Measles surveillance in Canada, 2019

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Abstract

Background: The Public Health Agency of Canada (PHAC) has conducted enhanced measles surveillance since 1998, the year endemic measles transmission was eliminated in Canada. The objective of this annual national measles surveillance report is to provide an epidemiologic summary of measles activity reported in Canada for 2019 in order to provide evidence to support the continued verification of Canada's measles elimination status.

Methods: Measles surveillance data are housed in the Canadian Measles and Rubella Surveillance System (CMRSS) database. Descriptive analyses of demographics and risk factors were performed. Outbreak characteristics were summarized and genotypic analyses conducted. Surveillance, laboratory and vaccine coverage data for 2019 were used to assess Canada's status against the Pan American Health Organization (PAHO) essential criteria for the verification of measles elimination.

Results: In 2019, 113 measles cases were reported in Canada (crude incidence rate of 3.0 cases per 1,000,000 population). Of these cases, 42 (37%) were imported into Canada, and of the imported cases, 12 (29%) resulted in further transmission. Infants younger than one year had the highest age-specific incidence rate at 13.1 cases per 1,000,000 population. Only 29% of cases had one or more documented doses of measles-containing vaccine. One-fifth (19%) of cases were hospitalized; no deaths were reported. Genotype information was available for 100% of outbreaks reported in 2019 and 90% of non-outbreak-related measles cases; of cases with genotype information available, 27% were B3 and 73% were D8.

Conclusion: Despite meeting/partially meeting only three out of four of PAHO's essential criteria for measles elimination status, there is no evidence that endemic measles transmission has been reestablished in Canada.

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Introduction

Although vaccine preventable, measles is still a major cause of morbidity and mortality, especially in children younger than five years (1). In 2018, the last year for which estimates are available, there were approximately 9.8 million measles cases and 142,000 measles-related deaths worldwide (2). Global efforts to eliminate measles (which is defined as the absence of endemic measles transmission for at least 12 months in a defined geographic area with a well-performing surveillance system) began in 1963 with the introduction of the first measles vaccine (1,3).

In 1998, Canada was one of the first countries to eliminate endemic measles transmission following the pan-Canadian introduction of routine two-dose measles-mumps-rubella (MMR) vaccination for children in 1996–1997 (3,4). However, Canada's elimination status is threatened by infected travellers importing measles into Canada, particularly into pockets of the Canadian population that have suboptimal measles vaccination coverage rates (3–5). As such, it is critical that Canada has a strong measles surveillance capacity, including laboratory capacity, to rapidly identify measles cases so that public health actions can be taken to reduce spread and prevent the reestablishment of endemic measles (6).

The Public Health Agency of Canada (PHAC), including the National Microbiology Laboratory (NML), works with provinces and territories to conduct national measles surveillance. The Agency reports on measles activity weekly both publicly on the canada.ca website and to the Pan American Health Organization (PAHO) (7,8).

The objective of this annual national measles surveillance report is to provide an epidemiologic summary of measles activity reported in Canada for 2019 in order to provide evidence to support the continued verification of measles elimination status.

Methods

Surveillance data

The Canadian Measles and Rubella Surveillance System (CMRSS) is an active, enhanced surveillance system supported by all Canadian provinces and territories. Confirmed cases of measles meeting the national case definition were reported weekly to PHAC by provinces and territories and housed in the CMRSS database (7,8). All confirmed cases of measles with rash onset between January 1, 2019, and December 31, 2019, were included in this report. PHAC assigns epidemiologic weeks of rash onset with week one ending on the first Saturday of the year. A data validation process was conducted with all provinces and territories; this process included querying for missing data, identifying incorrect entries and confirming values with reporting jurisdictions. Cases with missing data were included in the analysis as appropriate. Visitors to Canada who were diagnosed with measles during their stay were included in this analysis.

A case was considered to have received a dose of measles-containing vaccine if the date of the vaccination is documented; otherwise, the case was considered unvaccinated. Cases with an unknown vaccination history were considered unvaccinated. A case was considered to be hospitalized if admitted to hospital due to measles or due to measles-related complications, but not if they were only seen in the emergency department.

The reporting province or territory identified the source of exposure in the course of the public health investigation. The sources of exposure were classified as outside Canada (imported); within Canada and linked to an imported case (import-related); within Canada and linked to a case of unknown origin; or unknown source/sporadic.

Verification of measles elimination through national and international goals and targets

PAHO set out four criteria for the ongoing verification of measles elimination (9), (**Table 1**). The indicators, established by PAHO, of a well-performing surveillance system are based on investigation of measles-like illness (i.e. suspected cases), whereas only confirmed cases are nationally notifiable in Canada. As such, these data can only indirectly address the PAHO criteria.

