Modeling Spatio-Temporal Distribution of HIV Particles on Cervicovaginal Mucus and Nanoparticle-based Preventive Therapy

Human Immunodeficiency Virus (HIV) epidemics remain devastating around the world. Since there is no cure for HIV, preventive therapy has received tremendous attention. To find the immune cells, the primary target of HIV, the virus needs to cross the cervicovaginal mucus (CVM) layer, which acts as a barrier for the virus to move freely. The drug-filled nanoparticles that destroy viruses in CVM are one of the essential preventive therapies. In this study, we develop mathematical models to describe how the virus transports through the CVM and how this transport is affected by the CVM acidity. Since the motion of the virus in the acidic CVM is hindered, accurate modeling is necessary that can incorporate hindrance due to adherence in acidic media. We model the temporal dynamics of virus concentration using two model components diffusion and hindrance where diffusion is modeled using Fick's law and hindrance is modeled with pH dependency. We will use our model to evaluate the effects of nanoparticle-based therapy on virus distribution and transport across CVM. Our objective is to show that the proper implementation of nanoparticle-based therapy can significantly control virus entry through CVM, thereby avoiding the establishment of HIV infection. Such preventive approaches can be helpful to curb the global HIV epidemic.

Anuradha Agarwal *and Naveen K Vaidya*

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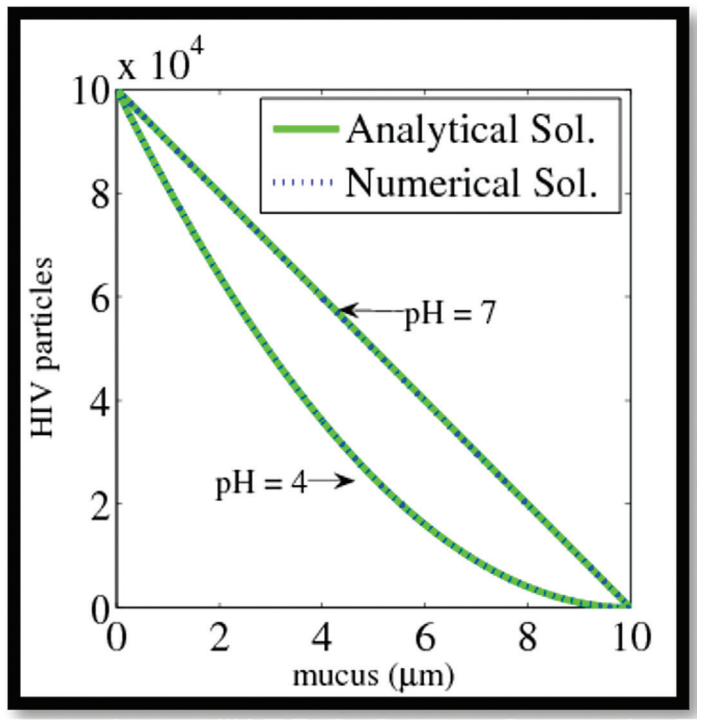
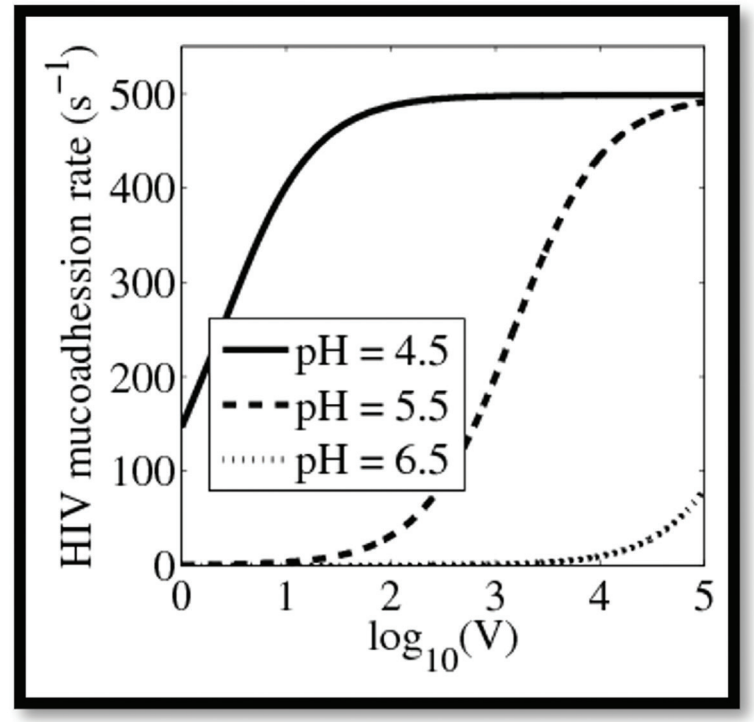
Main Equation:

