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*Original Article*

# Mathematical Modelling of the Effect of HIV/AIDS on Sickle Cell Genotype with Perturbation in the Production of T-Cells on the Choice of Stability

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***Abstract*** *- Sickle cell disease is a genetic disorder resulting from a mutation in the haemoglobin gene. Human immunodeficiency virus (HIV) infections destroys the body immune system, increases risks of certain pathogens, damages body organs and causes death eventually. A person with both SCD and HIV presents a management challenge particularly in a resource limited situation. Studies show that the presence of SCD helps to control the effects of HIV in an individual and its transformation into AIDS later on. This study presents a pre-existing mathematical model based on a set of differential equations. The model is formulated such that it takes into account HIV infected cells and its effect on Sickle cell disease when there is a perturbation in the production of T-cells. It is observed that the dynamical system maintained instability for both trivial and non-trivial steady state with the help of characteristics equations, linearization and ODE45 numerical approach. The results also show that the boundaries of the co-existence of both the trivial and non-trivial steady state solutions of the T-cells increases. Hence, there is no significant relationship between the genotype of a patient and the growth of the HIV.*

***Keywords*** *- HIV, Infections, Genotype, Patient, Stability, Perturbation, Eigen Values, CD4 + T-Cells and ODE45.*

## 1. Introduction

Real life problems are usually modelled and analyzed with the help of ordinary differential and partial differential equation [1]. HIV have no cure though scientists are in constant search for the solution, meanwhile the spread of HIV is linked strongly with the spatial distribution of high risk-groups. AIDS cases distributions do not just vary by town and states but also by geographical regions [2]; besides blood group antigens have been reported several times to be associated with several disease condition [3,4]. Investigations have proven that ABO blood groups have an impact on immunity to infection in individuals having a particular blood group as a result of its associations observed when studied [5,6,7,8]. The discovery of ABO blood system in 1901 is traced to Landstemer [9-11] which is one of the series of glycoproteins and glycolipids present on the human red blood cells which form the red cell antigen. Landstemer and Werner in 1941 [12] later discovered Rh. These antigens which are genetically controlled are inherited in Mendolian till death [11]. About 700 erythrocyte antigen have be analyzed and organized into 30 blood transfusion out of which ABO and Rh are more important [10]. Blood group plays essential role in transfusion safety, understanding genetics, inheritance pattern, as well as solving certain medico-legal issues [13]. Some blood groups can act as a receptor and Ligand for bacteria, parasites and viruses [13]. [14] studied mathematical modelling of the effect of HIV/AIDS on sickle cell genotype and discovered that there is no significant relationship between the genotype of a patient and the growth of the HIV. The more production of CD4 + T-Cells the more effective the virus becomes and the more the patient becomes more susceptible to the infection. In this paper, we consider the mathematical modelling of the effect of HIV/AIDS on Sickle Cell Genotype with perturbation in the production of T-Cells on the choice of stability.

## 2. Mathematical formulation

We have considered the following assumptions:

1. There is perturbation in the production of T-Cells from the thymus
2. The thymus only strengthens the sickle cells
3. The interactions between sickle cell with infected HIV cell leads to the death of the sickle cell

Hence,

$$\frac{dT}{dt} = \phi - \mu(T-h) - \alpha_1(T-h) \qquad 1$$

$$\frac{dS}{dt} = -\mu S + \alpha_2 HS \qquad 2$$

$$\frac{dH}{dt} = -\mu H + \alpha_1(T-h)H - \alpha_2 HS \qquad 3$$

***Where:***

S = Sickle cell population

H = HIV infected cell population

$\phi$ = T cells influx from the thymus

$\mu$ = Death rate of T cells

h = Perturbation in the production of T cells

## 3. Method of Analysis

We have fully employ the ordinary differential equation of order 45 (ODE45) as a computational approach to model and predict the Effect of HIV/AIDS on Sickle Cell Genotype with Perturbation in the Production of T-Cells on the choice of stability.

## 4. Results

On the application of the above mentioned computational approach, the following useful results are obtained which are presented and displayed as shown in table 1 – table 10.

**Table 1. Quantifying the effect of random perturbation h = 0.0000 to 3.8000 in the production of T cells on the type of stability of the dynamical system of a trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 0.0000 | 16129.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 0.2000 | 16129.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 0.4000 | 16129.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 0.6000 | 16129.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 0.8000 | 16129.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 1.0000 | 16130.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 1.2000 | 16130.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 1.4000 | 16130.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 1.6000 | 16130.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 1.8000 | 16130.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 2.0000 | 16131.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 2.2000 | 16131.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 2.4000 | 16131.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 2.6000 | 16131.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 2.8000 | 16131.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 3.0000 | 16132.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 3.2000 | 16132.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 3.4000 | 16132.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 3.6000 | 16132.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 3.8000 | 16132.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |

