Modeling COVID-19: Simulating the Effects of Waning Immunity Using a New Multi-Compartment Epidemiological Model

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The analysis of human coronaviruses and the confirmed cases of COVID-19 reinfection are indicative of waning immunity present to some degree in patients recovering from COVID-19. Therefore, controlling the pandemic in the long-term may rely upon an effective scheme to re-vaccinate populations to both suppress the disease and minimize the number of booster vaccinations required. In order to theoretically evaluate the effects of waning immunity and help optimize vaccine distribution, we propose a novel multi-compartment epidemiological model that simulates waning immunity and enables flexible immunization scenarios. We then study the long-term dynamical behavior of the resulting system of nonlinear differential equations. Our methods rely on a mixture of analytic and numerical techniques that include the Banach fixed point theorem to help determine the model's disease-free and endemic equilibria (abbreviated as DFE and EE below) and a linear stability analysis for the associated Jacobian matrices using the Gershgorin circle theorem. Our results yield the location of the DFE and EE for small rates of waning immunity and determine the model's basic reproductive number (R_0), the threshold at which the disease either persists or approaches the disease-free equilibrium. We also establish that R_0 can only be lowered with only one possible vaccination scheme within our model. This research shows the necessity for the optimization of vaccine distribution to battle the pandemic effectively.

Awards Won:
Second Award of $2,000
Mu Alpha Theta, National High School and Two-Year College Mathematics Honor Society: First Award of $ 1,500