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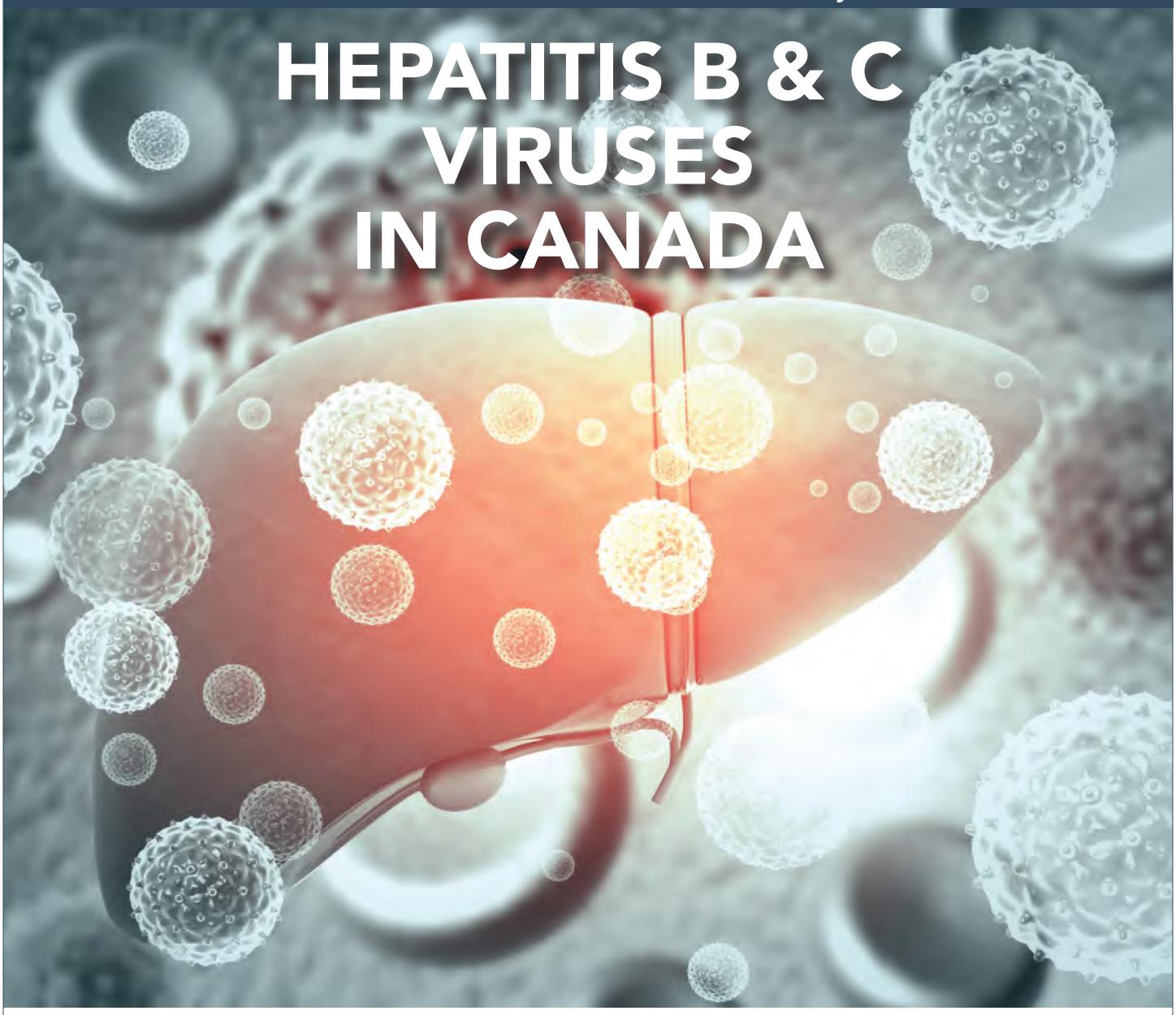
canada.ca/ccdr

June/July 2025 - Volume 51-6/7

HEPATITIS B & C VIRUSES IN CANADA



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CANADA COMMUNICABLE DISEASE REPORT

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ISSN 1481-8531 / Cat. HP3-1E-PDF / Pub. 250002

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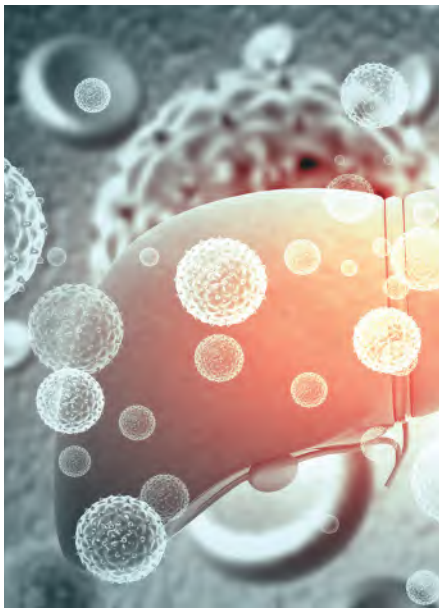

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Estimated prevalence of hepatitis B and C among immigrants in Canada

Laurence Campeau[1], Janelle Elliott[1], Anson Williams[1], Simone Périnet[1], Qiuying Yang[1], Joseph Cox[2], Jordan J Feld[3], Christina Greenaway[4], Nashira Popovic[1]

Abstract

Background: Canada's Sexually Transmitted and Blood-borne Infections (STBBI) Action Plan and the Global Health Sector Strategies on STBBI highlight the importance of putting people at the centre of the health system response. Several key populations are disproportionately affected by viral hepatitis, including immigrants. However, there is a limited body of evidence on the burden of viral hepatitis among immigrants in Canada. We seek to address this gap by estimating the prevalence of hepatitis B (HBV) and C (HCV) infections among immigrants in Canada.

Methods: Using country- and region-specific publicly available data on the prevalence of HBV and HCV, we estimated the number of immigrants with chronic HBV (CHB), HCV antibodies, and chronic HCV (CHC) by multiplying the number of immigrants from Statistics Canada's 2021 census of population data by the corresponding publicly available country or region-of-origin prevalence, including lower and upper bounds. Each country was categorized as low (<2%) or intermediate-to-high (≥2%) based on published prevalence. To capture changes over time, estimates were stratified by time-period, where possible.

Results: In 2021, the estimated prevalence of viral hepatitis among all immigrants was 4.03% for CHB, 1.43% for HCV antibodies, and 0.78% for CHC. The estimated prevalence of CHB, HCV antibodies, and CHC was 0.91%, 0.96% and 0.52%, respectively, among immigrants from low-prevalence countries (<2%). It was 5.57%, 4.04%, and 2.20%, respectively, among immigrants from intermediate-to-high-prevalence countries (≥2%).

Conclusion: This is the first study to estimate the burden of HBV and HCV among immigrants at the national level in Canada. The results show that the prevalence of viral hepatitis among immigrants is higher than the general Canadian population. However, grouping all immigrants into one category masks important variation, and potentially over-estimates the burden of HBV and HCV among immigrants. Strengthening our understanding of hepatitis prevalence among immigrants can improve our ability to connect those in need to care and treatment services.

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Suggested citation: Campeau L, Elliott J, Williams A, Périnet S, Yang Q, Cox J, Feld JJ, Greenaway C, Popovic N. Estimated prevalence of hepatitis B and C among immigrants in Canada. Can Commun Dis Rep 2025;51(6/7):214–22. https://doi.org/10.14745/ccdr.v51i67a01

Keywords: viral hepatitis, hepatitis B, hepatitis C, prevalence, priority populations, immigrants

Introduction

Hepatitis B and C are viral infections that pose a significant health threat, as they have the potential to induce chronic liver infection, culminating in severe complications, such as cirrhosis and liver cancer. Recognizing the urgency of this public health challenge, the World Health Organization developed the *Global health sector strategies 2022–2030*, on HIV, viral hepatitis and sexually transmitted infections to guide focused responses by member states towards eliminating sexually transmitted and blood-borne infections (STBBI) by 2030 (1). Canada endorsed these global goals and developed the Government of Canada's STBBI action plan 2024–2030 (2), building upon commitments for implementing the pan-Canadian STBBI framework for action (3).

These foundational documents (2,3) highlight the critical importance of putting people at the centre of the health system response by organizing services around individuals' needs, rather than around diseases. Several key populations are differentially affected by STBBI, including immigrants. These populations face inequities in accessing care and treatment services for STBBI for a variety of reasons, including stigma and discrimination, language barriers, cultural differences, economic difficulties, and issues related to transportation (4). An understanding of the burden of hepatitis B virus (HBV) and hepatitis C virus (HCV) prevalence among all key populations disproportionately impacted by viral hepatitis is needed for public health planning and to support elimination efforts.

In 2021, more than eight million people, or almost one-quarter (23.0%) of the Canadian population, were considered immigrants (5), many of whom were born in countries where HBV and HCV is more common. However, there is a limited body of evidence on the burden of viral hepatitis among immigrants in Canada. To our knowledge, only one national-level study from 2006 has examined the prevalence of hepatitis B among immigrants, and no national studies have assessed the prevalence of hepatitis C in this group. This paper seeks to address this gap by estimating the prevalence of HBV and HCV infections among immigrants in Canada, using country-specific epidemiological data.

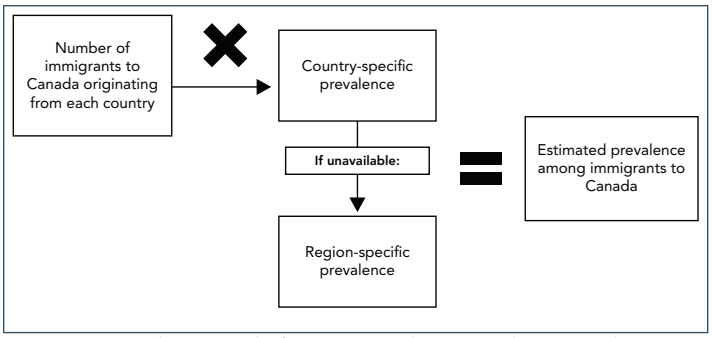
Methods

In the context of this study, the Statistics Canada definition of immigrant was used (6). An immigrant refers to anyone who has been granted the right to live in Canada permanently by immigration authorities. This includes people who are or who have ever been landed immigrants and permanent residents. It includes those who have obtained Canadian citizenship by naturalization (6). Individuals holding work, study or temporary resident permits, as well as those who have claimed refugee status, are considered non-permanent residents, and are therefore excluded from this study.

Data on immigration by country and period of arrival were obtained from Statistics Canada's 2021 census of population data (5). Countries of birth were grouped into world regions according to the regional classification system by Statistics Canada (5) for hepatitis B, and the Global Burden of Disease for hepatitis C (7).

Chronic hepatitis B (CHB) was defined as HBsAg serology positive. HBsAg seroprevalence estimates were obtained from Wong *et al.* (8). When country-specific data were not available, regional data were used as a substitute (8). The decision to use regional data was based on the assumption that prevalence trends within specific geographic regions are often reflective of national trends. Each country was categorized as low (<2%) or intermediate-to-high (≥2%) (9–11), based on the pooled HBsAg prevalence (8). To capture changes over time (e.g., due to changes in hepatitis B vaccination policies in country-of-origin), immigration was stratified by time period. The time periods were based on Statistics Canada periods of immigration: ≤1990, 1991–2000, 2001–2010, and 2011–2021. The number of immigrants with CHB was estimated by multiplying the number of immigrants for each time period of immigration by the corresponding country or region-specific estimated prevalence for each respective time period (**Figure 1**). To account for uncertainty, plausible ranges were calculated by applying the same method to the lower and upper bounds of the estimated prevalence.

Figure 1: Methodology to estimate hepatitis prevalence among immigrants



Note: Statistics Canada time periods of immigration used to estimate chronic HBV (HbsAg): ≤1990, 1991–2000, 2001–2010, 2011–2021; and chronic HCV (HCV RNA): <2016, 2016–2021. Note that time period data not available for anti-HCV
Source: Statistics Canada. Immigrant status and period of immigration by place of birth and citizenship: Canada, provinces and territories and census metropolitan areas with parts. Ottawa, ON: StatCan; 2022. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=9810030201

Both hepatitis C antibody prevalence (HCV antibodies), or history of HCV infection, and chronic hepatitis C (CHC) prevalence, defined as HCV-RNA positive were estimated. Countries were categorized as low (<2%) or intermediate-to-high (≥2%) (12,13) based on the country-specific prevalence of HCV antibodies estimated from the World Health Organization global hepatitis report (14) and region-specific estimates from Gower *et al.* (15), which were used as a substitute when country-specific estimates were not available. Chronic hepatitis C prevalence estimates were obtained from the Polaris Observatory (7). Since decade-specific data for CHC prevalence were not available, data were stratified as prior to 2016 and 2016–2021, accounting for the impact of the wide-scale implementation of direct-acting antivirals (DAA) curative treatment. The number of immigrants with a history of HCV infection and those with CHC were estimated by multiplying the number of immigrants from each period of immigration by the corresponding country or region-specific estimated prevalence for each respective time period (Figure 1). Again, plausible ranges were calculated by applying the same method to the lower and upper bounds of the estimated prevalence.

Results

In 2021, there were an estimated 8,359,005 immigrants in Canada (5). An estimated 67% of immigrants originated from countries with CHB prevalence ≥2% (list of countries in **Box 1**). An estimated 15% originated from countries with CHC prevalence ≥2% (**Box 2**).

Box 1: Countries with hepatitis B pooled seroprevalence (HbsAg positivity) ≥2%, sorted alphabetically

Afghanistan	Comoros	Italy	Myanmar	Sierra Leone
Albania	Congo, Democratic Republic of the	Jamaica	Namibia	Singapore
Algeria	Côte d'Ivoire	Jordan	Nauru	Sint Maarten
American Samoa	Curaçao	Kazakhstan	New Caledonia	Solomon Islands
Angola	Cyprus	Kenya	New Zealand	Somalia
Anguilla	Djibouti	Kiribati	Niger	South Africa, Republic of
Antigua and Barbuda	Dominica	Korea, North	Nigeria	South Sudan
Aruba	Dominican Republic	Korea, South	North Macedonia	Sri Lanka
Azerbaijan	Egypt	Kuwait	Northern Mariana Islands	Sudan
Bahamas	Equatorial Guinea	Kyrgyzstan	Oman	Taiwan
Bahrain	Eritrea	Laos	Pakistan	Tajikistan
Bangladesh	Estonia	Lesotho	Papua New Guinea	Tanzania
Belarus	Eswatini	Liberia	Philippines	Thailand
Benin	Ethiopia	Libya	Puerto Rico	Timor-Leste
Bermuda	Fiji	Lithuania	Qatar	Togo
Bhutan	French Polynesia	Macao	Réunion	Tonga
Bolivia	Gabon	Madagascar	Romania	Tunisia
Bonaire, Sint Eustatius and Saba	Gambia	Malawi	Russian Federation	Turkey
Botswana	Georgia	Malaysia	Rwanda	Turkmenistan
Brunei Darussalam	Ghana	Maldives	Saint Helena, Ascension and Tristan da Cunha	Turks and Caicos Islands
Bulgaria	Grenada	Mali	Saint Kitts and Nevis	Uganda
Burkina Faso	Guadeloupe	Marshall Islands	Saint Lucia	United Arab Emirates
Burundi	Guam	Martinique	Saint Martin	Uzbekistan
Cabo Verde	Guinea	Mauritania	Saint Vincent and the Grenadines	Vanuatu
Cambodia	Guinea-Bissau	Mauritius	Samoa	Viet Nam
Cameroon	Guyana	Micronesia, Federated States of	Sao Tome and Principe	Virgin Islands, British
Cayman Islands	Haiti	Moldova	Saudi Arabia	Virgin Islands, United States
Central African Republic	Hong Kong	Mongolia	Senegal	Yemen
Chad	India	Montenegro	Serbia	Zambia
China	Indonesia	Montserrat	Seychelles	Zimbabwe
	Iran	Mozambique		

Source: Wong RJ, Brosgart CL, Welch S, Block T, Chen M, Cohen C, Kim WR, Kowdley KV, Lok AS, Tsai N, Ward J, Wong SS, Gish RG. An Updated Assessment of Chronic Hepatitis B Prevalence Among Foreign-Born Persons Living in the United States. Hepatology 2021;74(2):607–26. https://doi.org/10.1002/hep.31782

Box 2: Countries with hepatitis C seroprevalence (anti-HCV positivity) ≥2%, sorted alphabetically

Angola	China, Province of Taiwan	Guinea-Bissau	Mongolia	Senegal
Armenia	Congo	Italy	Niger	Sierra Leone
Azerbaijan	Congo, Democratic Republic of the	Kazakhstan	Nigeria	Syrian Arab Republic
Belarus	Côte d'Ivoire	Kuwait	Pakistan	Tajikistan
Benin	Egypt	Kyrgyzstan	Papua New Guinea	Togo
Burkina Faso	Equatorial Guinea	Latvia	Puerto Rico	Turkmenistan
Burundi	Gabon	Liberia	Romania	Ukraine
Cabo Verde	Georgia	Mali	Russian Federation	Uzbekistan
Cambodia	Ghana	Mauritania	Saint Helena, Ascension and Tristan da Cunha	West Bank and Gaza Strip
Chad	Guinea	Moldova	Sao Tome and Principe	

Sources: World Health Organization. Web Annex B. WHO estimates of the prevalence and incidence of hepatitis C virus infection by World Health Organization region, 2015. Global hepatitis report 2017. Geneva, CH: WHO; 2017. https://iris.who.int/bitstream/handle/10665/277005/WHO-CDS-HIV-18.46-eng.pdf
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Chronic hepatitis B virus prevalence

The estimated CHB prevalence among all Canadian immigrants was 4.03% (3.02%–5.08%) or 336,834 people (252,572–424,621), at the end of 2021. Among immigrants who came from intermediate-to-high-prevalence countries (≥2%), the estimated CHB prevalence was 5.57% (4.23%–6.96%), representing approximately 311,847 people (237,073–389,642). Whereas, among immigrants who came from low prevalence countries (<2%), the estimated CHB prevalence was 0.91% (0.56%–1.27%), or 24,988 people (15,500–34,979) (**Table 1**).

Using time period of immigration, estimated CHB prevalence decreased for high prevalence countries, from 7.01% prior to 1990 to 3.94% between 2011–2021. Estimated CHB prevalence among immigrants from low-prevalence countries was relatively stable (0.84%–0.87%); however, the number of immigrants decreased from 10,791 prior to 1990 to 5,324 between 2011–2021 (Table 1).

Although the pooled HBsAG prevalence rate was highest in Western Africa (10.96%) (8), the estimated number of immigrants to Canada with CHB from Western Africa was 16,739, representing only 4.9% of all estimated immigrants living with HBV. Alternatively, the highest estimated number of immigrants to Canada with CHB was from Eastern Asia (102,661), representing 30% of all estimated immigrants living with CHB, despite having a lower pooled HBsAG prevalence rate of 7.0% (**Figure 2**).

Prevalence of hepatitis C virus antibodies

The estimated prevalence of HCV antibodies among all immigrants was 1.43% (0.91%–2.33%), or 119,432 people (76,216–194,635). Among immigrants who came from intermediate-to-high prevalence countries (≥2%), the estimated prevalence of HCV antibodies was 4.04%, compared to 0.96% among those who come from low prevalence countries (**Table 2**).

Chronic hepatitis C virus prevalence

The estimated CHC prevalence among all immigrants was 0.78% (0.55%–1.31%), or 65,172 people (45,684–109,168) at the end of 2021. Among immigrants who came from intermediate-to-high-prevalence countries (≥2%), the estimated CHC prevalence was 2.20% (1.55%–3.49%), or 28,139 people (19,796–44,582). Among immigrants from countries with low CHC prevalence, estimated prevalence was 0.52% (0.37%–0.91%), or 37,032 people. When comparing by time period, the estimated CHC prevalence decreased slightly for the period of 2016–2021 (1.76%) compared to before 2016 (2.31%) (**Table 3**).

The regional CHC prevalence was highest in those from Eastern Europe (2.90%) (7). However, the highest estimated number of immigrants with CHC was from South Asia (13,697) representing 21% of all immigrants estimated to be living with CHC (**Figure 3**).

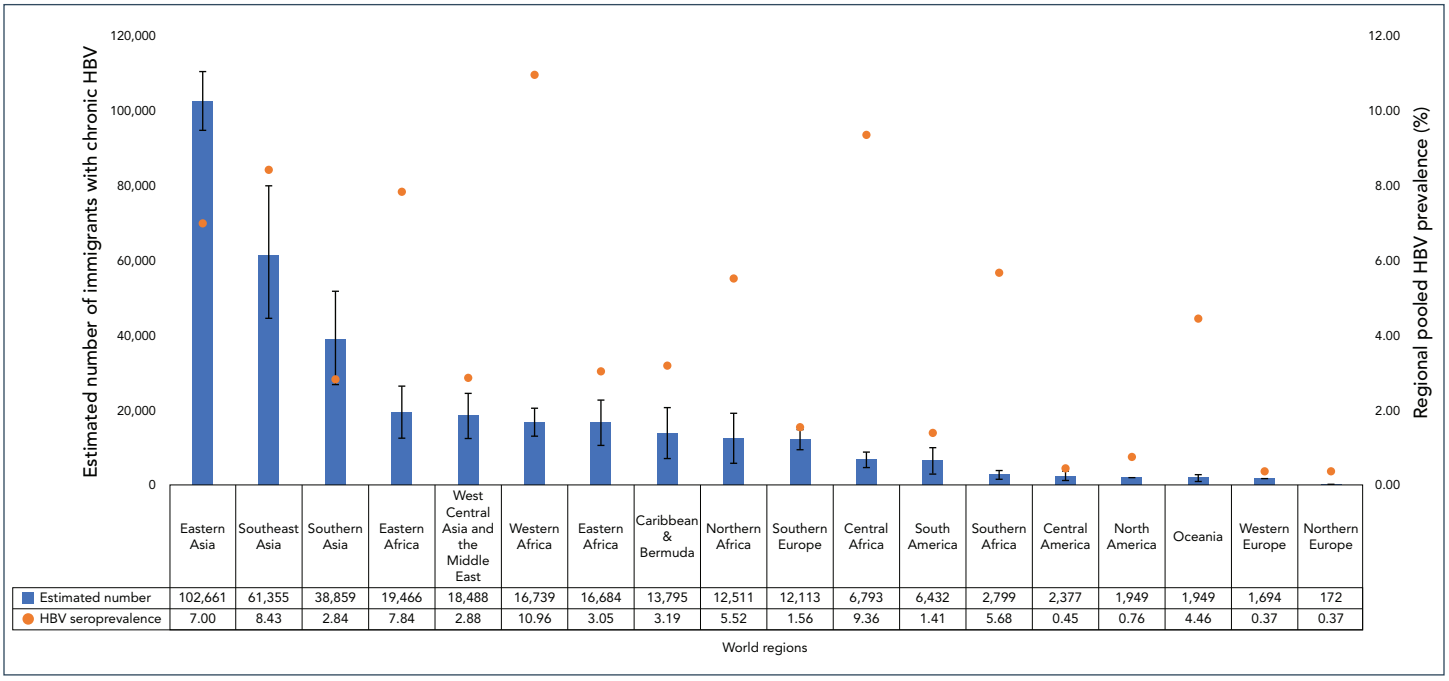
Discussion

As far as is known, this is the first study to estimate the burden of both hepatitis B and C among immigrants at the national level in Canada. The results show that the prevalence of viral hepatitis among all immigrants (estimated at 4.03% for CHB, 1.43% HCV antibodies, and 0.78% for CHC) is higher than the latest published estimates for the general Canadian population (estimated at 0.68% for CHB, 0.99% HCV antibodies, and 0.56% for CHC) (16). However, when separated into immigrants from low- and intermediate-to-high-prevalence countries, results show that the prevalence of CHB, HCV antibodies, and CHC among immigrants from low-prevalence

Table 1: Estimated prevalence of chronic hepatitis B virus (chronic hepatitis B) among immigrants in Canada, per time period of immigration and overall

Population	Population size estimate	≤1990		1991–2000		2001–2010		2011–2021		Overall	
		Prevalence (%)	Estimated number	Prevalence (%)	Estimated number	Prevalence (%)	Estimated number	Prevalence (%)	Estimated number	Prevalence (%)	Estimated number
Immigrants from countries with low prevalence (<2%)	2,759,465	0.84% (0.56%–1.14%)	10,791 (7,233–14,584)	1.14% (0.62%–1.69%)	4,457 (2,435–6,577)	0.93% (0.54%–1.36%)	4,415 (2,530–6,424)	0.87% (0.54%–1.21%)	5,324 (3,302–7,394)	0.91% (0.56%–1.27%)	24,988 (15,500–34,979)
Immigrants from countries with intermediate-to-high prevalence (≥2%)	5,599,485	7.01% (5.54%–8.50%)	82,718 (65,312–100,270)	6.77% (5.15%–8.44%)	75,885 (57,702–94,627)	5.53% (4.31%–6.78%)	80,631 (62,774–98,856)	3.94% (2.79%–5.21%)	72,612 (51,285–95,889)	5.57% (4.23%–6.96%)	311,847 (237,073–389,642)
All immigrants	8,358,950	3.80% (2.94%–4.66%)	93,510 (72,546–114,854)	5.32% (3.98%–6.70%)	80,341 (60,136–101,204)	4.41% (3.38%–5.45%)	85,046 (65,303–105,279)	3.18% (2.22%–4.21%)	77,936 (54,587–103,284)	4.03% (3.02%–5.08%)	336,884 (252,572–424,621)

Figure 2: Estimated prevalence and number of immigrants in Canada with chronic hepatitis B, by world region, 2021



Abbreviation: HBV, hepatitis B virus

Table 2: Estimated prevalence of hepatitis C virus antibodies among immigrants in Canada, 2021

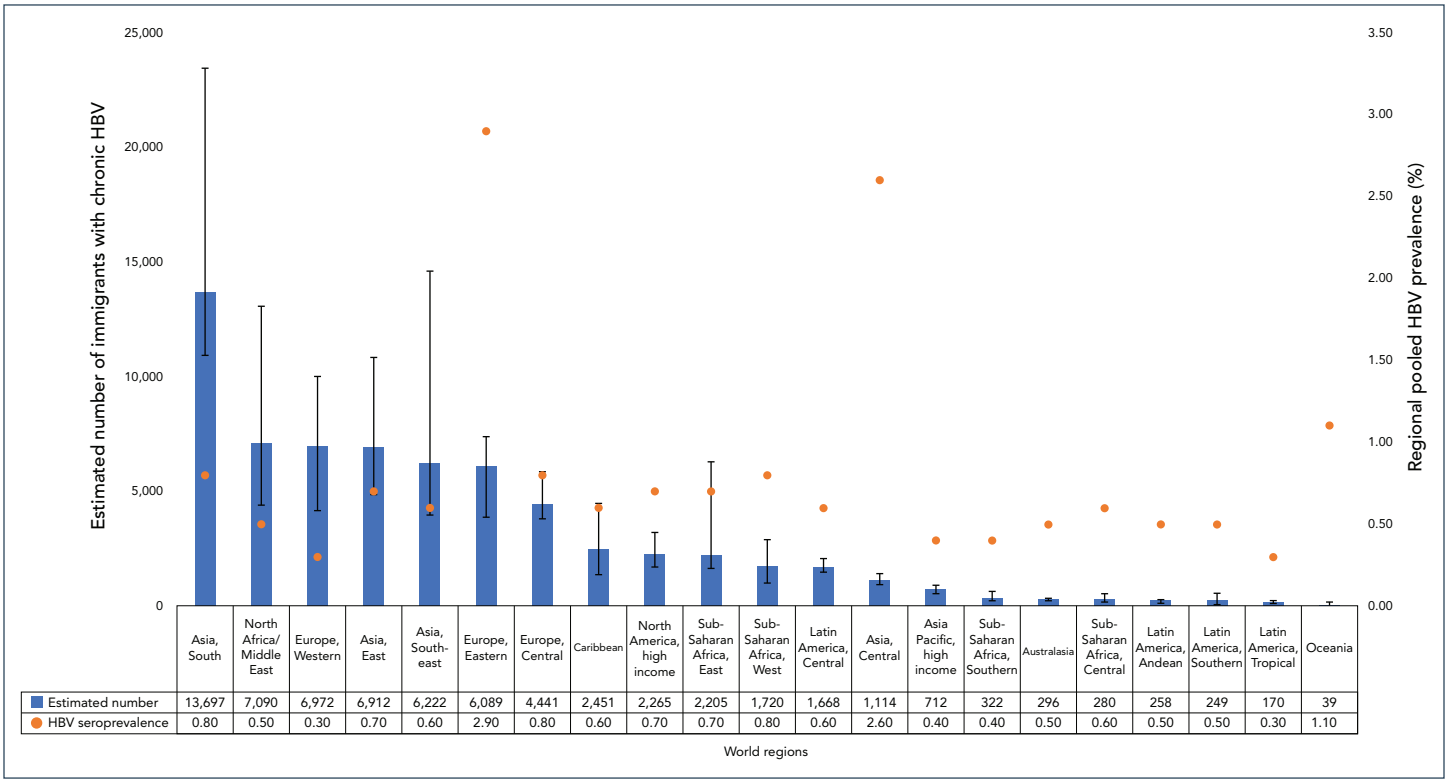
Population	Population size estimate	Prevalence (%)			Estimated number of immigrants with current or past HCV infection		
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound
Immigrants from countries with low prevalence (<2%)	7,082,480	0.96%	0.56%	1.54%	67,892	39,530	109,319
Immigrants from countries with intermediate-to-high prevalence (≥2%)	1,276,405	4.04%	2.87%	6.68%	51,540	36,686	85,316
All immigrants	8,358,885	1.43%	0.91%	2.33%	119,432	76,216	194,635

Abbreviation: HCV, hepatitis C virus

Table 3: Estimated prevalence of chronic hepatitis C virus among immigrants in Canada, per period of arrival and overall

Population	Population size estimate	Arrival before 2016		Arrival in 2016–2021		Overall	
		Prevalence (%)	Estimated number	Prevalence (%)	Estimated number	Prevalence (%)	Estimated number
Immigrants from countries with low prevalence (<2%)	7,082,480	0.53% (0.37%–0.91%)	31,680 (22,000–54,791)	0.49% (0.36%–0.91%)	5,352 (3,888–9,795)	0.52% (0.37%–0.91%)	37,032 (25,888–64,586)
Immigrants from countries with intermediate-to-high prevalence (≥2%)	1,276,405	2.31% (1.64%–3.53%)	23,838 (16,953–36,438)	1.76% (1.16%–3.32%)	4,301 (2,843–8,145)	2.20% (1.55%–3.49%)	28,139 (19,796–44,582)
All immigrants	8,358,885	0.79% (0.55%–1.30%)	55,519 (38,953–91,228)	0.73% (0.51%–1.35%)	9,653 (6,731–17,940)	0.78% (0.55%–1.31%)	65,172 (45,684–109,168)

Figure 3: Estimated number of immigrants in Canada with chronic hepatitis C by world region, 2021



	Asia, South	North Africa/ Middle East	Europe, Western	Asia, East	Asia, South-east	Europe, Eastern	Europe, Central	Caribbean	North America, high income	Sub-Saharan Africa, East	Sub-Saharan Africa, West	Latin America, Central	Asia, Central	Asia Pacific, high income	Sub-Saharan Africa, Southern	Australasia	Sub-Saharan Africa, Central	Latin America, Andean	Latin America, Southern	Latin America, Tropical	Oceania
Estimated number	13,697	7,090	6,972	6,912	6,222	6,089	4,441	2,451	2,265	2,205	1,720	1,668	1,114	712	322	296	280	258	249	170	39
HBV seroprevalence	0.80	0.50	0.30	0.70	0.60	2.90	0.80	0.60	0.70	0.70	0.80	0.60	2.60	0.40	0.40	0.50	0.60	0.50	0.50	0.30	1.10

Abbreviation: HCV, hepatitis C virus

countries (<2%) (0.91%, 0.96% and 0.52%, respectively) is similar to the Canadian general population. The estimated prevalence among immigrants from intermediate-to-high-prevalence countries from this study was 5.57% for CHB, 4.04% for HCV antibodies, and 2.20% for CHC. This demonstrates that grouping all immigrants into one category masks important variation, and potentially over-estimates the burden of hepatitis B and C among immigrants. In addition, the estimated number of immigrants with CHB and CHC varied over time. This could be the result of changes in immigration patterns and policies, the implementation of HBV immunization, and the introduction of direct-acting antivirals for the treatment of HCV. Strengthening our understanding of the variation in hepatitis prevalence among immigrants can improve our ability to connect those in need to hepatitis B care services and hepatitis C curative treatment, enabling the development of targeted programming for those populations. Surveillance systems and research provide important insights into where action is needed, helping to tailor interventions and reduce the health impact of STBBIs in key populations.

