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COVID-19 epidemiology in Canada from January to December 2020: the pre-vaccine era

David Waldner[a], Robyn Harrison[a], Jennie Johnstone[b], Lynora Saxinger[a], Duncan Webster[c], and Wendy Sligl[a*]

[a]University of Alberta, Edmonton, AB T6G 2B7, Canada; [b]University of Toronto, Toronto, ON M5S 1A1, Canada; [c]Dalhousie University, Halifax, NS B3H 4R2, Canada

*wsligl@ualberta.ca

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Abstract

This paper summarizes COVID-19 disease epidemiology in Canada in the pre-vaccine era—from January through to December 2020. Canadian case numbers, risk factors, disease presentations (including severe and critical disease), and outcomes are described. Differences between provinces and territories in geography, population size and density, health demographics, and pandemic impact are highlighted. Key concepts in public health response and mitigation are reviewed, including masking, physical distancing, hand washing, and the promotion of outdoor interactions. Adequate investment in public health infrastructure is stressed, and regional differences in screening and testing strategies are highlighted. The spread of COVID-19 in Canadian workplaces, long-term care homes, and schools is described and lessons learned emphasized. The impact of COVID-19 on vulnerable populations in Canada—including Indigenous Peoples, ethnic minorities and newcomers, people who use drugs, people who are homeless, people who are incarcerated, and people with disabilities—is described. Sex and gender disparities are also highlighted. Author recommendations include strategies to reduce transmission (such as test–trace–isolate), the establishment of nationally standardized definitions and public reporting, the protection of high risk and vulnerable populations, and the development of a national strategy on vaccine allocation.

Key words: COVID-19 epidemiology, Canada, public health, mitigation, severe disease, vulnerable populations

1. Executive summary

1.1. Overview of COVID-19 epidemiology in Canada

- Coronavirus disease 2019 (COVID-19), the disease caused by the novel coronavirus now known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), predominantly manifests as pneumonia; however, COVID-19 can also present with an array of extrapulmonary signs and symptoms.
- As of 5 December 2020, there have been 408 921 cases of COVID-19 in Canada and 1088 cases per 100 000 people.
- The first wave of the COVID-19 epidemic in Canada peaked in mid-April 2020 with subsequent reduction in cases due to various public health interventions.

- As the epidemic has progressed Canadians have become less adherent to public health recommendations, and these trends in self-reported public behaviour coincided with a national R_0 exceeding 1.0 in early August 2020, and the emergence of a “second wave”.
- As of early December 2020, Canada’s case fatality rate (CFR), which represents the proportion of deaths among individuals diagnosed clinically with COVID-19, is 3.4%.

1.2. Public health response and mitigating transmission

1.2.1. Key concepts

- Public health strategies strive to lessen the severity of the pandemic.
- Prevention of spread and amplification of cases within health care settings, including long-term care homes (LTCH), is paramount.
- General practices employed for mitigation include (*i*) masking, (*ii*) social/physical distancing, (*iii*) hand washing, (*iv*) cleaning of shared surfaces and objects, and (*v*) optimizing indoor ventilation and promoting outdoor interactions.
- With mitigation practices, the reproductive number of the virus (R_0) can be reduced.

1.2.2. Differences among provinces and territories

- Provinces and territories vary with regard to geography, population size and density, and health demographics, which results in variable pandemic impact.
- Provinces and territories, which have jurisdiction over health, have varied in their public health approach to the pandemic, though there are common themes.

1.2.3. Masking policies

- Though contentious to some, masking has been demonstrated to reduce transmission of SARS-CoV-2 from person to person in a variety of settings and in combination with other mitigating practices.

1.2.4. Testing strategies

- Screening and testing strategies are an important component of the Public Health response.
- Knowledge of risk and of confirmed positive COVID-19 cases is vital to the efficient and effective application of specific mitigation practices, including self-isolation and quarantine.
- Screening strategies may vary depending on population and pandemic factors within a region or province at a given time.

1.3. COVID-19 in Canadian workplaces

- Collaboration among experts in public health, occupational health and safety, infection prevention and control, and employers can help to prevent the spread of COVID-19 in occupational settings and communities by implementing tailored preventative measures.
- Timely, transparent, and factual communication with the working population about areas of risk and safety is essential.

- There are no nationally standardized definitions for outbreaks across various settings in Canada. Attempts to make comparisons across settings and jurisdictions must take this into account when considering or setting policy and when communicating about risk mitigation for the Canadian workforce.
- Supporting Canadian workers and establishing safe partnerships with public health teams in test–trace–isolate strategies will greatly facilitate disease control and help to contain other costs.
- Support for workers includes adequate and stringently monitored protections at work, access to testing, availability of protective equipment, education, sick day policies, job security, community supports, and the absence of discrimination.

1.4. The impact of the COVID-19 pandemic on LTCHs in Canada

- The COVID-19 pandemic has had a devastating impact on residents and staff of LTCHs in Canada.
- Residents of LTCHs have accounted for approximately 80% of all COVID-19 related deaths in Canada.
- Reasons for the frequency, size, and scale of outbreaks are multifactorial and complex, but involve delays in preparation, longstanding system challenges in the sector, as well as underlying resident factors.
- Outbreaks frequently overwhelm the local LTCH's ability to respond, requiring a larger system response, in some cases even involving the military.
- The clinical presentation varies widely in this population; morbidity and mortality in residents is high.

1.5. COVID-19 and the education system in Canada

- COVID-19 symptoms are generally milder in children compared with adults, and children are less likely to become seriously ill. Available knowledge shows that children are less likely to be infected on exposure, and that transmission between children is relatively limited.
- Transmission in schools is relatively rare, but school-based cases appear to increase as community transmission rates increase.
- School closures have an uncertain effect on overall community COVID-19 transmission as they have usually occurred within the context of a set of public health restrictions.
- Older children and teens appear to transmit SARS-CoV-2 more like adults, although remain at low risk of severe disease or complications.

1.6. Severe COVID-19 in Canada

- The spectrum of COVID-19 is varied; however, >90% infected Canadians have recovered at home, 8% have required hospitalization, and 20% of hospitalized patients have required intensive care; 25% of those in intensive care have required ventilators.
- Risk factors for severe disease in Canadians include age (>60 years old), male sex, and the presence of pre-existing medical conditions (such as diabetes, high blood pressure, chronic lung disease, and obesity).
- Hospitalization, if required, usually occurs approximately one week after the onset of symptoms.

- Severe disease most commonly presents as acute respiratory distress syndrome (widespread lung damage) and appears to be associated with hyperinflammation.
- Risk factors for death mirroring those factors associated with severe disease—namely age and pre-existing medical conditions.
- Most countries, including Canada, have had to increase their hospital and intensive care unit (ICU) capacity during the pandemic. This has been accomplished through increasing physical (ventilators, beds, space) and human (mainly via redeployment) resources, suspending or delaying elective and non-urgent procedures, utilizing triage criteria in some regions, and utilizing models to predict the timing and severity of surges.
- Some patients experience varied long-lasting post-viral symptoms for weeks or months after acute COVID-19, calling for the need for multi-disciplinary post-recovery clinics.

1.7. COVID-19 within vulnerable populations in Canada

1.7.1. Key concepts

- Vulnerable populations within Canada are at increased risk of acquiring SARS-CoV-2, do not access the health care system in traditional ways and appear to be at risk of more severe COVID-19.

1.7.2. Indigenous Peoples

- To date, there is a paucity of publicly available or published data on COVID-19 and Indigenous Peoples.
- Research may help to determine optimal pandemic strategies for Indigenous people and individual communities, though it is critical that the OCAP® principles (ownership, control, access, and possession) be respected.

1.7.3. Racial disparity—ethnic minorities and newcomers to Canada

- Reporting of comprehensive COVID-19 data in relation to race and ethnicity is currently limited in Canada.
- Minorities in Canada are more likely to have risk factors for severe COVID-19.
- Immigrants, refugees, and other newcomers appear to be disproportionately affected by COVID-19 in Canada.
- The development of a national strategy to collect and report race and ethnicity data during the COVID-19 pandemic response.

1.7.4. People who use drugs (PWUD)

- The public health crises impacting PWUD have been made worse by the pandemic.
- Mitigation strategies have made the management and prevention of substance use disorders more challenging.
- Unintentional illicit drug overdose deaths have increased during the pandemic.
- Many PWUD are at increased risk of acquiring COVID-19 and at risk of severe outcomes.

- Maintaining adequate management of substance use disorders during the pandemic will require advocacy and innovation.

1.7.5. People who are homeless

- Homelessness in Canada presents key challenges for pandemic planning due to complex health, situational, and structural vulnerabilities.
- The homeless population are at increased risk of viral acquisition and severe COVID-19.
- Ensuring adequate space for mitigating practices, including social distancing in shelters and other safe spaces for the homeless, is critical to community pandemic planning.

1.7.6. People who are incarcerated

- Correctional facilities are associated with high rates of respiratory virus transmission, including SARS-CoV-2.
- Outbreaks of COVID-19 are being reported in Canadian correctional facilities.
- Decreased incarceration and increased decarceration with community supported re-entry can ease the burden of COVID-19 in correctional facilities.
- In this setting, calls for changes to drug policy and decriminalization in Canada have grown stronger.

1.7.7. Sex and gender disparities

- Sex and gender influence COVID-19 risk and outcomes.
- The pandemic has accentuated existing disparities.
- Health surveillance systems should include information pertaining to sexual orientation or gender identity to optimize the pandemic response and to support sex and gender minorities while lessening the risk for further stigmatization.

1.7.8. People with disabilities

- Disabilities put many individuals at higher risk of COVID-19 infection.
- Disruption of services and supports due to the pandemic have a major impact on individuals with disabilities.
- There is a paucity of Canadian data pertaining to disabled communities during the pandemic.

1.8. Recommendations

1. Prioritize screening, testing, and contract tracing to prevent transmission of COVID-19 infection in all settings. Ensure adequate investment in public health infrastructure for test–trace–isolate strategies during future pandemics.
2. Ensure timely and transparent public reporting on infections, hospitalizations, deaths, risk factors, and outbreaks to maintain trust and understanding amongst Canadians. This can be used as a key strategy to keep Canadians engaged as partners in the prevention of COVID-19 transmission.

3. Develop a national strategy to collect and report race, ethnicity, and other population-specific data to bolster the evidence base informing the pandemic response and protections for high-risk and vulnerable populations.

4. Establish nationally standardized definitions and case reporting requirements for outbreaks in various settings including workplaces and schools during pandemics.

5. Develop mechanisms for reporting COVID-19 infections acquired amongst workers and ensure effective systems are in place to monitor the provision and maintenance of adequate protection in places of work and care. Care settings are those settings where protection of staff and residents are linked such as health care, congregate living, and correctional facilities.

6. Utilize standardized case epidemiology and outbreak tracking to inform policy on vaccine allocation and to facilitate communication with the public about vaccination program implementation.

2. Overview of COVID-19 epidemiology in Canada

A novel coronavirus, now known as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2), was first identified in Wuhan, China, in late December 2019. Coronavirus disease 2019 (COVID-19), caused by SARS-CoV-2, predominantly manifests as pneumonia; however, COVID-19 can also present with an array of extrapulmonary signs and symptoms (World Health Organization 2020c). In this document we will describe the epidemiology—the study of disease incidence, distribution, and control—of COVID-19 in Canada as of late 2020. We will explore the timeline, distribution, and determinants of SARS-CoV-2 transmission within Canada as well as describe Canada's public health response to COVID-19 within various sectors and populations including Canadian workplaces, health care settings including long-term care, and school settings. Our current understanding of the epidemiology of COVID-19 continues to evolve, and this summary, written in late 2020 prior to availability of vaccines for COVID-19 prevention, reflects information available as of 30 November 2020. It should be acknowledged that the epidemiology will continue to evolve over the weeks and months that follow.

SARS-CoV-2 continues to spread within Canada following the first domestic report of COVID-19 on 25 January 2020 in a patient returning to Toronto from Wuhan, China (Silverstein et al. 2020). Early transmission of COVID-19 within Canada was strongly associated with international travel and accounted for approximately half of cases in January 2020 (Public Health Agency of Canada 2020a). Government advisories against non-essential travel on 14 March followed shortly by international travel restrictions a week later, resulted in a sharp decline in cases, with less than 1% of all cases being directly related to travel by April (Public Health Agency of Canada 2020a). Despite these early efforts, progressive community transmission ensued in March, with rising case counts across Canada during the first epidemic wave, peaking in mid-April 2020 (Public Health Agency of Canada 2020c).

Quebec became the early epicentre of the COVID-19 pandemic within Canada at least in part due to an earlier spring break and associated travel as compared to other provinces and territories (Godin et al. 2021). COVID-19 related deaths in Quebec reached 65 per 100 000 in early July, exceeded only by Belgium and the United Kingdom globally (Public Health Agency of Canada 2020c). In April and May, COVID-19 was the leading cause of death in Quebec, and approximately equal to death from heart disease and cancer combined. Fortunately, early public health interventions (physical distancing, restrictions on gatherings, and closures of non-essential services and schools) had a favourable impact on transmission, with modelling estimates predicting double the hospitalizations had these interventions been delayed by one week (Godin et al. 2021). Subsequent public health measures effectively reduced the reproductive number (R_0), an epidemiologic metric used to describe the contagiousness of an infection, to below one for most of May and June, resulting in falling case numbers

(Public Health Agency of Canada 2020a). When R_0 values remain above one outbreaks are expected to continue and when they fall below one, they are expected to decrease and eventually end.

Public concern only began to rise after Canadians began to see significant community transmission, with 31% reporting COVID-19 as a serious threat in early February compared to 88% in late March (Angus Reid 2020b). In addition, there was strong adherence to public health recommendations early in the pandemic with 84% of all survey respondents stating they regularly complied with physical distancing measures (Angus Reid 2020b). This was further supported by Canadian mobile phone location data that suggested maximum cumulative travel from home fell by 90% during the spring of 2020 (Anderson et al. 2020).

Concerningly, a repeat national survey in August 2020 showed less adherence to public health recommendations with only 47% reporting compliance (Angus Reid 2020a). Manitoba, Saskatchewan, and Alberta were found to have the lowest public compliance at 30%, 32%, and 37%, respectively (Angus Reid 2020a). These trends in self-reported public behaviour coincided with a national R_0 exceeding one in early August 2020, and "second waves" of varied severity are now occurring in most provinces. The extent, however, to which seasonality has contributed to increasing cases has yet to be fully appreciated, but requires consideration given the epidemiology of other respiratory viruses (Mallapaty 2020; Merow and Urban 2020). It has been estimated that a reduction of physical contact by 45% within communities is required to reduce the R_0 to below one, a goal seemingly met by Canadians during initial widespread government-mandated lockdowns early in the pandemic, which now appears increasingly difficult to achieve (Anderson et al. 2020).

As of 5 December 2020, there have been 408 921 cases of COVID-19 in Canada at an incidence of 1088 cases per 100 000 people (Public Health Agency of Canada 2020c). These data likely underestimate the true burden of COVID-19 in Canada as a survey conducted early in the pandemic showed that only a minority of those with symptoms suspicious for COVID-19 were tested (Lapointe et al. 2020). To date, the majority of cases (75.5%) have occurred in Ontario and Quebec with relative sparing of northern territories and Atlantic provinces, with no cases of COVID-19 being reported in Nunavut until 6 November 2020 (Public Health Agency of Canada 2020c). In addition to ongoing transmission in Quebec and Ontario, a steep rise in case counts developed in Alberta, Manitoba, British Columbia, and Saskatchewan during November and December 2020 (**Fig. 1**). Of concern, an increasing number of COVID-19 cases have had no known or identifiable source, with approximately 35% of cases falling into this category (Public Health Agency of Canada 2020a). Outbreaks have accounted for almost 20% of COVID-19 cases within Canada with the majority occurring in long-term care and retirement homes; however, easing of restrictions over the summer has led to an increase in outbreaks associated with social gatherings, schools, and childcare along with homeless shelters, correctional facilities, and hospitals (Public Health Agency of Canada 2020a).

To date, most cases of COVID-19 in Canada have occurred in people under the age of 29 years. Presently, this age group accounts for 33.4% of all cases despite earlier studies showing that those under 20 years of age were half as susceptible to infection (Davies et al. 2020; Public Health Agency of Canada 2020a). While the incidence of infection in this age group has remained high, mortality is relatively low (0.1%) with only 16 deaths among those under the age of 30 reported through the end of 2020 (Public Health Agency of Canada 2020c). Transmission of SARS-CoV-2 does not appear to be uniform with numerous epidemiological studies showing that a small proportion of individuals (≤20%) account for the majority (approximately 80%) of infections (Adam et al. 2020; Bi et al. 2020). These findings suggest that transmission of SARS-CoV-2 is subject to overdispersion frequently manifesting as super-spreader events resulting in large outbreaks associated with social and other group gatherings (Adam et al. 2020; Bi et al. 2020).

