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Seeking the threshold for herd immunity in the synthetic population of a medium-sized city

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Motivation and Aim: The concept of herd immunity has been repetitively used by the public health authorities since the beginning of 2020 as a necessary condition for the end of the COVID-19 pandemic. It can be defined as a proportion of the population that is needed to be immune for the rate of the infection to decline [1]. From the mathematical point of view, the simplest way to calculate it is 1-1/R0, where R0 is a basic reproductive number of the infection. But the problem is that the estimates of R0 for COVID-19 varied widely, from 2 to 7 [2], that leads to different estimates for the threshold value of herd immunity. At the same time this formula does not contain the efficiency and the duration of the immunity and therefore it can be useful only within the short period of time when the recovered individuals are entirely protected. The aim of our work is to simulate the circulation of a respiratory virus in a synthetic population of 200 000 individuals and to reveal the leading factors in forming herd immunity.

Methods and Algorithms: We developed an agent-based model that consists of a synthetic population of agents and a set of rules that determine contacts between them. Each agent has a set of properties such as age, sex and social status the distributions of which were typical for medium-sizes Russian cities. Modeling disease transmission we considered only those physical contacts when people can be at a short distance from each other such as contacts between family members, classmates, colleagues and contacts in a public transport. For this purpose, we use data on the number of enterprises and public transport routs of several for medium-sizes cities. Using age-specific contact patterns [3] we simulate the spread of new virus in the population.

Results: By changing the number of contacts between agents we simulated the spread of viral infection with and without quarantine measures. We demonstrated that the quarantine measures strongly influence on the dynamics and help to control as well as an abrupt cancellation of all restrictive measures can provoke a postponed growth of the incidence. It was shown that the herd immunity can be achieved during one year only if the immunity after recovery is effective in more than 70 % cases of reinfection and without any restrictive measures. If the immune subpopulation protected from the viruses in less than 40 % cases of infections, the herd immunity is not achievable and the pathogen causes recurrent waves of infection.

Conclusion: The duration of natural immunity from COVID-19 and its effectivity against new strains are the subject of many investigations for the moment as well as the effectiveness of the vaccination. One way to assess the level of population immunity is to estimate the seroprevalence of anti-SARS-CoV-2 IgG antibodies [4, 5]. The following step is to incorporate such information in the model and to simulate the circulation of existing and new strains of SARS-Cov2.

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