Although there is limited national data for comparison, a study by Wong *et al*. estimated the prevalence of CHB among all Canadian immigrants in 2006 to be 4.81%. While this estimate falls within the plausible range of our estimate of 4.03% (3.02%–5.08%), it suggests a slight decrease in prevalence in recent years. Smaller-scale studies have also been conducted in Canadian provinces. A population-based study by Yasseen *et al*. (11) estimated the prevalence of CHB among immigrants from intermediate-to-high-prevalence countries living in Ontario at 5.4%, which aligns with this study's estimate of 5.57% among this group. While comparable national estimates for HCV are not available, modelling studies estimating the prevalence of HCV have been conducted at the provincial level. A study by Forouzannia *et al*. (17) estimated a CHC prevalence of 2.0% among all immigrants in Québec in 2016, and Yasseen *et al*. (18) estimated an HCV antibody prevalence of 0.7% among immigrants in Ontario in 2014. Although both of these estimates differ from our national estimates of 0.78% CHC prevalence and 1.43% HCV antibody prevalence, it may be indicative of regional variability in immigration across Canada.

Limitations

The methods used in our study present limitations. First, the use of country-of-origin prevalence data to estimate the burden of CHB and CHC among immigrants living in Canada may lead to overestimates. This phenomenon, known as the healthy immigrant effect, suggests that individuals who immigrate may differ from those who remain in their country of origin in terms of age structure, risk profile, socioeconomic status and, ultimately, health status (19,20). Nonetheless, while the true burden may more closely align with the lower bounds of our estimate, even a conservative interpretation of these estimates indicates a disproportionate disease burden among immigrants to Canada.

Second, although the method of applying country-of-origin specific prevalence has been found to be a good proxy for the expected prevalence in the immigrant population (13), this method also brings inherent uncertainty and could lead to either an over or underestimation of the prevalence among immigrants in Canada. Uncertainty in this method arises from the reliance on a smaller pool of studies for period-specific prevalence estimates, and a lack of prevalence data from smaller countries used in global hepatitis prevalence reports. This can lead to an over-reliance on regional data in some cases, and a bias towards larger countries due to weighted averages being more heavily influenced by countries with larger populations. Furthermore, the data extracted for this study was from published data, which was aggregated data. Thus, potential confounders or effect modifiers cannot be addressed. Third, while time-period-specific immigration and prevalence was considered to increase estimation accuracy, countries initially categorized as low (<2%) or intermediate-to-high (≥2%) may change categories over time and may lead to an under- or over-estimation of prevalence. Fourth, prevalence estimates included in published global studies were selected based on how well their results could be extrapolated to a country's general population, and in the study used for CHB prevalence, certain groups known to be at high risk for hepatitis B infection were excluded. Estimates included in this study should therefore be interpreted within the context of their plausible ranges because of these factors. Fifth, the estimates are national level only and have not been broken down by province/territory. The countries of origin of immigrants living in each province/territory varies and can be driven by linguistic preferences, cultural links, and job availability. Therefore, national-level estimates may not be helpful to support regional-specific programs tailored for immigrants. Lastly, the analysis does not account for differences by age and gender, which are important considerations to understanding the population at risk, and would help inform programming for specific subgroups within the immigrant population.

Conclusion

The availability of safe and effective hepatitis B vaccines, along with antiviral treatment capable of preventing transmission (21,22), and the ability to effectively cure hepatitis C, have created conditions in which the elimination of hepatitis B and C is increasingly within reach. However, while the prevalence of viral hepatitis within the general population of Canada is relatively low, some immigrants experience a higher burden of disease due to potential exposure in their countries of origin. This demographic factor brings additional challenges in achieving the goal of elimination. These data are an important first step in describing the burden of viral hepatitis among immigrants. Additional data on the prevalence of hepatitis B and C among immigrants in Canada, as well as region, age, and gender specific data, are needed to help address the specific needs of immigrant populations and improve health outcomes for those most affected.

Authors' statement

LC — Conceptualization, methodology, data curation, writing–original draft
JE — Conceptualization, methodology, data curation
AW — Conceptualization, methodology, data curation
SP — Conceptualization, methodology
QY — Conceptualization, methodology
JC — Conceptualization, methodology
JJF — Conceptualization, methodology
CG — Conceptualization, methodology
NP — Conceptualization, methodology, validation, writing–review & editing, supervision

All authors approved the final version of the manuscript.

Competing interests

JC has received research funds paid to his institution from Viiv Healthcare and Gilead. He has received honoraria as a speaker, paid by Viiv Healthcare and Gilead. He has also received the Canadian Association for HIV Research Health Care Professionals Travel Award to attend conferences.

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Acknowledgements

We thank non-co-author members of our working group for their expert guidance throughout the hepatitis estimates process: Eliverta Bicja, Mia J. Biondi, Carla S. Coffin, Brian Conway, Curtis Cooper, Peter K. Daley, Naveed Janjua, Marina Klein, Nadine Kronfli, Gisela Macphail, Sara Larney, Samuel S. Lee, Marjolaine Pruvost, Abdel Aziz Shaheen and William W.L. Wong.

Funding

This work was supported by the Public Health Agency of Canada.

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EPIDEMIOLOGIC STUDY

National hepatitis B and C estimates for 2021: Measuring Canada's progress towards eliminating viral hepatitis as a public health concern

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Abstract

Background: Hepatitis B virus (HBV) and hepatitis C virus (HCV) infections are major causes of morbidity and mortality worldwide. Measuring the epidemiological burden of HCV and HBV in Canada is essential to measure progress towards global elimination targets and to ultimately eliminate viral hepatitis as a public health concern.

Objective: This study aimed to provide the first national estimates of HBV prevalence and unawareness, and to update estimates of HCV incidence, prevalence, and unawareness in the general population and key populations in Canada for 2021. Progress towards elimination targets for 2025, namely incidence, awareness, mortality, and HBV vaccination, was also assessed.

Methods: A combination workbook method and mathematical modelling was used to estimate the prevalence and unawareness of chronic hepatitis B (CHB), prevalence and incidence of anti-HCV antibodies, and the prevalence and unawareness of chronic hepatitis C (CHC).

Results: The estimated prevalence of CHB was 0.68% (plausible range: 0.40%–0.97%) or 262,000 (152,000–371,000) people in the general population, of whom 42.5% (33.9%–51.0%) were unaware of their infection. Immigrants from countries where HBV is common had the highest prevalence at 4.2% (1.9%–5.6%). An estimated 8,212 new HCV infections occurred in 2021, and the estimated prevalence of CHC was 0.56% (0.15%–0.97%) or 214,000 (58,500–369,000) people, of whom 41.5% (34.3%–48.8%) were unaware of their infection. People who inject drugs had the highest prevalence and largest proportion who were unaware at 36.9% (12.6%–55.1%) and 49.9% (29.0%–70.2%), respectively.

Conclusion: While the overall viral hepatitis burden is low in the general Canadian population, these estimates indicate that certain populations and communities remain disproportionately affected. Although Canada has met some of the 2025 targets, more work is needed. To this end, efforts to obtain and standardize provincial and national data will be required to measure progress towards all elimination targets.

Suggested citation: Périnet S, Williams A, Campeau L, Elliott J, Zhang F, Yang Q, Cox J, Davis K, Feld JJ, Klein MB, Kronfli N, Biondi MJ, Daley PK, Popovic N. National hepatitis B and C estimates for 2021: Measuring Canada's progress towards eliminating viral hepatitis as a public health concern. Can Commun Dis Rep 2025;51(6/7):223–37. https://doi.org/10.14745/ccdr.v51i67a02

Keywords: viral hepatitis, hepatitis B, hepatitis C, prevalence, incidence, key populations, estimations, Canada

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Introduction

Hepatitis B virus (HBV) and hepatitis C virus (HCV) infections are sexually transmitted and blood-borne infections (STBBI) leading to chronic liver disease with a risk of progression to cirrhosis, liver failure and liver cancer (1), despite the availability of effective treatment and HBV vaccines. Following HBV infection, approximately 90% of newborns, 20%–30% of children younger than five years, and 5%–10% of adults younger than 50 years develop chronic hepatitis B (CHB) (2,3) which may cause progressive liver injury. Suppressive treatment is available (3) and reduces the risk of liver-related outcomes but must be taken long-term and rarely leads to clearance of the infection. People exposed to and infected with HCV develop antibodies that remain detectable regardless of spontaneous clearance or successful treatment. Detection of viral RNA is necessary to diagnose chronic hepatitis C (CHC) infection, defined as persistence of viremia beyond six months (4). More than 95% of people who take direct-acting antivirals (DAAs) treatment achieve a sustained virological response 12 weeks after the end of treatment and are therefore considered cured (5). Treatment is well tolerated and recommended for all people living with CHC (6).

Key guiding documents identify certain populations and communities that are disproportionately impacted by HBV and HCV (7–10), including immigrants from countries where HBV or HCV is common, gay, bisexual and other men who have sex with men (GBMSM), incarcerated people, people who inject drugs (PWID), First Nations, Inuit and Métis, and adults in the 1945–1975 birth cohort. Canada is committed to achieving the global targets in support of eliminating viral hepatitis as a public health concern (8,11). Global targets include a reduction of incidence and mortality, an increase in the proportion of people living with CHC or CHB who are diagnosed and treated, and an increase of HBV vaccine coverage.

This paper provides updated national estimates of HCV incidence, prevalence, awareness and treatment, as well as the first national estimates of HBV prevalence and awareness, for 2021 (9). These estimates are reported for the general population, as well as for key populations. Finally, Canada's progress towards some of the 2025 global viral hepatitis elimination targets are discussed.

Methods

A combination of a modified workbook method and mathematical modelling was used to estimate the prevalence of CHB and the proportion of people living with CHB who were unaware of their infection, and to estimate the prevalence of anti-HCV antibodies and CHC and the proportion of people living with CHC who were unaware of their infection. Incidence for HCV was estimated using mathematical modelling. Mortality, HBV vaccination and HCV treatment were estimated using administrative data. Rates were calculated using national population estimates (12).

Hepatitis B

Systematic review

A systematic search for literature published between January 1, 2016 and March 31, 2023, on prevalence and unawareness of HBV infection in Canada was conducted in the MEDLINE, Embase and Scopus databases and yielded an initial 355 records, with an additional 40 records identified through other sources. Using a previously described method (13), 14 records were selected to consider in the workbook method, in addition to unpublished data from organizations and researchers.

Mathematical modelling

National CHB modelling was described elsewhere (14) and used data from the Canadian Notifiable Disease Surveillance System (CNDSS), extracted in July 2023 for all provinces and territories, as input into the model.

Modified workbook

A modified workbook method (13) was used to estimate the prevalence of CHB infection (using the hepatitis B surface antigen (HBsAg) as a proxy for CHB, where applicable), and its proportion unaware, for the general population and for key populations informed by an environmental scan. Each measure extracted from the systematic search records were classified as "underestimate," "appropriate estimate" or "overestimate" based on a review of the methodology of each study. The underestimates and overestimates were used as plausible ranges. When measures from multiple records were available, evidence was ranked to prioritize representative data (e.g., national surveys) over data of lower representativity (e.g., local studies) to determine each plausible range. Where possible, results from comparable studies were averaged. Point estimates were calculated as the midpoint between bounds, except when representative data ("appropriate estimates") were used as the point estimate. In instances where only one representative estimate was available, the plausible range is the 95% confidence interval, computed as needed using the Wilson method (15). In instances where there was one data source of low representativity or no data, "insufficient data" was indicated. Proportions ≤1 were rounded to two decimal places, larger proportions were rounded to one decimal place, and absolute numbers were rounded to three significant digits.

Administrative data: Vaccination and mortality

Vital statistics data (16) were used to estimate the proportion of all live births in Canada that occurred in provinces and territories offering universal birth dose vaccination. Vaccination coverage was taken from the *Childhood National Immunization Coverage Survey* report (17).

Vital statistics data were used to directly estimate the number of deaths in 2021 for which HBV (ICD-10 codes B16.0, B16.1, B16.2, B16.9, B17.0, B18.0, and B18.1) was identified as the underlying cause or one of the other 19 contributing causes of death (18).

Hepatitis C

Systematic review

A search on prevalence, incidence and unawareness of infection in Canada was updated with records published between July 1, 2021 and March 31, 2023, yielding 187 records, with an additional 28 records found outside of the search. A total of 31 records were selected for consideration using the workbook method, in addition to the 22 records identified and used through the 2019 estimates process (13) and unpublished data from organizations and researchers.

Mathematical modelling

Back-calculation mathematical modelling (7,19) with least square method (20) for 2020–2021 pandemic adjustment was used to estimate HCV incidence and as input for the anti-HCV antibodies prevalence estimates. Data from a July 2023 CNDSS extraction for British Columbia, Alberta, Saskatchewan, Ontario, Québec and the Yukon were used as input and model outputs were projected to Canadian population.

Modified workbook

Using methods described in the HBV section, this study estimated the prevalence of anti-HCV antibodies (as a marker of current or past infection) as well as the prevalence of CHC infection (using detection of HCV RNA as a proxy where applicable) and its proportion unaware, for the general population and for key populations, based on priority populations identified in the blueprint to inform hepatitis C elimination efforts in Canada (7).

Administrative data: Treatment and mortality

Licensed data were obtained from IQVIA Solutions Canada (IQVIA) to estimate the number of people treated for HCV in Canada between 2012 and 2021. The 2012–2016 estimates were produced by the British Columbia Centre for Disease Control using Compuscript data from IQVIA, and the 2017–2021 estimates were projected patient counts computed by IQVIA using the GPM Custom Solutions information service.

Vital statistics data were used to directly estimate the number of deaths in 2021 for which HCV (ICD-10 codes B17.1 and B18.2) was identified as an underlying cause or one of the other 19 contributing causes of death (18).

Results

Chronic hepatitis B prevalence

The prevalence of CHB in the general population was estimated at 0.68% (plausible range: 0.40%–0.97%) or 262,000 (152,000–371,000) people at the end of 2021. Among key populations, the highest estimated prevalence was 4.2% (1.9%–5.6%) among immigrants from countries where HBV is common (≥2% HBsAg prevalence), followed by GBMSM at 1.4% (0.8%–2.1%) and people incarcerated in federal prisons (**Table 1**). Additional data are needed to estimate the prevalence in other key populations.

Unawareness of chronic hepatitis B infection

The proportion of people living with CHB who were unaware of their infection was estimated at 42.5% (33.9%–51.0%), or 111,000 (88,700–134,000) people (**Table 2**). Additional data are needed to estimate unawareness in key populations.

Hepatitis B vaccination

In the seven jurisdictions with a three-dose program for infants, the HBV vaccine coverage among two-year-old children was 82.6% (79.7%–85.1%) in 2021. The national HBV vaccine coverage among 14-year-old adolescents was 89.0% (86.3%–91.2%) in 2021 (17).

Three (New Brunswick, Northwest Territories and Nunavut) out of 13 provinces and territories have universal HBV vaccination programs initiated at birth, and 7,690 live births occurred in these jurisdictions between July 1, 2021 and June 30, 2022, representing 2% of live births in Canada during that period (16).

Hepatitis B-related mortality

In 2021, HBV was identified as a contributing cause for 274 deaths for a crude mortality rate of 0.72 per 100,000 population. Between 2015 and 2021, the annual mortality rate for HBV-related deaths was relatively stable (**Figure 1**).

Figure 1: Crude annual hepatitis B-related and hepatitis C-related mortality rates (per 100,000 population), Canada, 2015–2021

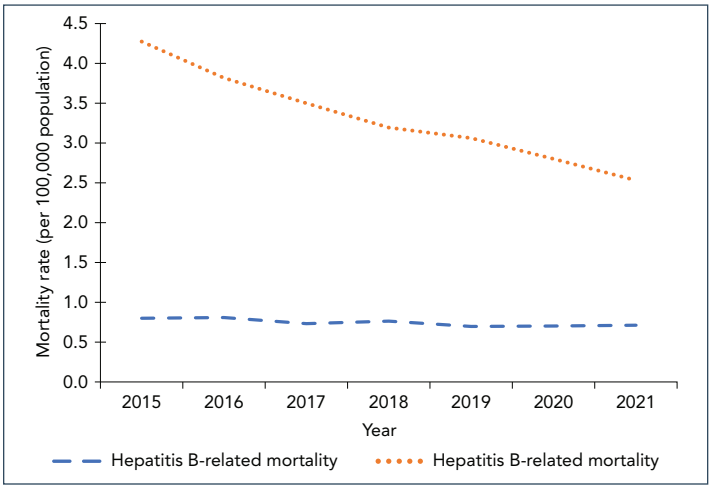


Table 1: Estimated chronic hepatitis B prevalence for the general population and key populations, Canada, 2021

Population	Population size estimate	Prevalence (%)			Estimated number of people living with CHB			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
General population	38,239,864	0.68%	0.40%	0.97%	262,000	152,000	371,000	(12,14,21–24)
Immigrants from countries where HBV is common (HBsAg ≥2%)	5,599,485	4.2%	1.9%	5.6%	237,000	106,000	312,000	(21,25,26)
GBMSM	669,613	1.4%	0.8%	2.1%	9,310	5,360	14,100	(27,28) Unpublished data from the Engage cohort study, 2017–2019
People incarcerated in federal prisons[a]	12,405	0.28%	0.19%	0.41%	35	24	51	Unpublished data from Correctional Service Canada, 2021 (*personal communication, 2024*)
People incarcerated in provincial prisons[b]	Insufficient information							
PWID	Insufficient information							
First Nations	Insufficient information							
Inuit	Insufficient information							
Métis	Insufficient information							

Abbreviations: CHB, chronic hepatitis B; HBsAg, hepatitis B surface antigen; HBV, hepatitis B virus; GBMSM, gay, bisexual and other men who have sex with men; PWID, people who inject drugs
[a] Who were sentenced for two years or more
[b] Who were sentenced for less than two years

Table 2: Estimated number and proportion of people living with chronic hepatitis B who were unaware of their infection for the general population and key populations, Canada, 2021

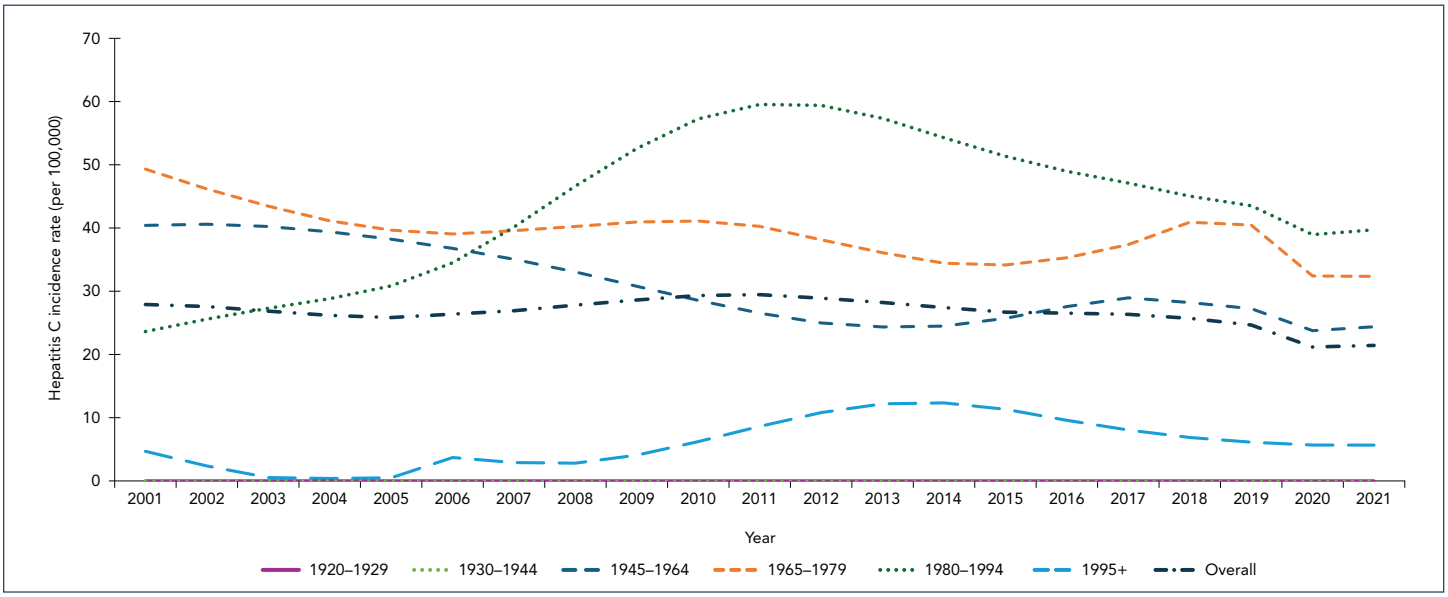
Population	Estimated number of people living with CHB	Proportion who were unaware (%)			Estimated number of people who were unaware			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
General population	262,000	42.5%	33.9%	51.0%	111,000	88,700	134,000	(14,21)
Immigrants from countries where HBV is common (HBsAg ≥2%)	Insufficient information							
GBMSM	Insufficient information							
People incarcerated in federal prisons[a]	Insufficient information							
People incarcerated in provincial prisons[b]	Insufficient information							
PWID	Insufficient information							
First Nations	Insufficient information							
Inuit	Insufficient information							
Métis	Insufficient information							

Abbreviations: CHB, chronic hepatitis B; HBsAg, hepatitis B surface antigen; HBV, hepatitis B virus; GBMSM, gay, bisexual and other men who have sex with men; PWID, people who inject drugs
[a] Who were sentenced for two years or more
[b] Who were sentenced for less than two years

Hepatitis C incidence

An estimated 8,212 seroconversions (representing new HCV infections) occurred in 2021 in Canada, corresponding to an annual incidence rate of 21.47 per 100,000 population. The overall incidence rate has been slowly declining since 2013 (**Figure 2**). When grouped by birth cohort, as a proxy for established generations, those born between 1980 and 1994 had the highest incidence in 2021 (Figure 2) with 3,179 estimated seroconversions, for a rate of 39.76 per 100,000 population (data not shown).

Figure 2: Estimated annual hepatitis C incidence rates (per 100,000 population), by birth cohort and overall, Canada, 2001–2021



Hepatitis C prevalence

The estimated prevalence of anti-HCV antibodies in Canada was 0.99% (0.68%–1.30%) or 378,000 (258,000–497,000) people who were ever infected with HCV at the end of 2021. Among key populations, the highest estimated prevalence was among PWID (within 12 months) at 64.2% (36.7%–91.8%), followed by those who have ever injected drugs (35.4%; 9.3%–61.5%). In absolute numbers, adults in the 1945–1975 birth cohort represented the population with the largest number of people ever infected at 270,000 (157,000–383,000) (**Table 3**).

The prevalence of CHC in Canada was estimated at 0.56% (0.15%–0.97%) or 214,000 (58,500–369,000) people living with CHC at the end of 2021. Among key populations, PWID (within 12 months) and those who have ever injected drugs had the highest estimated prevalence of CHC at 36.9% (12.6%–55.1%) and 18.1% (5.7%–30.5%), respectively. In absolute numbers, adults in the 1945–1975 birth cohort had the largest number of people living with CHC at 157,000 (30,000–284,000) (**Table 4**).

Table 3: Estimated anti-hepatitis C virus antibodies prevalence for the general population and key populations, Canada, 2021

Population	Population size estimate	Prevalence (%)			Estimated number of people with current or past HCV infection			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
General population	38,239,864	0.99%	0.68%	1.3%	378,000	258,000	497,000	(12,21,29–31) Unpublished data from PHAC, 2021 (this study)
PWID, within 12 months	100,300	64.2%	36.7%	91.8%	64,400	36,800	92,100	(32–35) Unpublished data from the Virtual Cascade of Care Cohort study, 2018–2019 (*personal communication, Stine Høj, 2023*) Unpublished data from the HEPCO study, 2022–2023 (*personal communication, Sarah Larney, 2024*)
People who have ever injected drugs	388,400	35.4%	9.3%	61.5%	137,000	36,100	239,000	(21,33,35–37) Unpublished data from the Virtual Cascade of Care Cohort study, 2018–2019 (*personal communication, Stine Høj, 2023*)

Table 3: Estimated anti-hepatitis C virus antibodies prevalence for the general population and key populations, Canada, 2021 (*continued*)

Population	Population size estimate	Prevalence (%)			Estimated number of people with current or past HCV infection			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
People incarcerated in provincial prisons[a]	18,950	14.2%	9.5%	19.0%	2,700	1,790	3,600	(38–41) Unpublished data from Alberta Health Services, 2023 (*personal communication, Kaylee Goralcyk, 2024*)
People incarcerated in federal prisons[b]	12,405	11.1%	10.2%	12.0%	1,370	1,260	1,490	Unpublished data from Correctional Service Canada, 2021 (*personal communication, 2024*)
First Nations	1,048,400	8.0%	3.5%	12.5%	84,000	36,600	131,000	(42–44) Unpublished data from the CHMS, Statistics Canada, 2014–2015
Immigrants from countries where hepatitis C is common (≥2% seroprevalence)	1,276,405	4.0%	2.9%	6.7%	51,500	36,700	85,300	(25)
GBMSM	669,613	3.0%	0.82%	5.2%	20,100	5,490	34,800	(27,45,46) Unpublished data from the Engage cohort study, 2017–2019
Adults in the 1945–1975 birth cohort	14,267,340	1.9%	1.1%	2.7%	270,000	157,000	383,000	(12,21,29–31,36,47) Unpublished data from PHAC, 2021 (this study)
Inuit	Insufficient information							
Métis	Insufficient information							

Abbreviations: CHMS, Canadian Health Measures Survey; HCV, hepatitis C virus; HEPCO, Hepatitis Cohort; GBMSM, gay, bisexual and other men who have sex with men; PHAC, Public Health Agency of Canada; PWID, people who inject drugs
[a] Who were sentenced for two years or more
[b] Who were sentenced for less than two years

Table 4: Estimated chronic hepatitis C prevalence for the general population and key populations, Canada, 2021

Population	Population size estimate	Prevalence (%)			Estimated number of people living with CHC			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
General population	38,239,864	0.56%	0.15%	0.97%	214,000	58,500	369,000	(12,21,30,31,48–52)
PWID, within 12 months	100,300	36.9%	12.6%	55.1%	37,000	12,600	55,300	(32–35,53,54) Unpublished data from the HEPCO study, 2022–2023 (*personal communication, Sarah Larney, 2024*) Unpublished data from the Virtual Cascade of Care Cohort study, 2018–2019 (*personal communication, Stine Høj, 2023*)
People who have ever injected drugs	388,400	18.1%	5.7%	30.5%	70,100	21,900	118,000	(21,35) Unpublished data from the Virtual Cascade of Care Cohort study, 2018–2019 (*personal communication, Stine Høj, 2023*)
People incarcerated in provincial prisons[a]	18,950	5.1%	4.4%	5.7%	957	834	1,080	(38,40,41) Unpublished data from Alberta Health Services, 2023 (*personal communication, Kaylee Goralcyk, 2024*)
First Nations	1,048,400	3.3%	1.5%	5.0%	34,300	15,800	52,800	(42–44,55,56)

Table 4: Estimated chronic hepatitis C prevalence for the general population and key populations, Canada, 2021 (*continued*)

Population	Population size estimate	Prevalence (%)			Estimated number of people living with CHC			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
People incarcerated in federal prisons[b]	12,405	3.2%	2.7%	3.7%	396	335	464	Unpublished data from Correctional Service Canada, 2021 (*personal communication, 2024*)
Immigrants from countries where hepatitis C is common (≥2% seroprevalence)	1,276,405	2.2%	1.6%	3.5%	28,100	19,800	44,600	(25)
Adults in the 1945–1975 birth cohort	14,267,340	1.1%	0.21%	2.0%	157,000	30,000	284,000	(12,21,48,49,57)
GBMSM	669,613	0.94%	0.18%	1.7%	6,290	1,210	11,400	(27,45,46) Unpublished data from the Engage cohort study 2017–2019
Inuit	Insufficient information							
Métis	Insufficient information							

Abbreviations: CHC, chronic hepatitis C; HEPCO, Hepatitis Cohort; GBMSM, gay, bisexual and other men who have sex with men; PWID, people who inject drugs
[a] Who were sentenced for two years or more
[b] Who were sentenced for less than two years

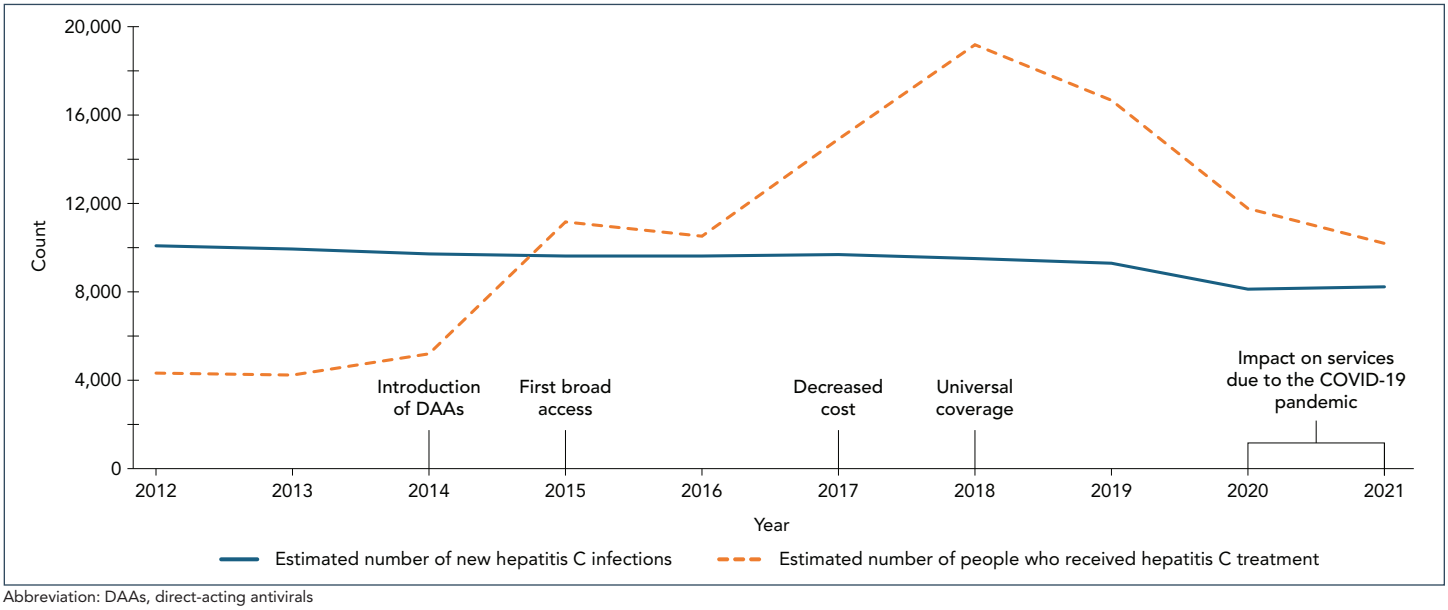
Unawareness of chronic hepatitis C infection

The proportion of people living with CHC who were unaware of their infection was estimated at 41.5% (34.3%–48.8%) or 104,000 people. Among key populations, the largest proportion was among PWID at 49.9% (29.0%–70.2%), followed by people incarcerated in federal prisons at 32.7% (28.2%–37.5%). In absolute numbers, adults in the 1945–1975 birth cohort had the largest number of people unaware of their infection at 45,200 (24,700–65,800) (**Table 5**). Additional data are needed to estimate unawareness in other key populations.

Hepatitis C treatment

It is estimated that, between 2012 and 2021, 108,000 people living with CHC received treatment. Since the introduction of highly effective DAAs in Canada in 2014, approximately 99,400 people were treated. Between 2015 and 2021, but drastically starting in 2017, the estimated number of people treated annually surpassed the estimated number of new infections annually (**Table 6**, **Figure 3**).