Genotyping

NML routinely performs virus genotyping of all reverse transcription polymerase chain reaction (RT-PCR) confirmed cases for which viral specimens (respiratory swabs and/or urine) are available. The terminal 450 nucleotides of the measles nucleoprotein (N) gene (the N-450) were sequenced in accordance with World Health Organization (WHO) guidelines (10,11). Sequences were aligned with WHO genotype reference sequences and maximum parsimony phylogenetic trees generated in MEGA X software (12). Measles viral sequences were deposited in the WHO Measles Nucleotide Surveillance (MeaNS) database and distinct sequence identifiers (IDs) acquired. Sequences were also compared to designated named strains and to sequences deposited by other members of the global measles laboratory network (11,13). All confirmed cases of measles with rash onset between January 1, 2019, and December 31, 2019, that had been genotyped were included in this report (n=73). The sequences were deposited in GenBank, the National Institutes of Health (NIH) genetic sequence database, with accession numbers MT386938 to MT387010.

Table 1: Pan American Health Organization essential criteria for the verification of measles elimination

Criterion	Indicator
Verify the interruption of endemic measles cases for a period of at least 3 years from the last known endemic case, in the presence of high-quality surveillance	Zero cases of endemic transmission
Maintain high-quality surveillance sensitive enough to detect imported and import-related cases	>2 suspect cases per 100,000 population adequately investigated
Verify the absence of endemic measles virus strains through viral surveillance	Measles genotype assessed in 80% of outbreaks
Verify adequate immunization in the population	95% of population cohorts aged 1–40 years have received a measles-containing vaccine

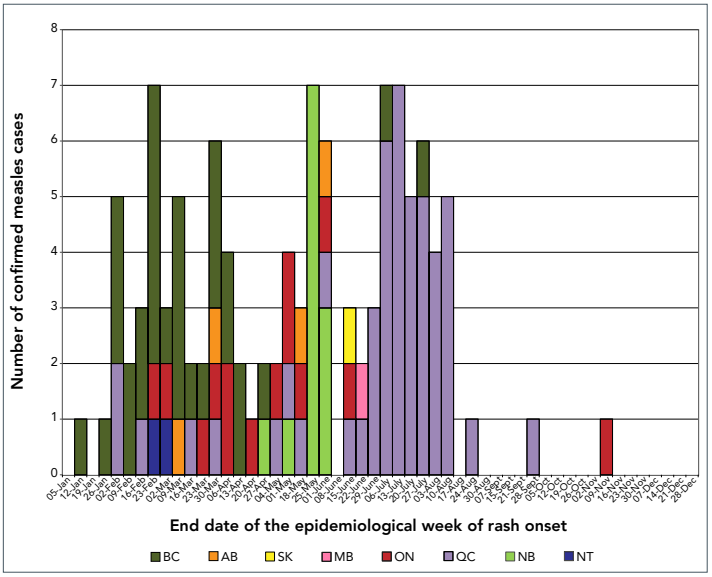
Analysis

Descriptive epidemiologic analyses were performed based on the available variables in the CMRSS database, including age, sex, location, onset date, vaccination, hospitalization, source of exposure and genotype (8). Statistical comparisons between frequencies were completed using Mid-P exact test, as appropriate. Measles outbreaks, defined as two or more confirmed cases linked epidemiologically, virologically or both, were described based on available information (14). Incidence rates were calculated using Statistics Canada population estimates for July 1, 2019.

Results

A total of 113 confirmed measles cases (incidence rate of 3.0 cases per 1,000,000 population) were reported from seven provinces and one territory, in 2019 (**Figure 1**). Approximately one-third of these cases were related to one outbreak in the province of Québec. Of the 113 total confirmed cases, 73 (65%) were genotyped. The genotypes detected were B3 (n=20) and D8 (n=53), both of which circulated globally in 2019, based on data submitted to the WHO MeaNS database (15). Altogether,

Figure 1: Number of reported measles cases (N=113), by epidemiologic week of rash onset and reporting province or territory, Canada, 2019



Abbreviations: AB, Alberta; BC, British Columbia; MB, Manitoba; NB, New Brunswick; NT, Northern Territories; ON, Ontario; QC, Québec; SK, Saskatchewan