**Table 2. Quantifying the effect of random perturbation h = 4.0000 to 7.8000 in the production of T cells on the type of stability of the dynamical system of a trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 4.0000 | 16133.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 4.2000 | 16133.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 4.4000 | 16133.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 4.6000 | 16133.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 4.8000 | 16133.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 5.0000 | 16134.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 5.2000 | 16134.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 5.4000 | 16134.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 5.6000 | 16134.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 5.8000 | 16134.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 6.0000 | 16135.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 6.2000 | 16135.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 6.4000 | 16135.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 6.6000 | 16135.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 6.8000 | 16135.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 7.0000 | 16136.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 7.2000 | 16136.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 7.4000 | 16136.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 7.6000 | 16136.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 7.8000 | 16136.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |

**Table 3.Quantifying the effect of random perturbation h = 8.0000 to 11.8000 in the production of T cells on the type of stability of the dynamical system of a trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 8.0000 | 16137.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 8.2000 | 16137.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 8.4000 | 16137.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 8.6000 | 16137.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 8.8000 | 16137.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 9.0000 | 16138.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 9.2000 | 16138.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 9.4000 | 16138.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 9.6000 | 16138.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 9.8000 | 16138.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 10.0000 | 16139.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 10.2000 | 16139.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 10.4000 | 16139.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 10.6000 | 16139.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 10.8000 | 16139.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 11.0000 | 16140.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 11.2000 | 16140.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 11.4000 | 16140.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 11.6000 | 16140.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 11.8000 | 16140.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |

**Table 4. Quantifying the effect of random perturbation h = 12.0000 to 15.8000 in the production of T cells on the type of stability of the dynamical system of a trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 12.0000 | 16141.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 12.2000 | 16141.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 12.4000 | 16141.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 12.6000 | 16141.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 12.8000 | 16141.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 13.0000 | 16142.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 13.2000 | 16142.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 13.4000 | 16142.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 13.6000 | 16142.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 13.8000 | 16142.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 14.0000 | 16143.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 14.2000 | 16143.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 14.4000 | 16143.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 14.6000 | 16143.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 14.8000 | 16143.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 15.0000 | 16144.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 15.2000 | 16144.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 15.4000 | 16144.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 15.6000 | 16144.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 15.8000 | 16144.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |

**Table 5. Quantifying the effect of random perturbation h = 16.0000 to 20.0000 in the production of T cells on the type of stability of the dynamical system of a trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 16.0000 | 16145.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 16.2000 | 16145.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 16.4000 | 16145.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 16.6000 | 16145.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 16.8000 | 16145.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 17.0000 | 16146.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 17.2000 | 16146.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 17.4000 | 16146.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 17.6000 | 16146.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 17.8000 | 16146.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 18.0000 | 16147.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 18.2000 | 16147.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 18.4000 | 16147.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 18.6000 | 16147.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 18.8000 | 16147.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 19.0000 | 16148.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 19.2000 | 16148.2323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 19.4000 | 16148.4323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 19.6000 | 16148.6323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 19.8000 | 16148.8323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |
| 20.0000 | 16149.0323 | 0.00 | 0.00 | -0.062000 | $-6.200000e^{-02}$ | 725.74 | Unstable |

**Table 6. Quantifying the effect of random perturbation h = 0.0000 to 3.8000 in the production of T cells on the type of stability of the dynamical system of a non-trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 0.0000 | 672211.0635 | 1875.29 | 0.18 | 29608.077828 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 0.2000 | 672220.4957 | 1875.29 | 0.18 | 29608.493276 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 0.4000 | 672229.9279 | 1875.29 | 0.18 | 29608.908725 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 0.6000 | 672239.3601 | 1875.29 | 0.18 | 29609.324173 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 0.8000 | 672248.7922 | 1875.29 | 0.18 | 29609.739621 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 1.0000 | 672258.2244 | 1875.29 | 0.18 | 29610.155069 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 1.2000 | 672267.6566 | 1875.29 | 0.18 | 29610.570518 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 1.4000 | 672277.0888 | 1875.29 | 0.18 | 29610.985966 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 1.6000 | 672286.5210 | 1875.29 | 0.18 | 29611.401414 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 1.8000 | 672295.9532 | 1875.29 | 0.18 | 29611.816862 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 2.0000 | 672305.3853 | 1875.29 | 0.18 | 29612.232311 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 2.2000 | 672314.8175 | 1875.29 | 0.18 | 29612.647759 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 2.4000 | 672324.2497 | 1875.29 | 0.18 | 29613.063207 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 2.6000 | 672333.6819 | 1875.29 | 0.18 | 29613.478655 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 2.8000 | 672343.1141 | 1875.29 | 0.18 | 29613.894103 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 3.0000 | 672352.5463 | 1875.29 | 0.18 | 29614.309552 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 3.2000 | 672361.9784 | 1875.29 | 0.18 | 29614.725000 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 3.4000 | 672371.4106 | 1875.29 | 0.18 | 29615.140448 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 3.6000 | 672380.8428 | 1875.29 | 0.18 | 29615.555896 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 3.8000 | 672390.2750 | 1875.29 | 0.18 | 29615.971345 | $-6.200000e^{-02}$ | 0.00 | Unstable |