Figure 3: Estimated annual number of people living with chronic hepatitis C who were treated and estimated annual number of new hepatitis C infections, Canada, 2012–2021



Abbreviation: DAAs, direct-acting antivirals

Table 5: Estimated number and proportion of people living with chronic hepatitis C who were unaware of their infection, for the general population and key populations, Canada, 2021

Population	Estimated number of people living with CHC	Proportion who were unaware (%)			Estimated number of people living with CHC who are unaware			Reference(s)
		Point estimate	Lower bound	Upper bound	Point estimate	Lower bound	Upper bound	
General population	214,000	41.5%	34.3%	48.8%	104,000	73,300	104,000	(21,48,49)
PWID, within 12 months	37,000	49.9%	29.0%	70.2%	18,500	10,700	26,000	(32)
People who have ever injected drugs	Insufficient information							
People incarcerated in provincial prisons[a]	Insufficient information							
First Nations	Insufficient information							
People incarcerated in federal prisons[b]	396	32.7%	28.2%	37.5%	129	112	148	Unpublished data from Correctional Services Canada, 2021 (*personal communication, 2024*)
Adults in the 1945–1975 birth cohort	157,000	28.9%	15.7%	41.9%	45,200	24,700	65,800	(21,48,49,58)
Immigrants from countries where hepatitis C is common (≥2% seroprevalence)	Insufficient information							
Inuit	Insufficient information							
Métis	Insufficient information							
GBMSM	Insufficient information							

Abbreviations; CHC, chronic hepatitis C; GBMSM, gay, bisexual and other men who have sex with men; PWID; people who inject drugs
[a] Who were sentenced for two years or more
[b] Who were sentenced for less than two years

Table 6: Estimated number of new hepatitis C virus infections and estimated number of people who received hepatitis C virus treatment by year, Canada, 2012–2021

Year	Estimated number of new HCV infections	Estimated number of people who received HCV treatment
2012	10,075	4,370
2013	9,912	4,221
2014	9,690	5,147
2015	9,557	11,138
2016	9,580	10,496
2017	9,673	14,887
2018	9,506	19,155
2019	9,298	16,619
2020	8,086	11,774
2021	8,212	10,155

Abbreviation: HCV, hepatitis C virus

Hepatitis C-related mortality

In 2021, HCV was identified as a contributing cause for 972 deaths for a crude mortality rate of 2.54 per 100,000 population. Between 2010 and 2021, the annual mortality rate decreased, starting in 2016 (Figure 1).

Progress towards viral hepatitis elimination

Table 7 summarises the intermediary global targets for 2025 in relation to the 2021 estimates. For HBV, these estimates suggest that, as of 2021, Canada was on track to meet or had met three of the seven targets for 2025. For HCV, these estimates suggest that, as of 2021, Canada was on track to meet or had met three of the eight targets for 2025.

Table 7: Progress towards viral hepatitis elimination targets for 2025 outlined in the Global Health Sector Strategy 2022–2030, Canada, 2021

Indicator	2025 target (11)	2021 estimates	Reference(s)
Hepatitis B			
Hepatitis B surface antigen prevalence among children 0–4 years old	0.5%	Additional data needed	
Number of new hepatitis B infections per year	11/100,000 population	Additional data needed	
Number of people dying from hepatitis B per year	7/100,000 population	0.72/100,000 population	This study using Vital statistics data (18)
Percentage of newborns who have benefitted from a timely birth dose of hepatitis vaccine and from other interventions to prevent the vertical (mother-to-child) transmission of hepatitis B virus	70%	Less than 2%	This study using Vital statistics data (18)
Hepatitis B vaccine coverage among children (third dose)[a]	90%	89.0% among 14-year-olds, 1 or more dose	(17)
Percentage of people living with hepatitis B diagnosed	60%	57.5%	This study
Percentage of people living with hepatitis B diagnosed and treated	50%	Additional data needed	
Hepatitis C			
Number of new hepatitis C infections per year	13/100,000 population	21.47/100,000 population	This study
Number of new hepatitis C infections among PWID per year	3/100	Additional data needed	
Number of people dying from hepatitis C per year	3/100,000 population	2.54/100,000 population	This study using Vital statistics data (18)
Number of needles and syringes distributed per PWID	200	Additional data needed	
Blood safety: proportion of blood units screened for blood-borne diseases	100%	100% of blood donations are tested for hepatitis B and C	(59)
Safe injections: proportion of safe healthcare injections	100%	Additional data needed	
Percentage of people living with hepatitis C diagnosed	60%	58.5%	This study
Percentage of people living with hepatitis C diagnosed and cured	50%	Additional data needed	

Abbreviation: PWID, people who inject drugs

[a] The domestic vaccine coverage goal in Canada is to achieve 90% vaccination coverage by 17 years of age for one or more doses of the hepatitis B vaccine, by 2025 (60). As of 2024, no other domestic targets were set

Discussion

Although the overall viral hepatitis burden is low in the general Canadian population, the 2021 national estimates indicate that certain populations and communities remain disproportionately affected, and that a significant number of people in Canada would benefit from targeted testing and treatment. These estimates mostly use data sources preceding the COVID-19 pandemic. Measuring post-pandemic estimates will be important to account for decreased demand for, and access to prevention, testing, treatment and care services for HBV and HCV. Given changes in methods and available evidence, these estimates replace previously published estimates and should not be compared over time.

It is estimated that 0.68% of people in Canada were living with CHB at the end of 2021. Other estimates for Canada include a 0.4% prevalence (2007–2011) (61) and a 0.6% HBsAg prevalence (2022) (62,63), which are comparable to the results in this study. Immigrants from countries where HBV is common have the highest burden, by far. Regarding progress towards HBV elimination, we cannot report on the incidence target using available data. Estimates suggest that Canada is close to meeting the 60% diagnosis target for 2025 with 57.5% people living with CHB who were aware of their infection. Awareness data for key populations is scarce, limiting the evidence base for planning targeted interventions. An estimated 0.72 deaths per 100,000 population were identified as HBV-related in 2021, suggesting that the 2025 target of seven per 100,000 population is met, which is supported by a modelling study estimating one per 100,000 population HBV-related deaths in Canada in 2019 (64). The HBV vaccine coverage of 89% in adolescents approximates the 2025 target of 90% among children. We estimate that less than 2% of infants born in Canada in 2021 had access to universal birth dose vaccination, far from the 70% global target set for 2025. Of note, health care is a provincial and territorial responsibility, and the *Canadian Immunization Guide* indicates that the HBV vaccine should be provided according to provincial and territorial immunization schedules (65). Hepatitis B treatment data were not nationally validated at the time of press.

An estimated 21.47 new HCV infections per 100,000 population occurred in 2021, highlighting that more prevention work, including harm reduction services in all settings (8,10), is needed to reduce the incidence of HCV and meet the 2025 target of 13 per 100,000 population. We estimate that 0.99% of the Canadian population was ever infected with HCV. Other estimates include a 0.07% anti-HCV prevalence among Canadian first-time blood donors in nine provinces, representing a low-risk and undiagnosed population (66). We estimate the CHC prevalence at 0.56% in the general population; other CHC estimates include a prevalence of viremic infection of 130,000 people (2022) (67), and of 0.03% among low-risk undiagnosed blood donors (2021) (66). Among people living with CHC, we estimate that 58.5% were diagnosed, suggesting that Canada is close to meeting the 2025 diagnosis target of 60%. However, additional data will be needed to quantify awareness of CHC in all key populations. We identified 2.54 HCV-related deaths per 100,000 population, suggesting that Canada has met the 2025 target of 3 per 100,000. However, this finding contrasts with other evidence suggesting a seven per 100,000 population mortality rate in Canada for 2021 (64). Of note, in absolute numbers, more deaths were attributed to HCV than HBV in 2021, despite the availability of curative treatment which is associated with reduced mortality (68).Treatment data suggest that more people are being treated for HCV each year than there are new infections. Administrative data for key populations is not available at the national level, although it is documented that self-reported treatment uptake varies by key populations (32,69). Since treatment estimates do not consider mortality among treated individuals, we are unable to report on the proportion treated among people living with diagnosed HCV.

Limitations

The main strengths of this study are the use of updated Canadian Health Measures Survey (CHMS) data, in combination with results from modelling using national surveillance data as model inputs for the first national HBV estimates and updated HCV estimates. We also compiled a thorough list of relevant scientific studies to inform the workbook estimates.

The analyses for this study have several limitations. First, mathematical modelling used for incidence (HCV) and as a lower bound for prevalence was based on reported cases, likely underestimating the true burden. The COVID-19 pandemic had an impact on STBBI testing in Canada (70–73), potentially making the modelled estimates for 2020–2021 an underestimation despite mathematical corrections. The workbook method produces large ranges of uncertainty given the heterogeneity of studies (e.g., participants, sampling, methods, geographic location) and data. In some instances, results from local studies were extrapolated nationally. These may impact the precision and accuracy of the estimates. Data is limited for key populations, restricting our capacity to provide estimates for all. Moreover, given the intersection of risks and identities across key populations, estimates cannot be added together or used to create proportions. The general population estimates for CHC rely on data for a reference period up to 2019, therefore this study's findings may be more representative of the burden for 2019 than for the end of 2021. Measures of HBsAg and HCV RNA, where applicable, were used as proxies for CHB and CHC infections, respectively. Both could potentially result in a slightly overestimated chronicity, given that HBsAg is a marker of active HBV infection that occurs in its acute or chronic phase (74), and that HCV RNA is detectable for most people in the acute phase of the infection (75). The measure of the HBV vaccine target is likely overestimated since it is measured in adolescents with at least one dose. For mortality, a direct measurement method of documented causes of deaths was used, which excludes all deaths among undiagnosed individuals. As well, potential underreporting of causes on death certification is likely, which could lead to underestimation of the measure towards the target for deaths not identified as viral hepatitis-related. On the other hand, deaths with other direct causes, such as accidents or drug toxicity, may be misclassified as viral hepatitis-related, which would result in overestimation of mortality. Given the nature of this study, we could not control for confounding and missing data.

Conclusion

Prevention of advanced liver disease caused by viral hepatitis is possible, and epidemiological estimates are essential to identify gaps in the care continuum by key population, contribute to planning evidence-based interventions, and track progress towards elimination as a public health concern. While these estimates suggest that Canada has met or is on track to meet six of the 15 global targets for 2025, more work is needed to address data gaps and to meet the targets that are not on track, such as HCV incidence. Additional national-level data are needed to produce estimates of prevalence and proportion unaware among all key population and to report Canada's progress towards all elimination targets, including validated treatment data for HBV and cascade of care data.

Authors' statement

SP — Conceptualization, methodology, formal analysis, validation, writing–original draft, writing–review & editing
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LC — Conceptualization, methodology, formal analysis, validation
JE — Methodology, formal analysis
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All authors approved the final version of the manuscript.

Competing interests

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MJB reports receiving presentation fees from AbbVie and Gilead, and grant funding from AbbVie, Gilead, and Cepheid. NK has received research funding from ViiV Healthcare, Abbvie, and Gilead, advisory fees from Gilead Sciences, ViiV Healthcare, Merck, and Abbvie, and speaker fees from Gilead Sciences, Abbvie, and Merck, all outside this work. MBK reports grants for investigator-initiated studies from ViiV Healthcare, AbbVie, and Gilead; and consulting fees from ViiV Healthcare, Merck, AbbVie, and Gilead.

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Acknowledgements

We thank non-co-author members of our Working Group for their expert guidance throughout the estimates process: Drs Carla S. Coffin, Brian Conway, Naveed Janjua, Curtis Cooper, Christina Greenaway, Gisela Macphail, Sara Larney, Samuel S. Lee, William W.L. Wong, Marjolaine Pruvost, Abdel Aziz Shaheen and Eliverta Bicja. We also thank Correctional Service Canada, Alberta Health Services, and teams for the Tracks bio-behavioural surveys (Public Health Agency of Canada), the Virtual Cascade of Care Cohort, the Hepatitis cohort (HEPCO) and the Engage cohort for sharing unpublished data. We thank the health librarians from the Health Canada Library for providing the systematic literature searches.

Funding

This work was supported by the Public Health Agency of Canada. MBK is supported by a Tier I Canada Research Chair. NK is supported by a career award from the *Fonds de Recherche Québec – Santé (FRQ-S; Junior 2).*

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Prevalence and awareness of hepatitis B and hepatitis C and vaccine-induced immunity to hepatitis B: Findings from the Canadian Health Measure Survey, 2016–2019

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Abstract

Background: Hepatitis B virus (HBV) and hepatitis C virus (HCV) infections are sexually transmitted and blood-borne infections that Canada is committed to eliminate as public health concerns. Accurate epidemiological estimates require cross-sectional data as input. The objective of this study was to estimate the prevalence of present HBV infection (hepatitis B surface antigen-positive) and proportion aware of their infection, the vaccine-induced HBV immunity, the prevalence of HCV antibodies (anti-HCV-positive), the prevalence of present HCV infection (RNA-positive) and proportion aware of their infection, in the household population in Canada. These outcomes were also examined by selected demographic characteristics.

Methods: A total of 7,543 sera from participants of the Canadian Health Measure Survey (CHMS) cycles 5 (2016–2017) and 6 (2018–2019) who consented to participate in Statistics Canada's Biobank were tested to determine their HBV and HCV status. Information from the CHMS household questionnaire was linked to the laboratory results to report on sociodemographic characteristics and awareness of infection.

Results: The stored serum combined response rate for this study, which takes into account households' and respondents' participation in the CHMS and the Biobank was 42.8%. The estimated prevalence of present HBV infection among people aged 14 to 79 years was 0.4% (95% CI: 0.1%–0.7%), of whom 49.0% (95% CI: 15.4%–82.6%) were aware of their infection. An estimated 39.0% (95% CI: 37.0%–41.0%) of people aged 11 to 79 years had laboratory evidence of vaccine-induced HBV immunity. An estimated 0.5% (95% CI: 0.2%–0.8%) of people aged 14 to 79 years were positive for anti-HCV, and 0.2% (95% CI: 0.0%–0.3%) had a present infection (RNA-positive), of whom 51.2% (95% CI: 9.5%–92.9%) were aware of their infection.

Conclusion: Cross-sectional data using nationally representative surveys are essential in assessing the burden of viral hepatitis.

Suggested citation: Périnet S, Williams A, Yang Q, Campeau L, Day J, Lamboo L, Lee ER, Osiowy C, Popovic N. Prevalence and awareness of hepatitis B and hepatitis C and vaccine-induced immunity to hepatitis B: Findings from the Canadian Health Measure Survey, 2016–2019. Can Commun Dis Rep 2025;51(6/7):238–48. https://doi.org/10.14745/ccdr.v51i67a03

Keywords: hepatitis B, hepatitis C, viral hepatitis, estimates, awareness, prevalence, Canada

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Introduction

Canada is committed to eliminating hepatitis B virus (HBV) and hepatitis C virus (HCV) infections as public health concerns (1). Certain populations and communities are disproportionately affected by these sexually transmitted and blood-borne infections (STBBI) (2,3). In Canada, people from countries where HBV is common have the highest estimated HBV prevalence (3), and people who inject drugs (PWID) have the highest HCV prevalence. However, people born between 1945 and 1975 account for the largest absolute number of people living with HCV (3), due to the large demographic weight of this group. Most infections in this cohort result from medical procedures or past injection drug use (4).

Cross-sectional data from representative surveys are essential to estimate prevalence and awareness, which is the first step in tracking Canada's progress towards eliminating viral hepatitis as a public health concern. The Canadian Health Measure Survey (CHMS), conducted by Statistics Canada, collects self-reported health information and direct physical measures, including blood samples. Specimens are stored as part of the Statistics Canada Biobank for future studies. The last viral hepatitis estimates derived from the CHMS were for the period 2007–2009 and 2009–2011 (5). In this study, Statistics Canada Biobank blood samples from the 2016–2017 and 2018–2019 CHMS cycles were used to estimate the prevalence and proportion aware for HBV and HCV infections among people aged 14 to 79 years living in Canadian households for the 2016–2019 period, by sociodemographic characteristics. Vaccine-induced HBV immunity among people aged 11 to 79 years and children aged 11 to 17 years for the same period is also reported.

Methods

Study design

The CHMS has been described in detail elsewhere (6). It collects health information through a questionnaire, direct physical measurement, and blood and urine samples to test for chronic and infectious diseases. The CHMS is designed to be representative of Canada's provincial population (excluding the territories). The sampling frame captured 97% of the household population for the cycles used (7), but excludes Indigenous people living in communities, full-time members of the Canadian Forces, the institutionalized population, and residents of some remote regions. The Public Health Agency of Canada (PHAC) partnered with Statistics Canada and the National Microbiology Laboratory (NML) to conduct HBV and HCV testing on a subsample of serum specimens that were stored as part of the Statistics Canada Biobank for cycles 5 (2016–2017) and 6 (2018–2019) of the CHMS. Informed consent from respondents to have their samples stored as part of the Biobank was obtained at the time of participation, and all respondents who provided biological samples have consented to the mandatory reporting of reportable disease to provincial authorities. All participants who had present HBV or HCV infection were contacted by Statistics Canada through multiple phone attempts to confirm their mailing address. When contact was made, and mailing address confirmed, a results report was sent to the participant via registered mail. The project was approved by the Health Canada and PHAC Research Ethics Board (protocol number REB 2021–001P).

Specimen collection

Blood samples were collected from consenting respondents, allowed to clot at room temperature, protected from light for 30 minutes, and centrifuged at 8°C for 15 minutes at 3,400 RPM. Each serum was aliquoted and stored in laboratory freezers until weekly shipment to the Statistics Canada biorepository, where they were stored at −80°C until sent to the NML reference laboratory for analysis.

Laboratory methods

Respondent serum samples were analyzed for the qualitative detection of HBV markers using the electrochemiluminescence immunoassay (ECLIA) technique on the Cobas e411 Immunoanalyzer (Roche Diagnostics, Laval, Québec). All samples underwent testing for HBV surface antibodies (anti-HBs) and total HBV core antibodies (anti-HBc) using the Elecsys Anti-HBs II Assay and the Elecsys Anti-HBc II, respectively. Samples that screened positive for anti-HBc were tested for the HBV surface antigen (HBsAg) using the Elecsys HBsAg II Assay on the same platform. Initial HBsAg positive results were confirmed using the Elecsys HBsAg Confirmatory Test.

The qualitative detection of HCV antibodies (anti-HCV) was performed using ECLIA on the Cobas e411 Immunoanalyzer (Roche Diagnostics, Laval, Québec) and a chemiluminescent microparticle immunoassay (CMIA) using the Architect i2000 SR Immunoanalyzer (Abbott Diagnostics, Mississauga, Ontario). If the initial Elecsys Anti-HCV II Assay was positive, the ARCHITECT Anti-HCV Assay was used as a confirmatory test. Anti-HCV-positive samples were assessed qualitatively for detection of RNA using reverse transcriptase polymerase chain reaction (RT-PCR) with the Xpert HCV Viral Load Assay using the GeneXpert system (Cepheid Canada, Markham, Ontario).

Each sample batch included positive and negative controls.

Statistical analysis

All statistical analyses were carried out using SAS Enterprise Guide 7.1 and were weighted to account for survey design and non-response. Weighted estimates are representative of the population covered by the survey, in this case the household population in provinces of Canada. Ninety-five percent

confidence intervals (95% CI) were computed using the Bootstrap method with 500 repetitions. For national-level estimates, 22 degrees of freedom were applied, and for regional-level estimates, 2–10 degrees of freedom were used, following the CHMS user guide (available upon request to Statistics Canada). Second order (Satterthwaite) likelihood ratio chi-square tests were conducted to assess statistical significance at a level of 5%. Due to variations in the available degrees of freedom, regional-level estimates were assessed using 95% CIs rather than producing *p*-values. Data were not shown for cells with five or less observations and absolute number estimates and proportions were rounded to the nearest hundred units and to one decimal, respectively.

Variable definitions

The detection of HBsAg was a marker of present HBV infection. An anti-HBs result was considered positive if ≥10 IU/L. Positive anti-HBs in combination with negative anti-HBc was used as an indication of vaccine-induced HBV immunity. Two respondents with unclear anti-HBs/anti-HBc status were excluded from the immunity analysis. Anti-HCV was used as a marker of past or present HCV infection, and HCV RNA as a marker of present infection (**Table 1**).

Table 1: Defining hepatitis B virus and hepatitis C virus infections and vaccine-induced immunity to hepatitis B

Characterization	Biomarkers
HBV	
Present infection	Hepatitis B virus surface antigen (HBsAg) positive
Vaccine-induced immunity	Hepatitis B virus core antibody (anti-HBc) negative and hepatitis B virus surface antibody positive[a] (anti-HBs)
HCV	
Present or previous infection	Hepatitis C virus antibody (anti-HCV) positive
Present infection	Hepatitis C virus RNA positive

Abbreviations: anti-HBc, hepatitis B virus core antibody; anti-HBs, hepatitis B virus surface antibody positive; HBsAg, hepatitis B virus surface antigen; HBV, hepatitis B virus; HCV, hepatitis C virus
[a] An anti-HBs result was considered positive if ≥10 IU/L

Participants who tested positive for HBsAg and indicated having hepatitis B were considered aware of their infection. These participants responded "hepatitis B" when asked 1) "What kind of liver disease or gallbladder problem do you have?", or 2) "What type of hepatitis do you have?", or 3) "Which sexually transmitted disease(s) or infection(s) have you been diagnosed with?". Details on skip logic are available in the Statistics Canada data dictionaries.

Participants who tested positive for HCV RNA and indicated having hepatitis C were considered aware of their present infection. These participants responded "hepatitis C" when asked 1) "What kind of liver disease or gallbladder problem do you have?", or 2) "What type of hepatitis do you have?". Details on skip logic are available in the Statistics Canada data dictionaries.

Infection status for HBV and HCV, awareness of infection, and vaccine-induced HBV immunity were examined by sex, age group/birth cohorts, province or region, being born outside of Canada, being born in an intermediate-to-high prevalence country, history of injection drug use, household income, and highest education level. Age groups/birth cohorts were grouped in larger categories as needed for statistical power considerations. Countries of birth with a country- or region-specific anti-HCV or pooled HBsAg estimate of 2% or greater were classified as intermediate-to-high prevalence countries (8–10). Participants in the CHMS were asked whether they had ever injected or been injected with drugs for non-medicinal purposes. Household income in dollars was available for cycle 6, but only as an ordinal variable for cycle 5; the cycle 6 incomes were first grouped as deciles and the data was dichotomized as median or less (i.e., lower), and higher than median (i.e., higher). Categories of highest education level achieved were dichotomized as needed for statistical power considerations.

Results

Survey participants

The household response rate (i.e., the proportion of respondent households among households within the scope of the survey) for this study was 74.0%. The stored serum combined response rate (SerCRR) for this study was 42.8%. The SerCCR takes into account the household response rate, the number of respondents for each household, their participation in the questionnaire and physical examination, successful blood draw, and whether the serum fraction was stored. SerCRRs ranged from 40.5% (12–19 years) to 45.5% (40–59 years) across age groups.

Sera from 7,543 participants were included in the analysis. Among those participants, 499 were aged 11 to 13 years, 880 were aged 14 to 17 years, and 6,164 were aged 18 to 79 years (50% female; median [IQR] age, 40 [36] years) (**Table 2**).

Table 2: Description of the analyzed sample (n=7,543)

Characteristic	Unweighted frequency	Weighted (%)
Sex		
Female	3,712	50.2
Male	3,831	49.8
Age groups		
11–13	499	2.4
14–17	880	5.2
18–24	580	9.8
25–34	924	16.7
35–44	1,568	16.5
45–54	913	17.2

Table 2: Description of the analyzed sample (n=7,543) (*continued*)

Characteristic	Unweighted frequency	Weighted (%)
Age groups (*continued*)		
55–64	983	17.2
≥65	1,196	14.9
Province or region of residence		
Atlantic	924	6.5
Québec	1,842	22.8
Ontario	2,500	39.4
Prairies	1,234	18.0
British Columbia	1,043	13.2
Born outside of Canada		
Yes	1,937	32.1
No	5,605	67.9
Not stated	-	-
Born in an intermediate-to-high HBV prevalence country[a]		
Yes	1,206	20.4
No	6,318	79.5
Not stated	19	0.1
Born in an intermediate-to-high HCV prevalence country[b]		
Yes	279	4.4
No	7,245	95.5
Not stated	19	0.1
Household income		
Lower	3,881	51.1
Higher	3,662	48.9
Education		
Less than secondary school graduation	532	8.1
Secondary school graduation	1,295	20.7
Post-secondary graduation	4,294	63.0
Not stated or not applicable (respondent aged <18 years)	1,422	8.5
Lifetime history of injection drug use		
Yes	69	1.1
No	7,421	98.1
Not stated	53	0.8
Total	7,543	100.0

Abbreviations: HBV, hepatitis B virus; HCV, hepatitis C virus; -, cell size does not meet diffusion guidelines
[a] Countries with estimated hepatitis B surface antigen (HBsAg) prevalence greater or equal to 2%
[b] Countries with estimated hepatitis C antibodies prevalence greater or equal to 2%

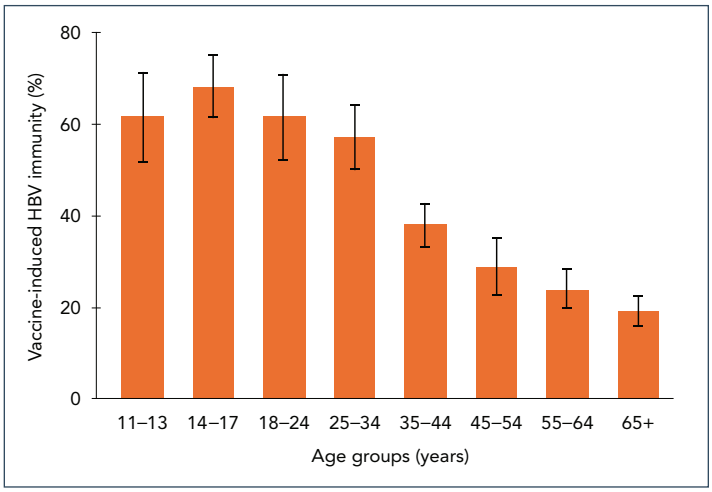
Hepatitis B prevalence and awareness

The estimated prevalence of present HBV infection in the household population aged 14 to 79 years was 0.4% (95% CI: 0.1%–0.7%). The prevalence among people born outside of Canada (1.2%; 95% CI: 0.5%–1.9%) was more than 10 times higher than the prevalence of those born in Canada (0.1%; 95% CI: 0.0%–0.1%; p=0.004). The prevalence among those born in intermediate-to-high prevalence countries was estimated at 1.9% (95% CI: 0.8%–3.1%) (**Table 3**). Among people with present HBV infection, 49.0% (95% CI: 15.4%–82.6%) were aware of their infection (**Table 4**).

Vaccine-induced immunity to hepatitis B

An estimated 39.0% (95% CI: 37.0%–41.0%) of the household population aged 11 to 79 years had laboratory evidence of vaccine-induced HBV immunity. There were statistically significant differences across age groups. Adolescents aged 14 to 17 years had the highest immunity at 68.3% (95% CI: 61.4%–75.2%), and adults aged 65 years or older had the lowest immunity at 19.4% (95% CI: 16.1%–22.7%). Immunity varied across regions, but differences did not reach statistical significance. People born outside of Canada had significantly lower vaccine-induced immunity (31.2%; 95% CI: 27.5%–35.0%) than those born in Canada (42.7%; 95% CI: 39.9%–45.4%; p<0.0001). Immunity was higher among people with higher household income, and those with higher level of education (**Table 5**, **Figure 1**). Among children and adolescents aged 11 to 17 years, 66.2% (95% CI: 62.1%–70.3%) had laboratory evidence of vaccine-induced immunity. Immunity varied by province or region (**Table 6**).

Figure 1: Vaccine-induced immunity to hepatitis B by age group, household population aged 11–79 years, Canada, 2016–2019



Hepatitis C prevalence and awareness

The prevalence of past or present HCV infection (anti-HCV-positive) was 0.5% (95% CI: 0.2%–0.8%) in people aged 14 to 79 years. People born between 1945 and 1975 had the highest prevalence at 0.7% (95% CI: 0.2%–1.2%). Among people who reported ever injecting drugs, the prevalence was 9.3% (95% CI: 0.0%–19.5%). People living in households with lower income had significantly higher prevalence than those living in households with higher income, at 0.8% (95% CI: 0.3%–1.3%) compared to 0.2% (95% CI: 0.0%–0.4%; p=0.01) (**Table 7**).

Table 3: Estimated prevalence of present hepatitis B infection by selected characteristics, household population aged 14–79, Canada, 2016–2019 (n=7,044)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	0.4	0.1–0.7	128,000	40,900–215,200	N/A
Sex					
Female	0.4	0.00–0.9	61,500	0–126,400	0.9
Male	0.5	0.1–0.8	66,600	10,500–122,700	
Age groups					
14–49	0.5	0.1–0.8	79,500	14,200–144,900	0.7
>50	0.4	0.1–0.7	48,500	6,900–90,200	
Lifetime history of injection drug use					
Yes				-	N/A
No	0.4	0.1–0.8	128,000	40,900–215,200	
Born outside of Canada					
Yes	1.2	0.5–1.9	116,700	35,600–197,900	0.004
No	0.1	0.0–0.1	11,300	276–22,400	
Born in an intermediate-to-high HBV prevalence country[a]					
Yes	1.9	0.8–3.1	116,700	35,600–197,900	0.005
No	0.05	0–0.1	11,300	300–22,400	
Household income					
Lower	0.4	0.1–0.7	58,500	12,900–104,000	0.7
Higher	0.5	0.0–1.0	69,600	3,000–136,200	
Education[b]					
Secondary school graduation or less	0.3	0.0–0.7	27,600	0–59,200	0.4
Post-secondary graduation	0.5	0.1–1.0	100,300	16,600–184,000	

Abbreviations: CI, confidence interval; HBV, hepatitis B virus; N/A, not applicable; -, cell size does not meet diffusion guidelines
[a] Countries with estimated hepatitis B surface antigen (HBsAg) prevalence greater or equal to 2%
[b] Among people aged >18 years (n=6,121)

Table 4: Awareness of present hepatitis B virus infection by selected characteristics, household population aged 14–79, Canada, 2016–2019 (n=32)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	49.0	15.4–82.6	62,700	1,900–123,510	N/A
Sex					
Female				-	0.8
Male	53.1	19.5–86.8	35,400	1,600–69,200	
Age groups					
14–49	57.0	8.4–100.0	45,400	0–103,400	0.5
>50	35.7	0.0–80.4	17,300	0–36,100	
Born outside of Canada					
Yes	48.3	8.7–88.0	56,400	0–117,500	0.9
No				-	
Born in an intermediate-to-high HBV prevalence country[a]					
Yes	48.3	8.6–88.0	56,400	0–117,500	0.9
No				-	
Household income					
Lower	30.2	0.0–70.6	17,700	0–42,900	0.2
Higher	64.7	21.5–100.0	45,000	0–102,000	
Education[b]					
Secondary school graduation or less	55.2	17.2–93.2	44,900	0–99,500	0.4
Post-secondary graduation	-	-	-	-	

Abbreviations: CI, confidence interval; HBV, hepatitis B virus; N/A, not applicable; -, cell size does not meet diffusion guidelines
[a] Countries with estimated hepatitis B surface antigen (HBsAg) prevalence greater or equal to 2%
[b] Among people aged >18 years (n=12)

Table 5: Vaccine-induced immunity to hepatitis B, by selected characteristic, household population aged 11–79, Canada, 2016–2019 (n=7,541)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	39.0	37.0–41.0	11,777,300	11,170,000–12,384,500	N/A
Sex					
Female	40.7	37.6–43.7	6,169,600	5,700,900–6,638,200	0.1
Male	37.4	34.6–40.2	5,607,700	5,185,800–6,029,600	
Age groups					
11–13	61.6	51.9–71.4	447,200	359,600–534,700	<0.0001
14–17	68.3	61.4–75.2	1,082,800	967,100–1,198,400	
18–24	61.7	52.3–71.0	1,828,000	1,424,300–2,231,600	
25–34	57.3	50.0–64.5	2,888,600	2,437,500–3,339,700	
35–44	38.1	33.1–43.1	1,900,500	1,495,000–2,306,000	
45–54	29.0	22.7–35.4	1,507,200	1,172,800–1,841,600	
55–64	24.1	19.7–28.5	1,248,800	992,900–1,504,600	
≥65	19.4	16.1–22.7	874,300	716,200–1,032,300	
Province or region of residence					
Atlantic	31.6	7.1–56.1	623,500	139,800–1,107,100	N/A
Québec	36.4	30.4–42.4	2,512,500	2,095,900–2,929,000	
Ontario	40.6	38.1–43.2	4,826,700	4,526,600–5,126,800	
Prairies	42.6	31.9–53.3	2,318,600	1,735,900–2,901,200	
British Columbia	37.4	27.5–47.4	1,496,100	1,097,200–1,895,000	
Born outside of Canada					
Yes	31.2	27.5–35.0	3,024,900	2,171,200–3,878,600	<0.0001
No	42.7	39.9–45.4	8,752,400	7,576,200–9,928,500	
Household income					
Lower	35.1	32.8–37.3	5,404,100	4,915,200–5,893,000	<0.0001
Higher	43.1	39.7–46.6	6,373,200	5,782,820–6,963,500	
Education[a]					
Less than secondary school graduation	20.2	14.2–26.2	491,600	308,300–675,000	<0.0001
Secondary school graduation	36.7	31.9–41.4	2,257,400	1,859,400–2,655,400	
Post-secondary graduation	39.2	36.8–41.7	7,465,900	6,953,500–7,978,200	

Abbreviations: CI, confidence interval; HBV, hepatitis B virus; N/A, not applicable
[a] Among people aged >18 years (n=6,119)

Table 6: Vaccine-induced immunity to hepatitis B, by sex and region, household population aged 11–17, Canada, 2016–2019 (n=1,379)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	66.2	62.1–70.3	1,529,900	1,391,900–1,668,000	N/A
Sex					
Female	64.6	59.5–69.7	763,300	685,100–841,600	0.4
Male	67.9	62.0–73.8	766,600	672,400–860,800	
Province or region of residence					
Atlantic	41.3	0.0–96.6	55,200	4,700–105,700	N/A
Québec	80.1	71.7–88.6	342,100	254,600–4,290,700	
Ontario	70.9	65.9–76	657,400	556,500–758,200	
Prairies	77.0	64.4–89.6	368,500	269,900–467,100	
British Columbia	31.0	4.5–57.4	106,700	22,000–191,400	

Abbreviations: CI, confidence interval; HBV, hepatitis B virus; N/A, not applicable

Table 7: Estimated prevalence of past or present hepatitis C virus infection (antibody-positive prevalence) by selected characteristics, household population aged 14–79, Canada, 2016–2019 (n=7,044)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	0.5	0.2–0.8	143,900	60,000–227,800	N/A
Sex					
Female	0.3	0.1–0.4	38,700	16,600–60,800	0.1
Male	0.7	0.1–1.3	105,200	19,600–190,800	
Birth cohorts					
<1945				-	0.2
1945–1975	0.7	0.2–1.2	102,500	33,500–171,500	
>1975	0.3	0.0–0.7	40,700	0–95,300	
Lifetime history of injection drug use					
Yes	9.3	0.0–19.5	29,700	8,300–51,000	0.2
No	0.4	0.1–0.7	113,700	28,829–198,700	
Born outside of Canada					
Yes	0.5	0.0–1.0	44,000	0–96,600	0.9
No	0.5	0.2–0.8	99,800	35,300–164,300	
Born in an intermediate-to-high HCV prevalence country[a]					
Yes				-	0.5
No	0.4	0.2–0.7	117,300	51,300–183,400	
Household income					
Lower	0.8	0.3–1.3	121,900	41,200–202,600	0.01
Higher	0.2	0.0–0.4	22,000	0–52,000	
Education[b]					
Less than secondary school graduation	2.1	0–4.6	51,200	0–109,400	0.3
Secondary school graduation	0.7	0–1.6	41,900	0–96,600	
Post-secondary graduation	0.3	0.1–0.4	50,800	0–82,600	

Abbreviations: CI, confidence interval; HCV, hepatitis C virus; N/A, not applicable; -, cell size does not meet diffusion guidelines
[a] Countries with estimated hepatitis C antibodies prevalence greater or equal to 2%
[b] Among people aged >18 years (n=6,121)

The prevalence of present HCV infection (RNA-positive) was 0.2% (95% CI: 0.0%–0.3%) among people aged 14 to 79 years. Among people born between 1945 and 1975, the prevalence was similar at 0.2% (95% CI: 0.0%–0.4%). Among people who reported ever injecting drugs, the prevalence was 5.7% (95% CI: 0.0%–13.5%) (**Table 8**). Of note, 37% of the anti-HCV-positive respondents were positive for RNA. Among people with present HCV infection, 51.2% (95% CI: 9.5%–92.9%) were aware of their infection. This proportion was 69.4% (95% CI: 13.2%–100.0%) among people born between 1945 and 1975 (**Table 9**).