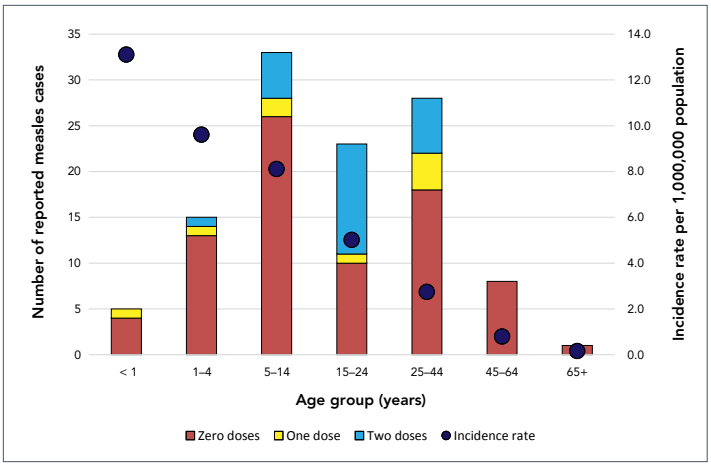
102 cases were laboratory-confirmed and 11 cases were epidemiologically linked to a laboratory-confirmed case.

Information on age, sex and province or territory of residence was complete for all measles cases reported in 2019. The cases were aged from younger than one year to 73 years, with a median age of 15 years. Cases were most often in the 5–14 year age group (29%, n=33) or the 25–44 year age group (25%, n=28). The incidence rate of measles declined across age groups, with the highest incidence rate reported in infants younger than one year (13.1 cases per 1,000,000 population) and the lowest in adults 65 years and older (0.15 cases per 1,000,000 population; **Figure 2**). The majority of cases (65%, n=73) were male.

Vaccination

Of the 113 measles cases reported in Canada in 2019, 71% (n=80) had no documented doses of measles-containing vaccine; of these, 16 cases had an unknown vaccination history. Over 40% of the unvaccinated measles cases (n=34) were related to an outbreak in a non-vaccinating community (see Outbreaks section, below). Of note, 57% (n=13) of cases in the 15–24 year age group had at least one documented dose of measles-containing vaccine; this is significantly higher than the proportion of cases with at least one dose of documented measles-containing vaccine in any other age group ($p<0.01$; Figure 2).

Figure 2: Confirmed measles cases (N=113) and incidence rates (per 1,000,000 population) by age group and vaccination status, Canada, 2019



Hospitalization

All 113 measles cases reported had hospitalization information complete. In total, 19% of cases (n=21) were hospitalized, resulting in a hospitalization rate of 0.6 per 1,000,000 population. The mean age of hospitalized cases was 31 years (median: 34 years, range: 1–73 years). On average, hospitalized cases were significantly older than non-hospitalized cases ($p<0.001$). Of the 21 hospitalized cases, only three (14%) had any documented doses of measles vaccination.

Molecular epidemiology by source of exposure

Of the 113 confirmed cases of measles in 2019, 42 (37%) were imported into Canada after exposure to measles during travel (**Table 2**). Twelve of these imported cases transmitted measles within Canada, which resulted in an additional 60 import-related cases (**Table 3**). In total, imported and import-related cases accounted for 90% (n=102) of the total cases, while 10% (n=11) had an unknown or sporadic source of measles exposure (Table 2, Table 3).

Table 2: Summary of imported measles cases by source of exposure (n=42) and by genotype, 2019

WHO region (number of cases)	Country	Number of cases	Genotype (number of cases)	WHO-named strain, if applicable, MeaNS Distinct Sequence ID (Number of cases)
Western Pacific (n=25)	Philippines	11	B3 (n=11)	MVi/Marikina City.PHL/10.18/, 5306 (n=4); N/A, 6018 (n=2); MVi/Gombak.MYS/40.15/, 4274 (n=1); N/A, 5654 (n=1); N/A, 5793 (n=1); N/A, 5904 (n=1); N/A, 6083 (n=1)
	Viet Nam	11	D8 (n=6)	MVs/Gir Somnath.IND/42.16/, 4683 (n=3); N/A, 5840 (n=2); N/A, 5823 (n=1)
	Cambodia	1	D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)
	Multiple countries	2	D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)

Table 2: Summary of imported measles cases by source of exposure (n=42) and by genotype, 2019 (*continued*)

WHO region (number of cases)	Country	Number of cases	Genotype (number of cases)	WHO-named strain, if applicable, MeaNS Distinct Sequence ID (Number of cases)
Europe (n=6)	France	1	B3 (n=1)	N/A, 5852 (n=1)
	Poland	1	D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)
	Ukraine	1	D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)
	United Kingdom	1	D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)
	Multiple countries	2	D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)
Americas (n=3)	United States of America	3	D8 (n=3)	MVs/Gir Somnath.IND/42.16/, 4683 (n=2); MVs/Dagon Seikkan.MMR/5.18, ID (n=1)
South-East Asian (n=3)	Bangladesh	2	B3 (n=2)	N/A, 5622 (n=1); N/A, 6218 (n=1)
	India	1	D8 (n=1)	N/A, 5970 (n=1)
Other (n=5)	Pakistan	2	B3 (n=1)	N/A, 5309 (n=1)
			D8 (n=1)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1)
	Multiple countries and regions	3	B3 (n=1)	MVi/Marikina City.PHL/10.18/, 5306 (n=1)
			D8 (n=2)	MVs/Gir Somnath.IND/42.16/, 4683 (n=1); N/A, 5601 (n=1)

