STRATEGIES FOR VACCINATION AGAINST SARS-COV-2 TO EFFICIENTLY BRING R<1

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ABSTRACT
With limited availability of vaccines, an efficient use of the limited supply of vaccines in order to achieve herd immunity will be an important tool to combat the widespread prevalence of COVID-19. Here, we propose a targeted vaccination approach (EHR) that provides a significant reduction in the necessary number of doses needed to achieve herd immunity compared to age-prioritized and random selection vaccination schemes. Using high-fidelity individual-based computer simulations with Oslo, Norway as an example, we find that for a community reproductive number in a setting where R=1.4 without population immunity, the EHR method reaches herd immunity at only 15% of the population vaccinated, whereas the common age-prioritized approach needs 40%. With R=1.9 in the absence of immunity, EHR needs 30% and age-prioritized needs 52%.
Population-wide vaccination is the most promising approach for long-term COVID-19 disease management. Due to limited vaccine availability, authorities have to choose vaccination prioritization schemes that balance potential total mortality, years of life lost, and cumulative levels of infections (1). In most European countries and the US, health care workers and the elderly are prioritized in order to reduce mortality and maintain health service readiness. However, in areas where prevalence is very low, mortality rate is of secondary importance to case prevention. In such areas, as vaccines not only prevent infection but also transmissions\textsuperscript{2}, one should identify vaccination strategies that bring the reproductive number R below unity with the least vaccination effort. After identified critical groups have been vaccinated, the same argument applies to areas with high prevalence, as this would allow faster restoration of normalcy for the whole society.

Using an individual-based model that includes SEIR, age-stratification and high-fidelity demographic data for Oslo, Norway\textsuperscript{3,4}, we have investigated the consequences of different vaccination strategies for the general population on reducing R. Compared to random vaccination, where every individual is equally likely to be selected, we find that prioritizing vaccinations by age (eldest first) requires a substantially larger number of vaccines to achieve herd immunity (Figure 1).

In contrast, we find that a vaccination strategy that reduces the impact of large households on epidemic spread by gradually reducing the maximum effective household size (number of unvaccinated individuals per household) produces a greater reduction in R for a given fraction of the population vaccinated. This strategy is motivated by observations in the UK\textsuperscript{5}, France and Norway\textsuperscript{3} that a large proportion of COVID-19 transmissions takes place in household settings, and that larger households are associated with increased risk of exposure to COVID-19.

Assuming R=1.9 prior to vaccination efforts being initiated, we find that the latter strategy achieves herd immunity with 30\% of the population vaccinated, compared to 40\% for randomly distributed vaccines and 52\% for purely age-focused strategy.

Given the unprecedented scale and urgency of the ongoing global vaccination project, which is expected to take at least several months, it is of vital importance to identify the most effective strategies to accelerate the acquisition of the herd immunity on which the long-awaited return to normalcy depends. If even moderate reductions in the number of required vaccines allows the world to reach this goal a few months earlier, the benefits would be extensive.
Figure 1: (A) Reduction in $R$ as function of vaccinated population fraction $F$ for three vaccination strategies; (orange) random selection, (green) age-prioritized selection, and (blue) effective household reduction (EHR). Horizontal dashed line indicates herd immunity threshold ($R=1$). For EHR, each individual is assigned a priority rating equal to the number of unvaccinated members of their household. When an individual of a household is vaccinated (eldest first), the remaining household members have their priority reduced by one. Eg. all six-person households would receive one vaccine each (to their eldest member) before any are given to five-person households. Software and simulation details are available\textsuperscript{4}. (B) Fraction of population vaccinated to reach herd immunity $F^*$ as a function of $R$ before vaccination for the three vaccination strategies.
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