$$\frac{\partial V}{\partial t} = D_v \Delta V - \frac{mV}{\phi + V}$$

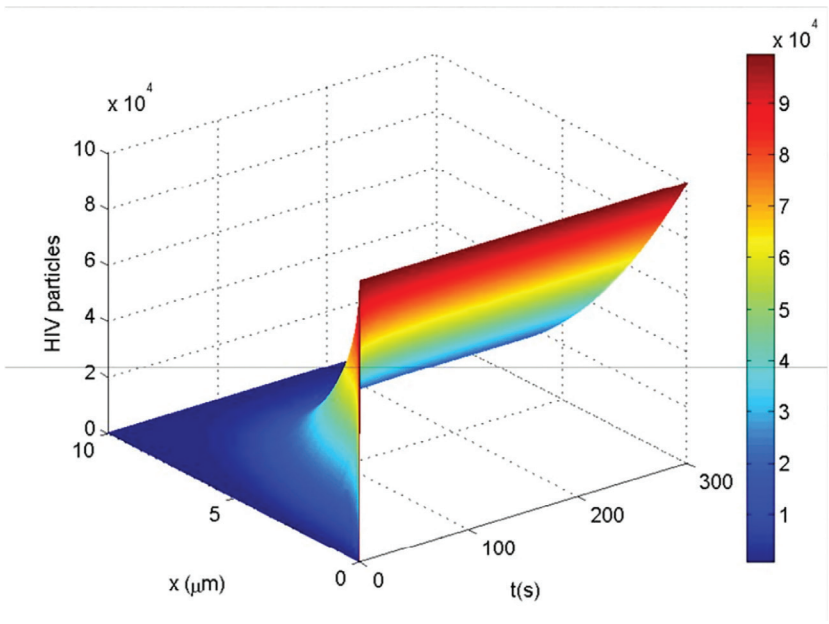
$$\text{B.C.:} V(0) = V_0, V(L) = 0$$



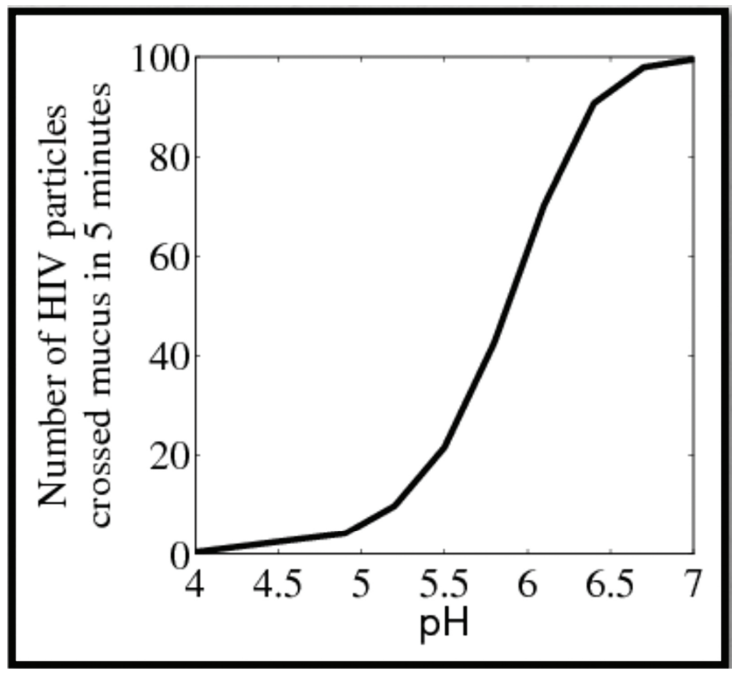
Steady state solutions: Analysis of steady state solutions gives the transit time from 0 to L. Transit time for base case computation with neutral pH is 3.3 minutes. Transit time for acidic pH is 13.9 hours.



Mucoadhesion rates for different pH values



Spatio temporal distribution of HIV in mucus



Number of HIV particles crossed mucus in 5 minutes