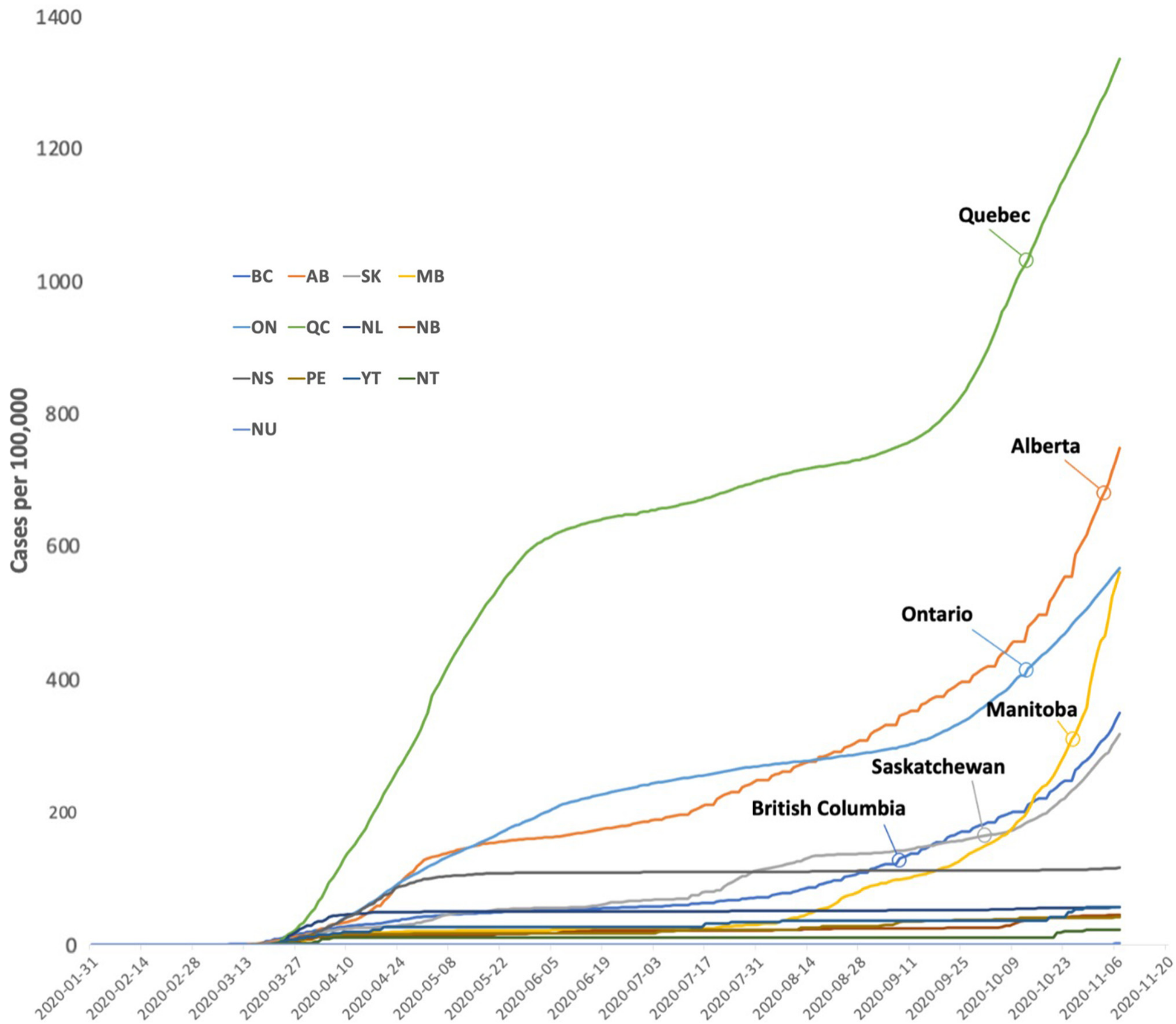

Fig. 1. COVID-19 in Canada: Cumulative incidence of COVID-19 cases (per 100 000 population) by province or territory.

Concerningly, a high number of cases have been observed in those over 80 years, with an incidence of 102 cases per 100 000 people (Public Health Agency of Canada 2020a). This is of particular concern as this age group has accounted for over 70% of COVID-19 related deaths, with 27.3% mortality (Public Health Agency of Canada 2020a). Advanced age has remained the leading risk factor for severe disease and death throughout the pandemic and has been well described in other countries (World Health Organization 2020c). Moreover, initial international reports of severe disease and increased mortality observed in those with pre-existing medical problems such as cardiovascular disease, diabetes, hypertension, and chronic lung disease have been reproduced in Canada, with 73.5% of those admitted to an intensive care unit (ICU) having at least one pre-existing medical condition in one early Canadian report (Mitra et al. 2020). Thus far in Canada, 7.8% of cases have required hospitalization of which 19.2% have required admission to an ICU and 4.6% of hospitalized patients have required mechanical ventilation with regional variation (Public Health Agency of Canada 2020c).

Reported COVID-19 mortality has varied widely, likely reflecting evolving management expertise, local health care system saturation, and variations in testing and reporting capabilities. Currently, Canada's case fatality rate (CFR), which represents the proportion of deaths among individuals diagnosed clinically with COVID-19, is 3.4% (Johns Hopkins Coronavirus Resource Center 2020). A strong association has been observed between a nation's CFR and the percent population over the age 75 years, with these differences accounting for up to 80% of country-specific mortality variation (Hoffmann and Wolf 2020). Case fatality rates are, however, subject to additional biases including under-detection of community and less severe cases which are often driven by discrepancies in testing and screening capabilities or strategies as those with asymptomatic or mild infection are less likely to be tested, potentially underestimating the true number of cases and overestimating the fatality rate (World Health Organization 2020a). Thus, these measurements should not be used in isolation and additional metrics such as deaths per population, excess deaths, and infection fatality ratios (IFR) should be considered (World Health Organization 2020a). Currently, IFRs, which in contrast to CFRs estimate the total number of infections based on serologic prevalence studies, are infrequently reported as these data are currently lacking. Ideally, surveillance and testing systems would result in a CFR equal to IFR. Canada's mortality as a proportion of the population is currently 32 deaths per 100 000 people, ranking 44th globally (Johns Hopkins Coronavirus Resource Center 2020).

Modelling by the Public Health Agency of Canada (PHAC) at the time of writing shows Canada is currently in a period of epidemic growth. Projections based on modelling data have become more accurate as the pandemic has progressed. Early models, during the first wave of the pandemic, simulated best- and worst-case scenarios based on data collected from the initial global epicentres. These models were limited by both evolving transmission parameter data and presumed population homogeneity. More recent models have been calibrated toward regional statistics and trends. Important lessons as to the heterogeneous risk of COVID-19 and variations in transmission based on variables such as socioeconomic status, residence (i.e., congregation, long-term care), and ethnicity have and will continue to improve future modelling efforts as the COVID-19 pandemic continues (Mishra et al. 2020b). Current PHAC models predict a continued rise in national case counts over time, with rising rates across most provinces throughout November.

3. Public health response and mitigating transmission

3.1. Key concepts

During any pandemic, a primary Public Health objective is to mitigate—"to make (it) less severe". The Public Health approach is based on the microbiology of the pathogen in relation to standard public health principles. Given the characteristics of the SARS-CoV-2 virus and the lack of immunity to this novel virus at the outset, the Public Health response to the COVID-19 pandemic has focused on risk reduction at both the individual and community levels.

While public safety is threatened, the medical sciences can assist in gathering and analyzing data and subsequently providing quality evidence to guide decisions. It has been noted, however, that science cannot say whether a decision is "right". In a democracy, it is up to our elected officials to determine how these data will be used. Furthermore, at the early stages of this pandemic, knowledge and information were incomplete (McConway et al. 2020).

In the context of earlier novel coronavirus (SARS and MERS-CoV) outbreaks, amplified spread was observed within health care settings (Chowell et al. 2015). As such, prevention of spread within acute care and other health care settings, such as long-term care homes (LTCH), was paramount. Minimizing community transmission, outside of the health care setting, is also important to avoid overwhelming the health care system. Flattening the curve aims to keep case numbers low enough that the health care system can adequately cope. Governments determine the balance of mandates on society and the roll-out of mitigating practices. The societal costs of a lockdown or specific policies (such as mandating masks in public spaces) may be seen as preferable to running the risk of over-filling hospitals (McConway et al. 2020).

Occasionally, the balance may lean towards more aggressive mitigation strategies, even if short term such as the aptly named "circuit breaker" (Chen et al. 2020; Gallagher 2020). Modelling suggests that with aggressive public health mitigation for a defined period, often two to four weeks, viral transmission can be disrupted and allow for health care system recovery with improved contact tracing and further control of community transmission. Ultimately, approaches to mitigation depend on risk and therefore may vary over time and place as risk varies. In parts of Canada where risks are low, approaches may differ from other jurisdictions where risks are higher. As risk changes over time, approaches may change within a given province or region.

The microbiology of SARS-CoV-2 is now better understood, in terms of modes of transmission, incubation period, and the period of communicability. However, this knowledge did take time to crystalize. As our understanding has grown, recommendations have evolved. Preventative strategies have been based on our knowledge of viral transmission (by droplet/contact spread), high-risk behaviours that amplify transmission, and the identification of at-risk or vulnerable populations for severe disease and (or) outcomes (World Health Organization 2020c). The incubation period, or time interval between initial exposure to the virus and appearance of symptoms due to infection, ranges from 1 to 14 days (median of 5–6 days) (Public Health Agency of Canada 2020b). Thereafter, the period of communicability may persist for 10 days. Some individuals can spread virus when pre-symptomatic or asymptomatic (i.e., in the 1–2 days before symptoms start or when symptoms are not apparent) (Petersen et al. 2020). This is critical and makes the containment and mitigation of SARS-CoV-2 much more challenging than previous novel coronaviruses.

From a global perspective, in the initial months of the pandemic, the infectivity of the virus (R_0; defined in sectopm 2) ranged widely and was dependent on the presence or absence of mitigating factors. Through January and February, various outbreaks in China and other countries outside of Canada were noted to be associated with R_0 values ranging from 1.4 to 6.5, with a mean of 3.3 (Liu et al. 2020). The Diamond Princess cruise ship gained notoriety in February 2020 as host to an early major outbreak outside China when the ship was quarantined for several weeks. More than 700 passengers and crew were infected with a median R_0 of 2.3 (Zhang et al. 2020).

With mitigation practices, the R_0 can be reduced. General practices employed for mitigation include (*i*) masking, (*ii*) social/physical distancing, (*iii*) hand washing, (*iv*) cleaning of shared surfaces and objects, (*v*) optimizing ventilation, and (*vi*) promoting outdoor interactions. In addition, knowledge of risk and of confirmed positive COVID-19 cases is critical to the application of specific mitigation practices such as self-isolation and quarantine. As such, screening and testing strategies are also an important component of the Public Health response. Knowing where to focus and augment strategies based on contact tracing also helps to decrease the R_0 and thus decrease new cases. Mitigation can work to reset the R_0. In the setting of growing case numbers, the R_0 must be brought down below 1.0 to avoid further exponential growth. There are circumstances where the R_0 must be reduced rapidly to avoid overwhelming limited health care capacity. At such times, aggressive strategies may be warranted but must be balanced against unintended direct and indirect consequences. Such consequences can include social, economic, and unrelated health impacts. It should be emphasized, however, that there does not appear to be a simple trade-off between COVID-19 mitigation strategy effectiveness and protecting the economy (Hasell 2020; Paes et al. 2020). On the contrary, many countries, such as Taiwan and South Korea, have been successful at controlling COVID-19 while only experiencing relatively modest economic consequences (Hasell 2020). Conversely, nations less successful at controlling the pandemic, such as Peru and Spain, have experienced more severe economic downturns (Hasell 2020). Moreover, it has been shown that consumer avoidance in regions of high infection rates affect economic contraction more than official lockdown policies (Chetty et al. 2020). Thus, it appears that the most effective strategy for economic recovery is to control SARS-CoV-2 transmission through strong, evidence-based, and coordinated public health policy.

3.2. Differences between provinces and territories

Provinces vary in geography, population size, and density, as well as age and health demographics. The interaction of these variables is complex. As individual provinces and territories have jurisdiction over health care, they have differed in their public health approach. There were also differences in the timeframe under which the pandemic struck various regions of the country. The timing of school and border closures also varied as the first wave was being felt in Canada by March 2020.

The first Canadian cases were identified in late-January and February in relation to travel from the region of the global epicentre in China's Hubei province and subsequently from other regions of the globe where COVID-19 cases were climbing, including Iran, Egypt, India, and Hong Kong (Global News 2020a). Ontario, British Columbia, and Quebec were the first provinces with cases and have the largest and most centralized populations. As of 3 March there were 33 confirmed cases of COVID-19 with 20 cases reported in Ontario, 12 in British Columbia, and one in Quebec.

As case numbers were increasing and nearing 100 cases on 10 March, the federal government issued recommendations for the adoption of work-from-home policies (Canadian Institute for Health Information 2020c). On 13 March, gatherings of more than 250 people were no longer permitted in Alberta or Ontario. On 14 March, recreation facilities and entertainment venues closed in Newfoundland and Labrador. On 16 March, British Columbia began to limit access to acute and long-term care facilities and postponed non-urgent and elective surgeries.

On 12 March, Quebec was one of the first provinces to announce school closures beginning 16 March (Canadian Broadcasting Corporation 2020a). New Brunswick, Alberta, and the Northwest Territories closed schools on the same date (Canadian Institute for Health Information 2020c). British Columbia, Newfoundland, and Labrador and Nunavut followed suit on 17 March. Ontario, Nova Scotia, Prince Edward Island, and the Yukon Territory announced school closures the same week as students were beginning their March break, and thus students did not return to classes on 23 March as would have been planned. Saskatchewan and Manitoba delayed closures until 20 and 23 March, respectively. The impact of school closure on mitigating transmission remains unclear (see section 6). In general, confirmed cases among school-aged children attending schools seem to be representative of transmission within the community, rather than transmission within schools.

With regards to travel and border restrictions, the federal government put out a travel advisory warning against all non-essential travel outside of Canada on 14 March (Canadian Institute for Health Information 2020c). Four days later, travel restrictions were announced on entry of all foreign nationals, with the exception of the United States. This remained in place until 3 d later when the United States was added to the restriction. Subsequently, mandatory self-isolation was required for all travelers arriving from outside Canada on 24 March. During the first wave, no additional isolation requirements or travel restrictions were put in place for British Columbia, Alberta, Ontario, or Quebec beyond those imposed by the Federal Government of Canada. Mandatory 14-day self-isolation periods for those returning from out-of-territory or province, however, were implemented in Nunavut, Northwest Territories, Yukon, Saskatchewan, and the Atlantic provinces (Canadian Institute for Health Information 2020c). In fact, it should be noted that the Atlantic "bubble" gained international attention as one of the safest places during the pandemic (Pictou 2020).

As a result of the mandatory 14-day isolation period following entry instituted in late March, the Atlantic provinces enjoyed relatively low case counts. Newfoundland and Labrador did see a spike in cases in early April following a super-spreader event at a funeral home in mid-March (Mercer 2020). The province's active case count peaked at 253 on 18 April and subsequently fell precipitously to low levels that have been maintained well into the second wave (Public Health Agency of Canada 2020c). Prince Edward Island and Nova Scotia saw their first waves peak on the same day with active case counts of 26 and 602 cases, respectively. The epicentre of Nova Scotia's first wave was the largest LTCH in Atlantic Canada, located in Halifax. During the outbreak, 246 residents and 99 staff were infected and 53 people in the facility died. As of the end of June, these deaths accounted for 84% of COVID-19 deaths in the province (Quon 2020).

New Brunswick had similar success through the first wave. The province's active case count peaked on 3 April at 72 cases. Case numbers remained low until June when an outbreak occurred in the north of the province along the Quebec border, involving a LTCH. During the outbreak, with intense public health mitigation and contact tracing, the active case count did not rise above 29 cases at any one time (ArcGIS 2020).

