MIKAILALSYS
Journal of Multidisciplinary Sciences

e-ISSN : 2987-2286
p-ISSN : 2987-3924

Index : Dimensions, Scilit, Crossref, Garuda, Semantic, Lens,Google Scholar,Base, etc

https://doi.org/10.58578/mikailalsys.v3i2.5323

Determinstic Modeling of Effect of HIV Screening Postioned for Sysmptomatic HIV Individuals: An Intervention for HIV/AIDS

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Article Info:

Submitted:	Revised:	Accepted:	Published:
Mar 7, 2025	Mar 22, 2025	Apr 3, 2025	Apr 8, 2025

Abstract

Literatures abound about the negative effects of the late detection of the Human Immuno-Deficiency Virus (HIV) on the effective screening and treatment of infected persons resulting in high number of mortality cases. For this study, Deterministic models to determine the effect of HIV screening at the symptomatic stage as HIV intervention was developed and evaluated. Result showed that HIV screening stationed at the hospital for HIV individuals at the symptomatic stage have the potential of reducing mortality due to AIDS, the higher the number of individuals detected in the symptomatic stage, the lower the mortality due to the infection. Based on this, early intervention where the HIV screening is taken out in search of those who have the infection and are at asymptomatic stage of the infection, may lead to reduced mortality due to the disease and its morbidity.

Keywords: HIV/AIDS, HIV Screening, HIV Symptomatic, HIV Asymptomatic, Deterministic Modeling

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INTRODUCTION

According to UNAIDS 2020 target to end the epidemic (UNAIDS 2017); it is expected that 90% of all people living with HIV should know their status, 90% of all people diagnosed with HIV infection should receive sustained antiretroviral therapy, and 90% of all the people receiving antiretroviral therapy should have viral suppression. But in Nigeria, the proportion of the general population that has ever been tested for HIV is low at 26% (NACA 2015). This implies more persons living with HIV may not be aware of their positive HIV status and are not in the HIV treatment and care provisions. For HIV/AIDS to become conquered, even though in the absence of cure, the citizens will need to be screen (Granich et. al., 2009, Bendavid et. al., 2010). And the effect of the screening patterns for HIV will be seen well from the mathematical point of view, modelling.

Many mathematical models have been created to study the effect of HIV screening (Alsolami et.al., 2012; Shabani et.al., 2011; King'aro et.al., 2013; Al-Sheikh et.al., 2011; Tegegne et.al., 2016), screening and counselling (Kaur et.al., 2016), and screening and treatment (Marsudi et.al., 2014; Safiel et.al., 2012; Okoson et.al., 2013). Most authors considered the unaware HIV infectives and through screening become aware of their HIV status, the impact of screening, counselling and treatment on the spread of the disease. Consideration needs to be given to the disease progression stages, and introducing screening to determine its effect on morbidity and mortality.

The aim of this study is to develop a model of HIV screening at the symptomatic stage in the population to determine its impact on mortality due to AIDS.

METHODS

The models considered above considered HIV screening followed by treatment as intervention for HIV/AIDS disease. Even though, HIV infected individuals can be identified at any stage of the disease progression by HIV screening, in reality, most people who are infected with the disease will ordinary be identified at their symptomatic stage, wherefore, by the symptoms of the disease, they might be tested and discovered positive to the disease. Therefore, considering screening at the pre-AIDS stage, which is more of the beginning of the symptomatic stage of the disease, if HIV screening is positioned at this stage, what will be its effect on mortality (deaths) due to the disease compared to when there is no HIV screening at all?

Now, consider the model where a susceptible population $S(t)$ is depleted by a force of HIV infection with rate λ, a result where a susceptible comes in sexual contact with an HIV infected individual in unprotected sex. The newly infected individual arrives at first into the asymptomatic stage $I(t)$, and then progresses into the symptomatic stage, the pre-AIDS stage $P(t)$, at a rate σ. Individuals at the pre-AIDS stage moves into the full-blown AIDS stage $A(t)$ at a rate σ, and then die due to AIDS-related disease at a rate δ. In order to give account of the susceptible who missed being infected at time t, we noted the compartment of susceptible $S^{\bullet}(t)$, but the compartment is not being considered as it is not of interest at the moment. The interest is the straight movement from the susceptible $S(t)$ to death due to AIDS $D(t)$. The schematic diagram of this model is given below in figure-1.

