Gabriele-Rivet V, Spence KL, Ogden NH, Fazil A, Turgeon P, Otten A, Waddell LA, Ng V.

Modelling the impact of age-stratified public health measures on SARS-CoV-2 transmission in Canada

R Soc Open Sci. 2021;8(11):210834.

Public health measures have helped to control transmission of SARS-CoV-2 in Canada but closing businesses, schools and recreation centres, limiting travel, and stay-at-home orders can have significant consequences on other health conditions (such as non-emergency surgeries or mental well-being) and on economics and social cohesion. Modelling studies have projected that without sustained community-wide public health measures (PHMs), the epidemic will resurge. This is one of the first studies exploring the effects of implementing PHMs for only certain portions of the population in mathematical models for the Canadian population. Proponents for imposing PHMs according to age and vulnerability hypothesize that focusing on protecting only vulnerable populations, while others resume life without any restrictions, could allow for gradual herd immunity while minimizing severe health outcomes and societal and economic disruptions.

This study used an age-stratified agent-based model based on population demographics and healthcare capacity in Canada, to test the idea that protecting people who are in vulnerable age groups by shielding them from infection, or by vaccination, allows restrictions to other age groups to be lifted.

Agent-based models (ABMs) can simulate disease transmission at the individual level, which allows for individual (agent) social and behavioural characteristics within defined spaces to be included. ABMs can use the same inputs to estimate a range of different outcomes for complex, dynamic systems. The theoretical scenarios in this model explored the effects of shielding or immunizing only older age groups under optimal, but unrealistic conditions (i.e., interventions which produce an instant effect and are applied simultaneously to the entire target population with perfect compliance). The model was intentionally designed to determine whether implementing 'near perfect' age-stratified measures would make it safe to lift PHMs for the rest of the community, compared with a scenario with sustained community-wide PHMs applied to everyone.

Methods

A stochastic age-stratified ABM was developed in **AnyLogic** Professional 8.7.1 to simulate the spread of SARS-CoV-2 in the Canadian population, incorporating both asymptomatic and symptomatic infections. (This same model was used to explore PHMs to control COVID-19 in Canada in **earlier studies**). The model is a simplified approximation of the general situation across Canada, running on a daily time step over a 2-year period (7 February 2020 - 7 January 2022). The model includes a population of 100,000 agents (individuals), representing the age structure and demographics of the Canadian population. Agents are each assigned to a household and have an age-specific daily probability of leaving the house to a designated common environment (school, workplace or mixed-age venue) according to their likelihood of spending time in a given location. Transmission of SARS- CoV-2 occurs within the community through contacts between individuals in any of these environments. Parametrization of transmission and virulence in the model was based on the original wild-type virus.

The benchmark scenario was based on available data on population mobility, under-reporting and individual compliance and incorporated the following PHMs:

(i) from 16 March 2020, onwards, a constant rate of 20% of symptomatic cases detected and isolated and 50% of the detected cases contact traced and quarantined. Contact tracing measures discontinued when the number of active clinical cases exceeded 50 per 100,000 to reflect health systems capacity limits; and

(ii) from 16 March to 7 September 2020, implementation of three phases of community closures and physical distancing reflecting closures and gradual reopening of schools, workplaces and mixed-age venues over time and varying levels of contact rate reduction outside of the household with age-specific compliance[1]

In the benchmark scenario all common spaces reopened after September 7, 2020, but shutdowns were activated when the daily number of active clinical cases surpassed 100 per 100,000 people, as happened across Canada. These shutdowns included closing 100% of schools, 50% of workplaces and 50% of mixed-age venues for a period of 42 days, which reflects the initial degree of closures in March 2020. Shutdowns were activated and personal physical distancing was maintained throughout the remaining simulation time. Personal physical distancing was modelled as reducing contact rates to 45% of those pre-COVID-19, with age-specific compliance based on Canadian survey data of behaviours.

The age-stratified scenarios explored the implementation of the following interventions to all individuals above a given age threshold: (i) vaccination with an infection-preventing vaccine, (ii) vaccination with an illness-preventing vaccine or (iii) shielding from the remainder of the community, without vaccination (Table 1). Three age groups – greater than or equal to 45, 55 and 65 years old – were used to test the age-stratified intervention scenarios while lifting various community-wide PHMs. Shutdowns and physical distancing ceased once the age-stratified interventions were applied, whereas minimal control through case detection and contact tracing, as in the benchmark scenario, continued for the duration of the model run. Each scenario was run for 100 realizations, considered sufficient based on past research using this mathematical model.

The outcomes of interest were: the overall attack rate, clinical attack rate, asymptomatic attack rate, clinical mortality rate, infection fatality rate, number of hospitalizations, number of intensive care unit (ICU) admissions, number of deaths, number of days over the estimated maximum Canadian hospital bed capacity (30 beds per 100 000), and the estimated maximum ICU bed capacity (9 beds per 100 000).

