Evaluating household-pooled universal testing to control COVID-19 epidemics, using an individual-based model

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AUTHOR SUMMARY

As pre-symptomatic transmission is an important driver of COVID-19 epidemics (i.e., the virus is transmitted before the infected individual is aware of its infectiousness), contact tracing efforts struggle to fully control SARS-CoV-2 epidemics. For this reason, the use of universal testing, where each individual of the community is tested on a regular basis, has been suggested. However, the large amount of PCR tests that is required to facilitate this approach, remains an important impediment. Therefore, we propose a new universal testing procedure that is feasible with a limited testing capacity, where we rely on PCR test pooling of individuals that belong to the same households. We consider the Belgian population as a multi-agent system, and we evaluate this universal testing procedure in a fine-grained epidemiological model (i.e., an individual-based model). Through this evaluation, we assess the procedure's performance to keep the epidemic under control, while allowing for various contact reductions. We assess the robustness of the universal testing procedure, by analysing different levels of community compliance, and we show that weekly universal testing could prove a successful strategy to control SARS-CoV-2 outbreaks.

We present an extended abstract of the paper titled "Assessing the feasibility and effectiveness of household-pooled universal testing to control COVID-19 epidemics" that has been published in PLOS Computational Biology [8].

KEYWORDS

universal testing, sample pooling, individual-based model, epidemic control, SARS-CoV-2, COVID-19

EXTENDED ABSTRACT

The SARS-CoV-2 pandemic has caused over 10 million COVID-19 cases and over 0.5 million deaths around the world in 2020 [10]. This infection count is presumably an underestimate due to the large proportion of asymptomatic cases [12]. Presently, there are different vaccines and treatment candidates under development and in different phases of clincal trials, including vaccines that are being approved by governmental regulatory agencies. Nevertheless, the control of SARS-CoV-2 outbreaks still predominantly relies on non-pharmaceutical interventions. Whereas, at the start of the pandemic invasive measures such as a full societal lock-down were used to avoid an overflow of the intensive care units [5], later on, many countries aimed to control their local SARS-CoV-2 epidemic using a combination of social distancing, teleworking, mouth masks and contact tracing. Yet, while these measures have the potential to reduce the number of detectable infections below 20 cases per 100.000 individuals per day, this still leaves regions prone to local outbreaks, that again require more stringent mitigation measures with societal and economical implications. As a result, in the fall and winter of 2020, many countries had problems controlling the virus.

The burden of hospitalisation and COVID-19 related mortality seems to be the major motivation to reduce the number of infections. However, keeping the number of infections as low as possible is in the overall population's interest, considering reports on COVID-19 related morbidities throughout all age groups, including neurological conditions, persistent post-recovery symptoms, cardiac injury and pulmonary fibrosis. However, as pre-symptomatic transmission remains an important driver of the epidemic, it comes as no surprise that contact tracing struggles to fully control SARS-CoV-2 epidemics [3, 6, 13]. This is further complicated by the fact that contact tracing is sensitive to the reported number of contacts, which depends on the reporting compliance of the traced individual [6, 13]. The use of universal testing (i.e., testing the entire population of a geographical region) has been suggested as a solution to suppress SARS-CoV-2 epidemics [2, 11]. Yet, the number of tests necessary to test a country's entire population in a reasonable time window, remains a serious impediment to this approach.

In this work, we use PCR test pooling, i.e., we combine a number of samples into a pool and test this pool using a single PCR test. As it is logistically most convenient to test household members at the same time, we construct pools out of individuals that belong to the same household. Additionally, testing household members simultaneously agrees with the fact that household members are prone to infect each other [7]. We consider sample pooling for pools of size 16 and 32, for which recently PCR test sensitivity scores were established [15].

This approach facilitates two isolation strategies. Firstly, *pool isolation*, where we isolate all individuals that belong to a positive PCR test pool, regardless of their individual infection status. Secondly, *individual isolation*, where we determine which of the individuals that belong to the positive PCR pool are positive, through an additional testing step. In this isolation strategy, the individuals in the positive PCR pool are kept in isolation until the individual testing results become available, upon which the individuals that test negative are released from isolation. Thus, in the individual isolation strategy, only the individuals that are responsible for the positivity of the pooled sample are isolated. Both isolation strategies have their advantages and disadvantages. On the one hand, when each individual that belongs to a positive pool is isolated (i.e., pool isolation), this means that negative individuals will be isolated as well, which might have implications for the community compliance with respect to isolation. The pool isolation strategy reduces the need for additional tests, rendering it a preferred strategy when the prevalence is high, and the required number of additional tests is unavailable. On the other hand, when prevalence is low, the number of additional required tests is expected to be low as well, and in such an epidemic phase, performing the additional tests necessary for the individual isolation strategy might prove worthwhile, as it could increase isolation compliance.

For both strategies, it is necessary that the pools have a similar number of households, i.e., that the difference in number of households between pools is minimal, to minimize the number of households that are affected when a pool tests positive. To meet this objective, we construct a heuristic allocation algorithm to assign households to a set of pools of equal size.

We evaluate this universal testing approach in a multi-agent environment, using an individual-based epidemiological model in the context of the Belgian COVID-19 epidemic [14] and demonstrate that it is possible to test the whole Belgian population (11 million individuals), in a time span of 1 to 4 weeks. For this, we rely on the testing capacity that was available in Belgium in autumn and winter of 2020, to accommodate the expected indidence of respiratory infections [9]. While we conduct experiments concerning the implementation of universal testing to test the whole Belgian population, we note that the presented framework can also be used to design reactive policies to control local outbreaks (e.g, cities) [4]. In order to assess the robustness of our universal testing approach, we consider different levels of testing and isolation compliance. Furthermore, we consider different false negative rates of the pooled PCR test and the impact of the pool size.

We use the *STRIDE* individual-based model to simulate households and the social interactions that take place within and between these households. *STRIDE* has been used to reproduce the Belgian COVID-19 epidemic and to evaluate different strategies to gradually exit the lock-down [14]. This model was able to closely match the data that was observed during the Belgian epidemic (i.e., hospital admissions, serial sero-prevalence) [1, 14]).

In this work, we show through simulation, that universal testing is able to control the epidemic, even when many of the contact reductions are relieved. Additionally, universal testing implicitly implements surveillance at a high resolution, resulting in a good estimate of the actual incidence and the heterogeneity of this incidence with respect to geography and age. This detailed view on the state of the epidemic will ensure that emergency signals are picked up more rapidly, enabling a swift response that might avoid more invasive control measures.

We acknowledge that the implementation of universal testing is challenging. Therefore, we discuss the different aspects related to sampling and PCR testing, to demonstrate the feasibility of universal testing when a decentralized testing approach is used. Finally, our models show that the use of universal testing in combination with stringent contact reductions, could be considered as a strategy to eradicate the virus locally, which is important when viral variants that interfere with vaccine efficacy would appear.

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