Table 8: Estimated prevalence of present hepatitis C virus infection (RNA-positive prevalence) by selected characteristics, household population aged 14–79, Canada, 2016–2019 (n=7,044)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	0.2	0.0–0.3	45,100	9,000–81,200	N/A
Sex					
Female	0.1	0.0–0.2	13,500	0–28,900	0.3
Male	0.2	0.0–0.5	31,600	0–65,700	
Birth cohorts					
<1945				-	0.8
1945–1975	0.2	0.0–0.4	31,000	0–65,100	
>1975				-	
Lifetime history of injection drug use					
Yes	5.7	0.0–13.5	18,000	180–35,900	0.4
No	0.1	0.0–0.2	27,100	0–59,700	

Table 8: Estimated prevalence of present hepatitis C virus infection (RNA-positive prevalence) by selected characteristics, household population aged 14–79, Canada, 2016–2019 (n=7,044) (*continued*)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Born outside of Canada					
Yes				-	0.6
No	0.2	0.0–0.4	34,700	600–68,900	
Born in an intermediate-to-high HCV prevalence country[a]					
Yes				-	0.2
No	0.2	0.0–0.3	44,400	8,200–80,600	
Household income					
Lower	0.2	0.0–0.4	30,100	6,900–53,200	0.5
Higher				-	
Education[b]					
Secondary school graduation or less	0.2	0–0.3	31,300	0–65,100	1.0
Post-secondary graduation	0.2	0–0.4	13,800	0–30,700	

Abbreviations: CI, confidence interval; HCV, hepatitis C virus; N/A, not applicable; -, cell size does not meet diffusion guidelines
[a] Countries with estimated hepatitis C antibodies prevalence greater or equal to 2%
[b] Among people aged >18 years (n=6,121)

Table 9: Awareness of present hepatitis C virus infection, by selected characteristic, household population aged 14–79, Canada, 2016–2019 (n=14)

Characteristic	Weighted proportion (%)	95% CI	Weighted frequency (n)	95% CI	*p*
Overall	51.2	9.5–92.9	23,000	0–53,500	N/A
Sex					
Female				-	0.04
Male	69.4	24.3–100.0	22,000	0–52,500	
Birth cohorts					
<1945				-	N/A
1945–1975	63.4	13.2–100.0	19,600	0–49,900	
>1975				-	
Born outside of Canada					
Yes				-	0.2
No	64.4	21.1–100.0	22,400	0–53,000	
Household income					
Lower	26.8	0.0–64.6	8,000	0–16,300	N/A
Higher				-	
Education					
Secondary school graduation or less				-	0.3
Post-secondary graduation	63.9	11.1–100.0	20,000	0–50,200	

Abbreviations: CI, confidence interval; HCV, hepatitis C virus; N/A, not applicable; -, cell size does not meet diffusion guidelines

Discussion

This study estimates the prevalence of HBV infection at 0.4% in the general population, of whom 49.0% were aware of their infection. The last estimates from the 2007–2009 and 2009–2011 cycles of the CHMS were 0.4% and 45.5% (95% CI: 21.3%–72.1%) for prevalence and proportion aware, respectively (5), indicating a relatively stable trend. The results of this study are comparable to a similar study done using the National Health and Nutrition Examination Survey (NHANES) data in the United States, which reported an HBsAg (and anti-HBc) prevalence of 0.2% (95% CI: 0.1%–0.3%) for the period 2017–March 2020 among people aged six years and older, among whom 49.8% (95% CI: 25.1%–74.6%) were aware of their infection (11). Another NHANES study for 2013–2018 estimated the HBsAg prevalence at 0.3% (95% CI: 0.2%–0.4%) for people aged six years or older, of which 65.6% were unaware (12).

This study estimates the prevalence of vaccine-induced HBV immunity at 39.0% (95% CI: 37.0%–41.0%) among 11- to 79-year-olds, and at 66.2% (95% CI: 62.1%–70.3%) among 11- to 17-year-olds, compared to "nearly 30%" of people aged 14 to 79 years reported by Roterman *et al*. (5), suggesting a small increase in immunity in recent years. The national vaccine coverage for 2019 (measured through self-reported or documented vaccine status) for at least one dose among adolescents aged 14 was much higher at 84.5% (82.1%–86.7%) (13), indicating an important difference between vaccination status, either documented or recalled, and laboratory evidence of immunity. One of the factors that could explain this difference is anti-HBs waning over time, therefore potentially leading to an underestimated vaccine-induced immunity. This could also contribute to explaining the differences in vaccine-immunity at the regional levels, given that the age at which HBV vaccines are offered varies from jurisdiction to jurisdiction (participants from provinces offering vaccination at birth or in infancy potentially showing waning over time and lower prevalence of anti-HBs, and those vaccinated later as part of school-based immunization potentially having higher prevalence of anti-HBs). Another factor that may explain the discrepancy between national vaccine coverage and our results is a potential overestimation of the vaccine coverage given that as it is measured for one dose or more, and the HBV-containing vaccines are routinely given as part of a two-dose or more vaccine schedule (14). A 2013–2018 NHANES study estimated that 21.4% (95% CI: 20.2%–22.6%) of people aged 25 years or more had vaccine-induced immunity (defined as anti-HBs positive). The study also found associations between younger age and being born in the United States and immunity (12).

This study estimates the prevalence of anti-HCV at 0.5%, and the prevalence of present HCV infection at 0.2%, of which 51.2% were aware of their infection. The last estimates from the CHMS were 0.5% for anti-HCV, of whom 30% were aware, indicating a stable trend with regard to past exposure (5). No RNA testing was performed in the previous study; therefore, awareness of current or past infection (anti-HCV-positive) cannot be compared to awareness of current infection (RNA-positive). Higher prevalence of present infection and proportion aware were reported for NHANES (2017–March 2020), respectively 0.9% (95% CI: 0.5%–1.4%) and 67.7% (50.2–82.2) (15). Another NHANES study for 2011–2016 identified a 2.3% viremic prevalence among people born between 1945 and 1965, a 0.47% viremic prevalence among foreign-born individuals, a viremic prevalence of 23.1% for PWID, and an inverse relationship between education level and prevalence, among others (16).

This study's descriptive analysis has several strengths. First, representative, cross-sectional data of both diagnosed and undiagnosed individuals are a critical source of information for efforts to accurately depict the burden of disease, which have not been available since 2011. Second, RNA testing for HCV was added, which allows for a better characterization of the disease. Third, the weighting allows adjustment for survey non-response and allows for inference on the Canadian population. The distribution of sociodemographic variables, including age, sex, province or region, being born outside of Canada, and education for this study is comparable to their distribution in the population of Canada for 2021.

Limitations

Several general limitations affect the findings. First, the CHMS excludes several groups of people and communities in Canada, which may affect generalizability of the findings. Second, the CHMS is likely to have underrepresentation of members of priority populations for STBBI (e.g., people who use drugs, or are incarcerated) who are likely to be disproportionately affected by HBV and HCV. Therefore, these results are considered to underestimate the "true" burden. In addition, several data elements of interest related to indigeneity, sexual orientation and sexual behaviours were not available. Third, some of this study's results lack precision due to small sample sizes and should be interpreted and used with caution. Fourth, there is an increased risk of potential bias for regional estimates and subgroup analyses, as the survey was designed to be representative of the population of Canada as a whole. Fifth, immunity may have been underestimated, since anti-HBs wanes over time in vaccinated individuals, which is not necessarily indicative of a loss of protection (14,17). Lastly, the data source was insufficiently powered to address confounding and effect modification for the rare outcomes (prevalence of infections and awareness).

Conclusion

This study provides updated estimates of HBV and HCV prevalence and the proportion of affected individuals who are aware of their infection, by sociodemographic characteristics. These results suggest a stable trend with regard to present HBV infection and awareness, as well as for exposure to hepatitis C in the household population aged 14 to 79. The results of this study should be used with caution where uncertainty is large and should be considered underestimates. Prevalence estimates from cross-sectional studies are essential to derive epidemiological estimates that include people who are unaware of their infection, in order to estimate the burden of disease. In addition, these analyses may be useful to inform future HBV and HCV screening guidance.

Authors' statement

SP — Methodology, data curation, formal analysis, validation, writing–original draft, writing–review & editing
AW — Validation, writing–review & editing
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All authors approved the final version of the manuscript.

Competing interests
None.

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Acknowledgements

We thank all participants in cycles 5 and 6 of the Canadian Health Measure Survey (CHMS). We also wish to acknowledge Jason DeGuire, Dylan Smith, Xiao Yan Wang and Janine Clarke at Statistics Canada for their support on this study.

Funding

This work was supported by the Public Health Agency of Canada.

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Healthcare-associated infections and antimicrobial resistance in Canadian acute care hospitals, 2019–2023

Canadian Nosocomial Infection Surveillance Program[1]*

Abstract

Background: Healthcare-associated infections (HAIs) and antimicrobial resistance (AMR) continue to contribute to excess morbidity and mortality among Canadians.

Objective: This report describes epidemiologic and laboratory characteristics and trends of HAIs and AMR, 2019–2023, using surveillance and laboratory data submitted by hospitals to the Canadian Nosocomial Infection Surveillance Program (CNISP) and by provincial and territorial laboratories to the National Microbiology Laboratory.

Methods: Data was collected from 109 Canadian sentinel acute care hospitals between January 1, 2019 and December 31, 2023, for *Clostridioides difficile* infections (CDI), methicillin-resistant *Staphylococcus aureus* (MRSA) bloodstream infections (BSIs), vancomycin-resistant *Enterococcus* (VRE) BSIs (specifically *Enterococcus faecalis* and *Enterococcus faecium*), carbapenemase-producing *Enterobacterales* (CPE) and carbapenemase-producing *Acinetobacter baumannii* (CPA) infections and colonizations and *Candida auris* (*C. auris*). Trend analysis for case counts, incidence rates (rates), outcomes, molecular characterization and AMR profiles are presented.

Results: Rates remained relatively stable for CDI (range: 4.90–5.35 infections per 10,000 patient days) and MRSA BSI (range: 1.00–1.16 infections per 10,000 patient days) and increased significantly for VRE BSIs (range: 0.30–0.37 infections per 10,000 patient days). Infection rates for CPE remained low compared to other HAIs but doubled non-significantly (rates: 0.08–0.16), CPA counts remained very low (n=4 cases) and *C. auris* isolates remained low (n=36 isolates).

Conclusion: The incidence of MRSA BSIs and CDI remained stable and VRE BSIs and CPE infections increased in the Canadian acute care hospitals participating in CNISP. Few *C. auris* isolates were identified. Reporting standardized surveillance data to inform the application of infection prevention and control practices in acute care hospitals is critical to help decrease the burden of HAIs and AMR in Canada.

Suggested citation: Canadian Nosocomial Infection Surveillance Program. Healthcare-associated infections and antimicrobial resistance in Canadian acute care hospitals, 2019–2023. Can Commun Dis Rep 2025;51(6/7):249–69. https://doi.org/10.14745/ccdr.v51i67a04

Keywords: healthcare-associated infections, community-associated infections, antimicrobial resistance, surveillance, *Clostridioides difficile* infection, methicillin-resistant *Staphylococcus aureus*, vancomycin-resistant Enterococcus, carbapenemase-producing *Enterobacterales*, *Escherichia coli*, *Candida auris*, Canadian Nosocomial Infection Surveillance Program

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Introduction

Healthcare-associated infections (HAI) represent one of the most common adverse events experienced by patients in acute care settings globally (1). In addition to increasing morbidity and mortality, they are associated with longer lengths of stay in hospitals and higher costs of care (1). In Canada, a point prevalence survey conducted in 2017 estimated that the

prevalence of patients with at least one HAI was 7.9% (2). The prevalence of HAIs between 2015–2018 has been estimated to be at 3.2% in the United States (US), 6.5% in Europe and 9.9% in Australia (and is likely two-fold greater in developing countries) (1,3–5). In Europe, the cumulative healthcare burden of six HAIs (urinary tract infection, pneumonia, surgical site infection, *Clostridioides difficile* infections [CDIs], bloodstream infections [BSIs] and neonatal sepsis) was greater than the burden of 32 other communicable diseases combined, including influenza and tuberculosis (6). Importantly, a large proportion of HAIs are preventable and evidence from the US showed that advancements in care and infection prevention and control can decrease HAI rates over time (4).

Many of the microorganisms that cause HAIs have a propensity for antimicrobial resistance (AMR) and growing rates of resistance threaten to undermine efforts to reduce HAI rates (6). Infection with a resistant organism is associated with an 84.4% increased risk of death and in 2019, bacterial AMR was associated with approximately five million deaths globally (7,8). Canadian data have shown that CDI is associated with a longer length of hospital stay, higher all-cause mortality and an average excess cost of $11,056 per patient (9). Other data from Canada and abroad have shown that *Staphylococcus aureus* (MRSA) BSIs contributed to significant morbidity and mortality, prolonged hospital stays and increased healthcare costs for hospitalized patients (10–13). The rate of AMR is predicted to reach 40% by 2050. In this situation, it is forecasted that 13,700 Canadians could die each year from resistant infections and the overall annual impact to Canada's GDP would be $21 billion (14). Moreover, emerging resistant pathogens, such as *Candida auris,* have necessitated enhanced surveillance and changes to existing infection prevention and control protocols (15). Coordinated global public health action, surveillance, improved antibiotic stewardship, infection prevention and control and public awareness are crucial to identify patterns of antimicrobial resistance and prevent and control emerging infections (16).

In Canada, the Public Health Agency of Canada (PHAC) collects national data on various HAIs and AMR through the Canadian Nosocomial Infection Surveillance Program (CNISP). Established in 1994, CNISP is a collaboration between the PHAC, the Association of Medical Microbiology and Infectious Disease Canada and sentinel hospitals from across Canada. The goal of CNISP is to facilitate and inform the prevention, control and reduction of HAIs and antimicrobial resistant organisms in Canadian acute care hospitals through active surveillance and reporting.

In line with the World Health Organization's core components of infection prevention and control (17), CNISP performs consistent, standardized surveillance to reliably estimate HAI burden, establish benchmark rates for national and international comparison, identify potential risk factors and assess and inform specific interventions to improve patient health outcomes. Data provided by CNISP directly support the collaborative goals outlined in the *Pan-Canadian Action Plan on Antimicrobial Resistance* (16).

In this report, we describe the most recent HAI and AMR surveillance data collected from CNISP participating hospitals between 2019 and 2023.

Methods

Design

The Canadian Nosocomial Infection Surveillance Program conducts prospective, sentinel surveillance for HAIs (including antimicrobial resistant organisms) (18).

Case definitions

Standardized case definitions for healthcare-associated (HA) and community-associated (CA) infections were used. Refer to **Appendix A** for full-case definitions.

Data sources

Between January 1, 2019 and December 31, 2023, participating hospitals submitted epidemiologic data and isolates for cases meeting the respective case definitions for CDIs, MRSA BSIs, vancomycin-resistant *Enterococcus* (VRE) BSIs (specifically *Enterococcus faecalis* and *Enterococcus faecium*) and carbapenemase-producing *Enterobacterales* (CPE) and carbapenemase-producing *Acinetobacter baumannii* (CPA) (infections or colonizations). *C. auris* isolates (infections or colonizations) were identified by provincial and territorial laboratories and participating hospital laboratories. In 2023, 109 hospitals in 10 provinces and one territory participated in HAI surveillance and are further described in **Table 1**. Hospital participation varied by surveillance project and year (**Appendix B,** supplemental figures and tables are available upon request from the author). In 2023, CNISP HAI surveillance, patient admissions were categorized according to hospital bed size; small (1–200 beds, n=56 sites, 51%), medium (201–499 beds, n=34 sites, 31%) or large (500 or more beds, n=19 sites, 17%). Hospital participation also varied by region: Western (British Columbia, Alberta, Saskatchewan and Manitoba, n=44 sites, 40%), Central (Ontario and Québec, n=38 sites, 35%), Eastern (Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador, n=26 sites, 24%) and Northern (Yukon, Northwest Territories and Nunavut, n=1, 0.9%) (Table 1).

Epidemiologic (demographic, clinical and outcomes) and denominator data (patient days and patient admissions) were collected and submitted by participating hospitals through the Canadian Network for Public Health Intelligence, a secure online data platform.

Table 1: Summary of hospitals participating in the Canadian Nosocomial Infection Surveillance Program, by region, 2023

Details of participating hospitals	Western[a]	Central[b]	Eastern[c]	Northern[d]	Total
Total number of hospitals	44	38	26	1	109
Adult[e]	23	21	16	0	60
Mixed[f]	17	13	9	1	40
Paediatric[g]	4	4	1	0	9
Small (1–200 beds)	20	13	22	1	56
Medium (201–499 beds)	15	16	3	0	34
Large (500 or more beds)	9	9	1	0	19
Total number of beds	12,340	13,164	3,197	25	28,726
Total number of admissions	469,988	558,545	110,607	2,093	1,141,233
Total number of patient days	3,691,976	4,180,827	1,031,841	6,952	8,911,596

[a] Western refers to British Columbia, Alberta, Saskatchewan and Manitoba
[b] Central refers to Ontario and Québec
[c] Eastern refers to Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland and Labrador
[d] Northern refers to Yukon, Northwest Territories and Nunavut
[e] Eleven hospitals classified as "adult" had a neonatal intensive care unit
[f] Mixed hospitals provide both adult and paediatric care
[g] Paediatric standalone hospitals excluding mixed facilities with women's and obstetric wards

Reviews of standardized protocols and case definitions are conducted annually by established infectious disease expert working groups; training for data submission is provided to participating CNISP hospital staff as required. Data quality for surveillance projects is periodically evaluated; additional details on the methodology have been published previously (19,20).

Laboratory data

All patient-linked laboratory isolates (stool samples for CDI cases) were sent to the PHAC's National Microbiology Laboratory for molecular characterization and antimicrobial susceptibility testing. Isolates for MRSA BSIs, VRE BSIs, CPE/CPA (infections or colonizations), *C. auris* (infections/colonizations) and paediatric CDIs were submitted year-round. Adult CDI isolates were submitted annually during a targeted two-month period (March 1 to April 30).

Statistical analysis

Rates of HAI were calculated by dividing the total number of cases identified in patients admitted to CNISP participating hospitals by the total number of patient admissions (multiplied by 1,000) or patient days (multiplied by 10,000). Due to low case numbers, rates for *C. auris* were not calculated. The HAI rates are reported nationally and by region. Due to the low number of CA-VRE BSI cases reported each year, stratified rates as well as mortality rates and laboratory results for CA-VRE BSIs were not included in this report. Sites that were unable to provide case data were excluded from rate calculations and missing denominator data were estimated using their previous years reported data, where applicable. Missing epidemiological and molecular data were excluded from analysis. The Mann-Kendall test was used to assess trends in rates over time. The chi-square test for trend was used to analyze trends in proportions over time. The chi-square test was used to compare two categorical variables, while the t-test was used to compare differences between groups. Significance testing was two-tailed and differences were considered significant at $p \leq 0.05$. The stability of rates over time indicates that there was no statistically significant trend observed. Where available, all-cause mortality were reported for HAIs. All-cause mortality rate was defined as the number of deaths per 100 HAI cases 30 days following positive culture.

Results

Clostridioides difficile infection

Between 2019 and 2023, overall CDI rates remained stable, ranging from 4.90 to 5.35 infections per 10,000 patient days. Rates initially rose from 2019 to 2020, then decreased from 2020 to 2022, before rising again in 2023. However, no significant trend was observed (p=1.0) (**Table 2**). The median age among CDI patients was 69 years (IQR: 55–79), with males and females each representing 50% of the total cases (Appendix B).

Source of infection: Stratified by the source of infection, from 2019 to 2023, the incidence of HA-CDI showed little change from 3.62 to 3.56 infections per 10,000 patient days (p=0.31) (Table 2). The CA-CDI rates increased from 1.17 to 1.42 infections per 1,000 patient admissions when comparing 2019 to 2023 rates; however, this trend was not significant (p=0.32) (Table 2).

Regionally, HA-CDI rates have fluctuated across all regions with non-significant changes observed between 2019 and 2023. Specifically, the Western region had an overall decrease from 3.34 to 3.13 infections per 10,000 patient days (p=0.46), the Central region remained stable (3.40–3.77 infections per 10,000 patient days (p=0.61), the Eastern region had a steady rate increase from 2019 to 2021 (2.90–3.58 infections per 10,000 patient days, p=0.09) with a significant drop from 2022

Table 2: *Clostridioides difficile* infection data, Canada, 2019–2023[a]

C. difficile infection data	Number of infections and incidence rates (per year)				
	2019	2020	2021	2022	2023
All cases					
Number of *C. difficile* infection cases	3,600	3,650	3,640	3,878	4,453
Rate per 1,000 patient admissions	3.69	4.10	3.93	4.13	4.06
Rate per 10,000 patient days	4.90	5.35	5.07	4.97	5.05
Number of reporting hospitals	73	82	82	82	98
All-cause mortality rate					
Number of deaths	63	54	66	64	74
All cause mortality rate per 100 cases (%)[b]	8.5	9	8.8	8.9	8.2
HA-CDI					
Number of HA-CDI cases	2,662	2,625	2,571	2,819	3,142
Rate per 1,000 patient admissions	2.73	2.95	2.78	3.00	2.86
Rate per 10,000 patient days	3.62	3.85	3.58	3.62	3.56
Number of reporting hospitals	73	82	82	82	98
All-cause mortality rate					
Number of deaths	47	39	50	54	58
All cause mortality rate per 100 cases (%)[b]	8.2	8.7	9.2	9.9	8.7
CA-CDI					
Number of CA-CDI cases	938	1,025	1069	1,059	1,311
Rate per 1,000 patient admissions	1.17	1.38	1.38	1.35	1.42
Rate per 10,000 patient days	1.57	1.83	1.81	1.65	1.77
Number of reporting hospitals	62	71	71	71	87
All-cause mortality rate					
Number of deaths	16	15	16	10	16
All cause mortality rate per 100 cases (%)[b]	9.4	9.6	7.4	5.8	6.3

Abbreviations: *C. difficile*, *Clostridioides difficile*; CA, community-associated; CDI, *Clostridioides difficile* infections; HA, healthcare-associated
[a] There was no resistance to tigecycline, vancomycin or metronidazole in *C. difficile* isolates submitted to the National Microbiology Laboratory 2019–2023
[b] Mortality data are collected during the two-month period (March and April of each year) for adults (aged 18 years and older) and year-round for children (aged one year to younger than 18 years old). Among paediatric patients, there was no death attributable to healthcare-associated *C. difficile* infection

to 2023 (3.58–3.02 infections per 10,000 patient days, p=0.05). For CA-CDI, rates per 1,000 patient admissions remain highest in the Central region from 2019 and 2023 (range: 1.39–1.65), followed by Western (range: 0.99–1.58) and Eastern (range: 0.68–1.05) (Appendix B).

Hospital types: The HA-CDI rates per 10,000 patient days were consistently higher in adult (range: 3.62–3.84, $p \leq 0.005$) and paediatric hospitals (range: 3.09–3.61, $p \leq 0.005$), with lower rates observed in mixed hospitals (range: 2.57–3.06). The CA-CDI rates per 1,000 patient admissions were higher in adult (range: 1.55–1.77, $p \leq 0.005$) and mixed hospital (range: 1.26–1.61), with lower rates observed in paediatric hospitals (range: 0.57–1.15, $p \leq 0.005$) between 2019 and 2023 (Appendix B). Stratified by hospital size, rates of HA-CDI were generally highest among large (range: 3.28–3.87), followed by medium (range: 3.15–3.55) and small size hospitals (range: 2.43–2.84). Rates of CA-CDI per 1,000 patient admissions were similar for large (range: 1.23–1.69) and medium sized hospitals (range: 1.22–1.47), and lower for small sized hospitals (range: 0.69–1.19) (Appendix B).

30-day all-cause mortality: Overall 30 day all-cause CDI mortality remained stable over time (range: 8.2–9.0 deaths per 100 cases) (p=0.81) between 2019 and 2023 (Table 2). In 2023, 30-day all-cause mortality was significantly higher for HA-CDI (8.7%) compared to CA-CDI (6.3%) (p=0.02).

Antimicrobial resistance: From 2019 to 2023, 27.1% (n=656/2,424) of CDI isolates were resistant to one or more tested antimicrobials. The proportion of *C. difficile* isolates resistant to moxifloxacin significantly decreased (p=0.002) between 2019 (11.6%, n=66/568) and 2023 (6.3%, n=32/506) (**Table 3**). Since 2019, moxifloxacin resistance decreased non-significantly among HA-CDI isolates (5.2%, p=0.22) while a smaller non-significant decrease was observed among CA-CDI (5.4%, p=0.31) (Appendix B). There was no resistance to metronidazole, vancomycin, or tigecycline for all *C. difficile* isolates tested.

Table 3: *Clostridioides difficile* antimicrobial resistance data, Canada, 2019–2023[a,b]

Antibiotic	Number of isolates and % resistance (per year)									
	2019		2020		2021		2022		2023	
	n	%	n	%	n	%	n	%	n	%
Clindamycin	221	38.9	62	17.0	67	12.4	101	22.8	66	13.0
Moxifloxacin	66	11.6	24	6.6	49	9.0	31	7.0	32	6.3
Rifampin	6	1.1	3	0.8	9	1.7	4	0.9	4	0.8
Total number of isolates tested[c]	568	N/A	365	N/A	542	N/A	443	N/A	506	N/A

Abbreviation: N/A, not applicable
[a] *Clostridioides difficile* infection isolates are collected for resistance testing during the two-month period (March and April of each year) for adults (aged 18 years and older) and year-round for children (aged one year to younger than 18 years old) from admitted patients only
[b] There was no resistance to tigecycline, vancomycin, or metronidazole in *C. difficile* isolates submitted to the National Microbiology Laboratory 2019–2023
[c] Total reflects the number of isolates tested for each of the antibiotics listed above

Molecular typing: From 2019 to 2023, the top five most prevalent ribotypes of isolates from HA-CDI defined cases were 106, 014, 020, 002 and 027, with overall prevalences of 15.3%, 9.0%, 6.9%, 6.0% and 5.7%, respectively, while the top five ribotypes of isolates from CA-CDI were 106, 014, 020, 015 and 002, with overall prevalences of 15.2%, 7.9%, 7.4% 5.8% and 5.2%. From 2019 to 2023, the prevalence of RT027 associated with NAP1 decreased from 7.3% to 3.3% and from 3.1% to 2.1%, in HA and CA-CDI populations respectively (Appendix B).

Methicillin-resistant *Staphylococcus aureus* bloodstream infections

Between 2019 and 2023, overall MRSA BSI rates remained stable, ranging from 1.00 to 1.16 infections per 10,000 patient days. Rates peaked in 2020 (n=1.16) and were lowest in 2022 (n=1.00); however, no significant trend was observed (p=0.462) (**Table 4**). The median age among MRSA BSI patients was 55 years (IQR: 39–70), with women accounting for 38% of cases (Appendix B).

Table 4: Methicillin-resistant *Staphylococcus aureus* bloodstream infections data, Canada, 2019–2023

MRSA BSI data	Year				
	2019	2020	2021	2022	2023
All cases					
Number of MRSA BSIs	881	868	875	841	913
Rate per 1,000 patient admissions	0.85	0.88	0.85	0.81	0.90
Rate per 10,000 patient days	1.14	1.16	1.12	1.00	1.13
Number of reporting hospitals	69	81	81	81	76
All-cause mortality rate[a]					
Number of deaths	144	152	166	167	174
All-cause mortality rate per 100 cases	16.3	17.5	18.9	19.9	19.1
HA-MRSA BSI					
Number of HA-MRSA BSIs	364	323	351	352	377
Rate per 1,000 patient admissions	0.35	0.33	0.34	0.34	0.37
Rate per 10,000 patient days	0.47	0.43	0.45	0.42	0.47
Number of reporting hospitals	69	81	81	81	76
All-cause mortality rate[a]					
Number of deaths	74	65	88	84	93
All-cause mortality rate per 100 cases	20.3	20.1	25.0	23.9	24.7
CA-MRSA BSI					
Number of CA-MRSA BSIs	450	480	471	453	527
Rate per 1,000 patient admissions	0.43	0.49	0.46	0.44	0.52
Rate per 10,000 patient days	0.59	0.65	0.61	0.55	0.67
Number of reporting hospitals	68	80	80	80	75
All-cause mortality rate[a]					
Number of deaths	61	76	71	79	80
All-cause mortality rate per 100 cases	13.6	15.8	15.1	17.4	15.2

Abbreviations: CA, community-associated; HA, healthcare-associated; MRSA BSI, methicillin-resistant *Staphylococcus aureus* bloodstream infection
[a] Based on the number of cases with associated 30-day outcome data

Source of infection: The CA-MRSA BSI rates increased slightly, from 0.59 in 2019 to 0.67 infections per 10,000 patient days in 2023, though the trend was not significant (p=0.81). Healthcare-associated-MRSA BSI rates remained stable (range: 0.42–0.47 infections per 10,000 patient days) (Table 4).

Regionally, HA-MRSA BSI rates have remained stable across all regions (Western range: 0.47–0.52; Central range: 0.37–0.52; Eastern range: 0.20–0.57; Northern range: 0.00 infections per 10,000 patient days) (Appendix B). The CA-MRSA BSI rates remained stable across all regions except for in the East where there was a significant increase by 0.41 infections per 10,000 patient days (p=0.027) (Western range: 0.70–0.83; Central range: 0.42–0.61; Eastern range: 0.09–0.50; Northern range: 0.00 infections per 10,000 patient days) (Appendix B). In 2023, CA-MRSA BSI rates were highest in Western Canada (0.77 infections per 10,000 patient days), and HA-MRSA BSI rates were highest in Eastern Canada (0.57 infections per 10,000 patient days) (Appendix B).