As the situation stabilized in the Atlantic region, by 3 July, there were just five active cases in the region (Public Health Agency of Canada 2020c). On this date, the Atlantic bubble was declared a unique travel-restricted zone. With agreement among the four Atlantic provinces, unrestricted travel was permitted among these four provinces. Individuals travelling into the bubble were subject to screening and required to quarantine for 14 days before moving freely within the bubble.

As mentioned, Ontario and Quebec were among the Canadian provinces hit the earliest and the hardest by COVID-19. Based on confirmed cases and hospitalizations, by raw numbers or a per capita comparison, the cases grew steadily in Ontario and Quebec. British Columbia, however, fared much better, due in part to their integration of laboratory services with public health epidemiology (McElroy 2020; Rose et al. 2020).

High population density may have contributed to the higher case incidence in Ontario and Quebec. In addition, Quebec was at a disadvantage with spring break taking place earlier than in other provinces, at a time when returning travelers and imported infections were driving Canada's epidemic. These and other factors, including local outbreaks, helped to ignite more widespread outbreak in the two most populated Canadian provinces. By 4 May, there were 60 615 confirmed cases of COVID-19 across Canada with Quebec and Ontario accounting for 83% of these cases and 92% of the nation's deaths (Vogel 2020).

With sustained community transmission and a rapid rise in cases, Quebec and Ontario were struggling to provide adequate levels of testing (Vogel 2020). In many provinces, there were barriers to assuring widespread accessible testing, including supply of necessary swabs, testing reagents, staffing, and needed infrastructure. Contact tracing teams also needed to be scaled up. In mid-May, concerns were raised that some provinces were reopening schools, daycares, and retail stores despite not being able to ensure adequate contact tracing, which is a critical component of the overarching mitigation strategy.

While Ontario and Quebec were not meeting testing targets and unable to determine the source of thousands of cases, in contrast Alberta and British Columbia were reported to be doing well with testing and contact tracing. Alberta excelled at ensuring widespread testing. Alberta had expanded to explore asymptomatic testing early in the pandemic. In late May, Quebec began to plan their reopening while promoting physical distancing and masks as key public mitigation strategies.

Overall, the first wave began to decline, and by 1 June 2020 Canada reported the lowest daily death toll in two months at just 31 new deaths and 759 new confirmed infections. Provinces and territories began to relax restrictions (Vogel 2020). Canada's chief public health officer warned that reopening too quickly could lead to a rapid increase in new cases (Aiello 2020). Furthermore, second waves of epidemics are frequently worse than the first and caution was warranted (Centers for Disease Control and Prevention 2018; Chen et al. 2020).

In late-August, a slight upward trend in case numbers was noted and by early September, case numbers were clearly on the rise across the country. By late October and early November, all provinces and territories, with the exception of the Atlantic provinces, were seeing case numbers that surpassed the peak of the first wave. As of 4 December, there were 69 977 active cases across the country with a 7-day case count of 116/100 000 population, more than tripling the national peak during the first wave at 33/100 000 on 5 May (Public Health Agency of Canada 2020c). Noting that a primary public health goal is to maintain the caseload within the capacity of the health care system, between 7 and 14 November the number of hospital beds occupied by COVID-19 patients increased from 1033 to 1375, the number of ICU beds occupied by COVID-19 patients increased from 254 to 355, and the number of COVID-19 patients who were mechanically ventilated increased from 96 to 149 (Public Health Agency of Canada 2020c). Interestingly, at that time, the acute care utilization numbers were below that of the peak of the first wave. These higher case numbers, yet lower acute care utilization, were because in the early stages of the second wave, a higher proportion of cases were among a younger demographic that were at lower risk of severe disease. The 7-day mortality in Canada peaked at 3/100 000 during the first wave in early May. As of 4 December, with cases climbing in the second wave, the 7-day mortality was still less than 2/100 000 population.

While Canadian cases were driven by Ontario and Quebec in the first wave, the country saw a shift during the second wave with the prairie provinces experiencing the highest number of cases per 100 000 population. During the first wave, Ontario's 7-day case count peaked at 27/100 000 on 26 April, while Quebec's rate exceeded three times this just several days later (Public Health Agency of Canada 2020c). As of 21 November, Ontario and Quebec had recorded 7-day case counts of 66/100 000 and 97/100 000; however, these were dwarfed by the prairie provinces, which experienced much higher increases in case counts. Of exceptional note was the 7-day case rate seen in Nunavut of 271/100 000.

Nunavut presents a unique approach to mitigation and an interesting pattern of cases. The territory had been quite aggressive with travel restrictions. As of 25 March, air entry into Nunavut by non-residents was prohibited, with few exemptions. Returning residents faced a 14-day quarantine with tight monitoring before returning by air (Driscoll 2020). Of Nunavut's 24 hamlets, some went so far as to prohibit outside visitors from other regions within the territory (George 2020a). Temporary restrictions on consumption, possession, or distribution of alcohol were also implemented by some hamlets to minimize social gatherings and ensure adherence to public health measures (George 2020b).

Until early November, Nunavut was the only province or territory in Canada that had not recorded a confirmed COVID-19 case. However, on 6 November, the territory reported its first case, followed by a large spike in cases. On 16 November, Nunavut issued a territory-wide 2-week shutdown. It appeared that initial cases were linked to an isolation hub in Winnipeg with subsequent community transmission driven by overcrowding within the territory's communities (Neustaeter and Ho 2020). Nunavut's 7-day case rate peaked on 23 November at 289/100 000 (Public Health Agency of Canada 2020c). While the territory had been untouched through the country's first wave, the early stages of the second wave presented a very different story. A major driver of Nunavut's trends appears to be its geography and the flow of the population. Although the territory has very low population density overall, the small communities are densely populated with close interactions among the community members, facilitating widespread transmission once in the community.

As was seen in Nunavut, other Canadian regions that did well during the first wave struggled in the early stages of the second wave. As noted, the prairie provinces have seen a troubling spike in cases with challenges in hospital capacity (Dyer 2020; Lefebvre 2020; Peterson 2020). The Atlantic bubble also managed to control the pandemic in the first wave but felt the stress of cracks in the border restrictions and COVID-19 fatigue within the communities. The bubble officially burst late November with rising cases, up to as high as 153 per 100 000 in Nova Scotia on 31 December 2020 (Groff 2020).

3.3. Masking policies

Among general mitigating practices, such as physical distancing, hand washing, and disinfecting, masking has been a somewhat contentious issue. Although masking has been used to decrease the risk of transmission and acquisition of respiratory viruses within the health care setting for decades prior to COVID-19, it is generally used as a component of a larger bundle of preventive practices and the risk reduction associated with mask use by itself is difficult to ascertain (Alberta Health Services 2020a). Furthermore, mask use in the community has been associated with different types of masks with different rates of adherence and differing community case rates, thus further confounding analyses.

Nonetheless, mathematical modelling suggests that universal masking within the general public has a significant impact on reducing not only infection to the wearer but also subsequent community transmission (Chu et al. 2020; Public and Global Health 2020). Recent meta-analyses estimate masks decrease person-to-person transmission by 40%–85%, with one study suggesting comparable effectiveness of medical and non-medical masks at 43% and 40%, respectively (Chu et al. 2020; IHME COVID-19 Forecasting Team 2021). The benefits of universal masking are significant, with an estimated 11 350 Canadian deaths averted over a 4-month period with universal masking (Public and Global Health 2020).

Different types of masks also result in varying levels of protection against transmission. N95 masks are the most protective and should be used when aerosol-generating procedures are being performed by health care providers. Outside of this context, however, medical masks are acceptable to reduce the risk of droplet spread in combination with other mitigating practices such as hand hygiene and cleaning high touch surfaces. Non-medical (cloth) masks (NMMs) can also reduce transmission risk; however, there is variability among these masks and their proper use. Three-layer masks that cover the mouth and nose are recommended for use by PHAC, though masking in general is preferred to reduce risk over no mask at all, regardless of mask design (Bhattacharjee et al. 2020). There is limited evidence of harm related to mask wearing and generally, mask use outweighs perceived harm.

On 20 May 2020, PHAC recommended the use of masks where maintaining a 2-m physical distance is not possible. Although most of the country was initially hesitant to adopt mandatory masking policies, most provinces and territories now require masking in indoor public spaces. Quebec was the first province to require wearing of NMMs in all indoor public spaces on 17 July. With rising cases across the country, most provinces followed suit (Government of Nova Scotia 2020a; Government of Prince Edward Island 2020a; Pindera and Thompson 2020; Province of Manitoba 2020a).

Some jurisdictions have had narrower mandates at different times during the pandemic. In Alberta, masking was made mandatory in all places of worship and in all indoor workplaces, but only in the Calgary and Edmonton areas (Government of Alberta 2020b). Masks only became mandatory in

British Columbia health care facilities as of 4 November (Canadian Broadcasting Corporation 2020b). In addition, mandatory masking policies in the Northwest Territories, Nunavut, and the Yukon were selective (not universal) or only strongly recommended at the time of writing (Canadian Broadcasting Corporation 2020c; Government of Northwest Territories 2020b; Government of Yukon 2020b).

As has been noted, mitigation strategies are employed to reduce risk, and as such, where risks differ, mitigation may differ. As an example, in New Brunswick, the mandating of NMMs was extended to outdoor public spaces in zones where community transmission was documented and accelerating. Such mandates have also been enforced by fines in New Brunswick (Canadian Broadcasting Corporation 2020d).

3.4. Testing strategies

Knowledge of risk and of confirmed positive COVID-19 cases is vital to mitigation practices, such as self-isolation and quarantine (Government of Canada 2020d). It is noted that there are different modalities of testing, such as direct testing to look for evidence of the virus (SARS-CoV-2) which is done most often with polymerase chain reaction (PCR) testing or antigen detection. There are also indirect methods of testing which can sometimes be used to look for the body's response to a potential prior exposure to the virus, such as serological testing. This section focuses on the role of these direct tests to look for evidence of the SARS-CoV-2 virus to determine the presence of an infection.

Testing informs knowledge of community case prevalence and can aid in identifying hotspots where mitigating practices can be strategically emphasized. Testing also allows for appropriate case finding which guides contact tracing, which is essential in reducing further exposures and breaking cycles of transmission. There is general agreement that widespread testing, in conjunction with aggressive contact tracing, is essential to containment. Some public health authorities have utilized what some label as "backward contact tracing" in addition to traditional (forward) strategies to determine the origin of infection. Given the propensity for super-spreader events with SARS-CoV-2, backward tracing improves the detection of these infection clusters and informs public health policy on high transmission risk settings.

It is critical that amplification of cases be prevented within health care settings due to the critical service provided in those settings, the vulnerable populations served in health settings, and the need for increased capacity of health services during a pandemic. Through identification of positive cases, hospital patients and care home residents can be placed in appropriately designated rooms/wards with relevant transmission-based precautions in place. Health care workers (HCWs) may also be selectively screened to minimize unintended workplace transmission. For reasons of preventing amplification of cases, accessibility to testing must also be strategic.

Accessing testing through acute care centres or emergency departments is problematic unless individuals can be effectively triaged and streamed into safe, expanded, and designated areas to avoid crowding, transmission, super-spreading events, or outbreaks within hospitals. As such, access to testing in an appropriately designed and designated community setting is preferred. As the country headed into a time of year that traditionally sees increased spread of community respiratory viruses such as influenza, the development of respiratory assessment centres outside of traditional health care settings were deemed to be of significant value.

Early adaptation and implementation of effective COVID-19 testing strategies by Canadian provinces were essential to early, successful control of the pandemic during the initial wave. Overall, Canada did well in this regard. In contrast, the United States experienced a disproportionally steeper rise in infections, which was at least in part due to a failure to implement accessible early testing. Early efforts by the Centre of Disease Control were reported to have been negatively impacted by distribution of faulty test kits (Maxmen 2020; Schneider 2020). Sensitive testing criteria and access to testing for all eligible people ensures that fewer cases are missed. Owing to resource constraints, such criteria must be thoughtful and evidence based and are expected to evolve over the course of the pandemic.

During the first wave, a standard short screening list was used in most parts of the country, including the presence of fever, new cough, or worsening chronic cough in combination with epidemiologic risk factors. In many provinces, testing initially targeted only symptomatic individuals. Alberta later included testing of asymptomatic individuals and has led the country in per capita testing, performing 3950 tests per 100 000 population since January, six times the number of tests per COVID-19 death relative to Ontario (Vogel 2020). However, as the proportion of positive cases had been very low in Alberta, employing this strategy was deemed ineffective in the face of utilizing limited resources. As such, the strategy later returned to targeting individuals based on selected symptoms.

The percent positivity of tests is the percentage of all tests performed that are found to be positive. This number can be used as an indicator of how widespread infection is in a defined area, and policy-makers may use this information to guide decisions on relaxing or tightening pandemic restrictions (Dowdy and D'Souza 2020). In May, the World Health Oraganziation (WHO) recommended that the percent positivity of tests remain below 5% for at least two weeks before a region re-opens, though the threshold may vary by region and over time. As of early May, more than 13% of tests in Quebec were positive, indicating widespread transmission (Vogel 2020). This measurement later fell through the summer months, only to increase again in the fall as the second wave hit (Government of Quebec 2020a).

As of mid-November, the Government of Quebec noted that the province's testing strategy was taking the context of each region into account (Government of Quebec 2020b). The number of tests available in each region was calculated based on population size, in addition to community transmission intensity. Designated testing and assessment clinics as well as mobile clinics were set up to enable access to testing, targeting symptomatic individuals, close contacts of positive cases, and those asked by public health for testing.

In Nova Scotia, the criteria for screening expanded at the end of the first wave to include an expanded list of 13 symptoms, with the rationale that a very low threshold for testing was desired. In late August, the province transitioned to a shortened symptom list based on review of case presentations across the country as well as low percent positivity of testing in the province (D. Webster and Dr R. Strang (Chief Medical Officer of Health), personal communication, 11 November 2020). With the percent positivity of testing being very low (0.95% as of 10 November), the province instituted an innovative testing strategy on 21 November to increase case finding (Government of Nova Scotia 2020c). They utilized an empty nightclub in Halifax to target a cohort seen to be driving new cases (Grant 2020). This pop-up testing site used a rapid antigen detection test. Although a less sensitive test with a higher false-negative, it did allow for on-site targeting of a high-risk population that may otherwise have gone without testing. Positive results were followed up with confirmatory PCR.

In areas of low prevalence, screening can also serve an important role, ensuring adequate surveillance to identify the introduction of cases into a region. In New Brunswick, where case numbers have been generally low, modelling suggests that with a provincial population of 750 000 and case prevalence of 0.1%, 3000 people should be tested over a given time period to ensure cases are not being missed (D. Webster and Dr. D. Dutton (Department of Community Health and Epidemiology, Faculty of Medicine, Dalhousie University), personal communication, 20 April 2020). As such, in provinces with low case rates and low community transmission, access to testing may be more open, to ensure adequate surveillance and case finding. In New Brunswick, asymptomatic testing has been available to vulnerable groups and those at risk of importing cases or transmitting cases at sites of concern (Government of New Brunswick 2020b). Limited sentinel testing of asymptomatic patients is also performed in emergency departments and hospitals in the province (D. Webster and P. Higdon (Director, Provincial COVID-19 Response Team, NB Department of Health), personal communication, 12 November 2020). As of 10 November, the percent positivity of tests in New Brunswick was 0.33% (ArcGIS 2020).

In early November, Manitoba was the province with the highest case rate in the country at 394/10 000 and a test percent positivity of 3.06% (Province of Manitoba 2020b). As case numbers were climbing, it was announced that Manitoba had received rapid test devices and supplies. Based on public health advice, most devices were to be located in remote communities, where delays due to transportation, weather, and other factors may impact access to traditional testing (Province of Manitoba 2020c). The hope is that rapid testing will help to bend the curve as we move into the winter months, through early case identification and prevention of transmission.

4. COVID-19 in Canadian workplaces

In Canada, COVID-19 has been acquired in places of work. When SARS-CoV-2 enters a work setting, there is risk for spread to others (transmission of infection) and for outbreak. Key themes have emerged over the course of the COVID-19 pandemic in Canada. These themes highlight areas of risk in places of work, but data on whether infections are occupationally acquired are sparse, and the available data can be challenging to interpret, or even misleading.

Canada does not currently have nationally standardized public reporting of occupationally acquired infections. Variations in reporting on testing, infections, or outbreaks amongst workers exist across provinces and territories. In addition, after a worker acquires infection, the likelihood that infection was acquired at work will remain unknown unless there is a detailed case investigation, ideally performed at the time of the infection. In Canada, similar to many other countries, information about infections from workplace settings comes primarily from published outbreaks and media reports (Leclerc et al. 2020; Public Health Agency of Canada 2020a).