Abbreviations: ID, identifier; MeaNS, Measles Nucleotide Surveillance, N/A, not applicable; WHO, World Health Organization

Table 3: Summary of measles with an unknown source of exposure (n=11), by earliest date of rash onset, 2019

Case number	Exposure category	End date of the epidemiologic week of rash onset	Genotype (WHO-named strain if applicable, MeaNS Distinct Sequence ID)[a]	Description
1	Unknown (exposed either in Canada or abroad)	February 16	B3 (N/A, 5800)	• The case travelled to France, where active measles outbreaks were ongoing, and spent time in Canada during the exposure period • Genotyping data excludes a link to other known active measles cases present in the case's area of Canada during the exposure period • The identified measles strain was not detected in any other case genotyped in 2019 • The case had no documented doses of measles-containing vaccine
2	Exposed in Canada, not linked to any case	February 23	B3 (N/A, 5654)	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases • The identified measles strain was detected in one earlier case with travel history to the Philippines • The case had two documented doses of measles-containing vaccine
3	Unknown (exposed either in Canada or abroad)	March 30	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• The case travelled to the Dominican Republic during the exposure period. At the time of travel, no known active cases or outbreaks were ongoing in the Dominican Republic • The case was also present in an area of Canada with other active measles cases during the exposure period • The identified measles strain was detected in 45 other cases and has been circulating globally since 2018 • The case had no documented doses of measles-containing vaccine
4	Exposed in Canada, not linked to any case	March 30	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases • The identified measles strain was detected in 45 other cases and has been circulating globally since 2018 • The case had one documented dose of measles-containing vaccine

Table 3: Summary of measles with an unknown source of exposure (n=11), by earliest date of rash onset, 2019 (*continued*)

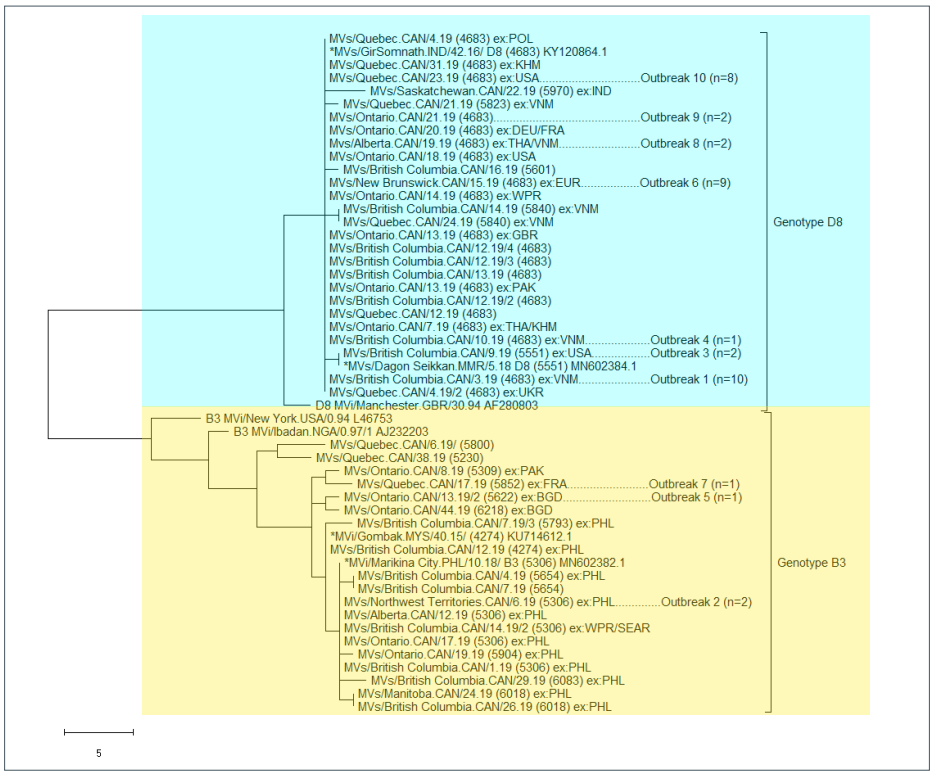
Case number	Exposure category	End date of the epidemiologic week of rash onset	Genotype (WHO-named strain if applicable, MeaNS Distinct Sequence ID)[a]	Description
5	Exposed in Canada, not linked to any case	March 30	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases • The identified measles strain was detected in 45 other cases and has been circulating globally since 2018 • The case had two documented doses of measles-containing vaccine
6	Exposed in Canada, not linked to any case	April 6	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• The case did not travel outside of Canada during the exposure period • Although the case had no known epidemiologic links to other confirmed measles cases, they were present in an area of Canada with other active measles cases during the exposure period • The identified measles strain was detected in 45 other cases, including some that were active in the area, and has been circulating globally since 2018 • The case had no documented doses of measles-containing vaccine
7	Exposed in Canada, not linked to any case	April 6	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases • The identified measles strain was detected in 45 other cases and has been circulating globally since 2018 • The case had two documented doses of measles-containing vaccine
8	Exposed in Canada, not linked to any case	June 1	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases • The identified measles strain was detected in 45 other cases and has been circulating globally since 2018 • The case had no documented doses of measles-containing vaccine
9	Exposed in Canada, linked to a sporadic case of unknown origin	June 15	D8 (MVs/ Gir Somnath. IND/42.16, 4683)	• One case was a household contact of a previous case whose source of exposure was unknown. Both cases had the same measles strain • The case had no documented doses of measles-containing vaccine
10	Exposed in Canada, not linked to any case	July 20	Not determined	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases • The case had two documented doses of measles-containing vaccine
11	Exposed in Canada, not linked to any case	September 28	B3 (N/A, 5230)	• The case did not travel outside of Canada during the exposure period and had no known epidemiologic links to other confirmed measles cases. The case did fly on multiple domestic flights during the exposure period and may have come in contact with the virus in an airport • The identified measles strain was not detected in any other case genotyped in 2019 • The case had no documented doses of measles-containing vaccine