Hospital types: Both HA- and CA-MRSA BSI rates were consistently higher from 2019 to 2023 in adult (HA-MRSA range: 0.44–0.54, p=0.007; CA-MRSA range: 0.57–0.71, p<0.001) and mixed hospitals (HA-MRSA range: 0.38–0.48, p=0.01; CA-MRSA range: 0.54–0.78, p=0.004), with lower rates observed in paediatric hospitals (HA-MRSA range: 0.24–0.41; CA-MRSA range: 0.28–0.36 infections per 10,000 patient days) (Appendix B). Stratified by hospital size, both HA-and CA-MRSA BSI rates were generally highest among medium (201–499 beds; HA-MRSA p=0.02; CA-MRSA p<0.001) and large size hospitals (500 or more beds; HA-MRSA p=0.07; CA-MRSA p<0.001) (Appendix B).

30-day all-cause mortality: Thirty day all-cause mortality remained stable from 2019 to 2023 (range: 16.4–19.9) (Table 4). In 2023, 30-day all-cause mortality was significantly higher for HA-MRSA (24.7%) compared to CA-MRSA (15.2%) (p<0.001).

Antimicrobial resistance: Clindamycin resistance among MRSA isolates decreased significantly from 40% to 20% between 2019 and 2023 (p=0.027) (**Table 5**). Since 2019, the proportion of MRSA isolates resistant to erythromycin and ciprofloxacin has stayed relatively stable and high at around 70% in relation to other antibiotics tested. All tested MRSA BSI isolates from 2019 to 2023 were susceptible to linezolid, daptomycin and vancomycin.

Comparing isolates from HA-MRSA with CA-MRSA cases, clindamycin resistance was consistently higher among isolates from HA-MRSA each year from 2019 (47.5%, n=160/337 vs. 30.3%, n=122/403) to 2023 (31.6%, n=87/275 vs. 17.0%, n=70/412) (Appendix B). There were no other notable differences in antibiotic resistance patterns by MRSA BSI case type.

Molecular typing: Between 2019 and 2023, the proportion of spa types identified as t002, most commonly associated with HA-MRSA, continued to decrease from 20.2% of all isolates in HA-MRSA cases in 2019 to 9.5% in 2023 (p<0.001) (Appendix B). Meanwhile, spa type t008, historically most commonly associated with CA-MRSA, continued to increase and account for the largest proportion of isolates identified in CA-MRSA (42.4% in 2019 to 48.8% in 2023, p=0.04) and HA-MRSA defined cases (28.5% in 2019 to 40.0% in 2023, p<0.001) (Appendix B).

Table 5: Methicillin-resistant *Staphylococcus aureus* bloodstream antimicrobial resistance data, Canada, 2019–2023[a]

Antibiotic	Year									
	2019		2020		2021		2022		2023	
	n	%	n	%	n	%	n	%	n	%
Ciprofloxacin	561	70.5	460	65.6	491	65.9	418	66.3	466	67.1
Clindamycin	297	37.3	234	33.4	221	29.7	159	25.2	161	23.2
Daptomycin	0	0	0	0	0	0	0	0	0	0
Erythromycin	603	75.8	507	72.3	510	68.5	431	68.4	487	70.1
Gentamicin	35	4.4	22	3.1	36	4.8	20	3.2	29	4.2
Linezolid	1	0.1	0	0	0	0	0	0	0	0
Rifampin	7	0.9	6	0.9	10	1.3	5	0.8	8	1.2
Trimethoprim/sulfamethoxazole	62	7.8	46	6.6	64	8.6	52	8.3	67	9.6
Tetracycline	0	0.0	1	0.1	6	0.8	5	0.8	4	0.6
Tigecycline	15	1.9	16	2.3	32	4.3	37	5.9	18	2.6
Vancomycin	0	0	0	0	0	0	0	0	0	0
Total number of isolates tested[b,c]	796	N/A	701	N/A	745	N/A	630	N/A	695	N/A

Abbreviation: N/A, not applicable
[a] All MRSA isolates from 2019 to 2023 submitted to the National Microbiology Laboratory were susceptible to nitrofurantoin
[b] In some years, the number of isolates tested for resistance varied by antibiotic
[c] Total reflects the number of isolates tested for each of the antibiotics listed above

Vancomycin-resistant *Enterococcus* bloodstream infections

From 2019 to 2023, VRE BSI rates significantly increased from 0.30 to 0.37 infections per 10,000 patient days (p=0.02) (**Table 6**). The median age among patients with VRE BSI was 62 years (IQR: 51–71) and women accounted for 40% of VRE BSI cases (Appendix B).

Source of infection: Vancomycin-resistant *Enterococcus* BSIs were predominantly HA, as 89.5% (n=1,199/1,339) of VRE BSIs reported from 2019 to 2023 were acquired in a healthcare facility. Stratified by source of infection, HA-VRE BSI rates significantly increased from 2019 to 2023 from 0.27 to 0.33 infections per 10,000 patient days (p=0.03) (Appendix B). CA-VRE BSI rates remained low and stable over time (range: 0.02–0.04 infections per 10,000 patient days).

Regionally, VRE BSI rates in Western Canada significantly increased from 0.29 to 0.48 infections per 10,000 patient days from 2019 to 2023 (p=0.04). No significant trend was observed in Central (range: 0.29–0.39 infections per 10,000 patient days, p=1.00) and Eastern Canada (range: 0–0.04 infections per 10,000 patient days, p=0.16) (Appendix B).

Hospital types: Stratified by hospital type, VRE BSI rates remained highest in adult hospitals from 2019 to 2023 (range: 0.38–0.48 infections per 10,000 patient days). From 2019 to 2023, VRE BSI rates in paediatric hospitals were low (range: 0–0.25 infections per 10,000 patient days). In 2019, VRE BSI rates were highest in small (1–200 beds) and large hospitals (500

Table 6: Vancomycin-resistant *Enterococcus* bloodstream infections data, Canada, 2019–2023[a]

VRE BSI data	Year									
	2019		2020		2021		2022		2023	
Vancomycin-resistant *Enterococcus* bloodstream infections data										
Number of VRE BSIs	241		224		251		305		318	
Rate per 1,000 patient admissions	0.23		0.23		0.24		0.29		0.29	
Rate per 10,000 patient days	0.30		0.30		0.32		0.36		0.37	
Number of reporting hospitals	70		81		80		80		84	
All-cause mortality rate[b]										
Number of deaths	83		82		84		117		117	
All-cause mortality rate per 100 cases	34.4		36.6		33.5		38.4		36.8	
Antimicrobial resistance of *Enterococcus faecium* isolates	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Ampicillin	173	100	132	98.5	166	98.8	199	97.5	216	97.7
Chloramphenicol	30	17.3	28	20.9	51	30.4	34	16.7	36	16.3
Ciprofloxacin	173	100	132	98.5	166	98.8	203	99.5	219	99.1
Daptomycin[c]	7	4.0	6	4.5	5	3.0	4	2.0	4	1.8
Erythromycin	166	96.0	128	95.5	159	94.6	199	97.5	214	96.8
High-level gentamicin	57	32.9	36	26.9	34	20.2	39	19.1	40	18.1
Levofloxacin	173	100	131	97.8	166	98.8	202	99.0	219	99.1
Linezolid	3	1.7	1	0.7	3	1.8	6	2.9	1	0.5
Nitrofurantoin	66	38.2	56	41.8	131	78.0	143	70.1	136	61.5
Penicillin	173	100	133	99.3	166	98.8	200	98.0	216	97.7
Quinupristin/dalfopristin	18	10.4	9	6.7	8	4.8	16	7.8	34	15.4
Rifampicin	160	92.5	115	85.8	155	92.3	188	92.2	204	92.3
High-level streptomycin	42	24.3	29	21.6	48	28.6	51	25.0	62	28.1
Tetracycline	119	68.8	89	66.4	134	79.8	180	88.2	180	81.4
Tigecycline	0	0	0	0	0	0	0	0	0	0
Vancomycin	170	98.3	130	97.0	163	97.0	203	99.5	221	100
Total number of isolates tested[d]	173	N/A	134	N/A	168	N/A	204	N/A	221	N/A

Abbreviations: N/A, not applicable; VRE BSI, vancomycin-resistant *Enterococcus* bloodstream infection
[a] Due to the low number of CA-VRE BSI cases reported each year, this table presents data for all cases combined (HA and CA)
[b] Based on the number of cases with associated 30-day outcome data
[c] Clinical and Laboratory Standards Institute (CLSI) resistance breakpoints came into effect in 2024 and was applied to all years (CLSI M100 ED34:2024)
[d] Total reflects the number of isolates tested for each of the antibiotics listed above
Note: Aggregate mortality data reported in-text due to fluctuations in the small numbers of VRE BSI deaths reported each year
Note: Antimicrobials presented are for surveillance purposes. Please refer to CLSI for appropriate treatment of BSI *Enterococcus* infections (CLSI M100 ED34:2024)

or more beds) at 0.35 infections per 10,000 patient days compared to 0.26 infections per 10,000 patient days in medium hospitals (201–499 beds). No significant trend was observed over time across all categories of hospital bed sizes. In 2023, VRE BSI rates in large hospitals were highest at 0.49 infections per 10,000 patient days compared to 0.31 in medium hospitals and 0.16 in small hospitals (Appendix B). The incidence rates for HA-VRE BSI by region, hospital type and hospital size are presented in Appendix B.

30-day all-cause mortality: All-cause mortality remained high and stable over time from 2019 to 2023 (range: 33.5–38.4) (p=0.23) (Table 6).

Antimicrobial resistance: Between 2019 to 2023, high-level gentamicin resistance among VRE BSI isolates (*E. faecium*) significantly decreased from 32.9% to 18.1% (p=0.01) (Table 6). Daptomycin resistance, significantly decreased from 4.0% (n=7 isolates) in 2019 to 1.8% (n=4 isolates) in 2023 (p=0.04).

Molecular typing: From 2019 to 2023, the majority of VRE BSI isolates were identified as *E. faecium*; however, one *E. faecalis* was identified in 2020 (0.7%), 2021 (0.6%) and 2022 (0.5%), respectively, and three (1.4%) in 2023 (Appendix B). The increased presence of VanB among *E. faecium* changed from 0.6% (n=1) in 2019 to 7.2% (n=16) in 2023 (Appendix B). Among *E. faecium* isolates, a shift in predominant sequence types was observed over the past five years. The proportion identified as sequence type (ST)1478 was highest in 2019 (31.2%, n=54/173) and significantly decreased to 1.4% (n=3/221) in 2023 (p=0.04) (Appendix B). The proportion of ST17 isolates increased non-significantly from 2019 (17.9% n=31/173) to 2023 (30.3%, n=67/221) (p=0.40) (Appendix B). The proportion of ST80 isolates increased significantly from 2019 (15.6%, n=27/173) to 2023 (31.7%, n=70/221) (p=0.01) (Appendix B) and now represents the predominant ST amongst all tested isolates.

Carbapenemase-producing *Enterobacterales* (CPE) and *Acinetobacter baumannii* (CPA)

From 2019 to 2023, CPE infection rates have remained low compared to other HAIs in Canada, although there has been a non-significant increase in the rates over this period (0.08–0.16 infections per 10,000 patient days, p=0.08) (**Table 7**).

Table 7: Carbapenemase-producing *Enterobacterales* data, Canada, 2019–2023

CPE data	Year									
	2019		2020		2021		2022		2023	
Number of infections and incidence rates										
Number of CPE infections	56		40		77		111		162	
Infection rate per 1,000 patient admissions	0.06		0.04		0.08		0.10		0.13	
Infection rate per 10,000 patient days	0.08		0.06		0.10		0.13		0.16	
Number of reporting hospitals	66		81		81		85		97	
All-cause mortality rate										
Number of CPE infection deaths	12		7		15		17		24	
All-cause mortality rate per 100 cases	27.3		17.5		19.7		18.9		16.4	
Carbapenemases identified[a]	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
KPC	131	42.4	98	40	178	50.1	214	45.3	319	34.9
NDM	104	33.7	80	32.7	85	23.9	131	27.8	317	34.7
OXA-48	46	14.9	48	19.6	57	16.1	94	19.9	189	20.7
SME[b]	1	0.3	2	0.8	1	0.3	0	0	1	0.1
NDM/OXA-48	16	5.2	9	3.7	12	3.4	14	3	52	5.7
GES	1	0.3	0	0	1	0.3	0	0	0	0
IMP	1	0.3	1	0.4	2	0.6	2	0.4	1	0.1
NMC	4	1.3	7	2.9	15	4.2	3	0.6	12	1.3
VIM	3	1	0	0	1	0.3	6	1.3	4	0.4
Other	2	0.6	0	0	3	0.8	8	1.7	18	2
Total number of isolates tested[c]	309	N/A	245	N/A	355	N/A	472	N/A	913	N/A

Abbreviations: CPE, carbapenemase-producing *Enterobacterales*; GES, Guiana extended-spectrum β-lactamase; IMP, active-on-imipenem; KPC, *Klebsiella pneumoniae*; carbapenemase; NDM, New Delhi metallo-β-lactamase; NMC, not metalloenzyme carbapenemase; N/A, not applicable; OXA-48, oxacillinase-48; SME, *Serratia marcescens* enzymes; VIM, Verona integron-encoded metallo-β-lactamase

[a] Includes data for all CPE isolates submitted (infections and colonisations)

[b] Only found in *Serratia marcescens*

[c] Some isolates contain multiple carbapenemases therefore the total number of isolates tested and the number of carbapenemases indicated may not match. *Acinetobacter baumanii* were not included in this table

Note: All-cause mortality only includes CPE infections that have a 30-day outcome available

The number of CPA infections were very low with five or fewer cases per year between 2019 and 2023. The median age for CPE infections was 65 years and 43% of cases were female (Appendix B).

From 2019 to 2023, the majority of CPE infections (94.8%) were almost equally distributed between Central (49.3%, n=220/446) and Western Canada (45.5%, n=203/446) while few infections were identified in the East (5.2%, n=23/446) (Appendix B). From 2019 to 2023, large hospitals (500 or more beds) generally reported the highest rates of CPE infections (0.09–0.22 infections per 10,000 patient days) compared to small hospitals (fewer than 200 beds) (0.1–0.07 infections per 10,000 patient days. During this period, 30.8% (n=102/331) of CPE-infected patients reported travel outside of Canada and of those, 83.3% (n=75/90) received medical care while abroad. The majority of CPE infections were acquired domestically with 84.2% (n=331/393) of CPE infections acquired in Canada and 81.9% (n=271/331) acquired within a Canadian acute care hospital between 2019 and 2023.

Organisms: Of all isolates submitted (infections and colonizations), the top four carbapenemase producing organisms during 2023 were *Escherichia coli* (41.3%), *Klebsiella pneumoniae* (16.4%), *Enterobacter cloacae* (16.4%) and *Citrobacter freundii* (14.2%). From 2019 to 2023, there has been an increase in the proportion of *E. coli*-producing carbapenemases (33%–41.3%) and a decrease in the proportion of *K. pneumoniae*- (21.4%–16.4%) and *E. cloacae*- (19.8%–16.4%) producing carbapenemases (Appendix B). The predominant carbapenemases, in order identified in Canada, were *K. pneumoniae* carbapenemase (KPC), New Delhi metallo-β-lactamase (NDM) and oxacillinase-48 (OXA-48), accounting for 96.2% to 96.0% of identified carbapenemases from 2019 to 2023. Historically, KPC has been the most commonly identified carbapenemase in Canada; however, the proportion of KPC and NDM have been continually trending closer and were almost equal in 2023.

30-day all-cause mortality: All-cause mortality for CPE infections fluctuated between 2019 and 2023 with a mean of 20% (Table 7).

Antibiotic resistance: Multidrug resistance (MDR) and extensive drug resistance (XDR) was observed among CPE (Appendix B) (21). In all years, NDM producing isolates were predominantly XDR (range: 83.8–91.8). Conversely, in 2019, OXA-48-like producers were previously associated with a higher proportion of XDR or MDR (89.1%) compared to 2023; (63.5%) showing an overall downward trend in resistance. *Klebsiella pneumoniae* carbapenemase has been more equally distributed throughout 2019–2023 for either XDR (range: 40.8–50.1) or MDR (range: 40.8–52.2). When examining resistance among the top three carbapenemases, we noted that there was an increase in resistance to all aminoglycosides from 2021 to 2023 in KPC producers (Appendix B). Conversely, among OXA-48-like producers, there was a decline in resistance to aztreonam, doxycycline, levofloxacin, minocycline, trimethoprim/sulfamethoxazole, carbapenems, cephalosporins, tobramycin and gentamicin. This agrees with observations that less OXA-48-like producers were XDR or MDR over time. From 2019 to 2023, the overall resistance in KPC, NDM and OXA-48-like producers to ertapenem was 78.2%, 97.8% and 66.9%, respectively, and for meropenem was 59.1%, 92.3% and 16.5%. respectively. Among new combination drugs, KPC and OXA-48-like producers were highly susceptible to meropenem/vaborbactam and ceftazidime/avibactam. Resistance to imipenem/relebactam by year ranged from 11.1%–17.4% in OXA-48-like producers and 86.3%–93.1% in NDM producers. Meropenem/vaborbactam resistance in NDM producers ranged from 61.3%–76% by year.

Candida auris

Sixty-six percent (n=72/109) of CNISP hospitals participate in *C. auris* surveillance and between CNISP and the National Microbiology Laboratory surveillance, a total of 36 isolates (colonizations and infections) have been reported from 2019 to 2023. The number of *C. auris* cases detected per year was seven in 2019, four in 2020, three in 2021, 12 in 2022 and 10 in 2023. Fourteen cases were from Western Canada, 20 cases were from Central Canada and two cases were reported from Eastern Canada. Of the 36 *C. auris* isolates, 19.4% were resistant to amphotericin B and 77.8% were resistant to fluconazole (**Table 8**). The amphotericin B resistant isolates were also fluconazole resistant, thus 19.4% of isolates were multidrug-resistant (resistant to two classes of antifungals). Based on available travel information, 73.3% of those reporting travel also received healthcare abroad (Table 8). Of the eleven patients who received healthcare abroad, seven had known carbapenemase-producing organism (CPO) status and two were CPO positive.

Table 8: Antifungal resistance of *Candida auris* isolates, Canada, 2019–2023

Isolate or patient characteristics	Number of cases (n=36)	
	n	%
Antifungal resistance of *Candida auris* isolates		
Fluconazole	28	77.8
Amphotericin B	7	19.4
Fluconazole and amphotericin B (multidrug resistance)	7	19.4
Micafungin	0	0
Travel history		
Receipt of health care abroad	11	73.3
Travel abroad (no health care reported)	1	6.7
No travel reported	3	20
Unknown travel history	21	N/A

Abbreviation: N/A, not applicable

Discussion

Canadian Nosocomial Infection Surveillance Program data have shown that between 2019 and 2023, infection rates in Canada have remained relatively stable for CDI (3%) and MRSA BSI (−0.8%). Rates have increased for VRE BSI and CPE infections (23.3% and 100%, respectively), but remain lower than CDI and MRSA BSI rates. A total of 36 *C. auris* isolates were identified from 2019 to 2023.

The MRSA BSI patients had a median age of 55 years (IQR: 39–70) and were younger compared to those with CDI (69 years) or VRE BSI (62 years) cases. The median time from admission to a positive test for HA-MRSA BSI patients related to your acute care facility was 13 days (IQR: 3–30), which was shorter than for VRE BSI (19 days) and CPE (20 days) but longer than CDI (10 days). The CDI infections occurred more equally between males and females (50% each), compared to 40% females for VRE BSI infections, 38% females for MRSA BSI infections and 43% females for CPE infections (Appendix B).

Trends in CDI rates observed in the CNISP network align with similar trends reported globally (22) where COVID-19 may have contributed to the increase in 2020 of both HA and CA-CDI rates following pre-COVID-19 pandemic declines (23). Beyond COVID-19, HA-CDI rates continued to decline while CA-CDI rates returned to pre-pandemic levels (23). When comparing globally, both HA- (3.85 per 10,000 patient days) and CA-CDI (1.83 per 1,000 patient admissions) rates observed in the CNISP network were higher than those reported in acute care hospitals in European Union/European Economic Area countries, which reported an HA-CDI rate of 2.58 per 10,000 patient days and a CA-CDI rate of 1.35 per 1,000 patient admissions in 2020 (22).

Clostridioides difficile antimicrobial resistance is less common in Canada than in the US or globally (24). In a representative sample of Canadian acute care hospitals, from 2019 to 2023, a 5.3% decrease in moxifloxacin resistance in both HA- and CA-CDI populations is concordant with an overall decrease in the prevalence of RT027. Furthermore, moxifloxacin resistance remained lower (6.3% in 2023) than previously published weighted pooled resistance data for North America (44.0%) and Asia (33.0%) (25,26). The decline in the prevalence of RT027 has been replaced with a concomitant increase in the prevalence of RT106, RT014 and RT020, consistent with trends observed in the US (27,28). Additionally, the emergence of RT106 now found worldwide, presents additional challenges as this strain has been shown to produce more spores, have higher rates of recurrence, and is highly resistant to erythromycin, clindamycin, fluoroquinolones and third-generation cephalosporins. The potential emergence of resistant ribotypes warrants further surveillance, monitoring and investigation (27,29).

Between 2019 and 2023, MRSA BSI rates in the CNISP network remained stable, fluctuating between 1.00 to 1.16 infections per 10,000 patient days. From 2019 to 2023, HA-MRSA BSI rates in CNISP (0.42–0.47 infections per 10,000 patient days), were notably higher than rates reported in Australian public hospitals between 2018 and 2022 (0.11–0.13 infections per 10,000 patient days), likely due to broader CNISP definitions that capture more cases with indirect healthcare links (30). However, the CNISP rate for 2023 (0.47 infections) is similar to the rate reported in US hospitals for the same year (0.49 infections per 10,000 patient days), where definitions for laboratory-based surveillance are similar (31). The CA-MRSA BSI rate in CNISP for 2023 (0.67 infections per 10,000 patient days) is lower than the rate reported in US hospitals for the same year (0.84 infections), reflective of different populations (31). Community-associated-MRSA BSI rates have shown a sustained increase in CNISP data since 2019, suggesting an expanding community reservoir of MRSA in Canada and globally (32,33).

The CNISP 30-day all-cause mortality rates for MRSA BSI (HA: 20.1%–25.0%; CA: 13.6%–17.4%) were lower than those reported in the US (HA: 29%; CA: 18%) (33). Differences may stem from CNISP's strict 30-day mortality cut-off versus undefined US time frames, or from variances in healthcare systems, infection prevention strategies and population characteristics (34,35).

A significant 20% decrease in clindamycin resistance among MRSA BSI isolates between 2019 and 2023 coincided with shifts in MRSA spa types. The proportion of spa type t002 (commonly HA-MRSA) declined, while spa type t008 (historically CA-MRSA) increased. Notably, t008 rose among CA-MRSA isolates (42.4% to 48.8%) and HA-MRSA isolates (28.5% to 40.0%). This shift underscores the increasing role of CA-MRSA clones in healthcare settings and highlights the dynamic nature of MRSA epidemiology. The growing prevalence of traditionally CA clones in hospitals emphasizes the need for ongoing surveillance and tailored infection prevention strategies. Continued monitoring of antimicrobial resistance patterns is critical for guiding treatment protocols and mitigating MRSA burden in healthcare and community settings. Populations at heightened risk for CA-MRSA infection include children, athletes, incarcerated individuals, seniors with comorbidities and people who inject drugs (34,35). Injection drug use in particular may signal the emergence of an at-risk population for CA-MRSA. Strategies such as screening and decolonization of MRSA carriers in high-risk populations could help reduce the overall burden of MRSA BSIs (34–36).

Vancomycin resistance related to VRE BSI has been shown to be associated with higher mortality rates and longer hospital stays, making it a significant public health concern (37–39). Vancomycin-resistant *Enterococcus* BSI rates observed in the CNISP network increased over time between 2019 and 2023 and were highest in 2023 (0.37 infections per 10,000 patient days). The success of certain sequence types likely contributes to the increased burden of VRE BSI in CNISP-participating hospitals. As of 2023, ST17 (30.3%) and ST80 (31.7%) were the predominant clones overtaking the previously dominant clone ST1478 (1.4%). Compared to other sequence types, a distinct association

has been identified between ST80 and the VanB gene. This association of VanB genes harboured predominantly among ST80 isolates has also been documented in recent studies related to VanB outbreaks in Sweden and Denmark (40,41). The VRE BSI trends are further impacted by the number of high-risk patients admitted to hospital (e.g., bone marrow transplants, solid organ transplants, cancer patients, etc.) (42,43). Most VRE BSI cases reported by CNISP-participating hospitals were healthcare-acquired, highlighting the importance of appropriate screening, adherence to infection prevention measures and antimicrobial stewardship. Although there is a lack of recent data on VRE BSI rates in comparable jurisdictions, there have been increasing trends noted in Europe (44–48), which may be associated, in part, with the introduction and spread of new clones and gaps in infection prevention practices (44,45,49).

Carbapenemase-producing *Enterobacterales* infections are a significant threat to public health as they are becoming increasingly prevalent in healthcare environments worldwide, are associated with high mortality and limited treatment options (50–53). The Centers for Disease Control and Prevention and the World Health Organization have classified CPE as one of the most urgent antimicrobial-resistance threats (54,55). While the number of CPE infections doubled from 2019 to 2023 in the CNISP network, incidence remained low compared to other HAIs. Data on the incidence of CPE infections in other countries, such as Denmark, Italy, Switzerland and the United Kingdom, have also shown an increasing incidence of CPE infections (56–59). Historically, CPE infections were mostly associated with international travel, but there has been a shift in recent years to domestic acquisition. From 2020 to 2023, 84.6% of CPE infections were domestically acquired and 80.8% were acquired in a Canadian acute care hospital, suggesting that within hospital transmission is driving the recent increase in CPE infection incidence. As a result, strict implementation of infection control measures, including screening in patients with a previous hospital admission domestically and abroad, are useful to reduce the transmission of CPE in Canadian acute care hospitals.

Candida auris is an emerging multidrug resistant fungus that can cause HA invasive infections and outbreaks (60). It has been detected across multiple countries and continents including Canada, since its first detection in 2009 (61–64). *Candida auris* has been associated with outbreaks in healthcare settings in many countries, including Canada and the US, although outbreaks in Canada to date have been limited with few cases (60). Reported crude mortality for *C. auris* ranges widely from 15%–60% but is generally similar to other *Candida* species (60–66). Though still relatively rare in Canada, the US reported over 4,500 clinical cases and over 9,000 screening cases in 2023 (67). The identification of *C. auris* in routine microbiology laboratories requires identification of *Candida* to the species level, which may not be routinely performed for isolates from non-sterile sites. Treatment options are limited for patients as approximately one-third of identified *C. auris* isolates in Canada were multidrug-resistant and additional resistance can develop during antifungal therapy (68). Therefore, rapid identification, screening for colonization in at-risk patients and strict implementation of infection prevention and control measures are required to reduce the transmission of *C. auris* in Canadian healthcare settings. Continued reporting on *C. auris* in Canada is important to assess and monitor the risk of this pathogen, in addition to identifying epidemiological and microbiological trends (69).

Strengths and limitations

The main strength of CNISP is the collection of standardized and detailed epidemiological and laboratory-linked data from 109 sentinel hospitals across Canada for the purpose of providing national HAI and AMR trends for benchmarking and to guide hospital infection prevention and control practices.

Epidemiological data collected by CNISP were limited to information available in-patient charts. Hospital staff turnover may affect the consistent application of CNISP definitions when reviewing medical charts; however, these data were collected by experienced and trained infection prevention and control staff who receive periodic training with respect to CNISP methods and definitions. Furthermore, data quality assessments were conducted to maintain and improve data quality. These data may be subject to potential selection bias due to the exclusion of sites with missing or incomplete data throughout the study period. A limitation of *C. auris* surveillance is that detailed epidemiologic data are only available on patients identified at CNISP participating hospitals. From 2019 to 2023, CNISP coverage of Canadian acute care beds has increased from 33% to 37%, including increased representativeness in northern, community, rural and Indigenous populations.

Conclusion

Surveillance findings from a national sentinel network of Canadian acute care hospitals indicate that rates of MRSA BSI and CDI have remained stable from 2019 to 2023, while rates of VRE BSI and CPE infections have increased. Few cases of *C. auris* were detected in Canada. Consistent and standardized surveillance of epidemiologic and laboratory HAI data are essential to providing hospital practitioners with benchmark rates and informing infection prevention and control and antimicrobial stewardship policies to help reduce the burden of HAI and the impact of AMR in Canadian acute care hospitals.

Efforts to improve the quality and representativeness of Canadian HAI surveillance data are ongoing. The enhanced hospital screening practices survey is conducted annually to better understand and contextualize changes in HAI rates in the CNISP network. In addition, CNISP conducts point prevalence survey (PPS) to assess the burden and incidence of HAIs and antimicrobial use in participating Canadian acute care hospitals, and to establish ongoing benchmark rates. CNISP's fourth PPS was conducted from February to March 2024. The CNISP

continues to update HAI, antibiotic-resistant organism rates and viral respiratory infection rates, including COVID-19, on a publicly available dashboard using Canada's Health Infobase (70). To further improve representativeness and generalizability of national HAI benchmark rates, CNISP has launched a simplified dataset accessible to all acute care hospitals across Canada to collect and visualize annual HAI rate data and has over 100 hospitals participating in the project. Finally, CNISP is exploring HAI surveillance in the long-term care sector in Canada to better understand the burden of HAIs among this at-risk population.

Authors' statement

Canadian Nosocomial Infection Surveillance Program hospitals provided expertise in the development of protocols in addition to the collection and submission of epidemiological data and lab isolates. The National Microbiology Laboratory completed the laboratory analyses and contributed to the interpretation and revision of the paper. Epidemiologists from PHAC were responsible for the conception, analysis, interpretation, drafting and revision of the article.

Competing interests

None.

Acknowledgements

We gratefully acknowledge the contribution of the physicians, epidemiologists, infection control practitioners and laboratory staff at each participating hospital: Vancouver General Hospital (VGH), Vancouver, British Columbia (BC); Richmond General Hospital, Richmond, BC; UBC Hospital, Vancouver, BC; Lion's Gate, North Vancouver, BC; Powell River General Hospital, Powell River, BC; Sechelt Hospital (formerly St. Mary's), Sechelt, BC; Squamish General Hospital, Squamish, BC; Victoria General Hospital, Victoria, BC; Royal Jubilee Hospital, Victoria, BC; Nanaimo Regional General Hospital, Nanaimo, BC; BC Women's Hospital, Vancouver, BC; BC Children's Hospital, Vancouver, BC; Kelowna General Hospital, Kelowna, BC; Penticton Regional Hospital, Penticton, BC; University Hospital of Northern BC, Prince George, BC; Abbotsford Regional Hospital, Abbotsford, BC; Burnaby Hospital, Burnaby, BC; Chilliwack General Hospital, Chilliwack, BC; Delta Hospital, Delta, BC; Eagle Ridge Hospital, Port Moody, BC; Fraser Canyon Hospital, Hope, BC; Langley Memorial Hospital, Langley, BC; Mission Memorial Hospital, Mission, BC; Peace Arch Hospital, White Rock, BC; Royal Columbian Hospital, New Westminster, BC; Ridge Meadows Hospital, Maple Ridge, BC; Surrey Memorial Hospital, Surrey, BC; Queen's Park Centre, New Westminster, BC; Fellburn Care Centre, Burnaby, BC; Fleetwood Place, Surrey, BC; Peter Lougheed Centre, Calgary, Alberta (AB); Rockyview General Hospital, Calgary, AB; South Health Campus, Calgary, AB; Foothills Medical Centre, Calgary, AB; Alberta Children's Hospital, Calgary, AB; University of Alberta Hospital, Edmonton, AB; Stollery Children's Hospital, Edmonton, AB; Royal University Hospital, Saskatoon, Saskatchewan (SK); Regina General Hospital, Regina, SK; Pasqua Hospital, Regina, SK; Moose Jaw Hospital, SK; St. Paul's Hospital, Saskatoon, SK; Health Sciences Centre-Winnipeg, Winnipeg, Manitoba (MB); University of Manitoba Children's Hospital, Winnipeg, MB; Children's Hospital of Western Ontario, London, Ontario (ON); St. Michael's Hospital, Toronto, ON; Victoria Hospital, London, ON; University Hospital, London, ON; Toronto General Hospital, Toronto, ON; Toronto Western Hospital, Toronto, ON; Princess Margaret, Toronto, ON; Mount Sinai Hospital, Toronto, ON; Bridgepoint Active Healthcare, Toronto, ON; Sunnybrook Hospital, Toronto, ON; Kingston General Hospital, Kingston, ON; The Hospital for Sick Children, Toronto, ON; McMaster Children's Hospital, Hamilton, ON; St Joseph's Healthcare, Hamilton, ON; Juravinski Hospital and Cancer Center, Hamilton, ON; Hamilton Health Sciences General Site, Hamilton, ON; The Ottawa Hospital Civic Campus, Ottawa, ON; The Ottawa Hospital General Campus, Ottawa, ON; University of Ottawa Heart Institute, Ottawa, ON; Children's Hospital of Eastern Ontario (CHEO), Ottawa, ON; North York General Hospital, Toronto, ON; Sudbury Regional Hospital, Sudbury, ON; Temiskaming Hospital, Temiskaming Shores, ON; Jewish General Hospital – Sir Mortimer B. Davis (JGH-SMBD), Montréal, Québec (QC); Lachine Hospital, Lachine, QC; Montreal Children's Hospital, Montréal, QC; Hôpital Maisonneuve-Rosemont, Montréal, QC; Hôtel-Dieu de Québec, QC; Centre hospitalier de l'Université de Montréal, Montréal, QC; Montreal General Hospital, Montréal, QC; Centre Hospitalier Universitaire Sainte-Justine, Montréal, QC; Royal Victoria Hospital, Montréal, QC; Montreal Neurological Institute, Montréal, QC; Hôpital régional de Rimouski, Rimouski, QC; Hôpital de Notre-Dame-du-lac, Témiscouata-sur-le-lac, QC; Centre hospitalier régional du Grand-Portage, Rivière-du-loup, QC; Hôpital Notre-Dame-de-Fatima, La Pocatière, QC; Hôpital d'Amqui, Amqui, QC; Hôpital de Matane, Matane, QC; The Moncton Hospital, Moncton, New Brunswick (NB); Halifax Infirmary, Halifax, Nova Scotia (NS); Victoria General, Halifax, NS; Rehabilitation Centre, Halifax, NS; Veterans Memorial Building, Halifax, NS; Dartmouth General Hospital, Halifax, NS; IWK Health Centre, Halifax, NS; General Hospital & Miller Centre, St. John's, Newfoundland and Labrador (NL); Burin Peninsula Health Care Centre, Burin, NL; Carbonear General Hospital, Carbonear, NL; Dr. G.B. Cross Memorial Hospital, Clarenville, NL; Janeway Children's Hospital and Rehabilitation Centre, St. John's, NL; St. Clare's Mercy Hospital, St. John's, NL; Sir Thomas Roddick Hospital, Stephenville, NL; Western Memorial Regional Hospital, Corner Brook, NL; Central Newfoundland Regional Health Centre, Grand Falls-Windsor, NL; James Paton Memorial Hospital, Gander, NL; Dr. Y.K. Jeon Kittiwake Health Centre, New-Wes-Valley, NL; Fogo Island Health Centre, Fogo, NL; Notre Dame Bay Memorial Health Centre, Twillingate, NL; Connaigre Peninsula Health Centre, Harbour Breton, NL; A.M. Guy Health Centre, Buchans, NL; Green Bay Health Centre, Springdale, NL; Baie Verte Peninsula Health Centre, Baie Verte, NL; Queen Elizabeth Hospital, Charlottetown, Prince Edward Island (PE); Prince County Hospital, Summerside, PE; Qikiqtani General Hospital, Nunavut.

