

RESEARCH PAPER



## Determinants of non-vaccination and incomplete vaccination in Canadian toddlers

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### ABSTRACT

Vaccination coverage remains suboptimal in Canada and sporadic outbreaks of vaccine-preventable diseases such as measles and pertussis continue to occur. This study was undertaken to identify sociodemographic determinants of total non-vaccination (having never received any vaccine), non-vaccination for measles (0 doses) and incomplete vaccination for pertussis (< 4 doses) among 2-year-old Canadian children. Data from the 2013 Childhood National Immunization Coverage Survey (CNICS) were used. Associations between sociodemographic factors and outcomes were measured by multiple logistic regressions and adjusted odds ratios (aOR) were calculated. A total of 5,477 children were included in the analyses of total non-vaccination, and 3,899 children were included in the analysis of non-vaccination for measles and incomplete vaccination for pertussis. Overall, 2.7% of children (95% CI 2.0–3.3) had received no vaccine at all. Lower parental education, i.e., the responding parent having a high school diploma, trade certificate or less (compared with university graduation) was associated with total non-vaccination (aOR 1.99, 95% CI 1.02–3.91). Non-vaccination for measles was more frequent among children of single parent families (aOR 1.63, 95% CI 1.01–2.61) and those of parents with lower education (aOR 1.86, 95% CI 1.26–2.76). The odds of incomplete vaccination for pertussis was greater among children born outside Canada (aOR 3.10, 95% CI 1.73–5.58), of parents with lower education (aOR 1.92, 95% CI 1.41–2.62), and those whose household income was between \$40,000 and \$59,999 (aOR 1.47; 95% CI 1.04–2.07) or lower than \$40,000 (aOR 1.58, 95% CI 1.13–2.22). Significant regional variation was also found for all outcomes. In conclusion, despite universal access to free childhood vaccines in Canada, regional variation and socioeconomic inequalities in vaccine uptake were still observed. Further analyses are warranted to identify barriers contributing to these variations.

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### Introduction

High immunization coverage is essential to control and eventually eliminate vaccine-preventable diseases (VPDs).<sup>1</sup> In Canada, national immunization coverage has been monitored through surveys since the mid-1990s.<sup>2</sup> Data from the Childhood National Immunization Coverage Survey (CNICS) revealed that immunization coverage estimates are below nationally defined targets for routine childhood vaccines,<sup>3</sup> and outbreaks of VPDs such as measles<sup>4</sup> and pertussis<sup>5</sup> continue to occur sporadically in Canada.

In Canada, immunization is a shared responsibility among the federal, provincial and territorial governments. For example, responsibilities at the federal level include the approval and regulation of vaccines and providing evidence-based recommendations on the use of vaccines in Canada through the National Advisory Committee on Immunization. Provincial and territorial governments are responsible for funding, program planning (including the immunization schedule used within the jurisdiction) and the delivery of immunization programs. Consequently, provincial and territorial schedules vary by jurisdiction in Canada. However, all provinces and territories follow immunization schedules that administer the first

dose for measles, mumps and rubella vaccine, with or without varicella (MMR or MMRV), at 12 months of age. Similarly, the first 4 doses of the diphtheria, tetanus, acellular pertussis, haemophilus influenza type B, and inactivated polio vaccine (DTaP-Hib-IPV) are given at 2, 4, 6 and 18 months (with some jurisdictions using an hexavalent vaccine with hepatitis B for 3 of these doses).<sup>6</sup>

Processes and systems for registering immunizations also vary greatly between jurisdictions, ranging from paper-based processes to electronic information systems specifically designed to record immunizations.<sup>7</sup> Records given to parents (cards or booklets) also differ by province or territory, organized by antigen or disease in some jurisdictions and by vaccine in others.

Factors influencing vaccine uptake include vaccine hesitancy, defined as a lack of confidence in the safety and effectiveness of vaccines,<sup>8</sup> and barriers to using available immunization services.<sup>9</sup> Both of these factors may be unevenly distributed in the population, leading to socioeconomic inequalities in vaccine uptake. Understanding which sub-populations are less likely to be vaccinated is important to inform the development of appropriate interventions ranging from program delivery

(i.e., improved access) to promotion strategies (i.e., improving public confidence in vaccination).