**Table 7.Quantifying the effect of random perturbation h = 4.0000 to 7.8000 in the production of T cells on the type of stability of the dynamical system of a non-trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 4.0000 | 672399.7072 | 1875.29 | 0.18 | 29616.386793 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 4.2000 | 672409.1394 | 1875.29 | 0.18 | 29616.802241 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 4.4000 | 672418.5715 | 1875.29 | 0.18 | 29617.217689 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 4.6000 | 672428.0037 | 1875.29 | 0.18 | 29617.633138 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 4.8000 | 672437.4359 | 1875.29 | 0.18 | 29618.048586 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 5.0000 | 672446.8681 | 1875.29 | 0.18 | 29618.464034 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 5.2000 | 672456.3003 | 1875.29 | 0.18 | 29618.879482 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 5.4000 | 672465.7324 | 1875.29 | 0.18 | 29619.294931 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 5.6000 | 672475.1646 | 1875.29 | 0.18 | 29619.710379 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 5.8000 | 672484.5968 | 1875.29 | 0.18 | 29620.125827 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 6.0000 | 672494.0290 | 1875.29 | 0.18 | 29620.541275 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 6.2000 | 672503.4612 | 1875.29 | 0.18 | 29620.956724 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 6.4000 | 672512.8934 | 1875.29 | 0.18 | 29621.372172 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 6.6000 | 672522.3255 | 1875.29 | 0.18 | 29621.787620 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 6.8000 | 672531.7577 | 1875.29 | 0.18 | 29622.203068 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 7.0000 | 672541.1899 | 1875.29 | 0.18 | 29622.618516 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 7.2000 | 672550.6221 | 1875.29 | 0.18 | 29623.033965 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 7.4000 | 672560.0543 | 1875.29 | 0.18 | 29623.449413 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 7.6000 | 672569.4865 | 1875.29 | 0.18 | 29623.864861 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 7.8000 | 672578.9186 | 1875.29 | 0.18 | 29624.280309 | $-6.200000e^{-02}$ | 0.00 | Unstable |

**Table 8. Quantifying the effect of random perturbation h = 8.0000 to 11.8000 in the production of T cells on the type of stability of the dynamical system of a non-trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 8.0000 | 672588.3508 | 1875.29 | 0.18 | 29624.695758 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 8.2000 | 672597.7830 | 1875.29 | 0.18 | 29625.111206 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 8.4000 | 672607.2152 | 1875.29 | 0.18 | 29625.526654 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 8.6000 | 672616.6474 | 1875.29 | 0.18 | 29625.942102 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 8.8000 | 672626.0796 | 1875.29 | 0.18 | 29626.357551 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 9.0000 | 672635.5117 | 1875.29 | 0.18 | 29626.772999 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 9.2000 | 672644.9439 | 1875.29 | 0.18 | 29627.188447 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 9.4000 | 672654.3761 | 1875.29 | 0.18 | 29627.603895 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 9.6000 | 672663.8083 | 1875.29 | 0.18 | 29628.019344 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 9.8000 | 672673.2405 | 1875.29 | 0.18 | 29628.434792 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 10.0000 | 672682.6726 | 1875.29 | 0.18 | 29628.850240 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 10.2000 | 672692.1048 | 1875.29 | 0.18 | 29629.265688 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 10.4000 | 672701.5370 | 1875.29 | 0.18 | 29629.681137 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 10.6000 | 672710.9692 | 1875.29 | 0.18 | 29630.096585 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 10.8000 | 672720.4014 | 1875.29 | 0.18 | 29630.512033 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 11.0000 | 672729.8336 | 1875.29 | 0.18 | 29630.927481 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 11.2000 | 672739.2657 | 1875.29 | 0.18 | 29631.342930 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 11.4000 | 672748.6979 | 1875.29 | 0.18 | 29631.758378 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 11.6000 | 672758.1301 | 1875.29 | 0.18 | 29632.173826 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 11.8000 | 672767.5623 | 1875.29 | 0.18 | 29632.589274 | $-6.200000e^{-02}$ | 0.00 | Unstable |