The PHAC uses web scraping techniques to gather data from media reports about outbreaks, in addition to data shared via provincial and territorial health agency internet sites (Public Health Agency of Canada 2020a). This information can be used to help explore which Canadians may be getting infected at work, but the aggregated anonymized data are subject to important limitations which are highlighted in the PHAC weekly epidemiology report technical notes (Public Health Agency of Canada 2020a). The data do not represent all outbreaks that have occurred in Canada over the course of the pandemic, and case-level data are generally not available for these outbreaks as the data sources are not traditional, and reporting is not standardized.

The story of HCWs in Canada can be used as an example to illustrate relevant key points to better understand worker epidemiology in Canada.

4.1. Health care workers

4.1.1. Transmission settings, percent positivity, testing rates, and incidence of infection

Early in the pandemic, it was assumed by some that HCWs would be at greater risk than the general public for COVID-19 infection. Indeed, early reports suggested they were, and to this day, absolute numbers alone could give a strong but likely false impression that they are at higher risk of acquiring infection based on their site of work.

For example, data summarized in a 3 September 2020 Canadian Institute for Health Information report are coupled with footnote comments to explain that the data are intended to represent HCW infections acquired at work, but the data could include HCWs who acquired infection outside of work (Canadian Institute for Health Information 2020a). This report notes that the comparability of the data from provinces and territories is impacted by differences in their overall COVID-19 testing practices (this is referred to as testing bias), and the data are from multiple and variable sources ranging from formal provincial reporting to media summaries. The report table states that as of 23 July 2020, 21 842/112 672 (19%) of all Canadian COVID-19 cases were in HCWs (Canadian Institute for Health Information 2020a).

Two key points stand out when considering these data:

1. The absolute number of cases tell nothing about where or how the infections were acquired.
2. Access to testing for SARS-CoV-2 has not been the same for everyone. Over the course of the pandemic, access to testing has been variable, and at times preferential in many jurisdictions. For example, early in the pandemic, some provinces allowed HCWs to be tested for COVID-19, but not other categories of workers. Some provinces only allowed travellers to be tested in the early weeks of the pandemic. Most provinces have allowed preferential access to testing for HCWs throughout the pandemic, but many other industries either did not have access to testing or the testing was organized outside of a public surveillance system (Brend 2020b; Government of Alberta 2020c)

To address these comparability concerns, rather than looking at absolute numbers, information pertaining to three coupled metrics, namely, (*i*) the percent positivity (the percent of tested HCWs who test "positive" for the infection), (*ii*) the testing rate per 1000–100 000, and (*iii*) the infection rate per 1000–100 000 as compared with the general population is preferred. A challenge for some employers, organizations, or policymakers is that test and infection data, or accurate population denominators are not always available for epidemiological study or reporting.

The province of Alberta has Canada's largest integrated health system and was thus well positioned to address this issue. The Workplace Health and Safety program within Alberta Health Services launched a HCW testing and infection dashboard that has enabled the organization to report items such as the HCW percent positivity, testing rates, and infection rates throughout the pandemic to their frontline workforce (**Fig. 2**). In addition, the estimated cause for infections amongst HCWs is being established for each case by using standardized questionnaires to interview infected HCWs and a case review format to classify cases. This work is demonstrating that the majority of these HCW infections have most likely been acquired outside the health care workplace. For example, data from the first 10 weeks in Alberta's COVID-19 epidemic from the start (5 March 2020) to the date of provincial re-launch and re-opening after shutdowns (14 May 2020) showed that access to testing was higher amongst HCWs (20 920 out of 118 733 HCWs (17.6%) were tested for SARS-CoV-2) than the general population of Alberta (188 514/4 441 289 (4.2%)), but the percent positivity of those HCWs tested (209/20 920 (1.0%) tested positive) was lower than that of the general population (5783/188 514 (3.1%)) (Government of Alberta 2020a). In addition, the majority of infections amongst HCWs were acquired outside the workplace (161/209 (77.0%) were categorized as having infection due to a non-occupational source). The median age of infected employees was 41 years with an interquartile range of 33–50 years (R. Harrison and S. Tsekrekos, personal communication 2020; Alberta Health Services Workplace Health and Safety).

These findings underscored the importance of ensuring HCWs are informed about their risks for acquiring infection in community settings. In addition, they are reminded to practise hand hygiene, physical distancing, masking, isolation when ill, or quarantine when identified as a contact, and adhere to all public health recommendations in the community as well as at work.

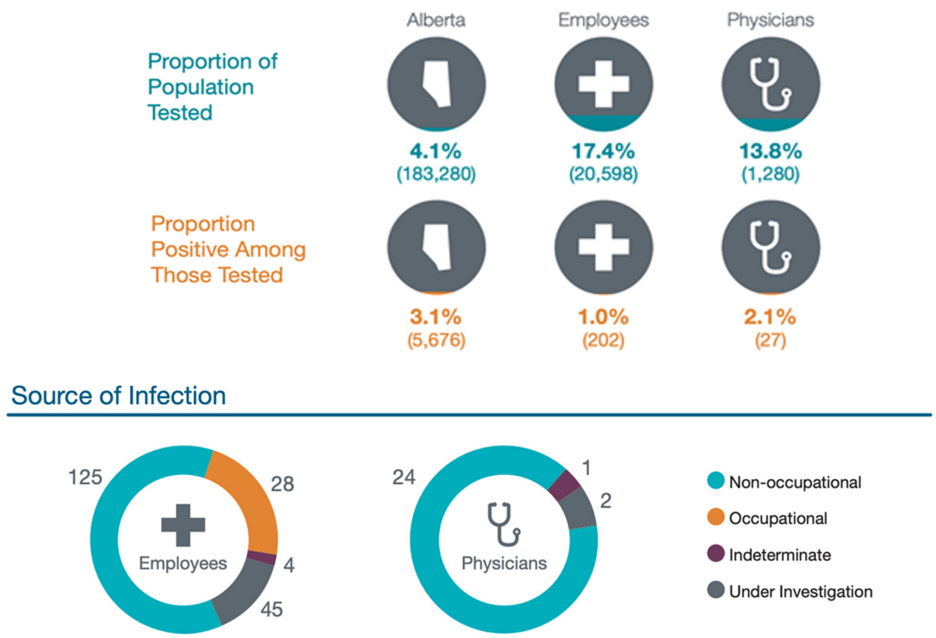

Fig. 2. The Alberta Health Services Healthcare Worker Testing Dashboard Infographic at the date of provincial re-launch after a lock down period (14 May 2020) (Image credit: Alberta Health Services Communications Team).

Similar findings to those reported by the Alberta program have also been described from Ontario according to a preprint manuscript (a preprint manuscript means that these findings are not yet peer reviewed or published in a scientific journal) (Schwartz et al. 2020). The Ontario work was done using retrospective data and is hence subject to limitations. It should be noted that it was learned early in the pandemic that HCWs represented a disproportionate number of COVID-19 cases in Ontario but with relatively low confirmed numbers of workplace-acquired infections. The analysis and stated conclusions by Schwartz et al. (2020) in the pre-print article comment on areas of risk such as co-worker to co-worker transmission. Protecting HCWs through appropriate personal protective equipment and physical distancing from colleagues is a key learning point stated in the pre-print report (Schwartz et al. 2020). Officials in the province of British Columbia have also highlighted the need to present data with adequate detail and context for meaningful interpretation, particularly when it comes to infections amongst HCWs (Brend 2020a).

Real-time dashboard reporting, like the Alberta model, or analyses such as that proposed by the Ontario group, can facilitate transparent and informed communication to frontline workers, which may help to ensure their psychological well-being. The Alberta Health Services HCW Testing and Infection Dashboard is also assisting in clarifying areas of risk for workers that guide protective policies. If others cano establish similar reporting in the future, then it would allow for comparisons across jurisdictions.

4.2. Business, industry, public service settings, and outbreaks

Further to the HCW stories, however diverse the experiences, every business, industry, and service sector has been impacted in some way by the COVID-19 pandemic. The outbreak data compiled by PHAC highlight key areas where occupational risk was observed over the first many months of the pandemic and point to closed (e.g., indoors, poorly ventilated) and crowded settings as areas of risk (Public Health Agency of Canada 2020a).

Many provinces including Ontario, Manitoba, Saskatchewan, and Alberta are publicly reporting current outbreaks by location/setting on government websites (Government of Alberta 2020a; Government of Manitoba 2020; Government of Saskatchewan 2020; Public Health Ontario 2020). The province of British Columbia reports health care location outbreaks and the Atlantic provinces, British Columbia, and Yukon and the Northwest Territories all list exposure venues on their provincial government websites (Government of New Brunswick 2020a; Government of Northwest Territories 2020a; Government of Nova Scotia 2020b; Government of Prince Edward Island 2020b; Government of Yukon 2020a; Public Health Services Authority 2020). The province of Quebec summarizes outbreaks by category/setting type (Government of Quebec 2020a). School settings are also reported in many provinces. Most often, once an outbreak is over, it disappears from the published website lists, but a scan on any given day highlights that the virus has not gone away, and outbreaks continue to be observed across a range of settings.

Early in the pandemic, Canadian long-term care facilities, retirement residences, and congregate living settings predominated and accounted for most outbreaks. Since that time, outbreaks have been detected in businesses, agricultural work settings, amongst farm workers, in meat processing plants, in acute care hospitals, and in institutions such as correctional facilities. Since September 2020, long-term care/retirement residences and schools/childcare centres continue to account for the highest number of reported outbreaks in Canada (Public Health Agency of Canada 2020a). The Canadian military Department of National Defense and Canadian Armed Forces report that 490 military personnel had been infected in the COVID-19 pandemic as of 30 November 2020 (Government of Canada 2020c). The denominator for the military workforce, and the estimated source for the infections amongst military personnel (i.e., workplace or community related) are not published on the national website (Government of Canada 2020c). From the Canadian Institute for Health Information HCW data, it is evident that 55 of those 490 were estimated to have had COVID-19 infection linked to LTCH outbreak work done through an operation called operation LASER in Ontario and Quebec (prior to 7 July 2020) (Canadian Institute for Health Information 2020b).

It becomes clear when looking at the diversity of work settings reporting outbreaks that key considerations for protection of workers must apply broadly. Prevention opportunities including access to testing, adequate and stringently monitored protections for workers at work, availability of PPE, sick day policies and job security, and the ability or inability to live and (or) work from home have not been equal across settings. Fear of income or job loss impacts some populations disproportionately when compared to others. This in turn can impact their desire or ability to seek testing or to participate safely in test–trace–isolation strategies. Not only does this affect individual Canadians, but it also affects the overall public health response that is critical to controlling the pandemic, and it carries significant financial and operational impact for industries.

It should also be noted that Canada's largest outbreaks early in the pandemic occurred in long-term care facilities and in industrial settings, specifically, food processing plants. Outbreak size matters. Information relating to the number of cases linked to outbreaks is important and should be available. Knowledge of this can help to improve early outbreak detection mechanisms, and to detail the swift actions that are required to prevent further spread.

Four key questions emerge whenever using outbreak data to learn where occupational risk exists:

1. How are outbreaks being defined?
2. Are the staff and workers getting infected in the outbreaks or not? (For example, is it customers, students, or patients that are infected, or are the workers infected too?)

3. If workers are infected, are they getting infected at work or outside of work?

4. How can risk be prevented and mitigated?

At present, there is not a nationally standardized COVID-19 outbreak definition in Canada; therefore, variability exists across provinces and territories or regions and settings. In broad terms, an outbreak is a clustering of cases (infected individuals) in space and time. Most outbreaks consist of at least two (often more) COVID-19-infected individuals and suspicion or evidence of transmission between those individuals. Variability in defining what constitutes an outbreak means that clusters of cases in some settings or in some jurisdictions may not be reported as an outbreak and therefore data (such as the number of outbreaks by settings summarized in the weekly PHAC epidemiology report and in Fig. 3) likely under-report the number of outbreaks that are occurring and do not identify all areas of risk (Public Health Agency of Canada 2020a).

In addition, attempts at comparisons when looking at absolute numbers of outbreaks are hindered due to variability in outbreak definitions. For example, in Alberta, an outbreak in a long-term care setting may be declared with a single case, whereas a business setting outbreak is not declared until there are 10 cases or more (Government of Alberta 2020a). In contrast, in Ontario, outbreaks in businesses may be declared when there are two or more cases within 14 days (Government of Ontario 2020).

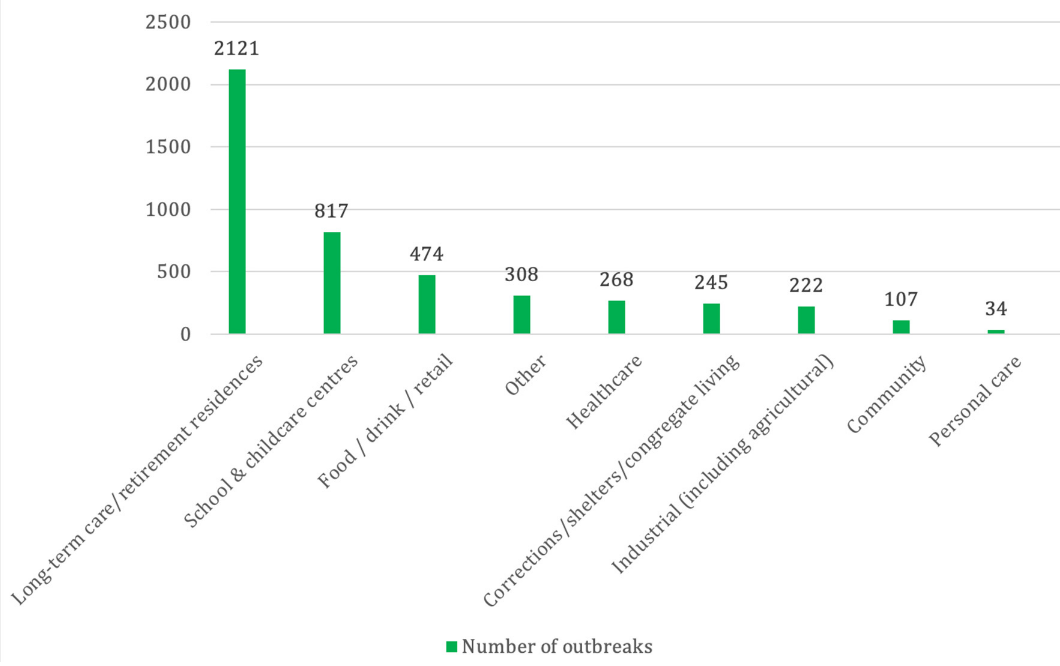

Fig. 3. The number of outbreaks in Canada by setting from 12 March 2020 to 14 November 2020 as compiled by the Public Health Agency of Canada. Note: “other” refers to social gatherings, office workplaces or recreational facilities; “Personal care” refers to items such as hair salons, or nail care etc; “Healthcare” refers to settings such as acute care settings, and health care settings apart from long-term care. Correctional facilities are labelled as “Corrections”. These data do not distinguish between provincial and federal correctional facilities. “Industrial settings” includes food processing plants. The categories presented in this graph are those shared by the Public Health Agency of Canada at the time of writing.

It has been learned from detailed outbreak work and epidemiological mapping of cases that numbers, percentages, and rates alone can be misleading. It is the stories behind the numbers that shed light and clarity on areas of risk.

For example, the workday break time moments, the travel times, and workday meetings are sometimes identified as cause for transmission among workers. Learning why workers who are ill might still come to work is critical to understand as well. This information is best learned through epidemiological mapping of outbreaks and detailed interviews with workers collected in real-time.

In some outbreaks, it has been learned through contact tracing and cross-referencing of worker interviews that there are factors that contribute to infection transmission that extend beyond the place of work (e.g., carpooling or living in crowded living quarters or workers who live together). These factors can also contribute to the size of workplace outbreaks.

As case numbers rise, if public health and contact tracing teams are stretched beyond capacity, then opportunities for learning through outbreaks will become increasingly challenging in Canadian settings. The fundamental approach of "test–trace–isolate" (testing anyone with symptoms, contacting those that were in contact with the ill, and quarantining those individuals exposed to the ill and isolating those individuals who are ill to protect others) is required to glean best estimates of where and when transmission events occurred and what factors contributed to those events.