Table 1 - Age-stratified interventions explored in the model

Scenario	Details
Infection-preventing vaccine	Administered to all individuals above the age threshold. Each vaccinated person has a 95% probability of developing immunity against infection. Individuals who develop immunity have a 0% probability of infection upon contact with an infected person (cannot become infected or transmit to others). Individuals maintain regular contacts within and outside of the household
Illness-preventing vaccine	Administered to all individuals above the age threshold. Each vaccinated person has a 95% probability of developing immunity against symptomatic infection. Individuals who develop immunity have a 0% probability of developing symptoms and are able to transmit disease to others if infected. Individuals maintain regular contacts within and outside of the household
Shielding	All persons above the age threshold remain in their households the majority of the time and have a 5% daily probability of leaving the household to go visit mixed-aged venues. Individuals reduce contact with other members of the household, regardless of their age, by 75%.

Results

The benchmark scenario generated steady epidemic curves across time, with a median fluctuating around 10 cases per 100 000 people. However, in all three age-stratified intervention scenarios, removing PHMs led to a substantial increase in the median attack rate (up to 61.2% attack rate) and an exponential growth in the daily incidence curves. Among all age-stratified interventions, the infection-preventing vaccine scenario generated the lowest number of cases, followed by the shielding scenario. For both scenarios, the incidence was further decreased as the age threshold decreased.

Similarly, all age-stratified scenarios resulted in increased hospitalizations, ICU admissions and cumulative deaths, compared to most runs of the benchmark scenario. Even in the most effective scenarios (vaccine scenarios for people 45 years or older), the median daily hospital and ICU beds exceeded capacities for a median of 1.5 to 3 months. The number of hospitalizations, ICU admissions and deaths varied by scenario, with shielding producing the worse outcomes for all three age thresholds.

For all age-stratified interventions, the population under the age thresholds saw increases in case numbers (up to 8-fold), hospitalizations (up to 8.5-fold), ICU admissions (up to 9-fold) and deaths (up to 20-fold), compared with the benchmark. In addition to these adverse effects on younger populations, the shielding scenario led to a substantial increase in severe outcomes for individuals above all three age thresholds (up to 5.7-fold and 11.6-fold increase in hospitalizations and deaths, respectively).

The vaccine scenarios did provide some benefit for those who were immunized; both the illness-preventing vaccine and the infection-preventing vaccine scenarios resulted in reduced hospitalizations and ICU admissions for those above the age threshold. Furthermore, the infection-preventing vaccine intervention also reduced the number of cases (≥45 and ≥55 scenarios) and deaths (≥45 scenario) for those above the corresponding age threshold.

Discussion

Overall, the results of this mathematical model show that applying interventions exclusively to the high-risk age groups without sustained PHMs in the community, would generate a resurgence of infections and increased hospitalizations, ICU admissions and deaths. If targeted age-stratified interventions are to be considered, PHMs must be maintained in the community to prevent a resurgence of COVID-19 until a sufficiently large proportion of the population is vaccinated. Across all modelled scenarios, the benchmark scenario, which reflects the recurrent community-wide shutdowns implemented in reality, was the safest option by far, as has been shown in Canada and worldwide.

Younger populations showed considerably worse outcomes in all the age-stratified scenarios compared with the benchmark, suggesting the targeted approaches would lead to a large number of avoidable deaths. This model does not take into account the effects of Long COVID-19 on the younger population who did survive infection. Actively promoting the spread of COVID-19 within a portion of the population, even in younger individuals, raises serious ethical concerns.

Across all age-stratified scenarios, the approach of shielding older populations while relaxing community-wide PHMs would be the most detrimental, leading to a substantial increase in severe outcomes for all age groups including the targeted population. The shielding approach is not sufficient to prevent transmission to the older population within their respective households or during infrequent visits to common venues. The ethical implications of strictly shielding up to 45% of the population (i.e. with a 45 years old threshold) from the remainder of the population for long periods of time also needs to be considered. There would likely be severe psychological impacts on the shielded population and a significant proportion of the workforce would be prevented from earning a living.

Administering a highly effective infection-preventing vaccine to all individuals 45 years or older (approx. 45% of the population) is insufficient to safely lift closures and physical distancing restrictions in Canada. Given the current knowledge on the epidemiology of COVID-19, a 45% vaccination coverage is not enough to achieve herd immunity even with a highly effective vaccine. Lifting PHMs too early during vaccine roll-out has been found to increase infections and severe outcomes in this and other research.

This research model is parametrized using the best available surveillance data on the age-specific proportions of cases that require hospitalization care and/or die (acocording to the original wild-type virus), and is consistent with observations and estimates used in other modelling studies of this type. Limitations in this research study include uncertainty in some data, such as the probability of asymptomatic individuals transmitting the virus, and the duration of immunity from natural infection. Furthermore, the model explored community transmission, but not transmission within health care and long-term care facilities, where PHMs would be implemented differently. Detection and isolation rates have likely varied over time and between jurisdictions during the pandemic but without specific data, rates were kept constant in the model for simplicity.

The idea of actively pursuing herd immunity through natural infection while focusing protection measures on "vulnerable populations" may seem appealing, however this modelling study found that such an approach could be devastating to younger age groups and to health care systems, even with 'near perfect' interventions applied under the most optimal conditions. If an age-stratified approach were to be considered, additional community-wide PHMs must be maintained to avoid detrimental outcomes resulting from SARS-CoV-2 transmission until a sufficiently large proportion of the population achieves immunity from vaccination