Modeling the Impact of Biomedical Interventions to Break the Cycle of HIV Transmission

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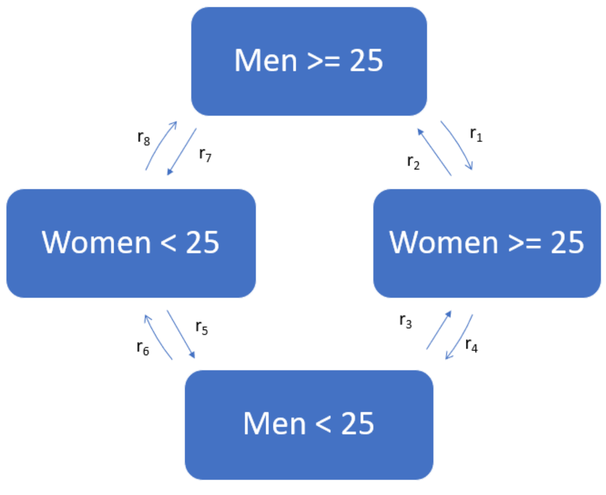
BACKGROUND

Research by CAPRISA and partners[1] in South Africa has documented a cycle of HIV transmission that results in high levels of HIV prevalence. Young women (< 25) with low HIV prevalence are infected when they have sex with older male partners with higher prevalence. Those male partners concurrently have sex with women of their same age who have higher levels of HIV than the male partners. This self-perpetuating cycle is characterized by a large age gap between young women and their older male partners (6.8-10.6 years), and by men who have both young women and older women as sexual partners.

METHODS

We developed a simulation model that reproduces this transmission cycle and used it to investigate the effects of combination prevention interventions on the cycle. The model has four population groups (females < 25, females >=25, males < 25 and males >=25). Model parameters determine the distribution of sexual partners by age and the base year prevalence. The model is fit by searching for values of the force of infection (r) between each set of sexual partners that produces a stable epidemic.



Five biomedical interventions are included that can impact the force of infection: ART for men >25, ART for women >25, voluntary medical male circumcision (VMMC) for men >25, VMMC for men < 25 and PrEP for women < 25. The median efficacy in preventing transmission/acquisition was set at 0.8 for ART, 0.6 for VMMC and 0.8 for PrEP.

Model Equations

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$$P_{m,a<25,t} = P_{m,<25,t-1} \times (1-\alpha_{<25}) + \pi_{m<25,f<25} \times r_5 \times P_{f,<25,t-1} + \pi_{m<25,f>25} \times r_4 \times P_{f,>25,t-1}$$

$$P_{m,a>25,t} = P_{m,>25,t-1} \times (1-\alpha_{>25}) + P_{m,<25,t-1} \times \alpha_{<25+} + \pi_{m>25,f<25} \times r_8 \times P_{f,<25,t-1} + \pi_{m>25,f>25} \times r_2 \times P_{f,>25,t-1}$$

$$P_{f,a<25,t} = P_{f,<25,t-1} \times (1-\alpha_{<25}) + \pi_{f<25,m<25} \times r_6 \times P_{m<25,t-1} + \pi_{f<25,m>25} \times r_7 \times P_{m,>25,t-1}$$

$$P_{f,a>25,t} = P_{f,>25,t-1} \times (1-\alpha_{>25}) + P_{f,<25,t-1} \times \alpha_{<25+} + \pi_{f>25,m<25} \times r_3 \times P_{m,<25,t-1} + \pi_{f>25,m>25} \times r_1 \times P_{m,>25,t-1}$$

Where

P = prevalence by sex (m or f) and age group (<25 or >25)

α = percentage of population aging out of age group each year (<25 or >25)

r = force of infection

π = percentage of partnerships with age group (<25 or >25)

From the de Oliveira *et al*. study,[1] prevalence in the base year population is 20% for men ages 14-24 years, 40% for men ages 25-40, 22% for women ages 15-24 and 60% for women ages 25-40. The distribution of partnerships is

· For women ages 15-24: 38% with men ages 15-24 and 62% with men ages 25-40

· For women ages 25-40: 37% with men ages 15-24 and 63% with men ages 25-40

· For men we assume an even distribution of partnerships between women 15-24 and 25-40

We estimated the force of infection parameters in order to produce stable prevalence in each age/sex group over time. We tested the effects of biomedical interventions by scaling up each intervention one at a time and in combination from current values to 90% for ART and VMMC and 25% for PrEP.

