

Effects of public health educational campaigns and the role of sex workers on the spread of HIV/AIDS among heterosexuals

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Abstract

This paper presents a sex-structured model for heterosexual transmission of HIV/AIDS in which the population is divided into three subgroups: susceptibles, infectives and AIDS cases. The subgroups are further divided into two classes, consisting of individuals involved in high-risk sexual activities and individuals involved in low-risk sexual activities. The model considers the movement of individuals from high to low sexual activity groups as a result of public health educational campaigns. Thus, in this case public health educational campaigns are resulting in the split of the population into risk groups. The equilibrium and epidemic threshold, which is known as the basic reproductive number (\mathcal{R}_0), are obtained, and stability (local and global) of the disease-free equilibrium is investigated. The model is extended to incorporate sex workers, and their role in the spread of HIV/AIDS in settings with heterosexual transmission is explored. Comprehensive analytic and numerical techniques are employed in assessing the possible community benefits of public health educational campaigns in controlling HIV/AIDS. From the study, we conclude that the presence of sex workers enlarges the epidemic threshold \mathcal{R}_0 , thus fuels the epidemic among the heterosexuals, and that public health educational campaigns among the high-risk heterosexual population reduces \mathcal{R}_0 , thus can help slow or eradicate the epidemic.

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1. Introduction

HIV/AIDS has killed more than 25 million people since it was first recognized in 1981, making it one of the most destructive epidemics in recorded history (UNAIDS/WHO, 2005). The epidemic has remained one of the leading causes of death in the world and has been destructive in Africa with Sub-Saharan Africa remaining the epidemiological locus of the epidemic. In Sub-Saharan Africa, heterosexuality including prostitution has remained the principal mode of transmission since the epidemic became visible (Mufune, 2004; UNAIDS, 2004). Overtime and due to the fact that women are inordinately affected, vertical transmissions from mother to child during childbirth are of increasing importance in transmission and this is in contrast to other areas of the globe where the principal mode of transmission includes men who have sex with other men (homosexuals) and intravenous drug users (Mufune, 2004). Sub-Saharan Africa remains hardest-hit and is currently home to 25.8 million (23.8–28.9 million) people living with HIV, almost one million more than in 2003 (UNAIDS/WHO, 2003). Two-thirds of all people living with HIV are in Sub-Saharan Africa, as are 77% of all women with HIV. An estimated 2.4 million (2.1–2.7 million) people died of HIV-related illnesses in this region in 2005, while a further 3.2 million (2.8–3.9 million) became infected with HIV (UNAIDS/WHO, 2003). In some Sub-Saharan Africa countries, declines in HIV prevalence related to changes in behaviour and prevention programmes have been observed. Among the notable new trends are the recent declines in national HIV prevalence in Kenya and Zimbabwe, urban areas of Burkina Faso and similarly in Haiti, alongside indications of significant behavioural change including increased condom

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use, fewer partners and delayed sexual debut (UNAIDS, 2006). However, the number of people living with HIV has continued to rise, due to population growth and, more recently, the life prolonging effects of antiretroviral therapy (UNAIDS, 2006).

