Journal of Nonlinear Modeling and Analysis
Volume 7, Number 2, April 2025, 552–582
https://journal.global-sci.org/jnma
DOI:10.12150/jnma.2025.552

Modeling the Influence of Treatment Accessibility and Treatment Compliance on the Dynamics of HIV/AIDS

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Abstract The invention of highly active antiretroviral treatment (HAART) revolutionalized the treatment of HIV and brought hope to millions of individuals living with the virus. However, the eradication of HIV has proved difficult owing to many factors including accessibility and treatment compliance, particularly among many individuals in low income countries. Thus, we developed a model in terms of a system of nonlinear ordinary differential equations to assess the influence of inaccessibility of treatment and noncompliance with treatment guidelines by the HIV infectives who are aware of their status on the spread of HIV. The model was studied qualitatively and quantitatively using the theory of reproductive ratio and the software Maple respectively. The results of the analysis showed that early detection, treatment accessibility and treatment compliance by the majority of the infectives who know their status are crucial to the minimization of HIV incidence and prevalence.

Keywords Isolation, incubation period, asymptomatic, symptomatic, equilibria

MSC(2010) 92D30, 60127, 91B70.

1. Introduction

The emergence of human immunodeficiency virus (HIV), the causative agent of the acquired immunodeficiency syndrome (AIDS), was announced by the Center for Disease Control and Prevention (CDC) at the start of the 1980s [1]. It was hoped that vaccines would be created to halt the spread of the disease or possibly eliminate it as soon as possible. But more than four decades later, no strategy has been effective to halt or eliminate the virus.

The transmission potential of HIV is affected by viral load - the quantity of virus in the blood. At present, highly active antiretroviral therapy (HAART) is the best method to suppress viral load as it reduces the chance of HIV spread by 96% [2]. However, the application of the drugs does not cure HIV permanently, but it does lower virus multiplicity and, as a result, AIDS related morbidity and mortality.

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Theoretically, HAART is thought to have three major effects: (i) a decreased risk of secondary infection [3,4], (ii) a decreased infectivity per contact [5,6], and (iii) an individual effect, such as an increased life span [7] that indicates a decreased risk of both AIDS and death from AIDS [8,9].

A number of issues shape dynamics of HIV. For example, some HIV-positive individuals who are aware of the risks and effects of their infection may not always have access to therapy because it is difficult for them to get it or because the cost is too expensive for them to bear. This situation neglects this group of infectious agents and frequently causes a sharp increase in the rate of disease transmission in the community. The scenario may be related to the fact that a significant number of HIV-positive individuals, despite being aware of their status and in need of treatment, do not have access to HAART or receive it effectively in low and middle income countries (LMICs) (particularly in sub-Saharan Africa, where the pandemic is most severe).

Up till 2019, AIDS accounted for 32.7 million deaths worldwide, and 75.7 million people became infected with HIV, based on the information from the United Nations Program on HIV/AIDS [10]. Worldwide, there were 38 million individuals infected with HIV as of the end of 2019. In addition, 1.7 million individuals became newly infected with the virus during that year, and over 690,000 people died of AIDS-related ailments. HIV/AIDS is one of the major obstacles to development; it is not merely a health problem. It has a significant impact in LMICs, where 95% of all HIV/AIDS patients reside [11].

Mathematical models remain a crucial tool in epidemiology for comprehending the transmission of infectious diseases and the effects of intervention initiatives. The literature and growth of mathematical epidemiology is well documented [12,13], also see for various models [14–19]. Basically, mathematics plays a crucial part in the prevention of virus spread by enabling decision-makers to predict the effects of certain intervention strategies or to develop more effective techniques following the insights from mathematics. Based on the importance of mathematical models in disease dynamics, several HIV/AIDS mathematical models have been developed with one of the earliest attributable to Anderson et al. [20] where two mathematical models were presented: the first model captured HIV transmission in two populations of susceptible and infectious individuals; the second model considered three populations where there is one susceptible population and two infectious populations with one of infectious populations being AIDS group. Motivated by Anderson et al. [20], several studies have been conducted over the years on various aspects of HIV/AIDS dynamics e.g. transmission [21,22], diagnosis [23,24], treatments [25,26] and optimal control [27–29].

In their contributions to the study of HIV/AIDS, Udoo and Ashezua [30] developed a mathematical model to analyze the contribution to the spread of HIV/AIDS of the HIV positive individuals who are in need of treatment but cannot receive it due to inaccessibility and poor delivery, particularly in resource-poor nations. The researchers considered five compartments - susceptible $S(t)$, infected individuals who are ignorant of their HIV infection $I_1(t)$, infected individuals who are not ignorant of their HIV infection $I_2(t)$, infected individuals who are not ignorant of their HIV infection but cannot access treatment $I_3(t)$ and infected individuals who are not ignorant of their HIV infection and are receiving treatment termed recovered class $R(t)$. The authors discovered that the inability to access treatment has the potential to increase and sustain the endemicity of HIV/AIDS epidemic.