RESULTS

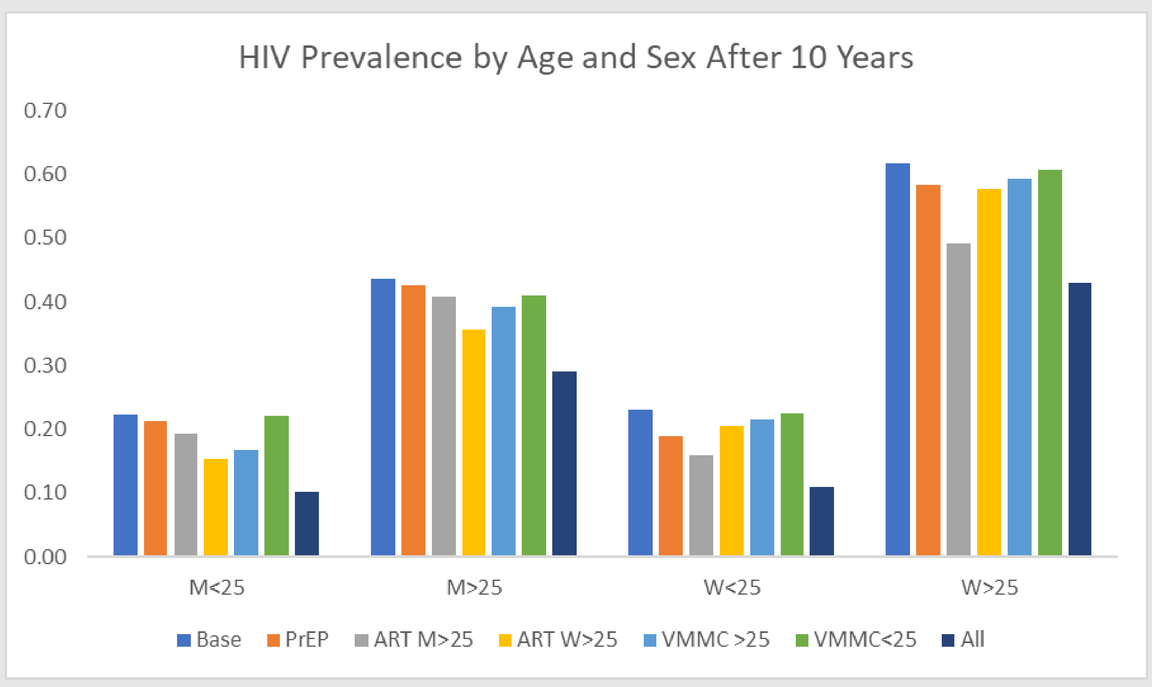
Force of Infection M->F (fitted)

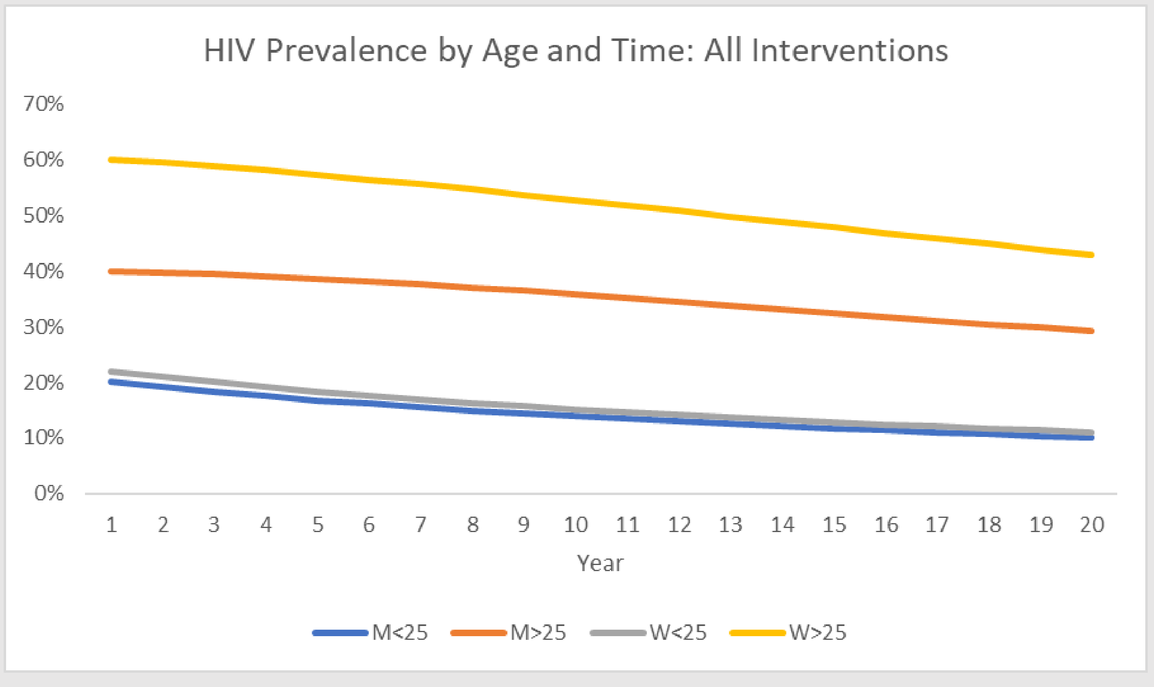
	Women 15-24	Women 25-40
Men 15-24	0.050	0.049
Men 25-40	0.073	0.057

Force of Infection F->M (fitted)

	Men 15-24	Men 25-40
Women 15-24	0.049	0.018
Women 25-40	0.049	0.015

The impact of the interventions differs by population group. The chart below shows the resulting prevalence after 10 years as a result of scaling up each intervention in isolation (PrEP, ART M>25, ART W>25, VMMC>25 and VMMC<25) and in combination (All). For all population groups, the largest impact comes from scaling up ART for older men. PrEP is beneficial for young women. ART for older women and VMMC are beneficial for young men. Combining all interventions reduces overall prevalence by 40% over 20 years.





CONCLUSIONS AND RECOMMENDATIONS

A simple force of infection model can replicate the cycle of transmission in Kwa-Zulu Natal. The model can be used to explore the effects of different biomedical interventions on HIV incidence and prevalence. In this application of the model, within each age and sex group, the greatest HIV prevalence reduction from a single intervention came from providing ART to adults of the opposite sex. Combining all interventions reduced HIV prevalence even further in all groups, strengthening the evidence for a combination prevention approach rather than exclusively relying on ART for prevention for epidemic control.

References: [1] de Oliveira, T., et al. (2017). "Transmission networks and risk of HIV infection in KwaZulu-Natal, South Africa: a community-wide phylogenetic study." Lancet HIV **4**(1): e41-e50.

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