.*[44] estimated that the risk of HIV infection attributable to unprotected sex among IDUs ranged from 15% to 45% in Odessa, Ukraine. This estimate, however, is based on heterosexual transmission and more data are needed to understand the roles and interactions among IDU and MSM. Our projections take into consideration the overlapping sexual and parenteral risks among MSM-IDU. The projections demonstrate the impact of MSM risk reduction interventions on this population, as a subgroup of the MSM population, and highlight the importance of MSM interventions to also access other networked risk group and suggest that, in a similar manner, interventions targeted for IDU may also impact a portion of the MSM population. These findings agree upon the need for developing strategies that effectively target and prevent HIV transmission among at-risk populations.

Critical to effectively decreasing transmission of HIV among MSM and the general population in all countries is enabling full access to ART for HIV positive MSM. Since the HPTN 052 results reported by Cohen *et al.*[7] have confirmed observational study findings, the importance of ART as prevention further supports the modelling projections reported here. The impacts observed with expansion of ART, however, should not be interpreted as an argument for expanding ART only; rather, the synergies of ART expansion in combination with MSM interventions are important. MSM interventions, particularly outreach, are a method to access hidden MSM, or MSM-IDU, populations for HIV counselling and testing and linkage to ART care.

Both assets and methodological challenges are associated with the Goals model, as highlighted by a recent assessment of mathematical models to evaluate health programmes.[45] While Goals is unique in its ability to project impacts based on varying coverage rates, it assumes that the intervention effects are additive and does not currently accommodate interaction effects. This is acceptable if there is agreement that the interaction effects are multiplicative (because then the model estimates would be lower bound estimates of the true impact); but may be problematic if interventions have synergistic effects. A key component of the Goals model is an impact matrix that indicates how behavioural changes when a group of people are exposed to specific prevention interventions. We did not include oral chemoprophylaxis with Truvada, as this intervention has only been tested in a single randomized control trial at the time of writing; however, given recent results,[46] further analysis is warranted to understand this use and its impact on general and at-risk populations. As the Goals model continues to be refined, estimates of impact should be updated and efforts to validate the projections should be made. As with any model, these projections rely on data availability and quality, and is particularly challenging where underreporting may occur due to pervasive stigma towards MSM. This work may be subject to reporting and publication bias.

Finally, more understanding of the costs associated with such interventions are required before policy-makers can make informed decisions, particularly as LMICs are often faced with limited financial resources and have to make difficult decisions about how to spend these resources among competing priorities.

Taken together, our findings suggest that responding to HIV among MSM is an important aspect of overall country-level responses, and this is true across diverse epidemic scenarios. Whether such levels can be achieved is a question of commitment, political will, and a willingness to provide resources for MSM. Continuing to provide current inadequate levels of services to these men will mean that HIV epidemic control will be difficult or impossible to achieve.

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APPENDIX

Goals model description

Overview

The Goals model was developed to estimate the national impacts of programmatic and budgetary decisions on HIV incidence and the achievement of HIV/AIDS programs' goals. The Goals model was applied here to investigate the effect on men who have sex with men (MSM) and adult infections with expansion of targeted interventions for MSM and combinations of these interventions with antiretroviral therapy (ART) expansion among the general population.

The Goals model is a deterministic model, integrated within the Spectrum suite of models/tools as a 'module', which uses demographic, behavioural and epidemiological data to project HIV prevalence and incidence. Each country model utilizes its own specific inputs and inputs are further specified to the defined risk groups. The Goals model uses population-level demographic and epidemic projections from other Spectrum modules, such as the AIDS Impact Model (AIM) and DemProj (population) and AIM is populated with each country's national ART strategy.

15-year-olds (male and female)

Appendix Figure 1A   **Goals model risk structure**

Risk groups

The Goals model simulates an HIV epidemic in an adult population aged 15–49. The adult population is disaggregated by sex and risk group. People enter the model at age 15 and are assumed to not be sexually active until they reach the median age at first sex, a value that is specified for each country. The focus is on this population because most new infections occur in this age group and most survey data on sexual behaviour refer to this age group.

The population risk groups within Goals risk groups are defined by sexual or drug-use behaviours and are divided into: low-, medium- and high-risk heterosexuals of both genders (high risk often pertains to female sex workers and their clients), people who inject drugs (both genders) and MSM. For the purposes of this exercise, we further developed the Goals model to include low, medium, and high MSM risk groups, as well as MSM who inject drugs (MSM-IDU). The Goals model can now be specified to allow for a single MSM category or four MSM categories. Once a person joins a risk group he or she remains in that risk group until any of the following occurs: the person ages out at age 50, dies from non-AIDS cases, dies from AIDS-related causes or changes behaviour. Behavioural change allows people to move from one risk group to a lower risk group and this is based on the specified duration in a risk group. For example, duration in sex work is often set to 5 or 10 years. For the purposes of this study, we do not assume any duration for time in any MSM category, other than MSM-IDU. Those leaving the highest risk groups (sex work or IDU) move to the medium heterosexual risk group (casual sex) and those leaving the casual sex group move to the stable couples risk group. Figure 1A, depicts the model risk structure in Goals.