Thank you to the staff at Public Health Agency of Canada in the Centre for Communicable Diseases and Infection Control, Ottawa, ON (J Bartoszko, J Cayen, KB Choi, D Lee, C Lybeck, C McClellan, E McGill, R Mitchell, A Neitzel, A-K Nguyen, N Papayiannakis, S Rudat, A Silva, Z Suleman, O Varsaneux) and the National Microbiology Laboratory, Winnipeg, MB (S Ahmed,

A Bangit, A Bharat, T Du, R Edirmanasinghe, K Fakharuddin, G Golding, G Grewal, R Hizon, X Li, L Mataseje, M McCracken, M Reimer, N Lerminiaux, J Tinsley).

Funding

This work was supported by Public Health Agency of Canada.

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Appendix

Appendix A: Surveillance case definitions and eligibility criteria, 2023

Clostridioides difficile infection

A "primary" episode of *Clostridioides difficile* infection (CDI) is defined either as the first episode of CDI ever experienced by the patient or a new episode of CDI that occurs greater than eight weeks after the diagnosis of a previous episode in the same patient.

A patient is identified as having CDI if:

- The patient has diarrhea or fever, abdominal pain and/or ileus AND a laboratory confirmation of a positive toxin assay or positive polymerase chain reaction (PCR) test for *C. difficile* (without reasonable evidence of another cause of diarrhea)

OR

- The patient has a diagnosis of pseudomembranes on sigmoidoscopy or colonoscopy (or after colectomy) or histological/pathological diagnosis of CDI

OR

- The patient is diagnosed with toxic megacolon (in adult patients only)

Diarrhea is defined as one of the following:

- More watery/unformed stools in a 36-hour period

OR

- More watery/unformed stools in a 24-hour period and this is new or unusual for these patient (in adult patients only)

Exclusion:

- Any patients aged younger than one year
- Any paediatric patients (aged one year to younger than 18 years) with alternate cause of diarrhea found (i.e., rotavirus, norovirus, enema or medication, etc.) are excluded even if the *C. difficile* diagnostic test result is positive

***Clostridioides difficile* infection case classification**

Once a patient has been identified with CDI, the infection will be classified further based on the following criteria and the best clinical judgment of the healthcare and/or infection prevention and control practitioner.

Healthcare-associated (acquired in your facility) CDI case definition:

- Related to the current hospitalization:
  - The patient's CDI symptoms occur in your healthcare facility three or more days (or 72 hours or longer) after admission
- Related to a previous hospitalization:
  - Inpatient: the patient's CDI symptoms occur less than three days after the current admission (or fewer than 72 hours) AND the patient had been previously hospitalized at your healthcare facility and discharged within the previous four weeks
  - Outpatient: the patient presents with CDI symptoms at your emergency room (ER) or outpatient location AND the patient had been previously hospitalized at your healthcare facility and discharged within the previous four weeks
- Related to a previous healthcare exposure at your facility:
  - Inpatient: the patient's CDI symptoms occur less than three days after the current admission (or fewer than 72 hours) AND the patient had a previous healthcare exposure at your facility within the previous four weeks
  - Outpatient: the patient presents with CDI symptoms at your ER or outpatient location AND the patient had a previous healthcare exposure at your facility within the previous four weeks

Healthcare-associated (acquired in any other healthcare facility) CDI case definition:

- Related to a previous hospitalization at any other healthcare facility:
  - Inpatient: the patient's CDI symptoms occur less than three days after the current admission (or fewer than 72 hours) AND the patient is known to have been previously hospitalized at any other healthcare facility and discharged/transferred within the previous four weeks
  - Outpatient: the patient presents with of CDI symptoms at your ER or outpatient location AND the patient is known to have been previously hospitalized at any other healthcare facility and discharged/transferred within the previous four weeks
- Related to a previous healthcare exposure at any other healthcare facility:
  - Inpatient: the patient's CDI symptoms occur less than three days after the current admission (or fewer than 72 hours) AND the patient is known to have had a previous healthcare exposure at any other healthcare facility within the previous four weeks

- Outpatient: the patient presents with CDI symptoms at your ER or outpatient location AND the patient is known to have had a previous healthcare exposure at any other healthcare facility within the previous four weeks

Healthcare-associated CDI but unable to determine which facility:

The patient with CDI DOES meet both definitions of healthcare-associated (acquired in your facility) AND healthcare-associated (acquired in any other healthcare facility) CDI, but unable to determine to which facility the case is primarily attributable to.

Community-associated CDI case definition:

- Inpatient: the patient's CDI symptoms occur less than three days (or fewer than 72 hours) after admission, with no history of hospitalization or any other healthcare exposure within the previous 12 weeks
- Outpatient: the patient presents with CDI symptoms at your ER or outpatient location with no history of hospitalization or any other healthcare exposure within the previous 12 weeks

Indeterminate CDI case definition:

The patient with CDI does NOT meet any of the definitions listed above for healthcare-associated or community-associated CDI. The symptom onset was more than four weeks but fewer than 12 weeks after the patient was discharged from any healthcare facility or after the patient had any other healthcare exposure.

Methicillin-resistant *Staphylococcus aureus* (MRSA) infection

MRSA bloodstream infection (BSI) case definition:

- Isolation of *Staphylococcus aureus* from blood

AND

- Patient must be admitted to the hospital

AND

- Is a "newly identified *S. aureus* infection" at a Canadian Nosocomial Infection Surveillance Program (CNISP) hospital at the time of hospital admission or identified during hospitalization

Infection inclusion criteria:

- Methicillin-susceptible *Staphylococcus aureus* (MSSA) or MRSA BSIs identified for the first time during this current hospital admission
- MSSA or MRSA BSIs that have already been identified at your site or another CNISP site but are **new** infections

Criteria to determine NEW MSSA or MRSA BSI:

- Once the patient has been identified with a MSSA or MRSA BSI, they will be classified as a new MSSA or MRSA if they meet the following criteria: more than 14 days since previously treated MSSA or MRSA BSI and, in the judgment of infection control physicians and practitioners, represents a new infection

Infection exclusion criteria:

- Emergency, clinic, or other outpatient cases who are **NOT admitted** to the hospital

Healthcare-associated (HA) case definition:

Healthcare-associated is defined as an inpatient who meets the following criteria and in accordance with the best clinical judgment of the healthcare and/or infection prevention and control practitioner:

- Patient is on or beyond calendar day 3 of their hospitalization (calendar day 1 is the day of hospital admission)

OR

- Has been hospitalized in your facility in the last 7 days or up to 90 days depending on the source of the infection

OR

- Has had a healthcare exposure at your facility that would have resulted in this bacteremia (using best clinical judgment)

OR

- Any patient who has a bacteremia not acquired at your facility that is thought to be associated with any other healthcare exposure (e.g., another acute-care facility, long-term care, rehabilitation facility, clinic or exposure to a medical device)

Healthcare-associated (HA) case definition (newborn):

- The newborn is on or beyond calendar day 3 of their hospitalization (calendar day 1 is the day of hospital admission)

- The mother was **NOT** known to have MRSA on admission and there is no epidemiological reason to suspect that the mother was colonized prior to admission, even if the newborn is fewer than 48 hours of age
- In the case of a newborn transferred from another institution, MSSA or MRSA BSI may be classified as HA your acute-care facility if the organism was **NOT** known to be present and there is no epidemiological reason to suspect that acquisition occurred prior to transfer

Community-associated case definition:

- No exposure to healthcare that would have resulted in this bacteremia (using best clinical judgment) and does not meet the criteria for a healthcare-associated BSI

Vancomycin-resistant *Enterococcus* (VRE) infection

VRE BSI case definition:

- Isolation of *Enterococcus faecalis* or *faecium* from blood

AND

- Vancomycin minimum inhibitory concentration (MIC) of **at least** 8 µg/ml

AND

- Patient must be admitted to the hospital

AND

- Is a "newly" identified VRE BSI at a CNISP facility at the time of hospital admission or identified during hospitalization

A newly identified VRE BSI is defined as a positive VRE blood isolate more than 14 days after completion of therapy for a previous infection and felt to be unrelated to previous infection in accordance with best clinical judgment by infection control physicians and practitioners.

Exclusion criteria:

- Emergency, clinic, or other outpatient cases who are **not admitted** to the hospital

Healthcare-associated (HA) case definition:

Healthcare-associated is defined as an inpatient who meets the following criteria and in accordance with the best clinical judgment of the healthcare and/or infection prevention and control practitioner:

- Patient is on or beyond calendar day 3 of their hospitalization (calendar day 1 is the day of hospital admission)

OR

- Has been hospitalized in your facility in the last 7 days or up to 90 days depending on the source of the infection

OR

- Has had a healthcare exposure at your facility that would have resulted in this bacteremia (using best clinical judgment)

OR

- Any patient who has a bacteremia not acquired at your facility that is thought to be associated with any other healthcare exposure (e.g., another acute-care facility, long-term care, rehabilitation facility, clinic or exposure to a medical device)

Community-associated case definition:

- No exposure to healthcare that would have resulted in this bacteremia (using best clinical judgment) and does not meet the criteria for a healthcare-associated BSI

Carbapenemase-producing *Enterobacterales* (CPE) infection

Case eligibility:

- Patient is admitted to a CNISP hospital or presents to a CNISP hospital emergency department or a CNISP hospital-based outpatient clinic
- Laboratory confirmation of carbapenem resistance or carbapenemase production in *Enterobacterales* spp.

Following molecular testing, only isolates determined to be harbouring a carbapenemase are included in surveillance. If multiple isolates are submitted for the same patient in the same surveillance year, only the isolate from the most invasive site is included in epidemiological results (e.g., rates and outcome data). However, antimicrobial susceptibility testing results represent all CPE isolates (including clinical and screening isolates from inpatients and outpatients) submitted between 2018 and 2022; duplicates (i.e., isolates from the same patient where the organism and the carbapenemase were the same) were excluded.

Candida auris

Patients admitted to a participating hospital or presenting to a hospital emergency department or a hospital-based outpatient clinic with laboratory confirmation of *C. auris* from any specimen.

Included in this surveillance project are all clinical or screening samples that were positive for *C. auris* by any method. Currently, *C. auris* can be identified by rRNA sequencing, Vitek MS MALDI-TOF (with either the clinical database v3.2 or later or the RUO database), or Bruker MALDI-TOF (with either the clinical database v6903 or later or the RUO database). The project also includes potential *C. auris* misidentifications or "No identification" as outlined in the **Table A1** below.

Table A1: Laboratory identification of *Candida auris*

Identification method	Identification of suspect isolates
Vitek MS MALDI Clinical database older than v3.2	*C. haemulonii* No ID/low discrimination *C. rugosa* (not a problem for v3.0 or later) *C. pulcherrima* (not a problem for v3.0 or later)
Bruker MALDI Clinical database older than v6903	No ID
Vitek 2 version 8.01	*C. haemulonii* *C. duobushaemulonii* No ID/low discrimination
Vitek 2 version before 8.01	*C. haemulonii* *C. duobushaemulonii* *C. lusitaniae* *C. famata* No ID/low discrimination
API 20C AUX	*Rhodotorula glutinis* (characteristic red colour not present) *C. sake* No ID/low discrimination
API Candida	*C. famata*
BD Phoenix yeast identification system	*C. haemulonii* *C. catenulata* No ID

Abbreviations: *C., Candida*; MALDI, Matrix-Assisted Laser Desorption Ionization; MS, mass spectrometry

Appendix B

Supplemental figures and tables are available upon request to the author: cnisp-pcsin@phac-aspc.gc.ca

Table S1.0: Summary of patient characteristics for *Clostridioides difficile* infections (CDIs), carbapenemase-producing Enterobacterales (CPE) infections, methicillin-resistant *Staphylococcus aureus* (MRSA) bloodstream infections (BSIs), and vancomycin-resistant *Enterococcus* (VRE) BSIs, 2019–2023
Table S1.1: Cases and incidence rates of healthcare-associated and community-associated *Clostridioides difficile* infection by region, hospital type and hospital size, Canada, 2019–2023
Table S1.2: Antimicrobial resistance of healthcare-associated and community-associated *Clostridioides difficile* infection isolates, Canada, 2019–2023
Table S1.3: Number and proportion of common ribotypes of healthcare-associated and community-associated *Clostridioides difficile* infection cases, Canada, 2019–2023
Table S2.1: Cases and incidence rates of healthcare-associated and community-associated methicillin-resistant *Staphylococcus aureus* bloodstream infections by region, hospital type and hospital size, 2019–2023
Table S2.2: Antimicrobial resistance of healthcare-associated and community-associated methicillin-resistant *Staphylococcus aureus* bloodstream infection isolates, Canada, 2019–2023
Table S2.3: Number and proportion of select methicillin-resistant *Staphylococcus aureus* spa types (with corresponding epidemic types) identified
Table S3.1: Number of vancomycin-resistant *Enterococcus* bloodstream infections incidence rates by region, hospital type and hospital size, 2019–2023
Table S3.2: Number of healthcare-associated vancomycin-resistant *Enterococcus* bloodstream infections and incidence rates by region, hospital type and hospital size, 2019–2023
Table S3.3: Number and proportion of vancomycin-resistant *Enterococcus* bloodstream infections isolate types identified, 2019–2023
Table S3.4: Distribution of vancomycin-resistant *Enterococcus faecium* bloodstream sequence types, 2019–2023
Table S4.1: Number of carbapenemase-producing *Enterobacterales* infections and incidence rates by region, hospital type and hospital size, 2019–2023
Table S4.2: Number and proportion of main carbapenemase-producing pathogens identified
Table S4.3: Antimicrobial Susceptibility Testing for *Klebsiella pneumoniae* carbapenemase, 2019–2023
Table S4.4 Antimicrobial Susceptibility Testing for New Delhi metallo-β-lactamase, 2019–2023
Table S4.5: Antimicrobial Susceptibility Testing for OXA-48, Oxacillinase-48, 2019–2023

Device and surgical procedure-related infections in Canadian acute care hospitals, 2019–2023

Canadian Nosocomial Infection Surveillance Program[1]*

Abstract

Background: Healthcare-associated infections (HAIs) are a significant healthcare burden in Canada. National surveillance of HAIs at sentinel acute care hospitals is conducted by the Canadian Nosocomial Infection Surveillance Program.

Objective: This article describes device and surgical procedure-related HAI epidemiology in Canada from 2019 to 2023.

Methods: Data were collected from 68 Canadian sentinel acute care hospitals between January 1, 2019, and December 31, 2023, for intensive care unit central line-associated bloodstream infections (ICU-CLABSIs), hip and knee surgical site infections (SSIs), cerebrospinal fluid (CSF) shunt SSIs and paediatric cardiac SSIs. Case counts, rates, patient and hospital characteristics, pathogen distributions and antimicrobial resistance data are presented.

Results: Between 2019 and 2023, 2,582 device-related infections and 1,029 surgical procedure-related infections were reported. Rates of ICU-CLABSIs fluctuated throughout the study period, with an overall increase in all intensive care unit settings except for the neonatal intensive care unit, where a 4% decrease was noted. An increase in SSIs following knee arthroplasty was observed, rising from 0.34 to 0.43 infections per 100 surgeries. Fluctuating trends were also observed in CSF shunt SSIs and paediatric cardiac SSIs over the study period. The most commonly identified pathogens were coagulase-negative staphylococci (23%) in ICU-CLABSIs and *Staphylococcus aureus* (42%) in SSIs.

Conclusion: Epidemiological and microbiological trends among selected device and surgical procedure-related HAIs are essential for benchmarking infection rates nationally and internationally, identifying any changes in infection rates or antimicrobial resistance patterns and helping inform hospital infection prevention and control and antimicrobial stewardship policies and programs.

Suggested citation: Canadian Nosocomial Infection Surveillance Program. Device and surgical procedure-related infections in Canadian acute care hospitals, 2019–2023. Can Commun Dis Rep 2025;51(6/7):270–82. https://doi.org/10.14745/ccdr.v51i67a05

Keywords: hospital-associated infection, acute care, surveillance, antimicrobial resistance, device-associated infection, surgical procedure-related infection, surgical site infection, ICU-CLABSI, central line-associated bloodstream infection, hip and knee arthroplasty surgical site infection, cerebrospinal fluid shunt surgical site infection, paediatric cardiac surgical site infection, Canada

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Introduction

Healthcare-associated infections (HAIs) are a common outcome of healthcare delivery, impacting patient morbidity and mortality, increasing the burden on hospitals and costs, and contributing to the rise of antimicrobial resistance (1). Healthcare-associated infections can result from various factors, including the use of invasive medical devices and surgical procedures (2). Surgical site infections (SSIs) are one of the most common HAIs reported in hospitals and are associated with an increased hospital length of stay, as well as higher intensive care unit (ICU) admissions and hospital readmissions (3). Device and surgical procedure-related infections are also associated with a high-financial burden on the healthcare system accounting for almost $50,000 per central

line-associated bloodstream infection (CLABSI) case and $28,000 per SSI case (4).

A point prevalence study conducted in 2017 in Canadian sentinel acute care hospitals revealed that 35.6% of all reported HAIs were linked to medical devices and surgical procedures (5). Among these, ICU-CLABSIs represented 21.2%, while SSIs associated with a prosthetic implant accounted for 19.4% (5). The risk of device and surgical procedure-related infections is associated with patient demographics and comorbidities, in addition to the type of hospital in which the patient received care (6–8).

Understanding the epidemiology of HAIs related to medical devices and surgical procedures is crucial for establishing benchmark rates over time. These benchmarks support the development of effective antimicrobial stewardship programs and guide infection prevention and control strategies. Collecting and analyzing antimicrobial susceptibility data are crucial for guiding appropriate antimicrobial use and combating antimicrobial resistance (9). This report presents an epidemiological summary of specific device- and surgical procedure-related HAIs reported between 2019 and 2023 across 68 hospitals participating in the Canadian Nosocomial Infection Surveillance Program (CNISP).

Methods

Design

Since its establishment in 1994, CNISP has conducted national HAI surveillance at sentinel acute care hospitals across Canada, in collaboration with the Public Health Agency of Canada and the Association of Medical Microbiology and Infectious Disease Canada. Data are presented for the following device and surgical procedure-related HAIs: ICU-CLABSIs; hip and knee arthroplasty SSIs; cerebrospinal fluid (CSF) shunt SSIs; and paediatric cardiac SSIs.

Case definitions

Device and surgical procedure-related HAIs were defined according to standardized protocols and case definitions (see **Appendix**). Complex infections, defined as deep incisional and organ/space, were included in hip and knee SSI surveillance, while CLABSIs identified in ICU settings were included in CLABSI surveillance. The adult mixed patient ICU, adult cardiovascular surgery intensive care unit (CVICU), paediatric intensive care unit (PICU) and neonatal intensive care unit (NICU) were included as eligible ICU settings. Adult mixed ICUs included any adult ICU with a mix of patient types as part of the ICU patient mix (i.e., medical/surgical, surgical/trauma, burn/trauma, medical/neurosurgical).

Data source

Epidemiological data for device and surgical procedure-related infections identified between January 1, 2019, and December 31, 2023 (using surgery date for SSIs and date of positive blood culture for CLABSIs) were submitted by participating hospitals using standardized data collection forms. Hospital participation varied by surveillance project and year. Data submission and case identification were supported by training sessions and periodic evaluations of data quality.

Statistical analysis

To calculate hip and knee SSI, CSF shunt SSI and paediatric cardiac SSI rates, the number of cases were divided by the number of surgical procedures performed (multiplied by 100). To calculate ICU-CLABSI rates, the number of cases was divided by line day denominators (multiplied by 1,000). Neonatal ICU CLABSI rates stratified by birth weight category were not included in this report. To calculate ICU-specific catheter utilization, the total number of ICU patient central line days was divided by the total number of ICU patient days. To calculate proportions of pathogens, the number of pathogens were divided by the total number of identified pathogens. Denominators may vary, as missing and incomplete data were excluded from analyses. Median and interquartile ranges (IQR) were calculated for continuous variables. Trends over time were tested using the Mann-Kendall test. The chi-square test was used to compare two categorical variables. Significance testing was two-tailed and differences were considered significant at a p-value of ≤ 0.05. Analyses were conducted using R version 4.3.2.

Results

Sixty-eight hospitals submitted device and surgical procedure-related infection data to CNISP between 2019 and 2023 (**Table 1**), with medium-sized (n=201–499 beds) mixed hospitals (n=15 sites, 22%) being the most common (data not shown). Overall, 2,582 device-related infections and 1,029 surgical procedure-related infections were reported. Among all SSIs reported (n=1,029), hip and knee infections represented 67% (n=694) of these types of infections.

A total of 2,854 pathogens were identified from device-related infections and 1,061 pathogens from surgical procedure-related cases between 2019 and 2023. Of the identified pathogens for ICU-CLABSIs, 60% were gram-positive, 25% were gram-negative and 16% were fungal. Of the identified pathogens for SSIs, 80% were gram-positive, 19% were gram-negative and 1% were fungal. Coagulase-negative staphylococci (CoNS) and *Staphylococcus aureus* were the most common pathogens associated with SSIs, while CoNS and *Enterococcus* spp. were most frequently identified in cases of ICU-CLABSIs, respectively (**Table 2**). From 2019 to 2023, the proportion of methicillin-resistant *S. aureus* (MRSA) was 14% for ICU-CLABSIs and 11% for SSIs (data not shown).

Table 1: Characteristics of acute care hospitals participating in device and surgical procedure-related healthcare-associated infection surveillance, 2023

Characteristic of hospitals	CLABSI-adult mixed ICU	CLABSI-adult CVICU	CLABSI-PICU	CLABSI-NICU	CSF shunt SSI	Paediatric cardiac SSI	Hip and knee SSI	Total unique hospitals
Total number of participating hospitals	40	9	12	20	13	6	31	68
Hospital type								
Adult[a]	27	6	N/A	3	4	N/A	15	34
Mixed[b]	13	3	4	9	1	N/A	16	25
Paediatric[c]	N/A	N/A	8	8	8	6	N/A	9
Hospital size								
Small (1–200 beds)	4	1	7	4	7	4	6	20
Medium (201–499 beds)	21	3	4	7	3	2	14	30
Large (500 and more beds)	15	5	1	9	3	0	11	18

Abbreviations: CLABSI, central line-associated bloodstream infection; CSF shunt SSI, cerebrospinal fluid shunt surgical site infection; CVICU, cardiovascular surgery intensive care unit; ICU, intensive care unit; N/A, not applicable; NICU, neonatal intensive care unit; PICU, paediatric intensive care unit; SSI, surgical site infection
[a] Three hospitals classified as "adult" also had a neonatal intensive care unit
[b] Mixed hospitals provide both adult and paediatric care
[c] Paediatric standalone hospitals excluding mixed facilities with women's and obstetric wards

Table 2: Distribution and rank of the most frequently reported gram-negative, gram-positive and fungal pathogens, 2019–2023[a]

Pathogen category	Rank	Pathogen	ICU-CLABSI		Hip and knee		CSF shunt		Paediatric cardiac	
			N=2,854		N=780		N=130		N=151	
			n	%	n	%	n	%	n	%
Gram-positive	1	Coagulase-negative staphylococci[b]	661	23.2	134	17.2	46	35.4	20	13.2
	2	*Enterococcus* spp.	590	20.7	34	4.4	3	2.3	0	0.0
	3	*Staphylococcus aureus*[c]	273	9.6	317	40.6	37	28.5	93	61.6
	4	*Streptococcus* spp.	60	2.1	81	10.4	4	3.1	10	6.6
	Other gram-positive[d]		124	4.3	59	7.6	12	9.2	2	1.3
	Total gram-positive		1,708	59.8	625	80.1	102	78.5	125	82.8
Gram-negative	1	*Klebsiella* spp.	159	5.6	14	1.8	8	6.2	5	3.3
	2	*Escherichia coli*	130	4.6	26	3.3	7	5.4	1	0.7
	3	*Enterobacter* spp.	110	3.9	33	4.2	4	3.1	6	4.0
	4	*Pseudomonas* spp.	82	2.9	28	3.6	3	2.3	2	1.3
	5	*Serratia* spp.	58	2.0	9	1.2	1	0.8	1	0.7
	Other gram-negative[e]		163	5.7	43	5.5	4	3.1	3	2.0
	Total gram-negative		702	24.6	153	19.6	27	20.8	18	11.9
Fungi	1	*Candida albicans*	227	8.0	2	0.3	0	0.0	2	1.3
	2	Other *Candida* spp.[f]	207	7.3	0	0.0	1	0.8	6	4.0
	Other fungi[g]		10	0.4	0	0.0	0	0.0	0	0.0
	Total fungal		444	15.6	2	0.3	1	0.8	8	5.3
Total			2,854	100	780	100	130	100	151	100

Abbreviations: CSF shunt, cerebrospinal fluid shunt; ICU-CLABSI, intensive care unit central line-associated bloodstream infections
[a] Frequency distribution percentage rounded to the nearest tenth decimal
[b] Coagulase-negative staphylococci included *S. lugdunensis*, *S. haemolyticus*, *S. epidermidis*, *S. capitis*, *S. hominis* and *S. warneri*
[c] *Staphylococcus aureus* includes methicillin-resistant *S. aureus*, methicillin-susceptible *S. aureus* and unspecified *S. aureus*
[d] Other gram-positive pathogens included anaerobic gram-positive cocci, *Finegoldia magna*, *Clostridioides* spp., *Lactobacillus* spp. and others
[e] Other gram-negative pathogens included *Stenotrophomonas spp.*, *Morganella morganii*, *Proteus mirabilis*, *Pantoea spp.*, *Prevotella spp.*, *Bacteroides fragilis* and others
[f] Other *Candida spp.* included *C. dubliniensis*, *C. glabrata*, *C. krusei*, *C. lusitaniae*, *C. parapsilosis* and *C. tropicalis*
[g] Other fungi included *Aspergillus* spp., *Trichophyton tonsurans* and unspecified fungi

Intensive care unit central line-associated bloodstream infections

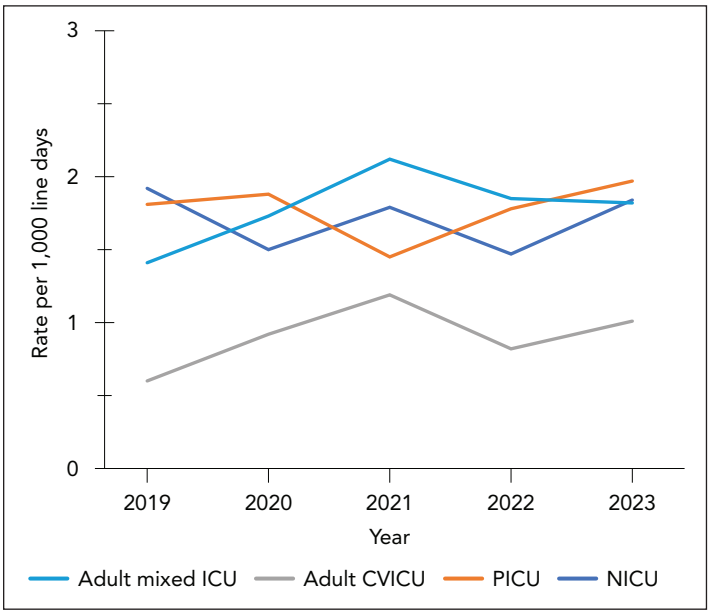
Infection characteristics: Between 2019 and 2023, a total of 2,582 CLABSIs were reported. The majority were reported in adult mixed ICUs (65%, n=1,677) and NICUs (19%, n=480), reflecting higher site participation in CLABSI surveillance in these ICU settings. Patient demographics and outcomes for ICU-related CLABSIs are presented in **Table 3**. The median age of patients with CLABSIs in adult ICUs was older in the adult CVICU compared to adult mixed ICUs ($p<0.001$). The majority of those with CLABSIs were male across all ICU settings, ranging from 58% in the PICU to 70% in the adult CVICU. Median days from ICU admission to infection was longest in the PICU (26 days, IQR: 11–65 days) while median days from ICU to infection was 11–14 days in all other ICU settings ($p<0.001$).

Trends over time: Adult mixed ICUs had the highest CLABSI rates (1.80 infections per 1,000 line days), followed by PICUs (1.79 infections per 1,000 line days), NICUs (1.71 infections per 1,000 line days) and adult CVICUs (0.90 infections per 1,000 line days) (Appendix, **Table A1**). From 2019 to 2023, CLABSIs rates in adult ICU settings fluctuated and increased non-significantly for adult mixed ICUs (29%, 1.41–1.82 infections per 1,000 line days, $p=0.46$) and adult CVICUs (68%, 0.6–1.01 infections per 1,000 line days, $p=0.46$) (**Figure 1**). Adult mixed ICU CLABSI rates peaked at a rate of 2.12 infections per 1,000 line days in 2021 and have since declined. Though rates of CLABSI in adult CVICUs were low overall, a sensitivity analysis among sites that submitted adult CVICU CLABSI data during the entire five-year study period (n=7 hospitals) confirmed a non-significant increase in CLABSI incidence, though less substantial (43%) (data not shown). Catheter utilization from 2019 to 2023 remained stable, ranging from 71%–74% in adult mixed ICUs. In adult CVICUs, catheter utilization was higher compared to adult mixed ICUs, ranging from 80%–87% in adult CVICUs, with an outlier of 66% in 2023 (data not shown).

In paediatric ICUs, NICU and PICU, CLABSI fluctuated from 2019 to 2023, with NICU CLABSI rates ranging between 1.47 to 1.92 infections per 1,000 line days while PICU CLABSIs were lowest in 2021 (1.45 infections per 1,000 lines days), followed by a return to pre-COVID-19 pandemic levels. Catheter utilization in PICUs ranged from 59%–67% from 2019 to 2023 while NICU had the lowest catheter utilization overall during the same time period, ranging from 29%–33%.

All-cause mortality at thirty days was highest in the adult mixed ICU and adult CVICU at 31% and 33%, respectively, while thirty-day all-cause mortality ranged from 9.6%–11% in paediatric and neonatal ICU settings. The most commonly identified pathogens among ICU-CLABSIs overall were CoNS and *Enterococcus* spp. (23.2% and 20.7%, respectively), which aligned with the most commonly identified pathogens among adult mixed ICUs and adult CVICUs. Among PICU and NICU CLABSIs, CoNS and *S. aureus* were the most commonly identified pathogens (data not shown).