Further to a call for transparent data on occupational infections in the province of Quebec, the Institut National de Santé Publique du Québec (INSPC) released data and a report outlining trends in new COVID-19 cases that are linked to workplace settings (Marotta 2020). Media headlines suggest the findings illustrate that almost 30% of new COVID-19 cases in Quebec are linked to workplace outbreaks and that there has been an upward trend since September 2020 in this regard. The data reportedly also point to specific industries and businesses such as manufacturing, retail, restaurants, and accommodations. Reports and data like this can help to shape and further policy, and when adequate detail can be obtained from individual case and outbreak analyses then prevention measures can be refined as best as possible.

4.2.1. Mitigating risk day-to-day in workplace settings

A tour of published workplace outbreaks from around the country reveals trends and illuminates areas for particular attention. Workers and management teams are advised to avoid what the WHO and PHAC label as "Three Cs": crowded spaces, confined spaces, and close person-to-person contact (Public Health Agency of Canada 2020f; World Health Organization 2020b). This applies to times when workers are on the job, on break times, and in the community. Knowledge of this, combined with a better understanding of the challenges workers face, help to hone present day public health and infection prevention messages. It also underscores why no single prevention measure stands alone.

Translated, the "Three Cs" means that risk of the disease spreading from one person to another in work settings is lower:

- when outdoors,
- when hand washing is routinely and correctly performed (20 seconds with alcohol-based hand rubs or soap and water),
- when people are spaced 2 m apart (physical distancing),
- when fewer individuals mix in-person (virtual is the way to go when possible),

- when anyone sick is supported to speak honestly and stay home from work (preventing importation of infection into the workplace),
- when those ill have access to COVID-19 testing and tracing (so that others can be placed on quarantine when applicable to prevent outbreak),
- when multilayer masks are worn by everyone. Personal protective equipment such as a mask is certainly not new to industry, but its placement in break room settings or at business meetings or during travel is novel to most.

Experience from the first 10 months of Canada's epidemic can be used to help to focus the next best steps in procuring, organizing, and analyzing data for the protection of workers and services and the community at large in Canada. Lessons learned could be formalized and standardized to ensure we are even better prepared to direct policy, actions, and resources for the next epidemic and to meet the overarching goals to protect working Canadians in the workplace, home, and community settings.

5. COVID-19 in long-term care in Canada

The COVID-19 pandemic has had a devastating impact on residents and staff of LTCH. In Canada, LTCHs in most provinces have been affected, and Ontario and Quebec have been particularly hard hit. In Ontario, in wave 1, 55% of all LTCHs experienced at least one COVID-19 outbreak, and outbreaks have continued in wave 2 (Ontario's Long-Term Care Commission 2020). Outbreaks have involved both residents and staff working in the homes, and to date, residents of LTCHs have accounted for approximately 80% of all COVID-19-related deaths in Canada (Canadian Institute for Health Information 2020d). The frequency, size, and scale of COVID-19 outbreaks were, and continue to be, unprecedented. Reasons for this are multifactorial and complex, but involve delays in preparation, longstanding system challenges in the sector, as well as underlying resident factors. Outbreaks frequently overwhelm the local LTCH's ability to respond, requiring a larger system response; in the case of Québec and Ontario, even the military. The clinical presentation of COVID-19 infection varies widely in this population; morbidity and mortality in LTCH residents is high.

5.1. Delayed preparation

When COVID-19 first emerged as a novel pathogen, the health system response focused primarily on hospital preparedness. Infected travelers returning to Canada were expected to present to hospitals. Media and news stories from China and then Italy focused on acute care hospitals becoming overwhelmed with patients. It was not until COVID-19 arrived in North America that the full potential impact of COVID-19 outbreaks on LTCHs was realized. This was likely due to differences in cultures and relative lack of LTCHs in the previously affected countries. When the first LTCH COVID-19 outbreak in Washington State was declared COVID-19 guidance documents for this setting did not yet exist (McMichael et al. 2020; Public Health Agency of Canada 2020g). COVID-19 moved through North America before LTCHs could prepare. There was not enough time to stockpile personal protective equipment, or update and operationalize pandemic plans. Importantly, pre-existing gaps in infection prevention and control (IPAC) practices could not be overcome. The degree of preparedness likely varied by LTCH and by jurisdiction, and some provinces and territories with better public health support for this sector may have been better prepared than others.

5.2. Systemic gaps

COVID-19 exposed longstanding systemic challenges within the LTCH sector. Many LTCHs lacked the IPAC education, knowledge, and capacity critical to pandemic planning and infection prevention (Bui et al. 2020). Few had IPAC specialists on the ground educating staff on essential protocols including appropriate selection, as well as donning and doffing, of personal protective equipment. In many cases, staff and resident syndromic surveillance systems did not exist, and there was limited access to timely and comprehensive COVID-19 testing (Hatfield et al. 2020; McGarry et al. 2021).

Even once LTCHs were able to access the personal protective equipment they needed, implemented universal masking of staff and visitors, and had improved access to testing, outbreaks have continued. Older infrastructure and multi-bedded ward rooms (and a paucity of bathrooms) make it difficult, if not impossible, to mitigate spread once COVID-19 enters the LTCHs (Brown et al. 2021). LTCHs typically do not have empty rooms to allow for movement of residents into isolation in the event someone becomes ill (Kain et al. 2020b). For-profit status is also a predictor of magnitude of LTCH outbreaks, in terms of numbers of residents affected and mortality (Stall et al. 2020d). It is hypothesized that the main driver of these worse outcomes is the higher proportion of for profit homes that have older infrastructure including multi-bedded ward rooms (Stall et al. 2020a).

Many jurisdictions implemented policies restricting the number of locations staff could work, which exacerbated pre-existing staffing shortages. Although credited as an important IPAC measure, it exposed the fact that many staff worked part-time jobs in multiple facilities to compensate for low pay. Furthermore, chronic staffing shortages become critical staffing shortages during outbreaks when many staff became ill.

5.3. Resident factors

Residents of LTCHs are a highly vulnerable population. Congregate living increases their risk of COVID-19 infection, and their older age and underlying medical conditions are risk factors for severe outcomes (Pat et al. 2020; Price-Haywood et al. 2020; Perez-Saez et al. 2021). Pre-existing medical conditions can also make IPAC control measures more challenging to implement. For example, adherence to mask wearing while outside their room and hand hygiene can be low amongst residents due to underlying cognitive or behavioral conditions. Many residents with dementia or cognitive impairment wander and do not adhere to physical distancing. Lastly, underlying illness, communication challenges, or atypical presentations of illness that can occur in the elderly may make it difficult to identify symptoms of COVID-19.

5.4. Outbreak response

COVID-19 outbreaks can overwhelm a LTCH's ability to respond. As the outbreak spreads, residents require more care as they become ill, and at the same time, staff illnesses can decimate staffing. Lack of redundancy in staffing, particularly in management positions, can lead to challenges in leadership as well as operations when illnesses arise at a point when both leadership and staffing are critical. Once staff are off work, many LTCHs do not have robust Occupational Health Departments to help to safely bring staff back to work in a timely manner. Large outbreaks therefore require a system response, drawing on resources beyond the LTCH. Some LTCHs were successful with hospital partnerships, where hospitals provided much needed staffing during outbreaks, as well as IPAC, cleaning, and Occupational Health support (Stall et al. 2020b). In the most severe outbreaks, LTCHs closed and residents were decanted to hospitals. In other scenarios, the Canadian military was required to help provide care for the residents.

Following wave 1, to help build LTCH capacity pre-emptively and to ensure IPAC on the ground support during outbreaks, some regions implemented hospital "hub" and LTCH "spoke" models (Elrod and Fortenberry 2017). In Ontario, this model has been applied to provide much needed IPAC support to LTCHs during wave 2. The approach has improved IPAC capacity in the LTCHs to help with outbreak prevention and control. Although it is too soon to draw definitive conclusions around the effectiveness of this approach, in Ontario, as of early 2021, the SARS-CoV-2 infection rate per day in residents has been lower in the second wave than the first wave, and the case fatality rate from COVID-19 has improved from 33% mortality in wave 1 to 17% in wave 2 (Stall et al. 2020a). Despite these improvements, it is clear there is far more work to be done to improve IPAC safety in LTCHs.

5.5. Approach to visitors in long-term care

At the beginning of the pandemic, many jurisdictions implemented strict no visitor policies as a public health strategy to minimize the risk of outbreaks in LTCHs (Stall et al. 2020c). It quickly became clear that there should be a distinction between types of visitors. Some were general visitors, but others were essential care partners, providing critical physical care for the residents as well as key mental health support. Accordingly, many regions have tried to maintain access for essential care partners, even as COVID-19 community transmission increases.

5.6. Clinical presentation and outcomes

COVID-19 in residents in LTCH's can manifest in many ways. Most will develop classic COVID-19 symptoms including cough, fever, and shortness of breath; however, COVID-19 can also manifest atypically, including confusion and falls (Kain et al. 2020a; Kennedy et al. 2020). The spectrum of illness varies widely. During outbreaks, approximately 15% of residents can remain asymptomatic, whereas many others go on to develop severe illness (Kain et al. 2020a). Mortality in this population is high, ranging from approximately 15% to 30% in this population (Temkin et al. 2020). As our understanding of COVID-19 treatment increases, it is important to ensure this is translated, as appropriate, into the LTCH setting.

The impact of COVID-19 on residents, their families, and staff of LTCHs is unparalleled in Canada. COVID-19 has exposed many gaps in the LTCH system, and opportunities for improvement are many. It is essential that we implement structural and system changes to LTCHs so that the COVID-19 experience is never replicated.

6. COVID-19 and the education system in Canada

Since the beginning of the pandemic, there has been uncertainty and varied opinions about the risk of COVID-19 infection in children, and the potential role of children in transmitting infection in the community. More recently, governments and parents alike have grappled with planning around education and childcare during increasing epidemic spread. At the start of the pandemic in April 2020, school closures affected an estimated 1.3 billion students (UNESCO 2020). The impact on the well-being of students, because of loss of educational, social, developmental, and school-associated non-academic supports is of significant concern (Hoffman and Miller 2020). In addition, school closures have negatively affected parents' work (particularly mothers) and family financial security. To address these important issues, epidemiologic and transmission studies and school system-based surveillance are relevant. It is important to note that contradictory findings have been described in many of these areas; therefore, this section focuses on what appears to be a consensus view of the stronger literature, and these conclusions may change as data evolve.

6.1. School closures, re-opening, and home-schooling

The rationale for school closures can be twofold: to protect children from illness and to reduce community transmission. Therefore, an accurate understanding of the risk of infection in children, the likelihood of children transmitting infection, the impact of school closures on epidemics, and understanding the counterbalancing of health risks associated with school closures are all important.

In the initial severe epidemics in China and Europe, it was clear that COVID-related hospitalizations in children were rare, and that children are less likely to have documented COVID-19 infection. Only 1% of confirmed cases in the United Kingdom and 1.9% in Europe were in children (Munro and Faust 2020). Initial testing focused on the severely ill, so this finding could be due to high rates of mild illness in children going undocumented. However, large-scale antibody testing across populations support that in many jurisdictions children have not been infected as much as adults. For example, a population-based study in Spain showed that children were less likely to have antibodies to SARS-CoV-2 (3.8% in <19 years old) with the highest rates of previous infection (6.0%) in those over 65 years and the lowest rates overall in those under 10 years (1.1% in <1 year, 2.2% in 1–4 years, and 3.0% in 5–9 years) (Gobierno de España and Ministerio de Sanidad 2020; Pollán et al. 2020). This increasing infection rate by age gradient has also been reported in other countries, including a study in Geneva, Switzerland, showing seroprevalence children aged 5–9 had one-thrid the risk of those aged 20–49 years (relative risk (RR) 0.32 (95% CI 0.11–0.63)) (Stringhini et al. 2020).

Only one seroprevalence study, which was also from Switzerland, showed higher rates in younger children across 12 cantonal districts (Ulyte et al. 2020). This random sampling seroprevalence study of schoolchildren showed the overall seroprevalence to be 2.8% (95% CI 1.6%–4.1%) (Ulyte et al. 2020). In these data, higher rates were seen in younger ages (3.8% in grades 4–5 versus 1.5% in grades 7–8) (Ulyte et al. 2020). Three-quarters of the children had COVID-19 compatible symptoms, but there were no symptom differences between COVID-19 seropositive and seronegative children (Ulyte et al. 2020). Antibody detection was similar in randomly selected adults in the same region (Ulyte et al. 2020). Therefore, patterns of exposure and mixing of children inside and outside of lockdown and school may be relevant, as well as the accuracy of the serologic tests used, especially when the overall incidence of disease is low. However, most studies suggest lower rates of COVID-19 infection in children. This may be due to less testing because of less severe infection, less exposure because of school closures, or to reduced susceptibility to infection.

Children do appear to be less likely to develop COVID-19 following exposure. A systematic review showed significantly lower attack rates in children than adults in household contact tracing studies, with 59% reduced risk as compared to adults in the same household (Viner et al. 2020). This review included 32 studies, and children and adolescents younger than 20 years had 44% lower odds of secondary infection with SARS-CoV-2 compared with adults 20 years and older in both household and non-household settings (Viner et al. 2020). This finding was most marked in those younger than 10–14 years. Proposed theories for reduced susceptibility to infection in children include cross-protective antibodies from other childhood coronavirus infections and increased angiotensin-converting enzyme 2 (ACE2) expression (Felsenstein and Hedrich 2020; Ng et al. 2020). ACE2 acts as the cellular receptor for SARS-CoV-2; however, it also functions to counteract and modulate proinflammatory and fibrogenic pathways by binding and converting angiotensin-2 to angiotensin-1-7 (Felsenstein and Hedrich 2020). Thus, those with higher density of ACE2 expression may better preserve these normal functions as SARS-CoV-2 competes against angiotensin-2 for binding to ACE2 (Felsenstein and Hedrich 2020).

Thus, children are generally at low risk of severe COVID-19 illness because they appear less likely to be infected and more likely to have very mild symptoms. However, as in the case of other respiratory viruses, do children spread infection within the community?

Most published observations from various countries suggest that children are more likely to be infected by adults than other children, and that children transmit relatively infrequently to adults, with no Canadian data available presently. However, a recent epidemiologic study in South India suggested more within age group transmission, and confirmed the observation that a small number of cases account for most transmission (Laxminarayan et al. 2020). In this study, 5% of cases accounted for 80% of the spread (Laxminarayan et al. 2020). However, even in this study, most secondary cases acquired infection from index cases who were 20–44 years old and transmission from children was less prominent (Laxminarayan et al. 2020). Infected children under 4 years old rarely transmitted outside their own age range, with a small signal of transmission in 65–70 year olds in high-risk contact, and school-aged children also tended to transmit to their own age range (Laxminarayan et al. 2020). This has also been observed in the Netherlands, where of the total number of infected contacts, 0.3% ($n = 14$) had a source patient under the age of 4 years, 0.7% ($n = 36$) had a source patient aged 4–11 years, and 4.6% had a source patient aged 12–17 years (National Institute for Public Health and the Environment 2020). In this report, the source patient was 18 years or older for 94.4% of infected contacts (National Institute for Public Health and the Environment 2020). In summary, existing data would suggest that children with COVID-19 are not significantly driving infection in adults, although it must be noted that risk reduction behaviours over time may have included reduced contact of high-risk older adults with children.

6.2. Incidence and transmission within schools

As countries recovered from their first wave, concerns about the negative effect of school closures on children's educational and social development, health, food security, and the disproportionate harm to disadvantaged children grew. School closures immediately highlighted financial and resource disparities within and between school systems, with disadvantaged students less able to access or participate fully in virtual learning opportunities due to problems with computer and internet access and the availability of an adult to supervise. Various guidance documents have outlined these concerns in detail (SickKids 2020).

Key questions remain unresolved: what is the risk of transmission in schools to both students and teachers under various prevention conditions, and what is the impact of open schools on community transmission?

Modelling has been performed to assess whether it is feasible to prioritize school opening in the face of community transmission. A recent modelling study from the United Kingdom suggested that unless contacts could be traced, and symptomatic cases tested and isolated efficiently, school opening and lockdown relaxation would likely contribute to a second pandemic wave (Panovska et al. 2020). In this model, adopting a part-time rota delayed the second wave peak by 2 months, and the results held if children were 50% less infectious than adults (Panovska et al. 2020).

Over the last 10 months, there has been experience gained as some areas have continued in-person schools, closed schools entirely, or closed schools just for older children and teens. The observed experience after school opening in several countries is instructive, and overall suggests that schools certainly can reflect community transmission, with school outbreaks increasing as community COVID-19 infection rates increase, with no clear link between school reopening and increases in community transmission thus far (European Centre for Disease Prevention and Control 2020). However, there is less data directly addressing the question of whether schools amplify community transmission.