Though this study does not focus on other risk groups such as female sex workers or people who inject drugs, the inclusion of these groups in the developed country models ensures that the variety of behaviours, HIV and STI prevalence, and differential risk observed in each modelled country is properly assessed. Risk group parameters are obtained and incorporated
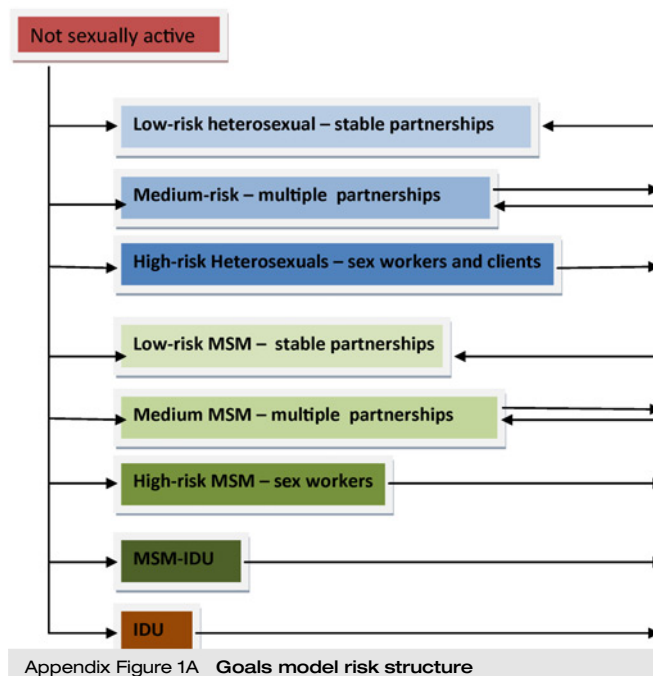
into the model through additional research, communication with country or risk group experts.

Within Goals, behavioural parameters, such as numbers of partners, condom use, etc. are edited according to research or surveillance data that are available. Specific inputs for each risk group can be manually specified and are typically obtained through published scientific research, national biobehavioural surveillance estimates, UNAIDS reports and other unpublished data. Baseline intervention coverage levels of behavioural interventions are estimated based on country-level reporting or expert input, presented as percentages. Goals then projects the number of new infections according to changes in interventions which effect changes to behaviours, and thus risk for HIV transmission. Change in coverage of an intervention is mapped to a change in the behaviour of those risk groups reached by the intervention, ultimately changing risk behaviour and the number of new infections. Depending on intervention effect, the risk group reached and associated behaviours, some interventions therefore have wider impact than others.

Transmission of HIV

Transmission of HIV from an infected partner to an uninfected partner depends on the characteristics of both partners and the partnership. For the susceptible partner the important characteristics are the number of partners and whether or not new prevention methods, such as PrEP or vaccines, are used. This study did not incorporate the use of PrEP or vaccines. Transmission from the infected partner is affected by the stage of infection (primary, asymptomatic or symptomatic) and whether the partner is receiving ART. Characteristics of the partnership that influence transmission are the number of acts per partner per year, whether either partner has a sexually transmitted infection, the type of contact (vaginal or anal sexual intercourse or needle sharing) and condom use.

New infections, I, are calculated as the susceptible population, X, multiplied by the probability of becoming infected, ι:

$$I_{s,k,t} = X_{s,k,t} \times \iota_{s,k,t}$$

where s = sex, male or female; k = risk group and t = time.

The probability of transmission to an uninfected partner during one year, ι, is given by the equation below:

$$1 - [P_{s',k,t} \times (1 - r \times R_t \times MC_{k,t} \times C_{k,t} \times V_{k,t} \times S_{k,t} \times \Pr_{k,t})^a$$
$$+ (1 - P_{s',k,t})]^n$$

where $P_{s',k,t}$ = HIV prevalence in the partner population of risk group k at time t; r = base probability of HIV transmission per act; R_t = multiplier for the effect of stage of infection; $C_{k,t}$ = multiplier for effect of condom use; $MC_{k,t}$ = multiplier for effect of male circumcision; $S_{k,t}$ = multiplier for effect of sexually transmitted infections; $\Pr_{k,t}$ = multiplier for effect of PrEP; $V_{k,t}$ = multiplier for effect of HIV vaccines; a = number of acts per partner per year and n = number of partners per year.