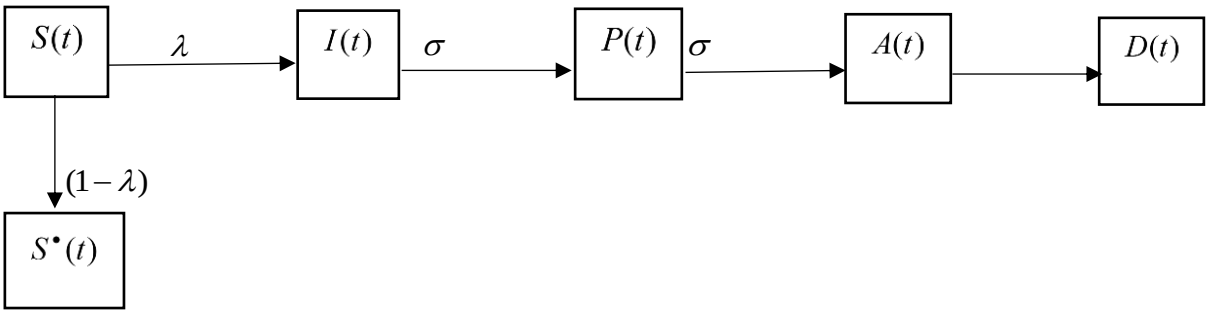


Figure 1. Model schematic diagram

It is assumed that the whole population consisting of the compartments in the models is heterosexual from age 15 years and above, and it is closed. The force of infection is a function of the proportion of infectives who are at the asymptomatic stage or Pre-AIDS stage. Exit out of the heterosexual population is death due to AIDS infection.

The deterministic equations of this model is given by,

$$\frac{dS}{dt} = -\lambda S, \tag{1}$$

$$\frac{dI}{dt} = \lambda S - \sigma_1 I, \tag{2}$$

$$\frac{dP}{dt} = \sigma_1 I - \sigma_2 P, \tag{3}$$

$$\frac{dA}{dt} = \sigma_2 P - \delta A, \tag{4}$$

$$\frac{dD}{dt} = \delta A. \tag{5}$$

where the force of infection, $\lambda = \frac{(\beta_1 I + \beta_2 P + \beta_3 A)}{S+I+P+A}$.

$\beta_1 \geq \beta_2 \geq \beta_3$, are sexual contact rates of $S(t)$ with $I(t)$, $P(t)$, and $A(t)$ respectively. And $\sigma \geq \delta$.

RESULTS

The parameters in model are given values as described in Table-1 below.

Table 1: Parameters, Descriptions, values and References

Parameter	Description	Value	Reference
β_1	Sexual Transmission Contact Rate with the I class	0.86	Safiel et.al., 2012, Marsudi et.al.,2017
β_2	Sexual Transmission Rate Contact with the P class	0.15	Marsudi et.al.,2017
β_3	Sexual Transmission Rate for Contact with the T_P class	0.015	Assumed
σ_1	Progression Rate from the I class into the P class	0.198	Yusuf et.al., 2011, Marsudi et.al.,2017
σ_2	Progression Rate from the P class into the A class	0.4621	Yusuf et.al., 2011, Marsudi et.al., 2017
ρ	HIV Screening Rate for I		
γ	Fail Treatment Rate for T class	0.0001	Safiel et.al., 2012, Marsudi et.al.,2017
δ	Mortality Rate due to AIDS Infection	0.0909	Yusuf et.al., 2011, Huo et.al., 2015, Marsudi et.al.,2017.

The screening rate ρ is experimented at the values 0.1, 0.3 and 0.5. Initial values for the variables in the models are given as

$S_0 = 10{,}000$, $I_0 = 2$, and $P_0 = A_0 = T_{P0} = D_0 = 0$.

The results for the effect of no HIV screening in the model with parameter values taking from Table 1, is seen on the number of deaths due to AIDS infection disease.

The results for the effect of no HIV screening in the model is seen on the number of deaths in figure-1 below.

