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A model for HIV transmission with two interacting high-risk groups

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ABSTRACT

We formulate a model of HIV transmission which keeps track of two interacting high-risk groups, namely female sex workers (FSW) and male injecting drug users (IDU), along with a third "bridge" group of male drug-free clients (DFC). To determine the global asymptotic behaviour of the model, we first consider the dynamics of an n-group SIR model featuring abstract, unspecified and possibly nonlinear forces of infection utilising the graph theoretic approach of Li and Shuai. It is determined that the basic reproduction number R_0, computed via the next generation method, is a threshold parameter for the stability of the disease-free and the endemic equilibrium. Global stability results for the model with two interacting high-risk groups are then obtained via suitable particularisations. We obtained partial reproduction numbers for each disease transmission route in the model, via which and our analytical results we are able to establish that if the goal of an intervention measure is to eradicate, significant reduction in transmission between FSW and IDU is needed, in addition to reduction in other routes of transmission. On the other hand, if the aim is to mitigate the disease spread, reduction in any one or more routes of disease transmission will be useful, albeit reduction in transmission between the two high-risk groups will be more impactful than others.

1. Introduction

HIV/AIDS model integrating high-risk groups has been a subject of significant interest. In particular, model with a high-risk group of female sex workers (FSW) and non-high-risk group of young unmarried males has been used to explain the rapid spread of HIV/AIDS in Thailand in the early 90s [1]. Another general model which incorporates treatment and behaviour change for HIV-infected FSW and a bridge population of young un-partnered males was proposed and analysed in [2,3]. A structured community model with two classes of direct (high activity) and indirect (low activity) FSW and two classes of sexually active

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male clients (highly active and less active) has been formulated in [3,4]. However, none of the articles above involve male injecting drug users (IDU) since there is little evidence of significant interaction between the FSW and IDU in Thailand at that time.

To provide real world background motivation for modelling interacting high-risk groups, we consider the HIV/AIDS epidemic in southwest China and how its high-risk groups became overlapped in time. The first HIV outbreak in China, recorded in 1989 in Yunnan Province, was confined to IDUs [5]. It has been estimated that 44% of the sex workers in southern China had unprotected commercial sex with their clients [6]. Peer disapproval of condom use and high intimate relationships with sex workers were determined to be barriers to consistent condom use by clients of sex workers [7], along with the fact that some FSW are often willing to engage in unprotected sex if their clients pay extra. Despite a significant decrease during 2000–2011, southwest China still bore the greatest HIV disease burden for FSW [8]. There is a high risk of HIV transmission from FSW to long-term partners or possibly to newborns through mother-to-child vertical transmission. Moreover, the male clients, once infected with HIV through buying sex, could in turn spread HIV to their partners or wives as a bridge population, since they may transmit HIV from a high risk group (FSW) to the general population [9].

Injecting drug use is another key factor in spreading HIV to the general population. A 2010 self-administered, standard behavioural surveillance survey of 12,622 FSW recruited from Guangxi indicates 2.6% non-injecting drug users and 0.5% IDU [10]. In November 2002, a community-based survey targeting HIV-seronegative IDUs was conducted in Xichang County of Sichuan Province, China. Over the following 36-month follow-up period observation, the study showed that the average HIV incidence rate was 2.3% [11,12]. In a study in Guizhou Province in 2000, nearly 30% of all IDUs were women, and a considerable number of them had engaged in commercial sex [13]. A 2004 study reported around 21% of female IDUs surveyed in Yunnan Province reported selling sex for money or drugs in the previous month [14], while 60% of female IDUs in Sichuan Province in 2003 reported selling sex for money or drugs and $<30\%$ of them reported consistent condom use with customers [15]. Surveys in Yunnan Province in early 2000's reported that HIV prevalence among female IDUs was significantly higher than HIV prevalence among male IDUs [16,17].

A 2005 study, motivated by the HIV epidemic in Yunnan province, China in 1989 which has progressed to a concentrated epidemic, compares the level of HIV risk behaviours of needle/apparatus sharing among male IDUs and unsafe commercial sex between FSW and male clients [18] and examines the effects of risk factors for HIV infection among these two groups. Prevalence rates as high as 74.5% were reported among IDUs, those reported among FSW being as high as 10% [19]. Therefore, unlike in other parts of China, there is evidence of significant interaction between the high-risk groups of FSW and IDUs, which provides motivation for our study.

More recently, a model which classifies the at-risk population into IDUs (who do not engage in commercial sex) and drug-free individuals who engage in commercial sex (sex workers and their clients) was proposed in [20]. However, in this model, the equations for the infected subpopulations decouple near the disease-free equilibrium which grossly simplifies the analysis and subsequently its biological significance. In this work, we will formulate a model with two interacting high-risk groups of FSW and IDU with which to carry out analysis.

2. The model

In this paper, we formulate an HIV transmission model with two interacting high-risk groups of FSW and IDU under the following assumptions.

1. Two HIV transmission routes are considered: needle/apparatus sharing between male IDU and commercial sex between FSW and sexually active male clients.