In the continuing absence of a cure for HIV/AIDS, the use of antiretroviral drugs (ARVs) has remained the only feasible option for infected individuals. Current combinations of ARVs increase the survival time of HIV-infected individuals, but do not lead to viral eradication within infected individuals hence do not cure and over time this causes the pool of potential transmitters of infection to grow; thus, the two factors decreased infectivity and increased duration of infectiousness have opposing effects on transmission (Blower et al., 2005). Studies (Anderson et al., 1991; Velasco-Hernandez and Hsieh, 1994; Hsieh and Velasco-Hernandez, 1995; Hsu Schmitz, 2000, 2002; Baggaley et al., 2006; Mukandavire and Garira, 2006) have also shown that, treatment which prolongs the incubation period but do not reduce HIV/AIDS transmission rate may even enlarge the epidemic. Further, Velasco-Hernandez and Hsieh (1994) showed that treatment can benefit the community if accompanied by sexual behaviour changes. On the issue of vaccines, there is no approved vaccine for HIV/AIDS despite the efforts on vaccine research and it is unlikely that a highly effective vaccine will be available soon; thus, vaccination as a control strategy is not yet available for HIV/AIDS. Mclean and Blower (1993, 1995), Blower and Mclean (1994), Blower et al. (2002, 2003a, b) and Smith and Blower (2004) studied theoretical models of partially effective HIV vaccines and the potential changes in risky behaviour associated with a vaccination campaign and found that the benefits offered by an only partly effective vaccination program may be offset by rises in potentially infectious contacts unless an education campaign accompanies it. Del Valle et al. (2004) studied the effects of education in a set up with vaccination and treatment on HIV transmission in homosexuals with heterogeneity following the concepts of Mclean and Blower (1993, 1995) and Blower and Mclean (1994) that partly effective vaccines should be accompanied by educational campaigns. The joint effects of vaccines and widespread treatment with antiretroviral therapy (ART) have also been theoretically examined by Blower et al. (2003a, 2003b) and Gray et al. (2003). They concluded that widespread ART that reduces infectiousness combined with low efficacy vaccine could reduce infections to very low levels as long as behavioural reversals do not overwhelm the reductions in the risk of transmission per sexual act.

In this paper we formulate and analyse a new sex-structured HIV/AIDS model in which the population is divided into three subgroups: susceptibles, infectives and AIDS cases. The model is formulated using integro-differential equations, which are shown to be equivalent to delay differential equations with a time delay due to incubation period. Any deterministic model without a fixed delay will permit some instantaneous progression to AIDS because of the structure of ordinary differential equations, but the average progression time in these models can still be made to coincide with the statistical average time (see Mukandavire and Garira, 2006, 2007 for a similar approach). The subgroups in the population are divided into two classes, consisting of individuals involved in high-risk sexual activities and individuals involved in low-risk sexual activities. Population numbers in each class denoted as functions of time by $S_{i_l}(t)$, $I_{i_l}(t)$ and $A_{i_l}(t)$ where $i = f, m$ denote female and male populations, $l = 1, 2$ denote high-risk and low-risk sexual activities, respectively. HIV/AIDS models with risk groups due to sexual activities have been studied (Hethcote and Van Ark, 1980; Roberts and Dangerfield, 1990; Griffiths et al., 2000a, 2000b). We differ from these studies in that; we consider movement from high to low sexual activity groups to be a result of public health educational campaigns, thus in this case public health educational campaigns are resulting in the split of the population into risk groups. We define public health education as the counseling of individuals to have fewer sexual partners, abstain, and/or otherwise reduce risky behaviour (see Del Valle et al., 2004). Further, we extend our HIV/AIDS model to explore the role of sex workers (which is one of the oldest profession in the world, New Internationalist, 1994) in the spread of HIV/AIDS in settings with heterosexual transmission and investigating the community gains if female sex workers are educated. We define a sex worker to be an individual who sales sexual intercourse for money. Sex workers have been found to be the major source of infection in Africa due to unemployment, poverty and underdevelopment (Caldwell and Quiggin, 1989; Kribs-Zaleta et al., 2005). To the best of our knowledge, no work has been done in modelling the effect of public health educational campaigns and exploring the role of female sex workers in the context of sex-structures incorporating discrete time delays due to the long incubation period of the disease in heterosexual settings.

The paper is organised as follows: in the next section we present the model formulation and analysis (including stability and reproductive numbers), in Section 3 we extend the model to explore the role of sex workers in the spread of HIV/AIDS in settings with heterosexual transmission and overall community gains if female sex workers are educated. In Section 4 we have the summary and concluding remarks.

2. Model description

The model classifies the heterosexually active community into the following categories: high-risk susceptible (S_{i_1}), high-risk infectives (I_{i_1}), high-risk AIDS cases (A_{i_1}), low-risk susceptibles S_{i_2} , low-risk infectives I_{i_2} and low-risk AIDS cases (A_{i_2}) where $i = f, m$ denote female and male, respectively. Individuals are referred to as male or female only in connection with features peculiar to their sex. In particular, the male to female infectivity rate is greater than that for female to male

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