Prevalence in the partner population is defined differently for each risk group. For sex workers or clients and those with multiple partners, it is the prevalence of the population of the opposite sex in the same risk group. For MSM it is the prevalence in the MSM group. For stable couples the prevalence in the partner population is a weighted average of the prevalence in each risk group P multiplied by the proportion of contacts with that risk group A.

$$P_{s,k,t} = \sum_k P_{s',k,t} \times A_{s,k,t}$$

For those in stable relationships the proportion of contacts with each risk group is calculated from the number of people in each risk group N_k and the proportion married m.

$$A_{s,k,t} = \frac{\sum_k m_{s,k} \times N_{s,k,t}}{\sum_k N_{s,k,t}}$$

The effect of stage of infection is calculated as a weighted average of infectiousness by stage i and the proportion of the population in each stage. Disease stages are primary infection, asymptomatic, symptomatic (CD4 count <200 cells/μL) and on ART.

$$R_t = \frac{\sum_i \sum_k \sum_s Y_{i,k,s,t} \times IM_i}{\sum_i \sum_k \sum_s Y_{i,k,s,t}}$$

where $Y_{i,k,s,t}$ = HIV + population in stage i risk group k sex s at time t and IM_i = infectiousness multiplier of stage i.

The impact of sexually transmitted infections (STIs) is calculated from the prevalence of STIs in either partner and the increase in transmission when STIs are present.

$$S_{k,t} = 1 + Sm \times Sp_{k,t}$$

where Sm = multiplier on the probability of transmission when either partner has an STI and $Sp_{k,t}$ = proportion of risk group k with an STI at time t.

The probability of transmission through drug injections is determined by a force of infection variable that expresses the

rate of contact between sharing groups f, the prevalence of HIV among IDU P, the multiplier for stage of infection R and any effects of new technologies such as vaccines V or PrEP Pr.

$$f_t \times P_{k,t} \times R_t \times \Pr_{k,t} \times V_{k,t}$$

The impacts of behavioural interventions is calculated using the transmission equation and variables for condom use, Cc, and the number of partners, n. Though not assessed for this study, behavioural change interventions may also affect age at first sex and needle sharing among IDUs, which determined the proportion of injecting drug users who are susceptible to infection.

The impact of interventions on each of these behaviours is determined by an impact matrix that describes the impact of each intervention on each behaviour for each risk group. The impact matrix is based on an extensive literature search[47] and prepopulated in the Goals model of the Spectrum suite. It is not specific to any particular country. This study further updated the Goals impact matrix for MSM; these inputs are also based on an extensive literature review[41] and these values are provided in Table 4.

The impact for condom use is calculated as a reduction in the non-use of condoms in order to allow for the aggregation of impacts when several interventions are present. Thus, condom use is calculated as one minus the non-use of condoms in the base year multiplied by the product across all interventions of the increase in coverage of each intervention and it impact on condom non-use:

$$Cc_t = 1 - (1 - Cc_o) \times \prod_i (coverage_{i,t} - coverage_{i,0})$$
$$\times condom\ impact_i$$

The impact on the number of sexual partners is determined as the number of partner in the base year multiplied by the product of the increase in coverage and the impact of each intervention.

$$n_t = n_0 \times \prod_i (coverage_{i,t} - coverage_{i,0})$$
$$\times number\ of\ partners\ impact_i$$

Calculations for other impacts may be found in the Goals manual.[5]

ART allocation

The model structure has seven CD4 compartments with specific eligibility criteria and mortality patterns. CD4 count is the determining factor for several HIV parameters: progression to lower CD4 counts, HIV-related mortality, probability of initiating ART and infectiousness. ART initiation may be specified and, for the purposes of this study was selected to initiate at CD4 <350 cells/μL, based on recent findings[8] and WHO guidelines.[40] The probability of HIV-related death, but also ART enrollment, increases as CD4 counts decrease. An assumption is made that most newly infected people start with CD4 counts above 500 CD4 cells/μL, although some portion, p, can start at 350–499 CD4 cells/μL.

The number of people on ART in each year is an input into Spectrum/AIM. It is used to determine the number of people

newly starting ART in each year in order to achieve the specified number of patients. Loss to follow up is indirectly captured by maintaining a specified number of coverage of those on treatment. New ART patients are allocated according to two equally weighted criteria: the same proportion of patients from each eligible CD4 category are started on ART, and new ART patients are allocated on the basis of expected HIV-related mortality without ART. Further details on ART allocation and other key parameter values may be found in the Goals manual.[5]