Mathematical modeling of COVID-19 in British Columbia: an age-structured model with time-dependent contact rates

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CIHR multi-province COVID modeling full-team meetings

Thursday, 21 April 2022.
**Goal:** Use the *real-time* information collected through the BC-Mix survey to inform a mathematical model of COVID-19.
Project goals

**Goal:** Use the *real-time* information collected through the BC-Mix survey to inform a mathematical model of COVID-19

**How we achieved this goal:**
- Develop an age-structured model to study the transmission dynamics of COVID-19
- Use BC-Mix survey data to compute
  - time-dependent contact rates for each age group
  - the population mixing pattern in BC during the pandemic
- Fit our model to the weekly reported cases of COVID-19 in BC
- Show that time-dependent contact rates are required to adequately capture the dynamics of COVID-19
- Validation: use the model to projected COVID-19 cases in BC
Mathematical model

- Susceptible individuals ($S$)
- Exposed population ($E_1$); Pre-symptomatic individuals ($E_2$)
- Infected individuals in the first half of their infectious period ($I_1$)
- Infected individuals in the second half of their infectious period ($I_2$)
- Recovered ($R$)

Model parameters:
- $\beta_j$: transmission rate
- $K_j(t)$: time-dependent average weekly contact rate (computed from BC-Mix survey)
- $C_{inf}^j$: the proportion of the total contacts of age group $j$th that is made with infectious individuals
- $H_1$: rate of transitioning from $E_1$ to $E_2$
- $H_2$: is the pre-symptomatic period
- $\gamma$: recovery rate
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- $H_1$: rate of transitioning from $E_1$ to $E_2$
- $1/H_2$: is the pre-symptomatic period
- $\gamma$ is the recovery rate
Model age groups and assumptions

- We stratify BC population into $N_{age} = 10$ age groups:
  - $< 2$ years, 2-5 years, 6-17 years
  - 18-24 years, 25-34 years, 35-44 years, 45-54 years,
  - 55-64 years, 65-74 years, and 75+ years

- We assume that kids 0-17 years are 50% as susceptible to COVID-19 as adults

- Incubation period of 5 days (Constant across age groups)

- Pre-symptomatic period of a day (Constant across age groups)

- Infectious period of 5 days (Constant across age groups)

- Considered a study period of Sept. 2020 to end of January 2021
Time-dependent weekly contact rate, $K_j(t)$

- Consider responses to the survey question: "How many people did you have in-person contact with between 5 am yesterday and 5 am today?"

- In-person contact is defined as either
  - having an in-person two-way conversation with three or more words
  - physical skin-to-skin contact, e.g. a handshake, hug, kiss, or contact sports

Inferred the contact rates for the age groups:
- $\leq 2$ years: 5.5280
- 2 - 5 years: 12.4169
- 6 - 17 years: 13.4486

from the model used to study the dynamics of 2009 H1N1 influenza in Vancouver.

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Population mixing matrix, $C$

- Survey respondents were also asked the age groups of their contacts

Each column shows the proportion of the total contacts of each age group that is made with the other age groups.

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Collected weekly reported cases of COVID-19 from a line list generated by BCCDC Public Health Reporting Data Warehouse (PHRDW) based on symptoms onset date.
Reported cases of COVID-19 in BC

- Collected weekly reported cases of COVID-19 from a line list generated by BCCDC Public Health Reporting Data Warehouse (PHRDW) based on symptoms onset date

- focused on community transmission
- removed cases identified as a patient or resident (not staff) of long-term care facility
Bayesian inference

- Fit our age-structured model to the weekly reported cases of COVID-19 in BC using Bayesian inference framework

- A seroprevalence rate of 4.5\%\(^1\) was used to calculated the ascertainment fraction of COVID-19 in BC as 0.255 of total cases (i.e., only 25.50\% of all cases were reported)

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From our model fits, we estimated:

- the total prevalence of COVID-19 in BC at the beginning of our study period.

- scaling parameters for the average weekly contact rates for each age group. The scaling parameters are used to:
  - translate self-reported contact rates (from BC-Mix survey) into impacts on transmission.
  - account for other factors that affect disease transmission not accounted for explicitly in our model.

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We consider four (4) Bayesian inference models to better understand the effects of contact rates and the scaling parameters on our model predictions.

SSFR model

- A single scaling parameter for the contact rates across all age groups and a fixed contact rate for each age group throughout the study period.
ASSFR model

- **Age-specific scaling parameters** and a **fixed contact rate** for each age group throughout the study period.
SSVR model

- A single scaling parameter across age groups and time-dependent average weekly contact rates for each age group
ASSVR model

- Age-specific scaling parameters and time-dependent average weekly contact rates
Model ranking

- Both the leave-one-out cross-validation (LOO) and widely applicable information criterion (WAIC) ranked the ASSVR model as the most preferred.

- This shows that age-specific scaling parameters and time-dependent contacts rates are required to adequately model COVID-19 transmission dynamics.
Model validation (using the ASSVR model)

We generated short-term projections of new cases:
- fit our model to a subset of the reported cases: September to December 2020
- project cases for January 2021 (4 weeks)
- compare predicted cases against actual reported cases for this 4-week period
Model validation (using the ASSVR model)

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Summary and future work

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- We developed an age-structured model to study the dynamics of COVID-19 in BC
- Used *real-time* BC-Mix survey data to
  - compute time-dependent weekly contact rate
  - construct a population mixing matrix

Future work:
- Incorporate time-dependent scaling parameters and mixing matrices

BC-CDC

Age-structured model

BC-Mix Survey
Summary:

- We developed an age-structured model to study the dynamics of COVID-19 in BC.
- Used *real-time* BC-Mix survey data to:
  - compute time-dependent weekly contact rate
  - construct a population mixing matrix
- Our study shows:
  - how empirical contact rate data can be integrated into a transmission modeling framework
  - that real-time contact survey data can provide improved estimates of infection rates
  - that self-reported contacts are adequate to capture interactions between age groups
  - that time-dependent contact rates are required to adequately capture COVID-19 dynamics

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- incorporate time-dependent scaling parameters and mixing matrices
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Thank you!!!