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A mathematical model of within-host COVID-19 dynamics

Systems of differential equations are a natural platform for modeling within-host infection dynamics. In particular, ODE-based models of COVID-19 are used for treatment optimization, determining appropriate length of isolation period or searching for infection source. Generally, the research in this area is based solely on numerical solutions. In our talk we present a number of analytical results that can be useful for model tuning and increasing application performance.

Key words: *ODE, COVID-19 model, within-host infection dynamics.*

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Systems of ordinary differential equations (ODE) are a natural apparatus for modeling within-host disease dynamics. In particular, a number of papers devoted to investigation of COVID-19 use the following system:

$$\frac{\mathrm{d}U}{\mathrm{d}t} = -\beta UV, \quad \frac{\mathrm{d}I}{\mathrm{d}t} = \beta UV - \delta I, \quad \frac{\mathrm{d}V}{\mathrm{d}t} = pI - cV, \tag{1}$$

where U and I denote the number of uninfected and infected cells, V is the number of virus particles, β is infection intensity, δ and c are intensities of death of infected cells and virus particles, respectively, p is virus generation intensity [1]. Attempts to fit the model to real data showed that this system is still too complex, so in [2] the authors used a quasi-steady state assumption to obtain the system in two variables

$$\frac{\mathrm{d}F}{\mathrm{d}t} = -\beta FV, \quad \frac{\mathrm{d}V}{\mathrm{d}t} = \gamma FV - \delta V, \tag{2}$$

where F is the fraction of uninfected cells. Numerical solution of this system was used to study treatment strategy optimization, select adequate isolation period, determine possible sources of infection. *In vitro* experiments showed that infected cells stay viable [3],

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and virus death rate is negligible, thus there emerges the system $(1')$ obtained from (1) by setting δ and c equal to 0. In the first part of our talk we present formal assertions on solutions of the systems (2) and $(1')$. In the second part we introduce the system of equations that adequately describes experimental data from [3].

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АННОТАЦИЯ

Системы обыкновенных дифференциальных уравнений являются естественным аппаратом для моделирования течения заболевания. В частности, модели протекания COVID-19, построенные на основе таких систем, использовались для оптимизации лечения, определения адекватного периода изоляции и поиска источников заражения. Большинство исследований такого рода основывается исключительно на численном решении. В статье представлен ряд аналитических результатов, которые могут быть использованы для подгонки моделей к реальным данным и для повышения производительности моделирования.

Ключевые слова: *системы дифференциальных уравнений, COVID-19.*