Figure 1: Rate of central line-associated bloodstream infection per 1,000 line days by intensive care unit type, 2019–2023



Abbreviations: CVICU, cardiovascular intensive care unit; ICU, intensive care unit; NICU, neonatal intensive care unit; PICU, paediatric intensive care unit

Table 3: Patient characteristics and outcomes of intensive care unit central line-associated bloodstream infections, 2019–2023

Characteristic	Adult mixed ICU (n=1,677)	Adult CVICU (n=153)	PICU (n=272)	NICU (n=480)
Age, median (IQR)	59 years (46 years, 69 years)	65 years (52 years, 72 years)	7 months (3 months, 36 months)	19 days (9 days, 48 days)
Sex, female, n/N (%)	557/1,677 (33%)	46/153 (30%)	113/272 (42%)	184/480 (38%)
Birthweight (g), median (IQR)	N/A	N/A	N/A	928 (IQR: 670–2,100)
Gestational age (weeks), median (IQR)	N/A	N/A	N/A	27 (IQR: 24–34)
Days from ICU admission to infection, median (IQR)	11 (IQR: 6–22)	11 (IQR: 6–20)	26 (IQR: 11–65)	14 (IQR: 8–35)
Death, thirty-day all cause, n/N (%)	526/1,673 (31%)	50/153 (33%)	26/272 (9.6%)	51/478 (11%)

Abbreviations: CVICU, cardiovascular surgery intensive care unit; ICU, intensive care unit; IQR, interquartile ranges; NICU, neonatal intensive care unit; N/A, not applicable; PICU, paediatric intensive care unit

Hip and knee surgical site infections

Infection characteristics: Between 2019 and 2023, a total of 694 complex hip and knee SSIs were reported, with hip arthroplasties accounting for the majority of cases (n=432, 62%). Among these SSIs, 51% (n=351) were organ/space infections, while 49% (n=343) were deep incisional infections (**Table 4**). The median patient age was 68 years (IQR: 59–75 years) for hip SSIs and 67 years (IQR: 60–74 years) for knee SSIs. The median time from procedure to infection onset was 22 days (IQR: 15–34 days) for hip SSIs and 24 days (IQR:17–37 days) for knee SSIs. The median length of stay was two days for both hip (IQR: 1–7 days) and knee (IQR: 1–3 days) SSIs.

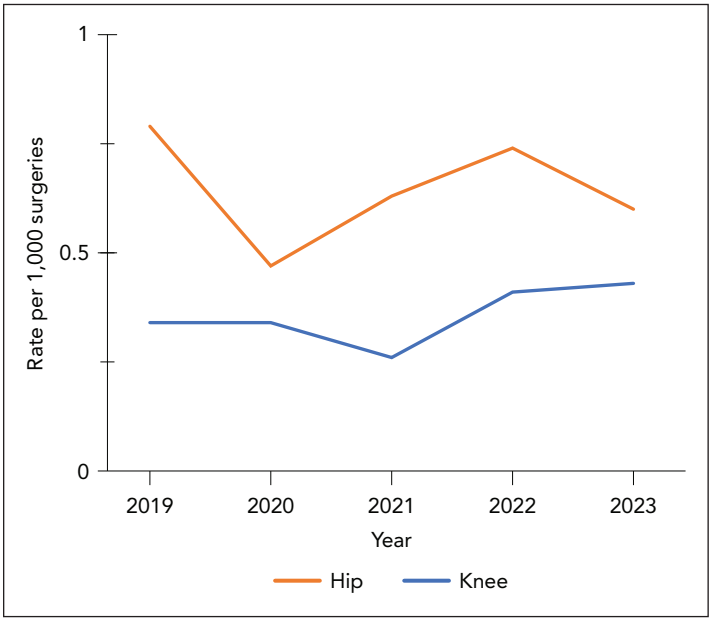
Table 4: Frequency of hip and knee surgical site infections by year and infection type, 2019–2023

Year	Deep incisional SSI		Organ/space SSI		All cases
	n	%	n	%	n
Hip arthroplasty					
2019	52	49.5	53	50.5	105
2020	22	44.9	27	55.1	49
2021	44	49.4	45	50.6	89
2022	48	46.2	56	53.9	104
2023	46	54.1	39	45.9	85
Overall	212	49.1	220	50.9	432
Knee arthroplasty					
2019	27	50.9	26	49.1	53
2020	14	37.8	23	62.2	37
2021	23	62.2	14	37.8	37
2022	33	54.1	28	45.9	61
2023	34	46.0	40	54.1	74
Overall	131	50.0	131	50.0	262

Abbreviation: SSI, surgical site infection

Trends over time: Between 2019 and 2023, knee SSI rates increased non-significantly by 26% (0.34–0.43 infections per 100 surgeries, p=0.62), while hip SSI rates fluctuated between 0.47 and 0.79 infections per 100 surgeries (p=0.21) (**Figure 2**; Appendix, **Table A2**). The majority of patients (79%, n=550/692) with a hip or knee SSI were readmitted, and 66% (n=453/685) required revision surgery. Within 30 days after the first positive culture, 14 all-cause deaths (3.3%, n=14/418) were reported among patients with a complex SSI following a hip arthroplasty, while no deaths were reported among knee arthroplasty SSI cases. The most commonly identified pathogens were *S. aureus* (41%) and CoNS (17%), with no significant differences by infection type (data not shown).

Figure 2: Rate of hip and knee surgical site infections per 100 surgeries, 2019–2023

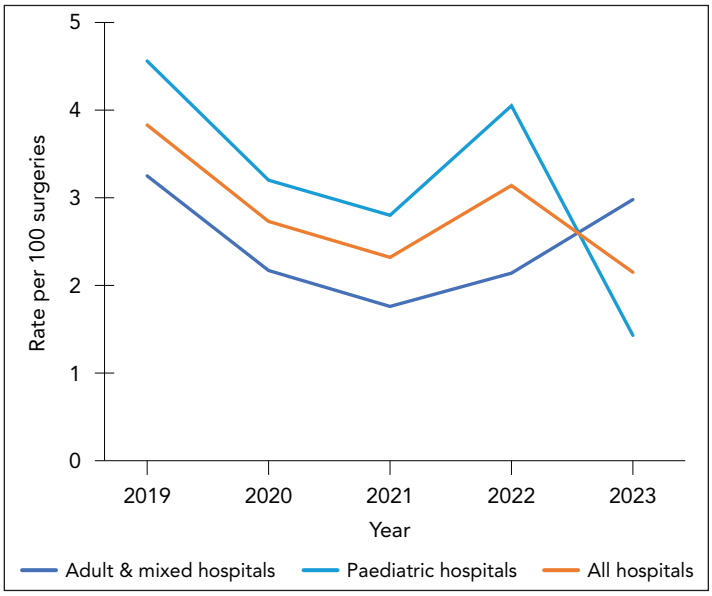


Cerebrospinal fluid shunt surgical site infections

Infection characteristics: Between 2019 and 2023, a total of 120 CSF shunt SSIs were reported. The median patient age was 48 years (IQR: 36–61 years) for adult patients and two years (IQR: 0.3–9 years) for paediatric patients. The median time from procedure to infection onset was 19 days (IQR: 10–40 days). More than half of CSF shunt SSIs (56%, n=67/120) were identified from new surgeries, while 44% (n=53/120) were from revision surgeries. Women represented 49% (n=59/120) of cases.

Trends over time: The overall rate of CSF shunt SSIs was 2.89 infections per 100 surgeries (range: 2.15–3.83 infections per 100 surgeries, Appendix, **Table A3**). Paediatric and adult/mixed hospitals infection rates were not significantly different at 3.28 and 2.49 infections per 100 surgeries, respectively (p=0.15). From 2019 to 2023, no significant trend was observed in CSF shunt SSI rates for adult and mixed hospitals (range: 1.76–3.25 infections per 100 surgeries, p=0.40), paediatric hospitals (range: 1.43–4.56 infections per 100 surgeries, p=0.11) and all hospital types combined (p=0.11) (**Figure 3**). The most commonly identified pathogens from CSF shunt SSIs were CoNS and *S. aureus* (35% and 29% of identified pathogens, respectively). Outcome data were not collected for CSF shunt SSI surveillance.

Figure 3: Cerebrospinal fluid shunt surgical site infection rates per 100 surgeries by hospital type[a], 2019–2023



[a] All hospitals include adult, mixed and paediatric hospitals participating in cerebrospinal fluid shunt surgical site infection surveillance

Paediatric cardiac surgical site infections

Infection characteristics: Between 2019 and 2023, a total of 184 paediatric cardiac SSIs were reported (**Table 5**). The majority of infections were superficial incisional SSIs (65%), followed by organ/space infections (26%) and deep incisional infections (9%). The median patient age was 63 days (IQR: 7–347 days), and the median time from surgery to infection onset was 15 days (IQR: 8–23 days). The proportion of deep incisional infections increased from 5.7% in 2019 to 15% in 2023, though this trend was not significant (p=0.09, Table 5).

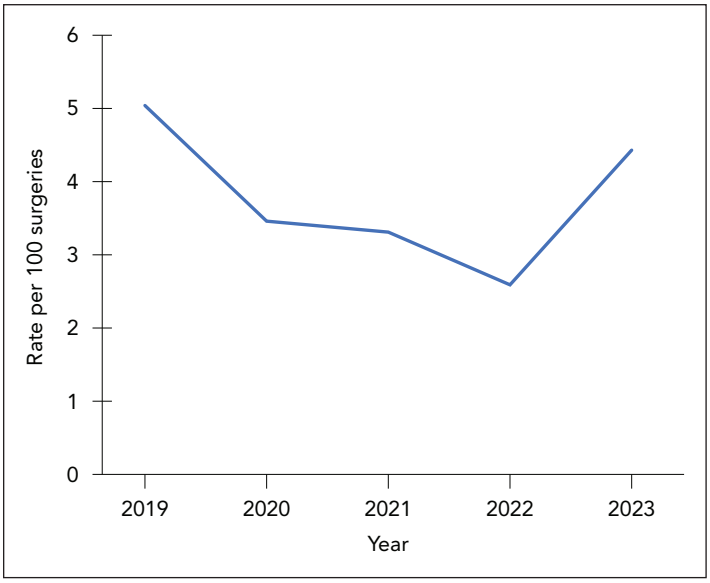
Table 5: Paediatric cardiac surgical site infection rates by year and infection type, 2019–2023

Year	Superficial incisional SSI cases		Organ/space SSI cases		Deep incisional SSI cases		All cases[a]
	n	%	n	%	n	%	
2019	19	54.3%	14	40.0%	2	5.7%	35
2020	29	78.4%	6	16.2%	2	5.4%	37
2021	23	65.7%	9	25.7%	3	8.6%	35
2022	16	64.0%	6	24.0%	3	12.0%	25
2023	32	61.5%	12	23.1%	8	15.4%	52
Overall	119	64.7%	47	25.5%	18	9.8%	184

Abbreviation: SSI, surgical site infection
[a] Excludes cases with missing infection type information

Trends over time: The overall paediatric cardiac SSI rate was 3.7 infections per 100 surgeries, with annual rates fluctuating between 2.59 and 5.04 infections per 100 surgeries (**Figure 4**; Appendix, **Table A4**). No significant trend was observed during this five-year period. At 30 days post-infection, 71% of patients had been discharged. Five deaths (2.7% of cases) were reported within 30 days of infection onset, including two deaths directly attributable to the paediatric cardiac SSI. The most commonly identified pathogens were *S. aureus* (61%) and CoNS (13%), with no differences observed by infection type (data not shown).

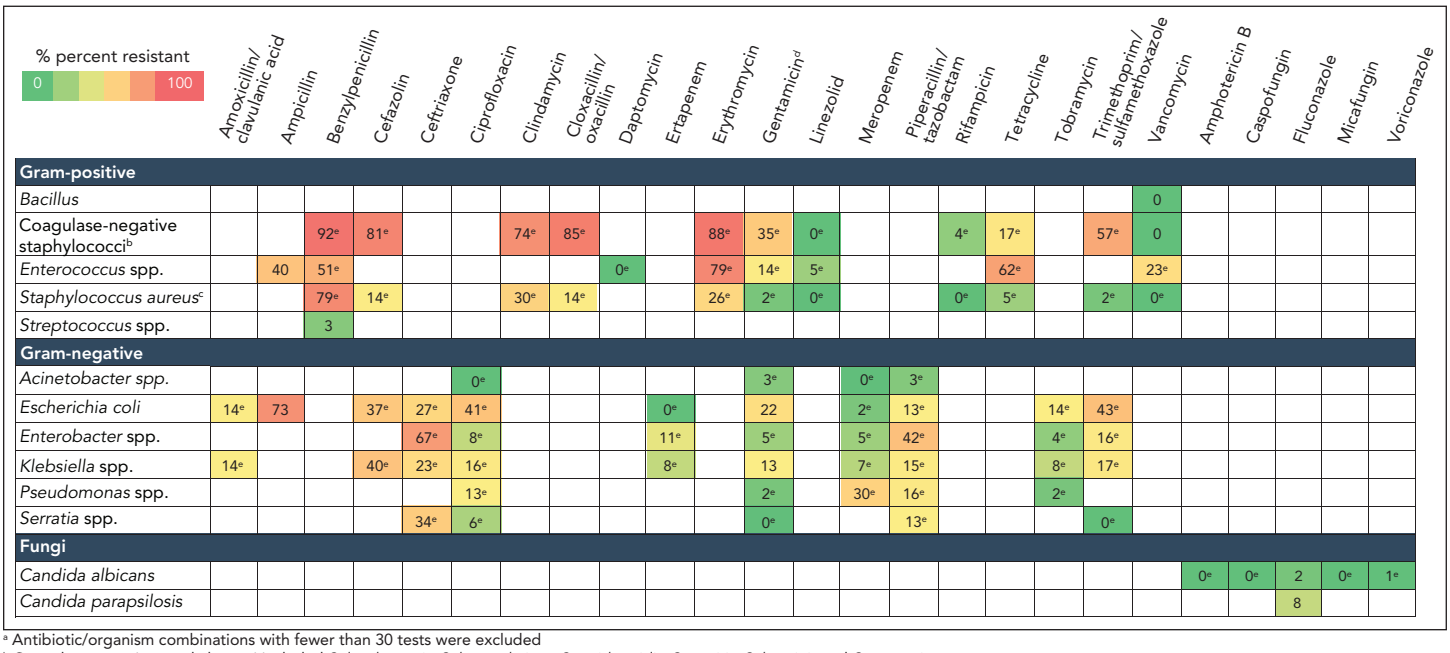
Figure 4: Paediatric cardiac surgical site infection rates per 100 surgeries, 2019–2023



Antibiogram

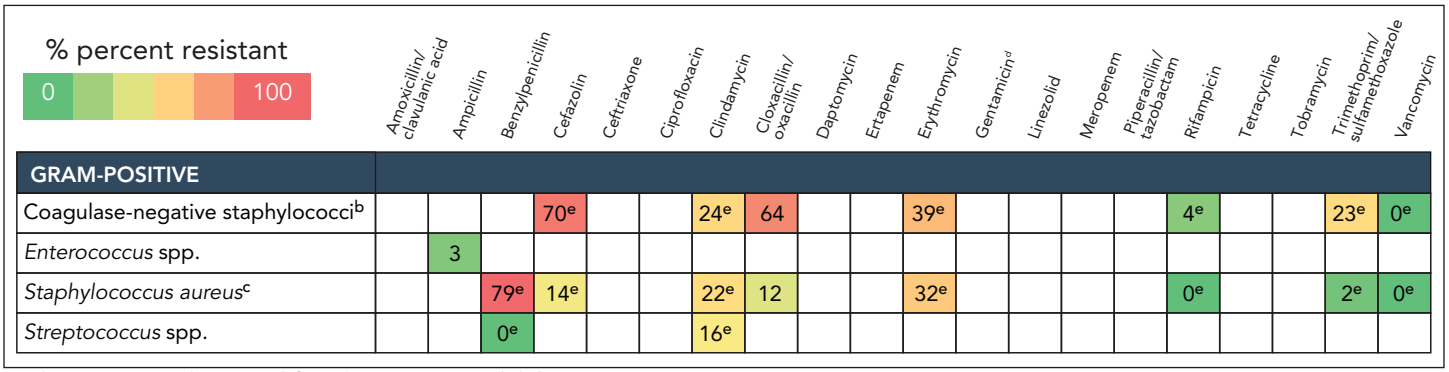
Results of antimicrobial susceptibility testing for the most frequently identified gram-positive, gram-negative and fungal pathogens from device and surgical procedure-related HAIs are listed in **Figure 5** and **Figure 6**. The *S. aureus* isolates were resistant to cloxacillin/oxacillin (MRSA) in 14% (n=27/198) of ICU-CLABSIs and 14% (n=46/337) of SSIs. Meropenem resistance ranged from 0% to 30% in gram-negative pathogens identified from ICU-CLABSIs. No meropenem resistance was observed among pathogens isolated from SSIs. Eighty-three vancomycin-resistant *Enterococci* were identified among ICU-CLABSIs (23%, n=335).

Figure 5: Antibiogram results[a] from pathogens identified from intensive care unit central line-associated bloodstream infections, 2019–2023[b,c,d,e]



[a] Antibiotic/organism combinations with fewer than 30 tests were excluded
[b] Coagulase-negative staphylococci included *S. lugdunensis*, *S. haemolyticus*, *S. epidermidis*, *S. capitis*, *S. hominis* and *S. warneri*
[c] Included methicillin-susceptible *S. aureus* and methicillin-resistant *S. aureus* (MRSA)
[d] Gentamicin synergy for gram-positive organisms
[e] Less than 90% of isolates were tested

Figure 6: Antibiogram results[a] from pathogens identified from hip and knee, cerebrospinal fluid shunt and paediatric cardiac surgical site infections, 2019–2023[b,c,d,e]



[a] Antibiotic/organism combinations with fewer than 30 tests were excluded
[b] Coagulase-negative staphylococci included *S. lugdunensis*, *S. haemolyticus*, *S. epidermidis*, *S. capitis*, *S. hominis* and *S. warneri*
[c] Included methicillin-susceptible *S. aureus* and methicillin-resistant *S. aureus* (MRSA)
[d] Gentamicin synergy for gram-positive organisms
[e] Less than 90% of isolates were tested

Discussion

This report summarizes 2,582 device-related infections and 1,029 surgical procedure-related infections as well as antibiogram data identified over five years of surveillance (2019–2023) from 68 hospitals across Canada. During this time, rates of device and surgical procedure-related HAIs have increased non-significantly by 26% for knee SSIs while ICU-CLABSIs have fluctuated and increased in all ICU settings throughout the study period except for in the NICU.

Intensive care unit central line-associated bloodstream infections

Central line-associated bloodstream infections were the predominant HAIs in this surveillance report, with observed case counts more than double those of all SSIs combined. Overall rates of CLABSIs in adult ICUs from 2019 to 2023 (1.80 and 0.90 infections per 1,000 line days in adult mixed ICUs and CVICUs, respectively) were lower than those reported in England during the same period (ranging from 1.7 to 3.3 infections per 1,000 line days) (10). Conversely, CNISP reported higher ICU-CLABSI rates than southeast Australia over the same timeframe,

ranging from 0.57 to 0.85 infections per 1,000 line days (11). Standardized infection ratios (defined as the ratio of observed number of infections compared to the 2015 baseline) from the United States have reported a 23% (95% CI: 21%–25%) decrease in 2023 CLABSI incidence across all ICU locations, with a 40% (95% CI: 36%–43%) decrease in CLABSIs noted in the NICU (12). According to CNISP-reported data in Canada, the incidence of CLABSIs in paediatric and neonatal ICUs was higher compared to England, where rates decreased from 2019 to 2023 and remained lower overall (0.95 and 1.26 infections per 1,000 line days, respectively) (10).

Surgical site infections

Hip and knee surgical site infections: Among SSIs included in this surveillance report, hip and knee SSIs were the most prevalent. Hip SSI rates fluctuated across reporting years, while knee SSI rates increased non-significantly. Over the same time period (2018–2023), surveillance from the United Kingdom showed a similar knee SSI rate to the CNISP data (0.4 infections per 100 procedures), while knee SSI rates in the United Kingdom were slightly lower than CNISP data (0.5 infections per 100 procedures vs. 0.65 infections per 100 procedures) (13). Hip and knee SSI rates in Southern Australia were higher overall than CNISP data and have also seen increases in recent years; hip SSI rates increased from 2018 to 2020 (1.80–1.91 infections per 100 procedures), while knee SSI rates increased from 0.79 to 0.88 infections per 100 procedures, during the same time period (14). The most common pathogens among hip and knee SSIs were *S. aureus* and CoNS, in accordance with results from other regions.

Cerebrospinal fluid shunt surgical site infections: The overall rate of SSIs from CSF shunts was 2.89 per 100 surgeries from 2019 to 2023. A national survey conducted in England in 2017 reported a mean brain shunt infection rate of 1.9% (range: 0%–4.4%), which is lower than the overall rate reported by CNISP (15). In contrast, a retrospective single-center study in Sweden reported a higher shunt infection rate of 4.8% in adult hydrocephalus patients who underwent surgery between 2013 and 2019 (16). Due to the lack of recent literature, comparisons with other regions are limited. To address this, we compared 2019–2023 data with historical CNISP surveillance data from 2011 to 2020 (17). Consistent with this earlier data, we observed a fluctuating trend in CSF shunt SSI rates from 2019 to 2023 (17). Stratification of CSF shunt SSI data by paediatric and adult/mixed hospitals showed that, from 2019 to 2023, paediatric rates (3.28 infections per 100 surgeries) and adult rates (2.49 infections per 100 surgeries) were not significantly different. Among paediatric patients, CSF shunt SSI rates from 2019 to 2023 (3.3%) were lower than those reported from 2000 to 2002 (4.9%), indicating a decline in SSI rates in this population compared to historical data (18). Similarly, the CSF shunt SSI rate among adult patients from 2019 to 2023 (2.5%) was lower than the rate reported from 2000 to 2002 (3.2%) (18).

Paediatric cardiac surgical site infections: Overall, from 2019 to 2023, 3.7 paediatric cardiac SSIs were reported per 100 surgeries. Data reported through the CNISP network indicated no significant trend in paediatric cardiac SSI rates from 2019 to 2023. Due to the lack of recent literature available, the ability to compare these results to other regions is limited; however, one academic medical centre in California reported a reduction in paediatric cardiac SSI rates from 3.4 SSIs per 100 surgeries in 2013 to 0.9 SSIs per 100 surgeries in 2017 following the implementation of a post-operative SSI reduction care bundle (19). In contrast, the United States reported a standardized infection ratio (defined as the ratio of observed number of infections compared to the predicted number of infections) of 0.71 (95% CI: 0.56–0.90) in 2023 when compared to the 2015 baseline period, indicating a decrease in paediatric cardiac SSI rates (12). However, only deep incisional and organ/space SSIs were included in these calculations (20).

Antibiogram

Due to the lack of recent literature, the ability to compare these results with other regions is limited. To address this, we compared 2019–2023 data with the previous 2018–2022 surveillance report; however, since the time periods overlap, observed changes may not reflect true trends and should be interpreted with caution (21). The percentage of *S. aureus* isolates that were MRSA among ICU-CLABSIs (14%) and SSIs (11%) in the CNISP network remained relatively stable over the 2019–2023 period compared to previous surveillance data from 2018–2022, where MRSA accounted for 15% of ICU-CLABSIs and 12% of SSIs. Among *Enterococcus* spp. identified in ICU-CLABSIs, 23% were vancomycin-resistant *Enterococci*, consistent with earlier findings (21). Similarly, meropenem resistance among gram-negative pathogens identified in ICU-CLABSIs remained highest in *Pseudomonas* spp. (30%), while resistance in other gram-negative pathogens ranged from 0% to 7% (21). Notably, meropenem resistance in *Pseudomonas* spp. identified in ICU-CLABSIs decreased from 38% in 2018–2022 to 30% in 2019–2023 (21).

Strengths and limitations

The main strength of CNISP surveillance is the standardized collection of detailed epidemiological and molecular linked data from a large representative network of sentinel hospitals across Canada. From 2019 to 2023, CNISP coverage of Canadian acute care beds has increased from 33% to 37%, including increased representativeness in northern, community, rural and Indigenous populations. To further improve representativeness, CNISP has launched a simplified dataset accessible to all acute care hospitals across Canada to collect and visualize annual HAI rate data. The number of hospitals participating in each HAI surveillance project differed and epidemiologic data collected were limited to the information available in the patient charts. For CLABSI surveillance, data were limited to infections occurring in the ICU settings, and as such may only represent a subset of CLABSIs occurring in the hospital. Further, when comparing our

infection rates with data from other countries, several limitations must be considered, including differences in surveillance methodologies, patient populations, and the number and types of hospitals under surveillance.

Conclusion

This report provides an updated summary of rates, pathogen distributions and antimicrobial resistance patterns among select device and surgical procedure-related HAIs and relevant pathogens. The collection and analysis of national surveillance data are important to understanding and reducing the burden of device and surgical procedure-related HAIs. These data provide benchmark rates for national and international comparison and inform antimicrobial stewardship and infection prevention and control programs and policies.

Authors' statement

Canadian Nosocomial Infection Surveillance Program hospitals provided expertise in the development of protocols in addition to the collection and submission of epidemiological and microbiological data. Epidemiologists from Public Health Agency of Canada were responsible for the conception, analysis, interpretation, drafting and revision of the article.

Competing interests

None.

Acknowledgements

We gratefully acknowledge the contribution of the physicians, epidemiologists, infection control practitioners and laboratory staff at each participating hospital: Vancouver General Hospital (VGH), Vancouver, British Columbia (BC); Richmond General Hospital, Richmond, BC; UBC Hospital, Vancouver, BC; Lion's Gate, North Vancouver, BC; Powell River General Hospital, Powell River, BC; Sechelt Hospital (formerly St. Mary's), Sechelt, BC; Squamish General Hospital, Squamish, BC; Victoria General Hospital, Victoria, BC; Royal Jubilee Hospital, Victoria, BC; Nanaimo Regional General Hospital, Nanaimo, BC; BC Women's Hospital, Vancouver, BC; BC Children's Hospital, Vancouver, BC; Kelowna General Hospital, Kelowna, BC; Penticton Regional Hospital, Penticton, BC; University Hospital of Northern BC, Prince George, BC; Abbotsford Regional Hospital, Abbotsford, BC; Burnaby Hospital, Burnaby, BC; Chilliwack General Hospital, Chilliwack, BC; Delta Hospital, Delta, BC; Eagle Ridge Hospital, Port Moody, BC; Fraser Canyon Hospital, Hope, BC; Langley Memorial Hospital, Langley, BC; Mission Memorial Hospital, Mission, BC; Peace Arch Hospital, White Rock, BC; Royal Columbian Hospital, New Westminster, BC; Ridge Meadows Hospital, Maple Ridge, BC; Surrey Memorial Hospital, Surrey, BC; Queen's Park Centre, New Westminster, BC; Fellburn Care Centre, Burnaby, BC; Fleetwood Place, Surrey, BC; Peter Lougheed Centre, Calgary, Alberta (AB); Rockyview General Hospital, Calgary, AB; South Health Campus, Calgary, AB; Foothills Medical Centre, Calgary, AB; Alberta Children's Hospital, Calgary, AB; University of Alberta Hospital, Edmonton, AB; Stollery Children's Hospital, Edmonton, AB; Royal University Hospital, Saskatoon, Saskatchewan (SK); Regina General Hospital, Regina, SK; Pasqua Hospital, Regina, SK; Moose Jaw Hospital, SK; St. Paul's Hospital, Saskatoon, SK; Health Sciences Centre-Winnipeg, Winnipeg, Manitoba (MB); University of Manitoba Children's Hospital, Winnipeg, MB; Children's Hospital of Western Ontario, London, Ontario (ON); St. Michael's Hospital, Toronto, ON; Victoria Hospital, London, ON; University Hospital, London, ON; Toronto General Hospital, Toronto, ON; Toronto Western Hospital, Toronto, ON; Princess Margaret, Toronto, ON; Mount Sinai Hospital, Toronto, ON; Bridgepoint Active Healthcare, Toronto, ON; Sunnybrook Hospital, Toronto, ON; Kingston General Hospital, Kingston, ON; The Hospital for Sick Children, Toronto, ON; McMaster Children's Hospital, Hamilton, ON; St Joseph's Healthcare, Hamilton, ON; Juravinski Hospital and Cancer Center, Hamilton, ON; Hamilton Health Sciences General Site, Hamilton, ON; The Ottawa Hospital Civic Campus, Ottawa, ON; The Ottawa Hospital General Campus, Ottawa, ON; University of Ottawa Heart Institute, Ottawa, ON; Children's Hospital of Eastern Ontario (CHEO), Ottawa, ON; North York General Hospital, Toronto, ON; Sudbury Regional Hospital, Sudbury, ON; Temiskaming Hospital, Temiskaming Shores, ON; Jewish General Hospital – Sir Mortimer B. Davis (JGH-SMBD), Montréal, Québec (QC); Lachine Hospital, Lachine, QC; Montreal Children's Hospital, Montréal, QC; Hôpital Maisonneuve-Rosemont, Montréal, QC; Hôtel-Dieu de Québec, QC; Centre hospitalier de l'Université de Montréal, Montréal, QC; Montreal General Hospital, Montréal, QC; Centre Hospitalier Universitaire Sainte-Justine, Montréal, QC; Royal Victoria Hospital, Montréal, QC; Montreal Neurological Institute, Montréal, QC; Hôpital régional de Rimouski, Rimouski, QC; Hôpital de Notre-Dame-du-lac, Témiscouata-sur-le-lac, QC; Centre hospitalier régional du Grand-Portage, Rivière-du-loup, QC; Hôpital Notre-Dame-de-Fatima, La Pocatière, QC; Hôpital d'Amqui, Amqui, QC; Hôpital de Matane, Matane, QC; The Moncton Hospital, Moncton, New Brunswick (NB); Halifax Infirmary, Halifax, Nova Scotia (NS); Victoria General, Halifax, NS; Rehabilitation Centre, Halifax, NS; Veterans Memorial Building, Halifax, NS; Dartmouth General Hospital, Halifax, NS; IWK Health Centre, Halifax, NS; General Hospital & Miller Centre, St. John's, Newfoundland and Labrador (NL); Burin Peninsula Health Care Centre, Burin, NL; Carbonear General Hospital, Carbonear, NL; Dr. G.B. Cross Memorial Hospital, Clarenville, NL; Janeway Children's Hospital and Rehabilitation Centre, St. John's, NL; St. Clare's Mercy Hospital, St. John's, NL; Sir Thomas Roddick Hospital, Stephenville, NL; Western Memorial Regional Hospital, Corner Brook, NL; Central Newfoundland Regional Health Centre, Grand Falls-Windsor, NL; James Paton Memorial Hospital, Gander, NL; Dr. Y.K. Jeon Kittiwake Health Centre, New-Wes-Valley, NL; Fogo Island Health Centre, Fogo, NL; Notre Dame Bay Memorial Health Centre, Twillingate, NL; Connaigre Peninsula Health Centre, Harbour Breton, NL; A.M. Guy Health Centre, Buchans, NL; Green Bay Health Centre, Springdale, NL; Baie Verte Peninsula Health Centre, Baie Verte, NL; Queen Elizabeth Hospital, Charlottetown, Prince Edward Island (PE); Prince County Hospital, Summerside, PE; Qikiqtani General Hospital, Nunavut.

Thank you to the staff at Public Health Agency of Canada in the Centre for Communicable Diseases and Infection Control, Ottawa, ON (J Bartoszko, J Cayen, K Choi, D Lee, C Lybeck, C McClellan, E McGill, R Mitchell, A Neitzel, A-K Nguyen, N Papayiannakis, S Rudat, A Silva, Z Suleman, O Varsaneux) and the National Microbiology Laboratory, Winnipeg, MB (S Ahmed, A Bangit, A Bharat, T Du, R Edirmanasinghe, K Fakharuddin, G Golding, G Grewal, R Hizon, X Li, L Mataseje, M McCracken, M Reimer, N Lerminiaux, J Tinsley).

Funding

This work was supported by Public Health Agency of Canada.

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Appendix

Case definitions

Central line-associated bloodstream infection

Only central line-associated bloodstream infections (CLABSIs) related to an intensive care unit (ICU) admission were included in surveillance.

Bloodstream infections case definition:

Bloodstream infection is **NOT** related to an infection at another site and it meets one of the following criteria:

Criterion 1: Recognized pathogen cultured from at least one blood culture, unrelated to infection at another site.