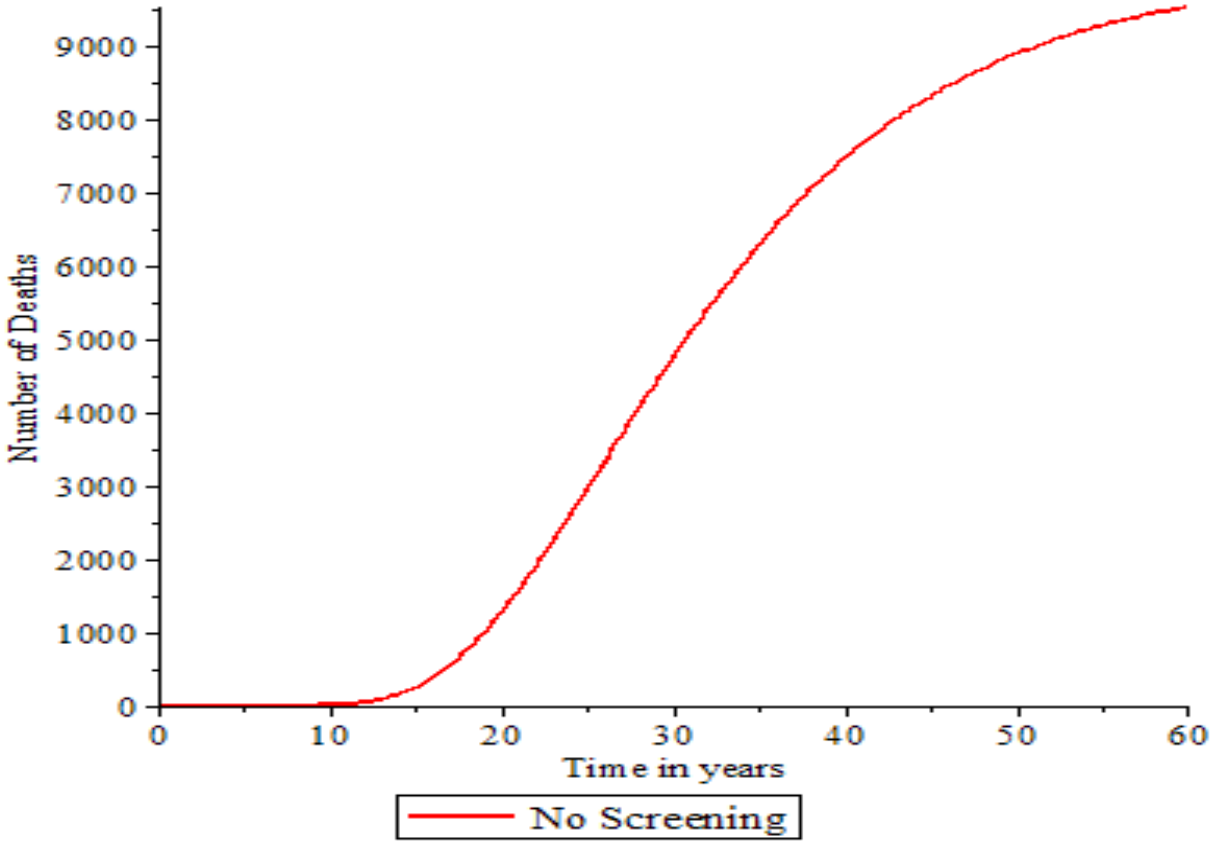


Figure 2: Graph on Number of Deaths when HIV Screening is not introduced

Figure-2 above shows the cumulative number of deaths rising above 0 in a logistic form after ten years. At 25-years, about 30% cumulative deaths has occurred cumulatively. At 35-years, about 65% cumulative deaths has occurred cumulatively. At 45-years, close to 85% cumulative deaths has occurred. At 60-years of the infection in the population, about 95% cumulative deaths has occurred out of the 10,000 individuals in the population. Between 20-40 years, a cumulative of almost 60% cumulative deaths has occurred. This is a scenario when HIV screening is not considered in a population.

Let now consider the scenarios of when screening is introduced into the symptomatic stage as it is in this present day, for a few different values of HIV screening rate. How will this screening at the pre-AIDS stage impact on the number of deaths?

Model 2: Modifying model-1 by adding a $T(t)$ compartment. This $T(t)$ class is assumed to be as a result of HIV screening at the Pre-AIDS stage with a rate τ, and then treatment follows immediately. Also, a small fraction of individuals in this class is assumed to suffer failed treatment due to drug resistant or failure of following drug modalities at a rate γ, and then die. Figure-3 below shows the schematic diagram.