Early in the pandemic, a high-profile Israeli secondary school outbreak occurred shortly after widespread societal re-opening, with 13% of students and 16% of staff testing positive on screening (Stein-Zamir et al. 2020). This took place during extensive community transmission and many factors made it difficult to determine how much in-school transmission had occurred. However, this did raise concerns about school opening and "second waves". However, a preprint detailed Italian contact tracing study of 43 cases during the second surge, including 5 teachers and 30 children, was more reassuring and supports that younger children are less likely to transmit infection, with the transmission rate in preschool settings was 0%, primary schools 0.4%, and secondary schools 6.6% (Larosa et al. 2020). In these schools, measures included 1 m between desks, masking except when seated (although masking was not mandatory in primary schools), they had staggered entry and exit times, and if the classroom space didn't support 1 m distancing, they had alternating in-person classes (Larosa et al. 2020). A larger data set with an interim analysis of >20 000 schools with >1 million children in England revealed 67 single cases and 30 outbreaks (S.A. Ismail et al. 2020). Of these, 22 outbreaks were due to adult staff index cases (S.A. Ismail et al. 2020). Importantly, outbreaks correlated with community prevalence. Measures in place included small classes in "bubbles" and hand hygiene (S.A. Ismail et al. 2020).

The risk of transmission to teachers has also been a focus of controversy. Occupation level data from Sweden suggested that teachers did not have an elevated risk of COVID-19 infection compared with the general population (Sunnee et al. 2020). A further Swedish analysis (in preprint) compared infection rates in lower grade secondary teachers (who conducted in-person classes) to upper grade secondary teachers (who conducted on line classes) and suggested an increased risk of infection of the in-person versus at home teacher population (OR 2.01; 95% CI 1.52–2.67) (Vlachos et al. 2020). The infection rate in the in-person teaching group was 0.46%, compared to 0.55% in non-HCW parents in the same study (Vlachos et al. 2020). It was noted that teachers at open schools were exposed to other adults at work and during their commute, and that during this period, there were no class size restrictions or face masks in use (Vlachos et al. 2020). These factors make this study difficult to interpret with respect to teacher's role-specific risk, as it essentially compares adults working from home to adults exposed to others in the community and in indoor spaces without personal protective equipment. By comparison, a seroprevalence study in two areas of Stockholm showed much higher incidence of infection overall and suggested geographic and socioeconomic risks play a large role, with 4.1% positivity in an area where working from home was common versus 30% positivity in area with many service workers as of June 2020 (Lundkvist et al. 2020). There are no specific data reported on teacher risk in a Canadian context.

In Canada, provinces and territories returned to in-person or hybrid in-person and virtual instruction for the Fall 2020 school year. Public attention to the prevention measures (and their variability) was intense, with hand and environmental hygiene measures universally supported, and variable use of symptom screening, masking in different age ranges, and more controversy over class size caps, and various methods of cohorting students. **Table 1** summarizes measures used across provinces and territories, with wide variation reflecting controversy over the efficacy of proposed prevention measures, a lack of standardized guidelines across jurisdictions, and differences in local transmission risk.

6.3. Experience after school re-opening

It is notable that in spite of school opening and enhanced testing in younger populations that, as of the end of November, the recognized COVID-19 infection rate is lowest in ≤19 year olds at 68/100 000 and is still highest in the ≥80 age group at 135/100 000. Those age groups account for 0.0% and 70.9% of the deaths in Canada, respectively (Public Health Agency of Canada 2020c).

Nonetheless, school outbreaks (defined by >2 cases in the federal public health reporting) were the largest outbreak category in September 2020 with over 300 outbreaks identified, but school outbreaks were surpassed by long-term care and retirement residence outbreaks in October and November (Public Health Agency of Canada 2020d). In spite of this, school opening over the fall was seen largely as a success, as case numbers arising from school settings remained modest, and the perception that increased testing around school opening resulted in capture of more clinically minimal or post infectious cases in children and youth. Of schools with ongoing case counts, 234/342 reported two to four cases, and 29% (100/342) reported five or more cases (Public Health Agency of Canada 2020d).

Table 1. COVID-19 prevention measures in place across Canada.

Region	Class size, cohorting measures	Mask recommendations	Other measures, provincial funding allocation	In school, at home/virtual options
British Columbia	No change Learning groups of 60 (elementary) and 120 (high school)	Mandatory (middle and high school) Optional (in classroom for staff/ students, common areas/buses)	Staggered breaks, barriers, individual activities 45.6 M funding	Virtual learning to supplement in-school learning
Alberta	No change Cohorts	Mandatory (grades 4–12, common areas/buses) Optional (K-3)	Staggered start times. No large gatherings 10M funding	At-home option for high school 30 November 2020 Grades 7–12 at-home learning until 8 January 2020
Saskatchewan	Class is cohort	Level 1: no mask required Level 2: masks required (grades 4–12 in common areas, grades 9–12 mask in class if cannot distance)	Staggered entry/exit and breaks 40M funding	—
Manitoba	Level 1: distancing—if not possible, cohorts Level 2: blended learning Level 3: remote learning Cohort maximum is 75	Mandatory (grades 4–12 if cannot distance, on buses)	For in person instruction: staggered break times, no assemblies 100M funding	At-home learning option for high school. Level 3: remote learning
Ontario	No change Some school boards (designated) capped at 15–20 students Cohorting by school board	Mandatory (grades 4–12, some school boards K-12 mandatory)	Staggered break times 35M funding	K-8 all in-person instruction Secondary schools in designated areas alternating virtual instruction
Quebec	Six-student "bubble" within class Classroom acts as cohort	Mandatory (grades 5–12, Postsecondary in common areas, in contact with other groups, and in "Red" zones)	1 m distance for 16 and under, 2 m for 17 and older 2 m between students and staff	Option for alternate day in-school and home learning.
Newfoundland and Labrador	Distancing per school boards, reinforce if increase in community transmission Cohort by class if possible	Masking allowed	—	In person classes through hybrid to at home depending on Public Health
New Brunswick	Cohort size (K-2: 15 if possible, grades 3–5: reduced if possible, grades 6–8 regular class)	Mandatory (grades 6–12 outside class) Encouraged (K-5) Teachers grades 9–12 mask or face shield if cannot distance	1 m distancing within classroom grades 9–12	High school alternate day in-school and home learning.
Nova Scotia	K-12 Cohort, outdoors if possible	Mandatory (grades 4–12 unless 2 m apart, on buses, in large groups)	Staggered entry/exit and breaks, no large assemblies Outdoors encouraged $40M	Option for home learning or hybrid if COVID-19 risk increases.

(*continued*)

Table 1. (*concluded*)

Region	Class size, cohorting measures	Mask recommendations	Other measures, provincial funding allocation	In school, at home/virtual options
Prince Edward Island	Cohorting Smaller class size if possible, distancing	Suggested (K-6) Recommended (grade 7–12 if cannot maintain distancing)	Staggered break times 2M funding	Possible at home learning as contingency plans
Yukon	Cohorting, smaller class size per school operational plan	Recommended (over age 10 and cannot distance 2 m)	Staggered breaks entry and exit	In Whitehorse, ½ d virtual grades 10–12
Northwest Territories	Distancing grades 7–12	Face shields and mask on bus and as needed by staff and students	Staggered breaks entry and exit Daily screening Gathering size limits 4.85M funding	Grades 7–12 blended if necessary Remote age 19+
Nunavut	Distancing, limited group activities (stages 1–3 increasing restrictions)	Not required	—	Stage 4 remote learning

Table 2 is derived from a public data compilation of school-based outbreaks, as provincial public health data are not comprehensively available and where available are not provided in a comparative format. Thus, these data should be interpreted with caution, although available public health reports were checked to ensure no large discrepancies in outbreak numbers exist. This data repository uses a definition of two linked cases as an outbreak thus mirrors the federal reporting, although individual provincial and territorial definitions vary. Based on these data and federal data, although school outbreaks have been occurring since September 2020, the number of possible outbreak-associated cases remain quite low, affecting from 0% to 0.5% of students in Canada (highest in Manitoba) in spite of large-scale in-person learning in the Fall 2020 school year with all provinces and territories offering in-class learning (People for Education 2020).

Overall, although school-based cases of COVID-19 undoubtedly have created considerable difficulties in quarantine and investigation, a small number of children overall have been infected, although larger numbers have been affected, and there has been considerable stress placed on the education system.

7. Severe COVID-19 disease in Canada

The spectrum of COVID-19 ranges from asymptomatic infection to mild-moderate, severe, and critical disease (Wu and McGoogan 2020). Patients who develop mild-moderate COVID-19 usually recover at home with supportive care and do not require hospitalization. Those with severe disease present with shortness of breath, need for supplemental oxygen, or have >50% lung involvement on radiologic imaging (Wu and McGoogan 2020). They require hospital admission and are generally treated on medical wards. Some hospitalized patients develop critical disease—with respiratory failure, shock, and (or) multiple organ failure—and require admission to ICU, often due to the need for invasive life support therapies.

PHAC estimated that, of a total 294 658 Canadians with COVID-19 for whom detailed case report data were available; 22 954 (7.8%) have been hospitalized to date (Public Health Agency of Canada 2020e). Among hospitalized patients, approximately one-fifth (4416 (19.2%)) have been admitted to

Table 2. Number of school-based outbreaks (2+ cases) and associated case count as of 4 December 2020 (open source).

Region	Cumulative number school-based outbreaks[a]	Cases/outbreak	Outbreak associated cases/1000 students[b]
British Columbia	535	2.29	2.2 (1230 of 553 377)
Alberta	614	2.39	2.3 (1468 of 640 869)
Saskatchewan	195	1.88	2.1 (367 of 177 246)
Manitoba	331	2.68	4.9 (889 of 181 023)
Ontario	1849	2.72	2.5 (5047 of 1 993 431)
Quebec	1905	N/A	N/A
Newfoundland and Labrador	0	N/A	N/A
New Brunswick	21	1.05	0.2 (22 of 97 911)
Nova Scotia	6	1.16	0.1 (7 of 118 152)
Prince Edward Island	0	N/A	N/A
Yukon	0	N/A	N/A
Northwest Territories	0	N/A	N/A
Nunavut	0	N/A	N/A

[a]These data are not available in a comparable format nationwide from any public health source and are derived from a crowdsourced website, masks4canada.org/canada-covid-19-school-case-tracker/, which is an aggregation of publicly available data and information "that has been disclosed on a voluntary basis in the public interest". Single/Unlinked cases are not included. Investigation of some outbreaks may be ongoing.
[b]Student population data by province from www150.statcan.gc.ca/n1/daily-quotidien/171103/t001c-eng.htm.

ICUs, and 1058 (4.6% of hospitalized patients and 24.0% of ICU patients) required mechanical ventilation (Public Health Agency of Canada 2020c). Additional forms of organ support, such as renal replacement therapy and extracorporeal membrane oxygenation, are rarely required; however, Canadian data are unavailable (Richardson et al. 2020; Wang et al. 2020).

Canadian hospitalization and ICU admission rates are similar or comparatively lower to other countries. From over 55 000 lab-confirmed COVID-19 cases in China, approximately 80% of patients had mild-moderate disease, 14% required hospitalization for severe disease, and 6% developed critical disease (World Health Organization 2020c). During the first wave in Italy, high ICU admission rates were observed—with the proportion of ICU admissions representing approximately 12% of all positive cases but only 16% of hospitalized patients. This may relate to varying ICU admission criteria, or more likely, population differences in risk factors for severe disease (such as age and pre-existing medical conditions) (Livingston and Bucher 2020).

High rates of hospitalization were also observed in New York City during the first wave, with 52% of COVID-positive patients requiring hospital admission, 24% of whom required mechanical ventilation. This may have been due to the high number of pre-existing medical conditions in their population; with 88% of admitted patients having two or more underlying conditions (Richardson et al. 2020).

Differences in hospital and ICU admission percentages by country vary. Reasons for this are complex and relate to population risk factors as described below, health care capacity and differences in case detection and reporting (which may affect accuracy of the denominator).

7.1. Risk factors for severe COVID-19

Many risk factors have been identified for the development of severe or critical disease.

Age has been consistently associated with severe disease (Petrilli et al. 2020; Wang et al. 2020; Zhou et al. 2020). Those >60 years of age seem to be at highest risk. In Canada, hospitalization rates of those with COVID-19 range from a low of 1.4% in those 0–19 years old, up to 33.7% in those greater than 80 years old. ICU admission rates similarly increase with advanced age, with 1.1% in those 0–19 years of age, 3.0%–8.7% in those 20–49 years, and 18.1%–25.7% in those greater than 50 years old (Public Health Agency of Canada 2020e). The highest ICU admission rates (~25%) have been observed in those 60–79 years of age. ICU admissions drop slightly in those greater than 80 years (13.9%), likely due to patient preferences (patients declining ICU care near the end of life) or limited access. Disease in young children appears to be rare (Dong et al. 2020). Sex differences in hospitalizations and ICU admissions are not striking; however, it does appear that males are more likely to develop severe disease. Males account for 56% of hospital admissions and 66% of ICU admissions in Canada.

Chronic medical conditions have been consistently associated with severe disease (Arentz et al. 2020; CDC COVID-19 Response Team 2020a; Wu and McGoogan 2020; Zhou et al. 2020). In Canada, among hospitalized cases with available data, 74% reported one or more pre-existing conditions. Such conditions include chronic lung disease, heart disease, hypertension, diabetes, kidney disease, liver disease, and stroke. In addition, those with immune compromise (e.g., receiving chemotherapy for cancer) and obesity (body mass index 40 or greater) are at higher risk (S.J. Ismail et al. 2020).

The majority of pregnant women with COVID-19 will experience mild to moderate illness, but studies have shown that pregnant women with more severe COVID-19 disease have had increased risk of ICU admission and mechanical ventilation as compared to non-pregnant women (Allotey et al. 2020; Watson et al. 2020; Zambrano et al. 2020; The University of British Columbia 2021).

Risk factor data from other countries are very similar (CDC COVID-19 Response Team 2020b). Individuals at highest risk for severe disease in China included those over 60 years and those with underlying medical conditions such as hypertension, diabetes, cardiovascular disease, chronic respiratory disease, and cancer (World Health Organization 2020c; Wu et al. 2020). In a large study of Italian patients admitted to the ICU with COVID-19, 68% had at least one pre-existing medical condition (Grasselli et al. 2020b).

In New York, the strongest risk factor for hospital admission was age, with an odds ratio (OR) of greater than 2 for patients 45 years and older and 38 for those 75 years and older (Petrilli et al. 2020). Other risk factors included heart failure (OR 4.4), male sex (OR 2.8), chronic kidney disease (2.6), and obesity (OR 2.5 for BMI >40). Those admitted to hospital were more likely to be men (61% vs. 37%). Similar risk factors predicted the need for ICU admission (Petrilli et al. 2020).

7.2. Presentation

The median incubation period from exposure to SARS-CoV2 to the development of COVID-19 (disease) is estimated at 4–5 days, but can be up to 14 days (Li et al. 2020). As mentioned previously, the spectrum of disease ranges from asymptomatic infection to severe viral pneumonia. In those who require hospitalization, shortness of breath and low oxygen levels often occur around 5–8 days from the onset of milder symptoms, such as fever and cough. Hospital admission usually occurs approximately 7 days from symptom onset (Huang et al. 2020; Wang et al. 2020). Progression to critical disease often happens quickly in this group of patients, with decreasing oxygen levels and the development of acute respiratory distress syndrome (ARDS)—a syndrome characterized by low oxygen levels and widespread inflammation in the lungs (Guan et al. 2020; Wang et al. 2020; X. Yang et al. 2020; Young et al. 2020; Zhou et al. 2020).

Additional complications can include acute cardiac injury (7%), shock (9%), kidney or liver failure, thrombotic complications (blood clots in the legs or lungs), and neurologic complications such as stroke (Wang et al. 2020). Some patients with severe disease appear to have a pronounced inflammatory response, characterized by persistent fevers and elevated laboratory markers of inflammation. Secondary infections (such as secondary bacterial or fungal pneumonias) do not appear to be common, with 8% reported in one study (Rawson et al. 2020). However, higher incidence (up to 28%) has also been reported, in particular among critically ill patients with COVID-19 (Bartoletti et al. 2020).

Chest X-ray findings in severe or critical disease generally show widespread abnormalities. Patients admitted to the ICU usually require either high-flow oxygen or mechanical ventilation. For patients who develop respiratory failure, mortality is between 15% and 31% (S.S. Yang et al. 2020; Murthy et al. 2021).