Abbreviations: ID, identifier; MeaNS, Measles Nucleotide Surveillance; N/A, not applicable; WHO, World Health Organization
[a] GenBank accession number for the listed named strain is KY120864

Unknown source

Eleven cases (10%) were neither imported nor import-related: eight had no recent history of travel or known links to other confirmed measles cases (sporadic cases); one was linked to a sporadic case of unknown origin; and the exact source of exposure for the other two cases could not be determined (unknown source) because exposure may have occurred either in another country with known measles activity or in Canada (Table 3). These cases originated from British Columbia (n=5), Québec (n=4) and Ontario (n=2). Six of these cases were female and five were male. Ten of these 11 cases were genotyped; in seven cases, the genotype D8 MVs/Gir Somnath.IND/42.16/ named strain was detected, which was circulating globally in 2019. Three distinct genotype B3 strains (sequence IDs 5230, 5654 and 5800) were identified in the remaining three cases, two of which were not detected in any other measles case genotyped in 2019 (5230 and 5800) (**Figure 3**, Table 3).

Figure 3: Maximum parsimony phylogenetic tree of measles N-450 sequences identified in Canada in 2019 (n=73) prepared using MEGA X software[a]



Abbreviations: ID, identifier; MeaNS, Measles Nucleotide Surveillance; WHO, World Health Organization

[a] Genotype B3 sequences are shown in the orange shading and genotype D8 sequences in the blue shading. WHO genotype B3 and D8 reference sequences are included, along with their GenBank accession numbers, and can be identified with the starting text "B3" or "D8". The four WHO-named strains that match Canadian sequences are included and begin with an asterisk (MVs/Gir Somnath.IND/42.16, MVs/Dagon Seikkan.MMR/5.18, MVi/Gombak.MYS/40.15 and MVi/Marikina City.PHL/10.18/). Canadian sequences are identified by their WHO name, which indicates province and week of rash onset (by number in the year, as assigned in accordance with WHO guidelines). Distinct sequence IDs, as identified and assigned by MeaNS, the WHO measles sequence database, are shown in brackets (4-digit number). Travel history is indicated where applicable with "ex:<country name>." Outbreaks are represented by a single sequence. These sequences are tagged with their outbreak number in accordance with Table 1 and with the number of identical sequences identified in the outbreak in brackets. The remaining sequences (without an outbreak number listed) are from non-outbreak-related cases (n=35). The scale bar indicates number of nucleotide differences between branches

Outbreaks

Ten measles outbreaks were identified for a total of 74 cases (**Table 4**). Seven of the 10 outbreaks were small (from 2 to 3 cases per outbreak), with limited transmission to household contacts or other close contacts of the index case. Three outbreaks were larger (from 12 to 34 cases per outbreak), with community-level transmission.