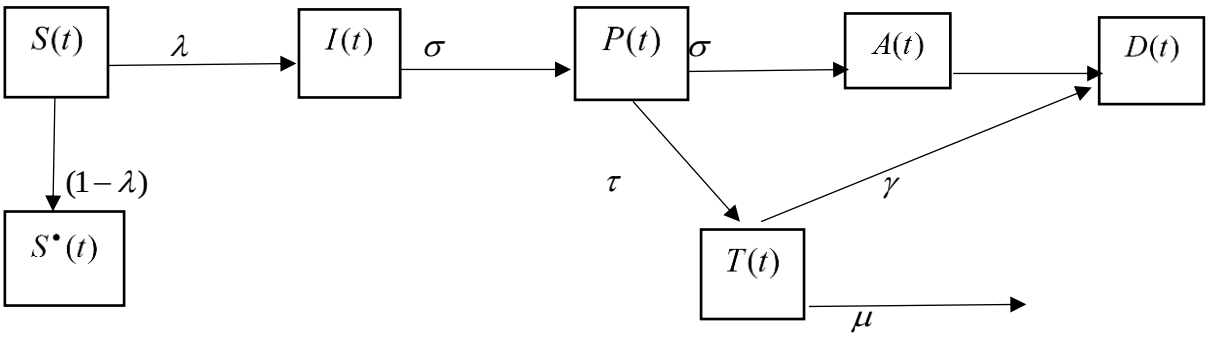


Figure 3. Model schematic diagram

It is assumed that the whole population consisting of the compartments in the models is heterosexual from age 15 years and above, and it is closed. The force of infection is a function of the proportion of infectives who are at the asymptomatic stage or Pre-AIDS stage, or screened and receiving treatment. Once an HIV infective is detected by screening, treatment follows immediately. Some infectives on treatment may fail treatment due to lack of following treatment modalities and some lost to follow-up. Exit out of the heterosexual population is death due to AIDS infection. By screening, it is also assumed that the sensitivity and predictive rate of the screening is 100% sensitive and predictive.

The differential system of equations are given below from equation (6) to equation (11).

$$\frac{dS}{dt} = -\lambda S, \tag{6}$$

$$\frac{dI}{dt} = \lambda S - \sigma I, \tag{7}$$

$$\frac{dP}{dt} = \sigma I - \sigma P - \tau P, \tag{8}$$

$$\frac{dA}{dt} = \sigma P - \delta A, \tag{9}$$

$$\frac{dD}{dt} = \delta A + \gamma T \,, \tag{10}$$

$$\frac{dT}{dt} = \tau P - \gamma T \,, \tag{11}$$

where $\lambda = \frac{(\beta_1 I + \beta_2 P + \beta_3 T)}{S+I+P+A+T}$.

$\beta_1 \geq \beta_2 \geq \beta_3$, are sexual contact rates of $S(t)$ with $I(t)$, $P(t)$ and $T(t)$ respectively.

The screening rate τ is experimented at the values 0.1, 0.3 and 0.5 for the scenario when population size is 10,000. The numerical simulation result is given in figure-4 below.