OR

Criterion 2: At least one of: fever (higher than 38°C core), chills, hypotension; if aged younger than 1 year, fever (higher than 38°C core), hypothermia (lower than 36°C core), apnea or bradycardia **AND** common skin contaminant (see list below) cultured from at least two blood cultures drawn on separate occasions or at different sites, unrelated to infection at another site. Different sites may include peripheral veins, central venous catheters or separate lumens of a multilumen catheter. Different times include two blood cultures collected on the same or consecutive calendar days via separate venipunctures or catheter entries. The collection date of the first positive blood culture is the date used to identify the date of positive culture. Two positive blood culture bottles filled at the same venipuncture or catheter entry constitute only one positive blood culture.

Central line-associated bloodstream infection case definition:

A CLABSI must meet one of the following criteria:

Criterion 1: A laboratory-confirmed bloodstream infection (LCBSI) where a central line catheter (CL) or umbilical catheter (UC) was in place for more than two calendar days on the date of the positive blood culture, with day of device placement being Day 1.

OR

Criterion 2: A LCBSI where a CL or UC was in place more than two calendar days and then removed on the day or one day before positive blood culture was drawn.

Intensive care unit-related central line-associated bloodstream infection case definition:

A CLABSI related to an ICU if it meets one of the following criteria:

Criterion 1: CLABSI onset after two days of ICU stay.

OR

Criterion 2: If the patient is discharged or transferred out of the ICU, the CLABSI would be attributable to the ICU if it occurred on the day of transfer or the next calendar day after transfer out of the ICU.

Note: If the patient is transferred into the ICU with the CL and the blood culture was positive on the day of transfer or the next calendar day, then the CLABSI would be attributed to the unit where the line was inserted.

Common skin contaminants:

Diphtheroids, *Corynebacterium* spp., *Bacillus* spp., *Propionibacterium* spp., coagulase-negative staphylococci (including *S. epidermidis*), viridans group streptococci, *Aerococcus* spp., *Micrococcus* spp. and *Rhodococcus* spp.

Hip and knee surgical site infection

Only complex surgical site infections (SSIs) (deep incisional or organ/space) following hip and knee arthroplasty were included in surveillance.

A deep incisional surgical site infection must meet the following criterion:

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure and involves deep soft tissues (e.g., facial and muscle layers) of the incision and the patient has at least **ONE** of the following:

- Purulent drainage from the deep incision but not from the organ/space component of the surgical site
- Deep incision that spontaneously dehisces or is deliberately opened by the surgeon and is culture-positive or not cultured when the patient has at least one of the following signs or symptoms: fever (higher than 38°C) or localized pain or tenderness (a culture-negative finding does not meet this criterion)
- An abscess or other evidence of infection involving the deep incision is found on direct examination, during reoperation or by histopathologic or radiologic examination
- Diagnosis of a deep incisional SSI by a surgeon or attending physician

An organ/space surgical site infection must meet the following criterion:

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure and infection involves any part of the body, excluding the skin incision, fascia or muscle layers, that is opened or manipulated during the operative procedure and patient has at least **ONE** of the following:

- Purulent drainage from a drain that is placed through a stab wound into the organ/space
- Organisms isolated from an aseptically obtained culture of fluid or tissue in the organ/space
- An abscess or other evidence of infection involving the organ/space that is found on direct examination, during reoperation or by histopathologic or radiologic examination
- Diagnosis of an organ/space SSI by a surgeon or attending physician

Cerebrospinal fluid shunt surgical site infection

Only patients who underwent a placement or revision of a cerebrospinal fluid (CSF) shunting device and the infection occurred within 90 days of surgery were included in surveillance.

Cerebrospinal fluid shunt-associated surgical site infection case definition:

An internalized CSF shunting device is in place **AND** a bacterial or fungal pathogen(s) is identified from the CSF **AND** is associated with at least **ONE** of the following:

- Fever (temperature 38°C or higher)
- Neurological signs or symptoms
- Abdominal signs or symptoms
- Signs or symptoms of shunt malfunction or obstruction

Paediatric cardiac surgery surgical site infection

Only surgical site infections following open-heart surgery with cardiopulmonary bypass among paediatric patients (younger than 18 years of age) were included in surveillance.

A **superficial incisional SSI** must meet the following criterion: Infection occurs within 30 days after the operative procedure and involves only skin and subcutaneous tissue of the incision and meets at least **ONE** of the following criteria:

- Purulent drainage from the superficial incision
- Organisms isolated from an aseptically obtained culture of fluid or tissue from the superficial incision
- At least **ONE** of the following signs or symptoms of infection:

- Pain or tenderness, localized swelling, redness or heat, and the superficial incision is deliberately opened by a surgeon, and is culture-positive or not cultured (a culture-negative finding does not meet this criterion)
- Diagnosis of superficial incisional SSI by the surgeon or attending physician

A **deep incisional SSI** must meet the following criterion:

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure **AND** involves deep soft tissues (e.g., facial and muscle layers) of the incision **AND** the patient has at least **ONE** of the following:

- Purulent drainage from the deep incision but not from the organ/space component of the surgical site
- Deep incision spontaneously dehisces or is deliberately opened by the surgeon and is culture-positive or not cultured when the patient has at least one of the following signs or symptoms: fever (higher than 38°C) or localized pain or tenderness (a culture-negative finding does not meet this criterion)
- An abscess or other evidence of infection involving the deep incision is found on direct examination, during reoperation or by histopathologic or radiologic examination
- Diagnosis of a deep incisional SSI by a surgeon or attending physician

An **organ/space SSI** must meet the following criterion:

Infection occurs within 90 days after the operative procedure and the infection appears to be related to the operative procedure **AND** infection involves any part of the body, excluding the skin incision, fascia or muscle layers, that is opened or manipulated during the operative procedure **AND** the patient has at least **ONE** of the following:

- Purulent drainage from a drain that is placed through a stab wound into the organ/space
- Organisms isolated from an aseptically obtained culture of fluid or tissue in the organ/space
- An abscess or other evidence of infection involving the organ/space that is found on direct examination, during reoperation or by histopathologic or radiologic examination

Table A1: Rate of central line-associated bloodstream infection per 1,000 line days by intensive care unit type, 2019–2023

Year	Adult mixed ICU	Adult CVICU	NICU	PICU
2019	1.41	0.6	1.81	1.92
2020	1.73	0.92	1.88	1.5
2021	2.12	1.19	1.45	1.79
2022	1.85	0.82	1.78	1.47
2023	1.82	1.01	1.97	1.84
Overall	1.80	0.90	1.79	1.71

Abbreviations: CVICU, cardiovascular intensive care unit; ICU, intensive care unit; NICU, neonatal intensive care unit; PICU, paediatric intensive care unit

Table A2: Rate of hip and knee surgical site infections per 100 surgeries, 2019–2023

Year	Hip	Knee
2019	0.79	0.34
2020	0.47	0.34
2021	0.63	0.26
2022	0.74	0.41
2023	0.60	0.43
Overall	0.65	0.36

Table A3: Cerebrospinal fluid shunt surgical site infection rates per 100 surgeries by hospital type, 2019–2023

Year	Adult and mixed hospitals	Paediatric hospitals	All hospitals[a]
2019	3.25	4.56	3.83
2020	2.17	3.2	2.73
2021	1.76	2.80	2.32
2022	2.14	4.05	3.14
2023	2.98	1.43	2.15
Overall	2.49	3.28	2.89

[a] All hospitals include adult, mixed, and paediatric hospitals participating in cerebrospinal fluid shunt surgical site infection surveillance

Table A4: Paediatric cardiac surgical site infection rates per 100 surgeries, 2019–2023

Year	Rate
2019	5.04
2020	3.46
2021	3.31
2022	2.59
2023	4.43
Overall	3.71

Ten years of Foodbook: Utilization of Foodbook survey data for research

Heather Grieve[1], Jillian Macleod[1], Lauren E Grant[1]

Abstract

Background: Enteric illnesses are a preventable cause of morbidity and healthcare utilization in Canada. To support public health and epidemiological activities, Foodbook was launched in 2014 by the Public Health Agency of Canada to collect representative information on food, water, and animal exposures, food safety knowledge, burden of gastrointestinal illnesses, and sociodemographic information. The aim of this overview was to identify how this valuable data source has been used in the past decade since its launch.

Methods: Peer-reviewed and grey literature were identified by applying the search term "Foodbook" to two academic databases and two grey literature sources, respectively. Citations were screened against eligibility criteria. Study information, including study characteristics, module of Foodbook data used, and how Foodbook data was used was extracted and synthesized in tabular format.

Results: A total of 27 articles were identified in the published literature that utilized Foodbook survey data in their analyses. The most common use was for outbreak investigations. In addition, Foodbook has been used to describe food, water, and animal exposures, determine food safety knowledge and practices of Canadians, estimate the burden of acute gastrointestinal illness, and evaluate data collection methods for foodborne illnesses.

Conclusion: By summarizing its use, the authors aim to encourage broader use of this publicly available data source to inform health protection and promotion activities to reduce the burden of enteric illnesses in Canada.

Suggested citation: Grieve H, Macleod J, Grant LE. Ten years of Foodbook: Utilization of Foodbook survey data for research. Can Commun Dis Rep 2025;51(6/7):283–91. https://doi.org/10.14745/ccdr.v51i67a06
Keywords: Foodbook, public health, population health, foodborne disease, foodborne illness, enteric illness, epidemiologic methods, surveys, questionnaires

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Introduction

Foodborne illnesses are a preventable cause of morbidity and healthcare utilization in Canada, with approximately 4 million annual episodes (1). While symptoms are often self-limiting, domestically acquired infections result in over 11,000 hospitalizations and 200 deaths each year (2). In Ontario alone, foodborne illnesses contribute to an estimated 137,000 primary care visits, 40,000 emergency department visits, and 6,200 hospitalizations annually, representing an important source of preventable healthcare utilization (3).

Foodbook is a population-based survey developed, conducted, and funded by the Public Health Agency of Canada (PHAC) to collect representative information on food, water, and animal exposures to support response to enteric illness outbreaks, inform health protection activities, and identify associations with sociodemographic factors and food safety behaviours (4). The first version of Foodbook (Foodbook 1.0) was conducted in all provinces and territories over a one-year period, from April 2014 to April 2015. The sampling frame consisted of cellphones (20%) and landlines (70% listed numbers plus 10% random digit dialing). Interviews were conducted in English, French, and Inuktitut and on demand translation was available for other languages. In addition to sociodemographic data and information on seven-day food consumption, information was also collected on other risk factors, including drinking and recreational water exposures, animal exposures, and food safety knowledge, as well as burden of acute gastrointestinal illnesses (4). Those who travelled outside the province or

territory during the recall period were excluded. In the first cycle, 10,942 interviews were completed, with an overall response rate of 19.9%. A Foodbook 1.0 public use microdata file (PUMF) is available through the Government of Canada Open Government Portal (5).

Data collection for the second version (Foodbook 2.0) was completed from January 2023 to January 2024, online and by telephone, and the second report was released in July 2024 (6). This provides a timely opportunity to review how Foodbook data has been utilized to date. This article offers a brief synthesis describing the use of Foodbook data to advance our understanding of the epidemiology of enteric illnesses in the Canadian population, as available in the published literature.

Methods

Peer-reviewed articles were identified by applying the search term "Foodbook" to two academic databases, PubMed and Web of Science, and two grey literature sources, namely Google Scholar and the PHAC website. No date or language limiters were applied. The initial search was conducted in July 2023 and updated in June 2024. Citations were screened according to the following inclusion criteria: 1) Foodbook was used as a data source and 2) the study was peer-reviewed. The initial list of included citations was then reviewed by a PHAC epidemiologist responsible for Foodbook to check for completeness. Study information, including study characteristics, module of Foodbook data used, and how Foodbook data was used was extracted and synthesized in tabular format.

Results

In total, 27 articles were included that used Foodbook for enteric illness-related studies. These studies were broadly categorized into five purposes: outbreak investigations (n=11), exposure types (n=9), food safety knowledge and practices (n=3), methods development (n=3), and burden of acute gastrointestinal illnesses (n=1). An overview of these studies, including the modules of Foodbook utilized, a brief description of how the data was used, and the main findings is provided in **Table 1**.

Table 1: Summary of publicly available, peer-reviewed articles using Foodbook for enteric illness-related studies

Title (reference) (publication year)	Category	Study type	Foodbook module used	How Foodbook data was used	Main findings
An outbreak of *Salmonella* Typhimurium infections linked to ready-to-eat tofu in multiple health districts - Ontario, Canada, May–July 2021 (7) (2023)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	Tofu was identified as the source of the outbreak.
Bi-national outbreak of *Salmonella* Newport infections linked to onions: the United States experience (8) (2022)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	Red onions were identified as the source of the outbreak.
2015 outbreak of cyclosporiasis linked to the consumption of imported sugar snap peas in Ontario, Canada (9) (2017)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	Fresh sugar snap peas imported from Guatemala were identified as the source of the outbreak.
Escherichia coli O121 outbreak associated with raw milk Gouda-like cheese in British Columbia, Canada, 2018 (10) (2021)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	Raw milk Gouda-like cheese was found to be the source of the outbreak due to contaminated raw milk.
International outbreak of multiple *Salmonella* serotype infections linked to sprouted chia seed powder - USA and Canada, 2013–2014 (11) (2017)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	Sprouted chia seed powder was the implicated source of the *Salmonella* outbreak.
Nuggets of wisdom: *Salmonella* Enteritidis outbreaks and the case for new rules on uncooked frozen processed chicken (12) (2017)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	Uncooked, frozen, processed chicken products produced at a single establishment were implicated as the source of the outbreaks.
Fermenting a place in history: the first outbreak of *Escherichia coli* O157 associated with kimchi in Canada (13) (2023)	Outbreak investigations	Descriptive	Food, animal	Reference values for comparing reported food exposures against	Kimchi was implicated as the source of the outbreak, with Napa cabbage being the most likely contaminant.

Table 1: Summary of publicly available, peer-reviewed articles using Foodbook for enteric illness-related studies (*continued*)

Title (reference) (publication year)	Category	Study type	Foodbook module used	How Foodbook data was used	Main findings
Investigation of a *Salmonella* Montevideo outbreak related to the environmental contamination of a restaurant kitchen drainage system, Québec, Canada, 2020–2021 (14) (2023)	Outbreak investigations	Descriptive	Food	Reference values for comparing reported food exposures against	A restaurant was implicated as the likely source of the outbreak, though no source was conclusively identified.
Use of a case-control study and control bank to investigate an outbreak of locally acquired cyclosporiasis in Canada, 2016 (15) (2019)	Outbreak investigations	Case-control	Food	Reference values for comparing reported food exposures against, the Foodbook control bank was also used to recruit controls for a case-control study	Foodbook reference values highlighted several items consumed more frequently by cases, whereas the case-control study identified just two of these items as being consumed more frequently by cases. The source of the outbreak was not conclusively identified.
A multi-provincial *Salmonella* Typhimurium outbreak in Canada associated with exposure to pet hedgehogs, 2017–2020 (16) (2022)	Outbreak investigations	Descriptive	Animal	Reference values for comparing reported animal contact exposures against	Direct and indirect contact with hedgehogs was determined to be the source of the outbreak.
Outbreak of *Salmonella* Typhimurium associated with feeder rodents (17) (2018)	Outbreak investigations	Descriptive	Animal	Reference values for comparing reported animal contact exposures against	Feeder rodents were implicated as the main source of the outbreak.
Examining the diversity of ultra-processed food consumption and associated factors in Canadian adults (18) (2020)	Exposure types	Descriptive	Food	To describe ultra-processed food (UPF) consumption across Canada and explore associations between sociodemographic variables and UPF consumption	Most Canadians consume UPFs at least weekly. When controlling for potential confounders, younger age and higher BMI was associated with higher UPF consumption in both men and women.
Fast food consumption in adults living in Canada: alternative measurement methods, consumption choices, and correlates (19) (2023)	Exposure types	Descriptive	Food	To compare methods for estimating fast food consumption and to describe the fast-food consumption of Canadians, including any associations with sociodemographic variables	Asking detailed questions about fast food consumption results in increased recall compared to asking more broadly. Fast food consumption is common and some of the factors associated with increased consumption are gender-specific.
Country food consumption in Yukon, Northwest Territories and Nunavut, Foodbook study 2014–2015 (20) (2021)	Exposure types	Descriptive	Food	To describe consumption of country food amongst residents of Yukon, Northwest Territories and Nunavut	The consumption of specific country foods varied by territory, but inter-territory comparisons are difficult due to differences in landscape, climate, populations, and cultural factors. Generally, country food consumption increased with age and lower income was associated with higher consumption.
Consumption of high-risk foods in the Canadian population, Foodbook study, 2014 to 2015 (21) (2021)	Exposure types	Descriptive	Food	To describe consumption of high-risk foods amongst the Canadian population	Consumption of high-risk foods is common in Canadians. The number of high-risk foods consumed was similar amongst males and females, but the types of high-risk food consumed varied by gender. Knowledge of risk did not appear to impact on consumption.
Drinking and recreational water exposures among Canadians: Foodbook study 2014–2015 (22) (2018)	Exposure types	Descriptive	Water	To describe drinking and recreational water exposures amongst the Canadian population	Drinking water sources differ between provinces with private well use being greater in the Maritime provinces than in the rest of the country. Recreational water exposures are highest amongst children aged 0–9 years.

Table 1: Summary of publicly available, peer-reviewed articles using Foodbook for enteric illness-related studies (*continued*)

Title (reference) (publication year)	Category	Study type	Foodbook module used	How Foodbook data was used	Main findings
Measuring animal exposure in Canada: Foodbook study, 2014–2015 (23) (2018)	Exposure types	Descriptive	Animal	To describe animal exposure, including direct and indirect contact, amongst the Canadian population	Cats and dogs were the most commonly reported animal exposures. Children aged 0–9 years reported relatively high exposure to higher risk animals such as rodents and reptiles.
Risk profile of hepatitis E virus from pigs or pork in Canada (24) (2017)	Exposure types	Descriptive	Food	To estimate pork and pork liver consumption amongst Canadians to inform development of a risk profile for hepatitis E virus from pigs or pork	The proportion of the population at high risk for acquiring hepatitis E from pigs or pork in Canada is considered to be relatively small.
A comparative exposure assessment of *Campylobacter* in Ontario, Canada (25) (2017)	Exposure types	Descriptive	Food, water, animal	To inform frequency estimates for modelling exposure to *Campylobacter* via food, water, and animal contact routes	The results suggest that some transmission routes such as raw milk and companion animal contact are underestimated in the existing literature.
A comparative exposure assessment of foodborne, animal contact and waterborne transmission routes of *Salmonella* in Canada (26) (2020)	Exposure types	Descriptive	Food, water, animal	To inform frequency estimates for modelling exposure to *Salmonella* via food, water, and animal contact routes	Chicken meat was the highest exposure route.
Canadian consumer food safety practices and knowledge: Foodbook study (27) (2017)	Food safety knowledge and practices	Descriptive	Consumer food safety	To describe the food safety practices and knowledge of Canadians	The majority of Canadians take appropriate cleaning and separating precautions to prevent foodborne illness, however, use of food thermometers is low. Differences in practices and knowledge were found between some sociodemographic groups, including gender and age.
Identifying predictors of safe food handling practices among Canadian households with children under eighteen years (28) (2023)	Food safety knowledge and practices	Descriptive	Food safety	To identify determinants of safe food handling amongst Canadian households with children younger than 18 years old.	Key differences in food safety practices were found between different sociodemographic groups, including education levels, and living in an urban area.
Predictors of safe food handling among Canadian seniors living at home (29) (2020)	Food safety knowledge and practices	Descriptive	Food safety	To identify determinants of safe food handling practices amongst Canadian seniors living at home	Most seniors followed instructions and food labels and appropriately refrigerated food. Women and younger seniors were more likely to have better food handling practices.
Online population control surveys: A new method for investigating foodborne outbreaks (30) (2020)	Methods development	Descriptive	Food	Online survey data collected during an outbreak investigation was compared to Foodbook data to evaluate the use of online surveys as a method for collecting data during outbreaks	Online surveys allow for rapid collection of control data which can be used in outbreak investigations, whilst also providing flexibility about what data is collected.
The use of an online survey for collecting food exposure information, Foodbook sub-study, February to April 2015 (31) (2021)	Methods development	Descriptive	Food	To compare food exposure data collected by online surveys to that collected via telephone survey	Reported food consumption was higher for those completing the online survey compared to the telephone survey.

Table 1: Summary of publicly available, peer-reviewed articles using Foodbook for enteric illness-related studies (*continued*)

Title (reference) (publication year)	Category	Study type	Foodbook module used	How Foodbook data was used	Main findings
Comparison of 3-day and 7-day recall periods for food consumption reference values in foodborne disease outbreak investigations (32) (2019)	Methods development	Descriptive	Food	A sub-sample of Foodbook respondents were asked about food exposures during the past 3 days (compared to 7 days for the main study). The food exposure frequencies for the two groups were compared	The majority of food consumption frequencies were similar for both groups, however, when applied during an outbreak investigation only the three-day recall period reference values supported the conclusion that chicken was the source of the outbreak.
The incidence of acute gastrointestinal illness in Canada, Foodbook survey 2014–2015 (33) (2017)	Burden of gastrointestinal illness	Descriptive	Acute gastrointestinal illness	To estimate the incidence of acute gastrointestinal illness in the last 28 days and describe healthcare seeking behaviours	It was estimated that there are 0.57 self-reported acute gastrointestinal illness episodes per person-year, and less than 10% of cases seek medical care.

Abbreviations: BMI, body mass index; UPF, ultra-processed food

Discussion

The most common use of Foodbook is to support outbreak investigations. There are several examples of outbreak investigations successfully using Foodbook food exposure data as reference values to which the reported exposures of cases are compared, including a *Salmonella* Typhimurium outbreak linked to pre-prepared tofu (7), *Salmonella* Newport infections linked to onions (8), cyclosporiasis linked to sugar snap peas (9), an *Escherichia coli* outbreak linked to raw milk Gouda-style cheese (10), *Salmonella* infections of multiple serovar types linked to sprouted chia seed powder (11), and *Salmonella* Enteritidis infections linked to frozen, uncooked, processed chicken (12).

In an *Escherichia coli* outbreak investigation, comparisons were made to the Foodbook reference values and significant differences were observed; however, the source of the outbreak was determined to be kimchi, which is not included in the Foodbook data (13). In another study, reference values for food exposures were used during a *Salmonella* Montevideo outbreak (14). While the source was later attributed to contaminated plumbing at a restaurant, it was suggested that the plumbing could have been contaminated by chicken, and indeed, cases were significantly more likely to have consumed chicken at a restaurant compared to the reference values provided by Foodbook.

An investigation into a cyclosporiasis outbreak utilized Foodbook for both reference values and for recruiting controls for a case-control study (15). This was made possible by creating a control bank of Foodbook participants who consented to being contacted to assist with future investigations. The authors highlight that having access to this control bank allowed for a case-control study to be conducted in a timely and cost-effective manner.

Two outbreaks of *Salmonella* Typhimurium utilized Foodbook as part of their investigations, where hedgehogs (16) and feeder rodents (17) were eventually identified as the respective causes, demonstrating that Foodbook can be used to investigate outbreaks with animal sources.

Characterizing different exposures

Food exposures

Collection of food exposure information has elucidated the eating patterns of Canadians. For example, ultra-processed foods (UPF) are commonly consumed, with these items being consumed at least weekly by 99.0% of respondents (18). Younger age and higher body mass index (BMI) were associated with UPF consumption in both males and females. Fast-food was consumed at least weekly by 48.0% of respondents, with highest fast-food consumption among men and those of younger age (19). Sex-specific multivariable logistic regression models highlighted differences between males and females. For example, women in central Canada (compared to the territories), and men with an income of $30,000 to $80,000 (versus a higher income) had higher fast-food consumption (19).

Foodbook respondents from Yukon (YT), Northwest Territories (NT) and Nunavut (NU), were also asked questions regarding consumption of country or traditional food items, referring to "food that is trapped, fished, hunted, harvested, or grown for subsistence or medicinal purposes, outside of the commercial food chain" (34). Consumption of country food during the previous seven days varied by territory, ranging from 60.7% of respondents in NT to 77.5% in NU (20). Overall, this food-specific data can support nutrition and food security research, in addition to outbreak investigations (20).

Consumption of foods considered high-risk for enteric illness, such as unpasteurized milk, cheese, or juice, is common among Canadians, with approximately 94% of respondents consuming at

least one high-risk food per week, and more than half consuming three or more foods (21). Importantly, knowledge of high-risk foods did not influence consumption, suggesting that improving food safety practices may be of greater benefit in reducing the risk of illness associated with these foods.

Water exposures

One study analyzed Canadians' exposure to drinking and recreational water (22). While most Canadians use municipal drinking water (68.5%), 10.8% of respondents indicated that a private well was their primary source of drinking water; however, this figure was as high as 40.2% to 55.6% in the Maritime provinces. Private well use was also highest among rural residents. Further, 18.8% of respondents used bottled water as their primary source, and residents of Saskatchewan (SK) were more likely to consume bottled water (22). Regarding recreational water, children aged 0–9 years were most exposed. Unsurprisingly, recreational water exposure was highest across all age groups during the summer months, during which up to 30% of respondents reported recreational water exposure. Together, this data informs private well water testing recommendations and messaging, as well as enhanced public health messaging during the summer months, with specific messaging aimed at parents and caregivers given the higher level of recreational water use among children (22).

Animal exposures

A descriptive analysis of animal exposure data showed that most respondents (63.4%) had contact with an animal, animal food or waste, or an animal habitat within the previous seven days (23). Animal contact was highest among children, an at-risk group for more serious enteric illness. Overall, dogs and cats were shown to be the most common animal exposure. Given that companion animals are often an overlooked source of zoonotic infections, this analysis provides the basis for continued awareness campaigns to reduce the risk of illness and improved surveillance for identifying outbreaks.

Comparative exposure assessments

Comparative exposure assessments have been conducted utilizing Foodbook to characterize different exposure routes to hepatitis E from pigs or pork (24), *Campylobacter* (25) and *Salmonella* (26). In the first study, the number of Canadians consuming pork liver supported the hypothesis that a relatively low number of Canadians are at high risk of contracting hepatitis E via this route (24). Foodbook was used more extensively in the *Campylobacter* and *Salmonella* studies. In both studies, chicken meat was the highest source of foodborne exposures, and the authors discuss how interventions could reduce risk posed by these pathogens (26).

Food safety knowledge and practices

Foodbook has been used to explore the food safety knowledge and practices of Canadians (27), including those at higher risk for severe enteric illness, namely, children (28) and seniors (29).

While most Canadians reported cleaning their hands after handling meat and taking appropriate measures to avoid cross contamination, the use of food thermometers and awareness of specific high-risk foods was low, highlighting the need for improved messaging and education (27).

Most seniors followed instructions on food labels and refrigerated leftovers within two hours (29). Following instructions on food labels was significantly associated with food safety storage practices. Interestingly, there was no association between knowledge that seniors are at an increased risk of foodborne illness and safe food storage practices, highlighting that food safety knowledge is not an accurate proxy for food safety practices among Canadian seniors (29).

Among households with children, higher earners, and those living in urban areas were less likely to wash their hands with soap after handling raw meat (28). The practice of separating food in the refrigerator to avoid cross contamination was more likely to be practiced by female caregivers and single-child households. Education level was inversely associated with food safety practices, as those with a bachelor's degree were less likely to refrigerate food within two hours and use a food thermometer. These findings demonstrate key demographic subgroups that may benefit from targeted public health messaging relating to food safety practices.

Methods development in foodborne illness research

Using the Foodbook telephone survey data as a comparator group, the utility of online surveys for collecting food exposure information was investigated by two studies (30,31), which found that online surveys present an efficient, accurate, and lower cost approach for data collection, which may be particularly useful during outbreak investigations when speed of response is important. Differences in exposure information collected online and by telephone may partially be explained by differing recall periods (14-day for the online survey versus 7-day for Foodbook) and changing food preferences (30).

The impact of recall periods on reported food exposures and their subsequent utility in identifying outbreak sources was examined by one study, which found no overall difference in reported consumption of most foods when comparing three- and seven-day recall periods (32). However, when data from a *Salmonella* Infantis outbreak was compared to the reference values for both groups, only the three-day recall period group showed a significant result for the identified source of the outbreak, suggesting that a three-day recall period is preferred when investigating illnesses with a short incubation period or where the source is a commonly consumed item (32).

A study discussed earlier, which utilized Foodbook data to explore fast food consumption, also demonstrated that question type can influence the reported consumption of fast foods (19). In the Foodbook survey, there are three questions relating to fast

food consumption; in one question, no examples of fast food were given, whereas in two more detailed questions, examples of specific fast-food types were provided. Respondents who answered the broader question reported less consumption of fast foods compared to those answering either of the two more detailed questions (19).

Estimating the burden of acute gastrointestinal illness
Analysis of Foodbook data provided the first estimate of acute gastrointestinal illness burden in Canada, with an estimated 19.5 million episodes each year (33). Differences in burden were demonstrated (albeit not significantly) between provinces and territories, highlighting the need to collect nationally representative data. This information, coupled with demonstrated seasonal patterns, can be used in the design of locally tailored public health interventions, and in healthcare services planning (33).

Limitations

Foodbook 1.0
The Foodbook 1.0 report lists several limitations, including potential non-response bias due to the exclusion of individuals without a telephone and those unable to communicate in one of the survey languages. This may have disproportionately impacted residents of Northern Canada, where there is a larger proportion of individuals living in remote communities without reliable access to a telephone, affecting representativeness of the data and resultant findings. Other types of bias outlined in the report include recall bias and low response rate (4).

Several of the included articles identified additional limitations of Foodbook, including recall bias (21–23,33) and non-response bias (18,19,20–22,27,28,33). Several studies discussed the potential for social desirability bias, including in relation to consumption of UPFs (18), fast-food (19), high risk foods (21) and food handling practices (28,29). The lack of demographic variables, including ethnicity, pregnancy status, and health status (i.e., whether an individual is considered high risk for enteric illness) also limits exploration of food consumption in particular groups (20,21,27). The small sample size for some sub-populations, such as parents and caregivers, was also highlighted as a limitation (28), and the availability of data regarding education level (22). Further, the sample size of respondents selected to participate in the online survey sub-study (31) and three-day recall period sub-study (32) were highlighted as limitations.

The utility of Foodbook exposure data is also limited by the specific foods included in the study (10,13,14,18,21). This includes lack of information relating to serving size or frequency of intake, which is of particular importance when attempting to quantify exposure to particular food groups (18). For one study, the seven-day recall period selected by Foodbook presented a limitation as this did not match with case interviews, where a 14-day period was chosen to align with the incubation period for cyclosporiasis (15). In terms of animal exposure, Foodbook did not capture data regarding where the animal exposure occurred, meaning that it is not possible to draw conclusions about high-risk animal environments (23). Lastly, data for the food safety practices module were collected from November to April, and this was identified as a limitation given the potential for food safety practices to vary over time (27).

Foodbook 2.0
Foodbook 2.0 includes several key updates. First, a dual sampling frame was utilized with 75% of the sample derived from a list of mailing addresses and the remainder from listed telephone numbers (6). To increase the number of children participating, after the fifth month of data collection in households with children, a child was selected to participate 100% of the time. Ethnicity data was also collected as part of Foodbook 2.0.

Additional exposure data included information on special diets, food shopping habits, and information relating to types of water and animal exposures. We also note that additional food items identified as potential sources of enteric illness are included in Foodbook 2.0, expanding the utility of Foodbook as a resource for use in outbreak investigations (6).

Conclusion

Foodbook is a valuable data resource for food, water, and animal exposures, food safety behaviours, and socio-demographic factors that increase risk of enteric illnesses in Canada. This resource has supported multiple public health activities, most predominantly, outbreak investigations. In this commentary, we have focused on the use of Foodbook as described in the published literature. However, it is recognized that other uses of Foodbook may not have resulted in publications. By synthesizing published studies, the aim is to increase the visibility of Foodbook as an openly accessible resource for conducting epidemiological studies. In particular, the release of Foodbook 2.0 provides an opportunity to assess how patterns in food, water, and animal-related exposures have changed over time and to update associations with socio-demographic and behavioural factors. Moreover, there is an opportunity to utilize Foodbook to inform food safety and health promotion activities. Lastly, linkage to other data sources, application of a health equity lens to assess differential risk across key socio-demographic groups, and novel use of methodological tools, such as artificial intelligence, will provide further insights to reduce enteric illness burden in Canada.

Authors' statement

HG — Data curation, writing–original draft
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The content and view expressed in this article are those of the authors and do not necessarily reflect those of the Government of Canada.

Competing interests

The authors have no conflicts of interest to declare.

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Acknowledgements

None.

Funding

HG is funded by the Public Health Agency of Canada Infectious Disease and Climate Change Fund program (Grant Number 2324-HQ-000026 held by LEG). JH was supported by an Undergraduate Research Assistantship from the University of Guelph.

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Public Health Agency of Canada

Published by authority of the Minister of Health.

This publication is also available online at

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Relevé des maladies transmissibles au Canada