7.3. Mortality

The overall Canadian case fatality rate, as of 25 November 2020, was 3.4% (Johns Hopkins Coronavirus Resource Center 2020; World Health Organization 2020d). Mortality ranges from 0% to 10% by province and territory—reflecting differences in disease activity and local outbreaks. Overall, case fatality rates are similar in other countries. For example, as of late-November 2020, mortality rates in China, Italy, and the United States were 5.1%, 3.5%, and 2.1%, respectively (Johns Hopkins Coronavirus Resource Center 2020). Reported case fatality rates have declined globally, which may relate to a number of factors—more widespread testing (including asymptomatic individuals), an increase in cases among younger patients, and better therapies (such as anti-inflammatories as reported in the RECOVERY Trial) (The RECOVERY Collaborative Group 2020). In those requiring hospitalization, mortality has been approximately 14%. For those patients requiring ICU admission, case fatality is higher, at 25% (Quah et al. 2020). It does appear that case fatality rates are also declining in this population over time (Dennis et al. 2021; Horwitz et al. 2021).

Mortality, not surprisingly, has been associated with advanced age given this is one of the strongest risk factors for severe or critical disease (CDC COVID-19 Response Team 2020b; X. Yang et al. 2020; Zhou et al. 2020). Mortality remains relatively low in young populations, with 0%–0.2% mortality in those 0–39 years old and 0.6% in those 40–49 years of age. The highest mortality has been observed in 70–79 year olds (18.4%) and those greater than 80 years old (71%). Canadian provincial and territorial mortality reporting is available at health-infobase.canada.ca/covid-19/epidemiological-summary-covid-19-cases.html.

In Canada, 53% of deaths have been in females; however, other countries have observed higher mortality in males compared to females. The higher female mortality rate in Canada may relate specifically to a larger number of female deaths in those over 80 years, which may be explained by longer life expectancy (and a larger proportion of elderly females at risk of developing COVID-19) in Canadian women compared to men. In the United States, 54% of deaths have been in males, despite fewer overall case counts in male patients (48% of all infections) (Centers for Disease Control and

Prevention 2020). Higher male mortality has also been observed in Italy with a 3:1 male-to-female ratio (Di et al. 2020).

In China, the overall case fatality rate reported in February 2020 was 3.8%. At that time, mortality varied by region and intensity of transmission, with the highest rates in Wuhan (5.8%) and much lower rates (0.7%) in other regions in China. In addition, mortality was higher early in the outbreak and has decreased over time, perhaps due to changes in standard of care and increased health care capacity. Mortality was also associated with advanced age in China, with the highest case fatality rates among those over 80 years. Males were more likely to die compared to females (4.7% vs. 2.8%) and those with no pre-existing conditions had lower case fatality rates (1.4%) compared to those with pre-existing medical conditions (7.6%–13.2%) (World Health Organization 2020c; X. Yang et al. 2020).

In Italy, the overall case fatality rate was reported as 7.2% during the first wave, which was substantially higher than in other countries. This higher mortality appeared to be due a larger proportion of older COVID-19 patients, and higher mortality specifically in those aged over 70 years. This is likely explained by the older mean age in this eldest cohort, with a higher proportion of over 90 year-olds (Onder et al. 2020). In addition, the higher mortality in Italy may have been overestimated given that COVID-19-related deaths were defined by test positivity, independent of pre-existing diseases that may have caused death (Onder et al. 2020).

Similar overall mortality trends are being observed in the United States, with disproportionately higher mortality in older populations (15% in 50–64, 21% in 65–74, 27% in 75–84 and 32% in those 85 years or older). Members of minority racial and ethnic groups are also disproportionately at risk of death from COVID-19 (Gold et al. 2020).

7.4. ICU capacity

The creation of hospital and ICU capacity to care for large numbers of COVID-19 patients has been, and continues to be, a major challenge during the pandemic. An assessment done after the 2009 H1N1 pandemic showed that provinces and territories vary significantly in baseline ICU capacity, with ventilator-capacity ICU beds ranging from 5.5 to 19.3 per 100 000 population, and acute care beds ranging between 200 per 100 000, which are relatively low compared to peer countries.

Some countries had the opportunity to engage in advance capacity planning (Canada, United States) while others hit earlier during the global pandemic (China, Italy), unfortunately did not. Considering approximately 20% of hospitalized patients require ICU admission, of which up to 70% can require mechanical ventilation, additional staffing, supplies and space are required to care for these patients (Aziz et al. 2020; Grasselli et al. 2020a).

Staffing needs have been met in many countries by reclaiming and redeploying health care staff. For example, in the early days of the pandemic, China deployed 40 000 health care workers to Wuhan. In addition to human resource shortages, supply chains (e.g., personal protective equipment) have been threatened, but have been met in Canada, at least for now by an increase in manufacturing. Ventilator inventory and stockpiling has been essential as part of ICU capacity planning.

Additional physical space has been required for assessment centres and to expand medical wards and ICUs. Much of this space has been refurbished or borrowed space from other clinical services. To increase resources, many countries (including Canada) have suspended or delayed elective (including non-urgent but necessary) medical and surgical procedures. For example, 60% of elective surgeries were on hold in Alberta at the time of writing. ICU restructuring, with non-critical care trained staff delivering ICU care through team nursing has been required in many settings.

The development of triage criteria and documents to guide practitioners in deciding who should receive care when health care resources are insufficient have varied by country. Some have been published widely while others have received little to no publicity (Camporesi and Mori 2020; Orfali 2020). Clear societal guidance on triage is important, as otherwise undue stress and responsibility is placed on physicians to make these decisions—which can have legal consequences.

Mathematical modelling has been employed widely to help plan capacity needs. Unfortunately, predictive models—even with best case, worst case, and most likely scenarios—are not always accurate (Aziz et al. 2020). This is likely due to insufficient early data, temporally and geographically dynamic outbreak settings, and the complexity of the models where variables may be difficult to predict (Eker 2020). Such variables include infectivity, hospitalization, and ICU admission rates; ventilation and advanced life support needs; hospital and ICU lengths of stay; and the effect of physical distancing, mandatory masking, or lockdown measures. Despite this, real-time modelling remains an important element in attempting to predict the health care needs of Canadians and planning for resource allocation (canada.ca/en/public-health/services/diseases/coronavirus-disease-covid-19/epidemiological-economic-research-data/mathematical-modelling.html) (Bertozzi et al. 2020; Holmdahl and Buckee 2020).

7.5. Multisystem inflammatory syndrome in children (MIS-C)

As mentioned previously, children of all ages can develop COVID-19; however, they appear to be less affected than adults, accounting for approximately 10%–15% of total cases (Public Health Agency of Canada 2020e). In addition, children appear to have milder symptoms than adults, and more than one-third of children with COVID-19 show no symptoms (King et al. 2021). Severe disease, although rare, has been reported in approximately 2% of childhood cases with even fewer develop critical disease (0.7%) (Liguoro et al. 2020). Additionally, it was recognized in May 2020 that some children with COVID-19 were developing symptoms resembling the rare inflammatory syndrome Kawasaki disease, with significant multiorgan dysfunction and shock (Riphagen et al. 2020). This surge was recognized in pediatric centres, following four weeks after the initial peak of the COVID-19 pandemic in the surrounding community. Now called "multisystem inflammatory syndrome in children associated with COVID-19" (MIS-C), this illness tends to affect 8–10 year-old children (Riphagen et al. 2020).

This syndrome is extremely rare, affecting approximately 0.02% of children with documented COVID-19, using UK data (Munro and Faust 2020). Similarly, a rapid review of pediatric transmission yielded an estimate of 0.05% on informal analysis of reported cases in New York State (Alberta Health Services 2020b). Peaks of cases have occurred 2–4 weeks after the peak in incidence of COVID-19 and almost all children from various reported cohorts are positive for SARS-CoV-2 IgG antibody when diagnosed. Children from Latino, Black, Asian, or other minority ethnic backgrounds are over-represented in the cases described so far (Munro and Faust 2020). Given that most children have had positive antibody tests at the time of illness (suggesting immunity and previous infection), this disease seems to be a post-viral inflammatory state. Children may have persistent fever, abdominal pain, diarrhea and vomiting, and occasionally rash and mouth findings (Munro and Faust 2020). Shock, heart dysfunction, and respiratory distress may occur (Munro and Faust 2020). Therapies being studied include intravenous immune globulin and steroids, as well as other immune modulators. Although this disease can be severe and require critical care support, most children recover quickly, with an overall mortality around 2% (Feldstein et al. 2020). This syndrome has caused a great deal of concern; however, it remains rare, with an overall good prognosis, and increasing knowledge about most appropriate therapies.

7.6. Post-acute COVID or prolonged post COVID-19 symptoms

Some patients reportedly experience symptoms lasting weeks or months after acute COVID-19 (Carfì et al. 2020; Greenhalgh et al. 2020; Rubin 2020; Tenforde et al. 2020). Many terms have been used to describe this entity in the literature—"post-acute COVID", "post-COVID syndrome", "long haulers", "long COVID", or "chronic COVID". These patients appear to have recovered from the most serious symptoms of infection and do not have evidence of active viral infection; however, they have ongoing symptoms. The underlying mechanisms are not well understood; however, it is believed to be a post-viral phenomenon. Whether this syndrome is unique to COVID-19, or represents a non-specific syndrome related to illness recovery remains unclear. Symptoms such as fatigue, shortness of breath, chest pain/tightness, and cough are often present (Carfì et al. 2020; Nehme et al. 2020). In addition, physical impairment (deconditioning, muscle weakness), psychiatric disorders (anxiety, depression, and post-traumatic stress disorder), and cognitive impairment (deficits in attention/concentration, memory, and executive function) may be present (Taquet et al. 2020; Wong et al. 2020).

Validated or agreed-upon definitions for "long COVID" do not exist. Some describe post-acute COVID by symptoms extending beyond three weeks from the onset of first symptoms and chronic COVID when symptoms extend beyond 12 weeks (Greenhalgh et al. 2020). It is estimated that approximately 10% of COVID-19 patients develop this syndrome (Rubin 2020). Risk factors are not described—thus far it appears patients of any age, any pre-existing medical state or any severity of acute illness can develop "long COVID". Most patients did not require hospitalization in the acute phase of illness, and even fewer have required ICU-level support.

Symptoms are varied and inconsistent but include cough, shortness of breath, fatigue, body and joint pain, headache, insomnia, and cognitive changes (predominantly impaired memory and concentration). Relapsing or waxing/waning symptoms are also common. Further research to explore differences in objective lung function, as well as associations between infection and less quantifiable symptoms (such as fatigue), is needed. An understanding of the distribution and magnitude of these associations will help us better understand the disease, guide patient care, and ensure adequate resources are available.

Post-COVID recovery clinics have been developed in many centers in Canada, to address the need for more chronic care and follow-up. These are specialized care clinics for those who were diagnosed with COVID-19 and are now in recovery, where they can receive comprehensive care including access to a multidisciplinary team of physicians and allied health services.

8. COVID-19 in vulnerable populations in Canada

The pandemic has had a historic impact on the global community. In this section, we review populations in Canada that may not access the health care system in traditional ways or are at increased risk of acquiring or dying from COVID-19. These populations may also be disproportionately affected by the public health and societal responses to the pandemic (Mishra et al. 2020a). There is not one COVID-19 epidemic in Canada, but many micro/regional-epidemics. Data on these heterogeneous groups can inform a risk-tailored approach to individual communities and unique cohorts. This practice is not uncommon when approaching communicable diseases. The end goal of specific targeting would be to prevent infections, hospital admissions, and deaths and promote health equity.

8.1. Indigenous Peoples

Data pertaining to cases of COVID-19 on First Nations reserves is publicly available through Indigenous Services Canada (ISC) (Government of Canada 2020a). According to ISC, as of 3 December, there have been 4303 confirmed COVID-19 cases. Of these, 1564 were active cases at that time. A total of 192 cases required hospitalization and a total of 39 deaths were reported. The vast majority of these cases have been observed in the prairie provinces, with 1323 cases in Alberta, 1102 cases in Manitoba, and 1185 cases in Saskatchewan.

In contrast to predictions made early in the pandemic, Canadian First Nations, Inuit, and Métis communities have actually had lower COVID-19 incidence rates and mortality compared with non-Indigenous peoples (Government of Canada 2020e). This is despite social determinant of health and structural inequities associated with poor outcomes that existed prior to the pandemic. As of 9 November, the percentage of reported COVID-19 cases among Indigenous Peoples living on reserve was half the rate of the general Canadian population, and the case fatality rate was 20% that of the general Canadian population (Government of Canada 2020a). However, there are well-founded concerns that cases may be amplified in the second wave (winter months) in communities that traditionally have had higher rates of community virus transmission.

Certainly, there is heterogeneity among Indigenous communities, and this also pertains to health care and access to COVID-19 screening. Furthermore, the data above pertains to on-reserve individuals and does not account for those living off-reserve. Many Indigenous people living off-reserve may find themselves marginalized and facing barriers to access medical care and diagnostics. Some communities are remote and face challenges due to their geography. Although the remoteness of some Indigenous communities may decrease the risk of entry of the virus into the community, once within the community, there is high risk of spread. Mitigation strategies such as social distancing and hygiene practices, the mainstay of Canada's approach to containing the pandemic, require adequate housing and water, which may be a challenge in Indigenous communities (Lane 2020; Richardson and Crawford 2020).

In early May, an outbreak was reported in northern Saskatchewan where two Dene Elders living in a long-term care facility died. The community was locked down to all but essential travel. Two nearby Indigenous communities also reported cases at that time (Vogel 2020). An additional outbreak was noted in northern Saskatchewan in July. Through the early stages of the second wave, cases in Indigenous communities were on the rise with associated deaths. This was noted in communities in the Yukon, Manitoba, Ontario, and Quebec (Canadian Broadcasting Corporation 2020e).

Tracking outbreaks in Indigenous communities across Canada has been challenging; however, the ISC has used 10 or more cases in a community as a proxy for community outbreaks to assist with operational planning. As of 16 November, there were greater than 50 Indigenous communities fitting that definition (D. Webster, Dr M. Trubnikov (Communicable Disease Control Division, First Nations and Inuit Health Branch, Indigenous Services Canada), personal communication, 18 November 2020]. It is important that these communities determine the approaches that work best within their own settings. The First Nations Health Managers Association has developed the *Pandemic Planning Tool for First Nations Communities* to assist in the development of individualized pandemic plans (First Nations Health Managers Association 2020). During the pandemic, many communities have shown self-determination, articulating and implementing rules pertaining to entrance into communities. Frequently, the measures employed have been stricter than those of other local municipalities, provinces, and territories (Richardson and Crawford 2020).

To date, there is a paucity of publicly available or published data on COVID-19 and Indigenous Peoples. Research may help to determine future strategies. Where research is undertaken, however, it is critical that the principles of ownership, control, access, and possession—commonly referred to as OCAP®—be applied (First Nations Information Governance Centre 2020). Indigenous Peoples own their cultural knowledge and community data collectively in the same way that an individual owns his or her personal information. Indigenous leaders have appropriately advocated for the collection of Indigenous-specific COVID-19 data with clear data sovereignty agreements related to access, control, ownership, and possession of the data (Richardson and Crawford 2020).

8.2. Racial disparity—ethnic minorities and newcomers to Canada

Racial disparities and health inequities are known to exist in Canada (Ramraj et al. 2016). Beyond the inequities experienced by Indigenous Peoples, there are other notable racial disparities in Canada. Existing data suggests that visible minorities and newcomers to Canada may experience higher rates of discrimination, associated with risk factors for chronic disease as well as higher rates of COVID-19 (Siddiqi et al. 2017).

Similar disparities exist outside of Canada. A published review of preliminary data from Connecticut demonstrated higher rates of COVID-19 infection and death among Black Americans (Laurencin and McClinton 2020). Similar findings were observed among those living in England and Wales of Black ethnicity (Black Caribbean, Black African, Black Other) where COVID-19 mortality was found to be nearly double that of those of White ethnicity (White British, Irish Traveller, Other White) in the same communities, even when adjusted for age and other socio-demographic characteristics. Females of Bangladeshi and Pakistani ethnicity had a mortality rate 1.6 times greater than their white counterparts. For males in these ethnic groups, the risk of death due to COVID-19 was 1.8 times greater (Office for National Statistics 2020).

The reporting of comprehensive COVID-19 data by race and ethnicity in Canada has been limited to date. Within weeks of recognition of the first cases in Canada, emergent case data indicated that the highest infection and mortality rates were concentrated among minority populations (Gibb et al. 2020). An outbreak at a shelter for refugees in the North York district of Toronto was publicized following the release Toronto Public Health data, which showed 88 residents tested positive for SARS-CoV-2 (Knope 2020).