**Table 9. Quantifying the effect of random perturbation h = 12.0000 to 15.8000 in the production of T cells on the type of stability of the dynamical system of a non-trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 12.0000 | 672776.9945 | 1875.29 | 0.18 | 29633.004722 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 12.2000 | 672786.4267 | 1875.29 | 0.18 | 29633.420171 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 12.4000 | 672795.8588 | 1875.29 | 0.18 | 29633.835619 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 12.6000 | 672805.2910 | 1875.29 | 0.18 | 29634.251067 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 12.8000 | 672814.7232 | 1875.29 | 0.18 | 29634.666515 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 13.0000 | 672824.1554 | 1875.29 | 0.18 | 29635.081964 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 13.2000 | 672833.5876 | 1875.29 | 0.18 | 29635.497412 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 13.4000 | 672843.0198 | 1875.29 | 0.18 | 29635.912860 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 13.6000 | 672852.4519 | 1875.29 | 0.18 | 29636.328308 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 13.8000 | 672861.8841 | 1875.29 | 0.18 | 29636.743757 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 14.0000 | 672871.3163 | 1875.29 | 0.18 | 29637.159205 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 14.2000 | 672880.7485 | 1875.29 | 0.18 | 29637.574653 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 14.4000 | 672890.1807 | 1875.29 | 0.18 | 29637.990101 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 14.6000 | 672899.6128 | 1875.29 | 0.18 | 29638.405550 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 14.8000 | 672909.0450 | 1875.29 | 0.18 | 29638.820998 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 15.0000 | 672918.4772 | 1875.29 | 0.18 | 29639.236446 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 15.2000 | 672927.9094 | 1875.29 | 0.18 | 29639.651894 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 15.4000 | 672937.3416 | 1875.29 | 0.18 | 29640.067343 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 15.6000 | 672946.7738 | 1875.29 | 0.18 | 29640.482791 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 15.8000 | 672956.2059 | 1875.29 | 0.18 | 29640.898239 | $-6.200000e^{-02}$ | 0.00 | Unstable |

**Table 10. Quantifying the effect of random perturbation h = 16.0000 to 20.0000 in the production of T cells on the type of stability of the dynamical system of a non-trivial steady state solution using ODE45 computational approach.**

| h | T | S | H | ev1 | ev2 | ev3 | TOS |
|---|---|---|---|---|---|---|---|
| 16.0000 | 672965.6381 | 1875.29 | 0.18 | 29641.313687 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 16.2000 | 672975.0703 | 1875.29 | 0.18 | 29641.729135 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 16.4000 | 672984.5025 | 1875.29 | 0.18 | 29642.144584 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 16.6000 | 672993.9347 | 1875.29 | 0.18 | 29642.560032 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 16.8000 | 673003.3669 | 1875.29 | 0.18 | 29642.975480 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 17.0000 | 673012.7990 | 1875.29 | 0.18 | 29643.390928 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 17.2000 | 673022.2312 | 1875.29 | 0.18 | 29643.806377 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 17.4000 | 673031.6634 | 1875.29 | 0.18 | 29644.221825 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 17.6000 | 673041.0956 | 1875.29 | 0.18 | 29644.637273 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 17.8000 | 673050.5278 | 1875.29 | 0.18 | 29645.052721 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 18.0000 | 673059.9600 | 1875.29 | 0.18 | 29645.468170 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 18.2000 | 673069.3921 | 1875.29 | 0.18 | 29645.883618 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 18.4000 | 673078.8243 | 1875.29 | 0.18 | 29646.299066 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 18.6000 | 673088.2565 | 1875.29 | 0.18 | 29646.714514 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 18.8000 | 673097.6887 | 1875.29 | 0.18 | 29647.129963 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 19.0000 | 673107.1209 | 1875.29 | 0.18 | 29647.545411 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 19.2000 | 673116.5530 | 1875.29 | 0.18 | 29647.960859 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 19.4000 | 673125.9852 | 1875.29 | 0.18 | 29648.376307 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 19.6000 | 673135.4174 | 1875.29 | 0.18 | 29648.791756 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 19.8000 | 673144.8496 | 1875.29 | 0.18 | 29649.207204 | $-6.200000e^{-02}$ | 0.00 | Unstable |
| 20.0000 | 673154.2818 | 1875.29 | 0.18 | 29649.622652 | $-6.200000e^{-02}$ | 0.00 | Unstable |

## 5. Discussion of Results

The effect of perturbation in the production of T-Cells to the blood stream causes the increase in infection due to the inability of the Perturb T-Cells to clear the virus, hence being infected by the virus and increasing the multiplication of the viral load, meanwhile the result shows clearly when there is no perturbation, the response of the dynamical system is unstable, as a perturbation increases the dynamical system still maintain instability. Though it increases the boundaries of the coexistence of both the trivial and non-trivial steady state solutions as reported in IV.

## 6. Conclusion

It is observed that the dynamical system maintained instability irrespective of the effect of HIV/AIDS on Sickle Cell Genotype with Perturbation in the Production of T-Cells and there is no significant relationship between the genotype of a patient and the growth of the HIV.

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