The WHO-named strain MVs/Gir Somnath.IND/42.16 was the most frequently detected in 2019. In total, 46 measles cases were identified with this strain (41% of all cases), and these cases were associated with six distinct outbreaks and 14 sporadic cases for a total of 20 chains of transmission. In the longest sustained outbreak associated with this strain, Outbreak 10, illness onset occurred during the week ending June 15 in the earliest case and during the week ending August 24 in the last case.

Table 4: Summary of measles outbreaks in Canada (N=10), by earliest date of rash onset, 2019

Outbreak number	Province/ territory	Number of cases (number of generations)	End date of the epidemiologic week of rash onset of index case	Genotype (WHO-named strain, if applicable, MeaNS Distinct Sequence ID)[a]	Description
1	British Columbia	13 (n=5)	February 2	D8 (MVs/Gir Somnath.IND/42.16, 4683)	• Three co-index cases reported travel to Viet Nam • 10 subsequent cases were reported later • Primary exposure occurred in two schools • Four of the 13 cases (31%) had at least one documented dose of measles-containing vaccine
2	Northwest Territories	2 (n=2)	February 16	B3 (MVi/Marikina City.PHL/10.18, 5306)	• The index case reported travel to the Philippines • The secondary case was a contact of the index case • The index case was unvaccinated • The secondary case had two documented doses of measles-containing vaccine prior to exposure

Table 4: Summary of measles outbreaks in Canada (N=10), by earliest date of rash onset, 2019 (*continued*)

Outbreak number	Province/ territory	Number of cases (number of generations)	End date of the epidemiologic week of rash onset of index case	Genotype (WHO-named strain, if applicable, MeaNS Distinct Sequence ID)[a]	Description
3	British Columbia	2 (n=2)	March 9	D8 (MVs/Dagon Seikkan.MMR/5.18, 5551)	• The index case reported travel to the US • The secondary case was a family contact of the index case • The index case was unvaccinated • The secondary case had two documented doses of measles-containing vaccine prior to exposure
4	British Columbia	2 (n=2)	March 9	D8 (MVs/Gir Somnath.IND/42.16, 4683)	• The index case reported travel to Viet Nam • The secondary case was a family contact of the index case • The index case was unvaccinated • The secondary case had one documented dose of measles-containing vaccine prior to exposure
5	Ontario	2 (n=2)	March 23	B3 (N/A, 5622)	• The index case reported travel to Bangladesh • The secondary case was a household contact of the index case • The index case was unvaccinated • The secondary case had one documented dose of measles-containing vaccine
6	New Brunswick	12 (n=3)	April 27	D8 (MVs/Gir Somnath.IND/42.16, 4683)	• The index case reported travel to various countries in Europe • The secondary case was a healthcare contact of the index case • 10 tertiary cases followed after exposures in a school and in the community • The index case was unvaccinated • 10 of the 11 subsequent cases had at least one documented dose of measles-containing vaccine • Nine of the cases (75%) in this outbreak had two documented doses of measles-containing vaccine
7	Québec	3 (n=2)	May 4	B3 (N/A, 5852)	• The index case reported travel to France • Two secondary cases were contacts of the index case • The index case was unvaccinated • One of the secondary cases was unvaccinated, while the other had two documented doses of measles-containing vaccine
8	Alberta	2 (n=2)	May 18	D8 (MVs/Gir Somnath.IND/42.16, 4683)	• The index case reported travel to Viet Nam and Thailand • The secondary case was a workplace contact • Neither case had any documented doses of measles-containing vaccine
9	Ontario	2 (n=2)	June 1	D8 (MVs/Gir Somnath.IND/42.16, 4683)	• The index case did not report travel outside of Canada during the exposure period • The secondary case was a household contact • Neither case had any documented doses of measles-containing vaccine
10	Québec	34 (unknown)	June 15	D8 (MVs/Gir Somnath.IND/42.16, 4683)	• The index case reported travel to an area of heightened measles activity in the US • Several generations of transmission were linked to a shopping mall and a non-vaccinating community in the Montréal area • 32 cases, including the index case, were unvaccinated • Two cases had at least one documented dose of a measles-containing vaccine

Abbreviations: ID, identifier; MeaNS, Measles Nucleotide Surveillance; US, United States; WHO, World Health Organization

[a] GenBank accession number for the listed named strains are KY120864, MN602382 and MN602384

Verification of measles elimination through national and international goals and targets

The data in this report are provided as evidence in support of the ongoing verification of measles elimination in Canada, for which the PAHO has set out four essential criteria (9). Based on the information available, Canada met or partially met three of the four criteria in 2019 (**Table 5**).