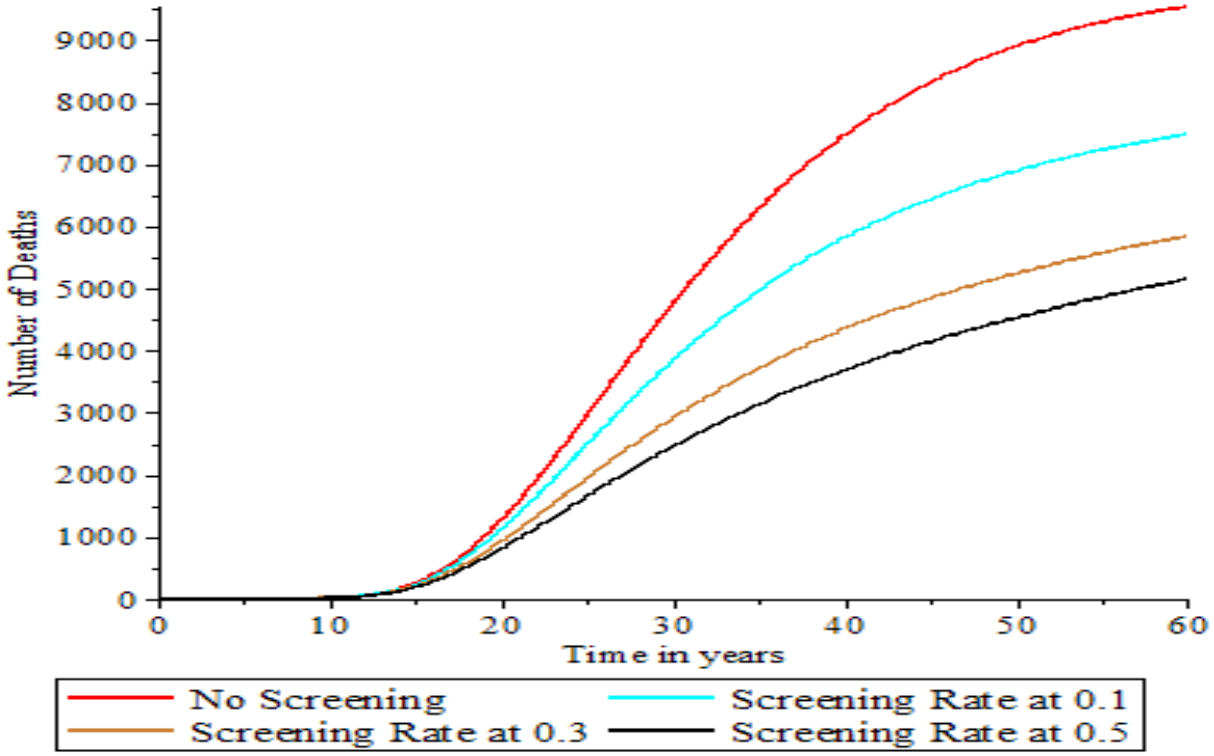


Figure 4: Graph on Number of Deaths when HIV Screening is introduced

From figure-4 above, at 15-years of the infection in the population cumulative number of deaths is below 5% for all the four curves. At 25-years, about 30% cumulative deaths has occurred on the no screening curve; 25% cumulative deaths have occurred on the screening at rate 0.1 curve; 20% cumulative deaths have occurred on the screening at rate 0.3 curve; and 17.5% cumulative deaths has occurred on the screening at rate 0.5 curve. At 35-years, about 65% cumulative deaths has occurred on the no-screening curve; 50% cumulative deaths have occurred on the screening at rate 0.1 curve; 37.5% cumulative

deaths have occurred on the screening at rate 0.3 curve; and above 30% cumulative deaths have occurred on the screening at rate 0.5 curve. At 45-years, close to 85% cumulative deaths has occurred on the no-screening curve; 65% cumulative deaths have occurred on the screening at rate 0.1 curve; close to 50% cumulative deaths has occurred on the screening at rate 0.3 curve; and little above 40% cumulative number of deaths has occurred on the screening at rate 0.5 curve. At 60-years, about 95% cumulative deaths has occurred on the no-screening curve; 70% cumulative deaths have occurred on the screening at rate 0.1 curve; close to 60% cumulative deaths has occurred on the screening at rate 0.3 curve; and little above 50% cumulative deaths has occurred on the screening at rate 0.5 curve.

Generally, percentage cumulative deaths are lower when screening is considered, and the higher the rate of screening the lesser the occurrence of mortality due to the disease.

DISCUSSION

By these results, HIV screening at pre-AIDS stage in the population is very crucial to the reduction of mortality due to the AIDS related disease. Once identified as infected, then care and treatment is assumed to follow immediately. The mortality curves showed that after the rising from zero occurrence of the events, when screening is introduced, there is reduction in the mortality due to treatment. The effect of higher screening rates showed to be more impactful on the outcome of mortality as time progresses. So, if the effect of screening is maximized in a population, mortality will likely be brought low tending to elimination among the infected in a community. By this, it is necessary to explore screening massively in a population.

Also, by the impact of screening discovered at this pre-AIDS stage, the symptomatic which normally will be burdened with pain as a result of illness setting in, may possibly be averted in addition with mortality if the infection is, may be, discovered earlier in the infected individuals. Therefore, it is necessary to seek another screening point in the progression of the disease whereby more of the infected will be identify, perhaps at an earlier infection stage of the disease, and then morbidity and mortality will be reduced more. Also, how often should HIV screening be done to reduce or eliminate mortality and morbidity is what we are working on presently.

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