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Restricted Occupancy Models for Human Immunodeficiency Virus Neutralization by Antibodies

Viruses are not able to replicate by themselves. They need a host cell, which they manipulate to produce offspring according to the genetic code they provide. To this end, the virus has to enter the cell. The Human Immunodeficiency Virus (HIV) has spikes on its surface that consist of three identical envelope proteins. These spikes attach to target cell receptors and induce the infection of the cell.
To prevent the infection, the immune system elicits antibodies that bind to specific structures on the envelope proteins. If the number of spikes necessary for infection and the number of antibodies binding to one spike such that the spike is rendered non-functional are known, one can estimate the number of antibodies needed to neutralize one virion or a population of virions.
However, the number of spikes on the virion's surface vary from virion to virion and antibodies can bind randomly to the envelope proteins of different spikes. These effects make it impossible to directly determine the number of neutralizing antibodies. We present mathematical models that incorporate these random effects and allow to derive lower and upper bounds for the number of antibodies that have to bind to neutralize a virion or a virion population. In addition, by using restricted occupancy theory, we are able to calculate the mean number of antibodies neutralizing one virion and a population of virions.