Table 5: Pan American Health Organization essential criteria for the verification of measles elimination

Criterion	Indicator
Verify the interruption of endemic measles cases for a period of at least 3 years from the last known endemic case, in the presence of high-quality surveillance	Criterion met Canada achieved measles elimination status in 1998. Since then, molecular and epidemiologic data continue to demonstrate that no viral strain has circulated for a period of ≥1 year (Figure 4) (4,16–19)
Maintain high-quality surveillance sensitive enough to detect imported and import-related cases	Criterion partially met In Canada, national measles surveillance conducted through CMRSS consists of confirmed case surveillance and does not capture the number of clinical or suspect cases investigated, which are investigated at the provincial and territorial levels. However, based on data obtained by the Measles and Rubella Surveillance Pilot Project (which does not include all provinces and territories), the national rate of suspected case investigations has been previously estimated to be between 12 and 19 per 100,000 population (17). Although the indicator cannot be met, the criterion has been met as the epidemiologic and laboratory evidence provided in this report indicates that Canada's measles surveillance capacity is sufficiently sensitive to detect imported and import-related cases and conduct case investigations
Verify the absence of endemic measles virus strains through viral surveillance	Criterion met Genotype information was available for 10/10 of outbreaks reported in 2019. Genotype information was also available for 90% of non-outbreak-related measles cases (35 genotyped of 39 cases)
Verify adequate immunization in the population	Criterion not met Canada currently measures (biennially) measles vaccination coverage rates at 2 and 7 years of age, and therefore is unable to assess measles vaccination coverage for all ages 1–40 years. The 2017 childhood National Immunization Coverage Survey estimated first dose measles-containing vaccine coverage in two year olds to be 90%, and two-dose measles-containing vaccine coverage in seven year olds to be 86% (5)

Abbreviation: CMRSS, Canadian Measles and Rubella Surveillance System

Discussion

There were 113 confirmed cases of measles reported in Canada in 2019, the majority of which were imported or import-related (90%) and unvaccinated against measles (71%). This is higher than the median number of cases reported from 1998 to 2018 (median of 32 cases per year), and coincides with a trend of increasing rates of measles globally since 2017 (2,20–22). The United States (US) had the greatest number of measles cases since 1992 in 2019. Over 73% of cases in the US were linked to outbreaks in New York, and the majority of the cases in these outbreaks were not vaccinated against measles (23). These US outbreaks had a direct impact on measles rates in Canada, with the largest Canadian outbreak of 2019 epidemiologically linked to a large outbreak in the US. Other large outbreaks in Canada were caused by unvaccinated travellers to Viet Nam and Europe, where outbreaks were also occurring in 2019. These outbreaks underscore the ongoing risk that any international travel places on the spread of measles in Canada, and validates PHAC's 2019 broadening of its travel health notice for measles exposure risk to any international travel, and not only to certain areas (24).

Globally, only four of the 24 recognized measles genotypes continue to be detected, genotypes B3, D4, D8 and H1, as a result of elimination efforts (4), and only genotypes B3 and D8 were detected in confirmed measles cases in Canada in 2019. The genotype classification system captures viruses with similar yet distinct genetic (N-450) sequences, and for effective molecular epidemiology, additional granularity is required. The WHO global measles rubella laboratory network developed a system of "named strains" that are defined in the MeaNS database and represent a lineage, a precisely defined virus strain with a specific N-450 sequence, that has been frequently detected within a 2-year period in multiple countries (11). In addition, the MeaNS database assigns a 4-digit identifier to all distinct or unique N-450 sequences within the database. All sequences obtained from cases of measles with the same N-450 sequence will share the same distinct sequence ID. In this way, all possible genetic sequences of reported measles cases can be tracked with their distinct sequence ID and some will also be designated as belonging to a named strain lineage, representing those with broader circulation. In 2019, 19 distinct sequence IDs, including four named strains, were identified in the 73 confirmed cases of measles that were genotyped.

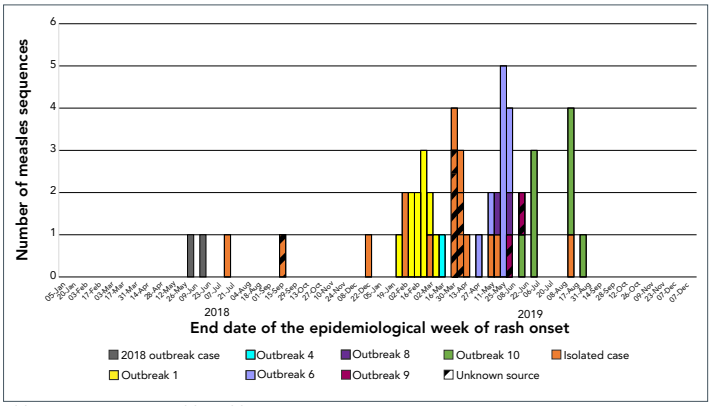
The WHO-named strain MVs/Gir Somnath.IND/42.16 was the only strain detected in 2019 that was also detected in a handful of cases in 2018 (16). This strain has been circulating globally since 2018, based on submissions to the MeaNS database, as reflected in the number of cases with travel history associated with this strain both in 2018 and 2019 (**Figure 4**). In 2018 to 2019, 51 measles cases were identified with this strain and these cases were associated with seven distinct outbreaks and 17 sporadic cases for a total of 24 chains of transmission. The time between illness onset in the first and last cases in the longest