A CBC report from mid-June suggested significant disparity and health inequity related to COVID-19 among Black residents in Montreal (Rocha et al. 2020). Although Canadian data on the race of COVID-19 patients is not publicly available, such data may aid in identifying and protecting vulnerable populations. To assess how race and socio-economic factors have impacted communities during the pandemic, the CBC cross-referenced census data with case numbers for each borough or municipality. They found that lower-income neighbourhoods with higher numbers of Black residents had registered the most cases of COVID-19 in the city. For example, Montréal-Nord, home to a large Haitian community, had the highest case counts, with 2911 cases per 100 000 people as of 9 June.

Using Ontario health insurance plan data, researchers in Ontario reviewed patterns of COVID-19 testing and results for immigrants and refugees (Guttmann et al. 2020). It was found that while immigrants, refugees, and other newcomers make up roughly one-quarter of Ontario's population, they accounted for 43.5% of all COVID-19 cases by June 2020. Among those tested, refugees had the highest percent positivity at 10.4%, compared to 7.6% positivity among other immigrants and 2.9% among Canadian-born and long-term residents. In addition, Ontario Laboratories Information System data up to 12 October revealed that those living in the most ethnically diverse neighbourhoods of Ontario had an almost 10-fold higher percent positivity for COVID-19 (3.7%) compared to those living in the least diverse neighbourhoods (0.4%) (ICES 2020).

To effectively protect and support vulnerable communities and marginalized people, data pertaining to COVID-19 cases and outcomes within these communities is vital. PHAC reports that it is working with federal partners, provinces, and territories towards the development of a pan-Canadian Health

Data Strategy. Race and ethnicity data pertaining to COVID-19 are among the list of short-term priorities.

8.3. People who use drugs

Prior to the pandemic, people who use drugs (PWUD) were caught in the concurrent public health crises due to human immunodeficiency virus (HIV), hepatitis C virus (HCV), and the opioid epidemic. It is well established that when viral infections such as HIV and HCV co-exist with poverty and homelessness, the result is accelerated disease progression and worse outcomes (Klein et al. 2013). It has been acknowledged that interventions aimed at reducing harm from substance use in combination with increasing the delivery of health care are critical to reducing adverse health outcomes. The arrival of the COVID-19 pandemic has compounded this syndemic (Bonn et al. 2020). Many public health mitigation strategies employed to combat the pandemic have made the management and prevention of substance use disorders more challenging (Alexander et al. 2020).

Opiate agonist therapy (OAT), needle exchange programmes, withdrawal management, and counselling services have been disrupted during the pandemic resulting in unmitigated substance use and high-risk behaviours, as well as increased risk of individual COVID-19 infection and transmission within the community (Dunlop et al. 2020; Whitfield et al. 2020).

British Columbia is the epicentre of Canada's opioid epidemic (British Columbia Center on Substance Use 2020). Beginning in April, as the pandemic evolved, a large spike in overdose deaths was reported. In fact, the illicit drug overdose death toll in June was the highest monthly count in the province's history—greater than the number of deaths resulting directly from COVID-19. The number of illicit drug toxicity deaths in September 2020 equated to roughly 4.2 deaths per day and 70% of those dying were aged 30–59 years (British Columbia Coroners Service 2020). To adhere to social/physical distancing, many PWUD have been more inclined to use alone, increasing the risk of unintentional overdose. Cuts to supervised consumption site budgets and increased deaths among PWUD have been felt across the country (DiMatteo 2020; Rai and Sharma 2020).

While increased harms in relation to substance use have resulted indirectly from the COVID-19 pandemic, PWUD are also at increased risk of acquiring COVID-19 and developing severe disease (Jozaghi et al. 2020; Slaunwhite et al. 2020). Many PWUD live in poverty and have other medical conditions such as immune deficiency and chronic lung disease (Jozaghi et al. 2020). Sub-optimal and crowded housing may increase the risk of viral transmission. Unstable housing, food insecurity, and precarious social supports may also compromise recovery. PWUD may also prioritise drug use above other health concerns and self-manage symptoms by increasing opioid use (Dunlop et al. 2020).

To date, COVID-19 has had a devastating impact on PWUD with pre-existing challenges further compounded by sudden and dramatic changes in social and health care systems (CIHR Institute of Neurosciences, Mental Health and Addiction 2020). In general, PWUD have been more vulnerable during the COVID-19 pandemic, due to poor health literacy, stigma, and discrimination. Access to testing in PWUD has been challenging (Bonn et al. 2020; Dunlop et al. 2020).

Maintaining adequate management of substance use disorders during the pandemic will require advocacy and innovation. As individuals may require periods of isolation during the pandemic, they may need a sustained supply of OAT. Ensuring access to take-home naloxone is also crucial to reduce overdose (Dunlop et al. 2020).

8.4. People who are homeless

In 2016, 129 000 Canadians made use of emergency shelter beds with an estimated average of 14 000 Canadians using an emergency homeless shelter each night (Jadidzadeh and Kneebone 2020). Approximately 400 emergency shelters across the country offered 15 400 beds per night during that year. Four years later, the pandemic is drawing attention to the serious implications of policies and approaches that have allowed shelters to become permanent homes for many of the country's most marginalized people.

Despite being a safer place for many, most shelters are only open from the evening through to the morning hours and individuals must seek out other safe places during the day. The pandemic, however, has uprooted established routines (Boucher 2020). The loss of this limited structure has thrown further chaos into already frail lives. Increased food insecurity and difficulty accessing required services to meet basic needs have been observed (Tucker et al. 2020).

The homeless may also be at increased risk of viral acquisition and severe COVID-19. Viral transmission within shelters may occur given the congregate setting (Jadidzadeh and Kneebone 2020). An American study assessed the prevalence of COVID-19 in homeless shelters in four cities in March/April 2020. Atlanta had a prevalence of just 4% among residents; however, Seattle, Boston, and San Francisco had much higher rates of 17%, 36%, and 66%, respectively. The prevalence among shelter staff ranged from 2% in Atlanta to 30% in Boston (Mosites et al. 2020).

Systematic testing in Toronto recorded outbreaks at 14 Toronto shelters by April 2020, with 110 confirmed cases at one site (Knope 2020). Toronto's shelters have struggled with capacity issues with roughly 7000 people using shelters in the city every night (Casey 2020). During the first wave of the pandemic, many Canadian cities sought to move residents from shelters to other centres set up to alleviate overcrowding. Victoria's city council passed an emergency resolution on 17 April, calling on the use of empty hotels to house the homeless to assist with physical distancing and self-isolation (Wells 2020). Similarly, in Toronto by late-April, more than 1000 shelter residents had been moved to hotels, permanent housing, or other shelter space.

Homelessness in Canada presents key challenges for pandemic planning due to complex health, situational, and structural vulnerabilities (Schiff et al. 2020). Medical issues combined with marginalization lead to significant vulnerability to infection. Transmission risk is greater given the inability of people experiencing homelessness to self-isolate (Jadidzadeh and Kneebone 2020). In addition, shelters are characterized by overcrowded sleeping conditions, poor air quality, and a range of public health issues that predispose to higher risk of transmission (Jadidzadeh and Kneebone 2020). Addiction and mental illness may complicate adherence to mitigating strategies (Schiff et al. 2020). Furthermore, shelter staff must face many of the same exposure risks as health care workers yet have not had the same access to personal protection equipment, nor the relevant infection control training (Jadidzadeh and Kneebone 2020).

Individuals with a longer history of homelessness have higher rates of pre-existing medical conditions and are at risk of more severe COVID-19 illness (Culhane et al. 2020). Making matters worse, homelessness is associated with less access to health care and a delay in seeking care when ill (Khandor et al. 2011; Rogers et al. 2019). As shelters are often closed during the daytime, the unwell homeless have limited options for adequate rest and recovery (Schiff et al. 2020).

8.5. People who are incarcerated

Correctional facilities have a long history of high rates of infectious diseases, including communicable respiratory illnesses. Previous respiratory virus pandemics have been associated with outbreaks in prisons, including the 1918 influenza pandemic (Stanley 1919). There are many factors that contribute to infectious diseases transmission among the incarcerated. Prisoners have a high prevalence of infections at baseline. Overcrowded communal spaces, frequent delays in medical care, and sub-optimal communicable disease contact tracing, prevention, and treatment further increase the risk of outbreaks (Bick 2007). Infection control practices may be insufficient and further complicated by the high incidence of mental illness in correctional facilities, where adherence to transmission-based precautions is more challenging (Kouyoumdjian et al. 2016).

As such, correctional facilities have seen COVID-19 outbreaks. In late February, 41% of incident cases of COVID-19 reported in Wuhan, China, were from the correctional system (Barnert et al. 2020). Mid-March saw the first case of COVID-19 at Riker's Island in New York City, and within two weeks there were over 200 cases diagnosed within the facility (Hawks et al. 2020). Many correctional facilities have subsequently reported outbreaks of COVID-19 with related deaths (Hawks et al. 2020). Crude COVID-19 deaths, as of 6 June, were 39 deaths per 100 000 prisoners in the United States, in contrast to 29 deaths per 100 000 in the US general population. COVID-19 deaths in prisoners were noted to be 5.5 times greater than the general population (Saloner et al. 2020).

There have been COVID-19 outbreaks in correctional facilities in several provinces in Canada to date (Correctional Services Canada 2020; Neufield 2020). As of 25 November, there were 4308 tests performed, of which 477 were positive with an overall percent positivity of 11.1%. Quebec recorded the highest percent positivity at 18.1% (Correctional Services Canada 2020). British Columbia and Manitoba have similarly high percent positivity rates at 16.4% and 13.8%, respectively.

With cases in many facilities across the country and limited resources, questions have been raised about ill prison inmates under partial lockdown without adequate health care (Global News 2020b). Many conditions within corrections facilities mirror the issues among other marginalized populations. Corrections facilities see higher rates of First Nations, minorities, and those with pre-existing medical conditions, including mental illness. PWUD experience higher incarceration rates where they may not be able to access harm reduction and associated services. Many required programs have struggled to maintain even low levels of service during the pandemic where resources were already limited, and mitigating strategies have created new barriers.

Solutions do exist and include less incarceration and increased decarceration with community supported re-entry (Bonn et al. 2020). Accelerated release of individuals with non-violent offences with re-entry support has been seen to be a safe and effective prevention strategy during the pandemic (Franco-Paredes et al. 2021). Within facilities, individuals should be ensured adequate spacing and receive education to promote hygiene and sanitation (Barnert et al. 2020). When vaccines for COVID-19 become available, immunization of inmates and staff should be prioritized (S.J. Ismail et al. 2020). Screening, contact tracing, and medical care must be available with the appropriate standards.

8.6. Sex and gender disparities

While sex is a biological attribute, gender is a social construct incorporating identity, roles, and behaviours. Both sex and gender may influence infectious disease risk and outcomes, including those associated with COVID-19 (Tadiri et al. 2020).

COVID-19 disease outcomes, as discussed previously, appear to be influenced by sex. Global data have shown higher case rates, hospitalization rates, and death among men (Klein et al. 2020). There are a variety of influences, however, and disease outcomes between country vary by sex. Men appear to be at higher risk of severe disease and death globally from COVID-19. Despite this, the mortality rate is higher for women in Canada, accounting for 53.1% of deaths, with women only comprising

47.6% of hospitalizations and 37.2% of intensive care admissions as of 27 November (Public Health Agency of Canada 2020c). As previously mentioned, this higher female mortality rate likely relates to more female deaths in those over 80 years, which is presumably due to longer life expectancy and thus a larger proportion of elderly females at risk compared to men. Researchers in Canada have called for greater sex-based analyses to be incorporated into research to inform clinical care and guide pandemic management (Lien et al. 2020).

Indirect effects of the pandemic by gender have also been observed. With the closure of schools, there has been a reversion to traditional gender roles, with increased family care falling to women (Chen and Bougie 2020). There have also been reports of increased gender-based violence (Chen and Bougie 2020) and an increase in the use of women's emergency shelters during the pandemic (United Nations 2020). It is noted that the unprecedented scale of stay-at-home advisories likely resulted in separation from support networks and increased tensions in households—increasing the risk of domestic violence (Lane 2020). Impacts on the Canadian labour market have also disproportionately affected women, with increased unemployment and decreased employment recovery compared to men (Lemieux et al. 2020; Statistics Canada 2020).

Sex workers across Canada have experienced risks to their health and safety due to decreased access to services and safe locations for work (Jozaghi and Bird 2020). Of approximately 2600 sex workers in Vancouver, it is estimated that up to 20% rely on their work to cover the cost of food, rent, or illegal drugs, putting them at increased risk of infection as they cannot afford to stop working (Jozaghi and Bird 2020).

Among those experiencing a compounding of vulnerabilities during the pandemic are sexual and gender minorities (SGM), which collectively include lesbian, gay, bisexual, transgender, two-spirit, queer, intersex, and asexual (LGBT2SQIA+) people (Gibb et al. 2020). Structural barriers exist with decreased access to employment, housing, and health care. Interpersonal discrimination can manifest through physical attacks or inequities through policy. Heightening of such discrimination has been reported in many countries during the pandemic. Strategies to mitigate viral transmission may disproportionately impact the health of SGM people in part due to inequitable social, economic, and political conditions. In addition, SGM needs are often left out of research, policy, and infrastructure. Research and health surveillance systems should include information pertaining to sexual orientation or gender identity to optimize the public health response to support SGM people.

8.7. People living with disability

People with disabilities—described as those who have long-term physical, mental, intellectual or sensory impairments which may hinder full and effective participation in society on an equal basis with others—represent 22% of the Canadian population (Government of Canada 2013). Many are at higher risk of acquiring COVID-19 and of severe outcomes. Difficulties with hand hygiene, trouble understanding and (or) following public health guidance on physical distancing, or the need of the visually impaired to physically touch objects for support or to obtain information place individuals at increased risk of viral acquisition (Government of Canada 2020b). Many disabled are also medically fragile and thus at increased risk for severe outcomes.

Many individuals with disabilities live in care homes or assisted living, putting them at increased risk of infection (Pettinicchio and Maroto 2020). The disruption of services and supports have also had a major impact on those with disabilities (Government of Canada 2020b). Visitor and support person restrictions implemented to reduce viral transmission have put persons with disabilities who require personalized assistance at increased risk for adverse outcomes (Government of Canada 2020b).

It is also noted that many strategies and programs developed during the pandemic have been developed for those without disabilities in mind. The Canada Emergency Response Benefit (CERB), as an example, is not available to many who receive disability benefits. As a result, those with disabilities may end up receiving less financial support compared with other Canadians (Pettinicchio and Maroto 2020).

As with other marginalized groups, there is a need for local assessment to identify issues, develop appropriate responses, and support ongoing advocacy (Spinal Cord Injury Canada—Lésions Médullaires Canada 2020). National disability organizations came together early in the pandemic and provided recommendations to the federal government (Spinal Cord Injury Canada—Lésions Médullaires Canada 2020). Top priorities included the provision of accessible pandemic communication, service provider guidelines, task force development, income protection, and earmarking of funds to support the health of people with disabilities.

New pandemic response processes must also acknowledge the disabled community. COVID-19 screening and assessment centres, for example, must be accessible. Many provincial and territorial public health departments have worked with local public health authorities to establish designated, accessible pandemic assessment centres for those with disabilities (Government of Canada 2020b).

Unfortunately, at this time, there is a paucity of Canadian data pertaining to disabled communities during the pandemic (Courtenay and Perera 2020). The federal government, however, has put in place a COVID-19 Disability Advisory Group, whose role is to advise the Minister of Employment, Workforce Development and Disability Inclusion on the real-time lived experiences of persons with disabilities during the pandemic (Government of Canada 2020b). By identifying challenges and systemic gaps through this process, the hope is for the opportunity to offer solutions.

Land acknowledgement

The headquarters of the Royal Society of Canada is in Ottawa, the traditional and unceded territory of the Algonquin nation.

Author contributions

DW, RH, JJ, LS, DW, and WS conceived and designed the study. DW, RH, JJ, LS, DW, and WS performed the experiments/collected the data. DW, RH, JJ, LS, DW, and WS analyzed and interpreted the data. DW, RH, JJ, LS, DW, and WS contributed resources. DW, RH, JJ, LS, DW, and WS drafted or revised the manuscript.

Competing interests

The authors have declared that no competing interests exist.

Data availability statement

All relevant data are within the paper.

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