sustained outbreak associated with this strain was 70 days, which is far short of the 12 months of ongoing transmission that would signal endemic circulation. The detection of this strain in a large number of chains of transmission over an extended time demonstrates the value of integrating laboratory and epidemiologic data and necessitates the adoption of extended genotyping methods.

Both in Canada and abroad, maintaining high vaccination coverage rate with measles-containing vaccine requires a sustained public health effort and is an essential component of a strategy for achieving and maintaining measles elimination. As in previous years, the large majority of measles cases were unvaccinated, highlighting the importance of adhering to vaccination guidelines (16,17,25–27). Only one in five measles cases in 2019 had received two doses of measles vaccination, including five cases who were aged younger than one year and not yet eligible to receive the first routine dose of measles-containing vaccine under the routine vaccination schedule (25).

The age distribution of measles cases reported in 2019 was similar to that seen in previous years, with younger age groups affected to a higher degree than older age groups (16–18). Of note, over half of the measles cases in the 15–24 year age group had received two doses of measles-containing vaccine. The majority (n=7) of the fully vaccinated cases from this age

Figure 4: Number of measles cases with genotype D8, WHO-named strain MVs/Gir Somnath.IND/42.16 detected in 2018 and 2019 (n=51), by epidemiologic week of rash onset, chain of transmission status and source of exposure, Canada[a]



Abbreviation: WHO, World Health Organization

[a] Chains of transmission (outbreak or sporadic case) are identified by colour with 2019 outbreaks numbered as per Table 4. Solid bars reflect cases with known source of exposure. Bars with diagonal stipes indicate cases with unknown source

group were related to a large outbreak in a secondary school in which many students were exposed. Given the large number of individuals exposed in this outbreak, some breakthrough cases, or cases that developed measles despite being fully vaccinated, would be expected even with high vaccine coverage. In addition, seroepidemiology conducted in the province of Ontario has found that this age group may have waning immunity to measles (28). Breakthrough cases may have either failed to develop an appropriate immune response; their immunity may have waned to non-protective levels by time of exposure; or the vaccine they were given may have been stored, handled or administered improperly (29,30).

Based on the information available, Canada met or partially met three of the four PAHO essential criteria for the verification of measles elimination in 2019. Canada falls short of the criterion regarding measles-containing vaccine coverage. Canada currently measures (biennially) measles vaccination coverage rates at 2 and 7 years of age, and therefore is unable to assess measles vaccination coverage for all ages between 1 and 40 years, as set out in the PAHO elimination framework. The 2017 estimate for two year olds receiving measles-containing vaccine is 90% and for seven year olds receiving the second dose of measles-containing vaccine is 86%, below the PAHO indicator of 95% (5). This estimate is derived from a survey that collected data from parent-held vaccination records, in which some information may be incomplete, erroneous or missing altogether. As vaccine doses with missing or invalid date are not counted in the calculation of coverage, the survey most likely underestimates coverage.

Strengths and limitations

This report has several limitations that bear consideration. Only measles cases that interact with the Canadian health system are captured in enhanced measles surveillance, and therefore cases with mild symptoms or visitors to Canada who do not seek health care may not be detected. Other federal or provincial surveillance systems may use case attribution methods that differ from CMRSS, which can cause discrepancies in annual case counts (31). Information on mortality and detailed information on morbidity (e.g. length of hospitalization, sequelae) are not currently captured by CMRSS, limiting the ability to completely describe the burden of illness due to measles. However, despite these limitations, this report serves to provide a detailed picture of measles in Canada in 2019 through an integrated analysis of both laboratory and epidemiologic case data for all reported cases.

Conclusion

The occurrence of measles cases and subsequent measles outbreaks in Canada in 2019, which were largely due to measles importations, underscore the importance of continued enhanced measles surveillance and efforts to increase vaccine uptake across the country. Although importation of measles and areas of low vaccination coverage continue to challenge Canada's elimination status, the laboratory and epidemiologic evidence provided by this report indicates that endemic transmission of the measles virus has not been re-established in Canada.

Authors' statement

CC — Methodology, software, formal analysis, investigation, data curation, writing–original draft, writing–review and editing, visualization
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Competing interests

None.

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