The objective of this study was to identify the sociodemographic determinants of non-vaccination and incomplete vaccination among 2-year-old Canadian children. We were interested in exploring whether there were any vaccine-specific findings with regards to sociodemographic correlates, thus we examined total non-vaccination, i.e., not having received any vaccine, in addition to non-vaccination with measles-containing vaccine and incomplete vaccination for pertussis. Parental knowledge, attitudes and beliefs toward vaccines among unvaccinated and under-vaccinated children in Canada will be addressed in a separate study.

Data from the 2013 Childhood National Immunization Coverage Survey (CNICS)<sup>10</sup> were used for this study.

## Results

Of the 8,686 2-year-old children selected from the sampling frame, the parents or guardians of 6,744 were reached by telephone, and 5,512 agreed to participate, yielding a participation rate of 63.5%. A total of 5,477 children were included in the analysis of total non-vaccination, after excluding those whose parents did not know whether or not their child had ever been vaccinated. The analysis of non-vaccination for measles and incomplete vaccination for pertussis included 3,899 children for whom immunization information was available.

Overall, 2.7% (95% CI 2.0–3.3) of 2-year-old children had not received any vaccine. Rates of total non-vaccination were

significantly higher in Quebec, the Prairies and British Columbia than in the Atlantic Region, the region with the lowest rate. In addition, the responding parent having high school diploma, trade certificate or less education (compared with university graduation) was associated with higher odds of total non-vaccination (aOR 1.99, 95% CI 1.02–3.91) (Table 1). The main reasons for not having received vaccines were concerns about vaccine safety (56.4%) and philosophical or religious reasons (32.8%) (Table 2).

Measles-containing vaccine had not been received by 10.3% (95% CI 8.9–11.6) of 2-year-olds (this includes those who have received no vaccines at all). The proportion was significantly higher in the Prairies, in British Columbia and in the Territories, compared with in Ontario, the region with the smallest proportion of children who had not been vaccinated against measles. In addition, non-vaccination for measles was significantly higher in children whose responding parent had a high school diploma, a trade certificate or less education (aOR 1.86, 95% CI 1.26–2.76) as compared with university graduation; in children of households earning between \$40,000 and \$59,999 (aOR 1.70, 95% CI 1.06–2.72) compared with households earning \$80,000 or more; and in children whose responding parent was single (aOR 1.63, 95% CI 1.01–2.61), compared with those married or common-law, in the adjusted analysis (Table 3). A sensitivity analysis conducted by restricting the above-mentioned analysis to children for whom information was obtained from immunization providers and to those children never-vaccinated yielded similar patterns except that single responding parent was no longer a significant factor (Table 4).

**Table 1.** Determinants of total non-vaccination in Canadian 2-year-old children, 2013.

	% never vaccinated (95% CI)	unadjusted OR (95% CI)	P	adjusted <sup>b</sup> OR (95% CI)	p
Sex					
Female	2.3 (1.5–3.2) <sup>a</sup>	Reference			
Male	3.0 (2.0–4.0) <sup>a</sup>	1.29 (0.77–2.15)	0.336		
Region					
Atlantic	1.0 (0.6–1.5) <sup>a</sup>	Reference		Reference	
Quebec	2.5 (1.2–3.7) <sup>a</sup>	<b>2.47 (1.20–5.10)</b>	<b>0.015</b>	<b>2.43 (1.15–5.15)</b>	<b>0.020</b>
Ontario	1.8 (0.7–2.9) <sup>a</sup>	1.76 (0.74–4.17)	0.202	1.91 (0.79–4.64)	0.151
Prairies	4.9 (3.4–6.3) <sup>a</sup>	<b>4.92 (2.74–8.83)</b>	<b>&lt;0.001</b>	<b>5.18 (2.83–9.47)</b>	<b>0.000</b>
British Columbia	2.9 (1.2–4.6) <sup>a</sup>	<b>2.88 (1.27–6.56)</b>	<b>0.012</b>	<b>3.18 (1.36–7.45)</b>	<b>0.008</b>
Territories	2.3 (1.5–3.2) <sup>a</sup>	<b>2.32 (1.27–4.22)</b>	<b>0.006</b>	1.88 (0.99–3.56)	0.053
Born outside Canada					
No	2.8 (2.1–3.5)				
Yes	0				
Education					
High school, trade certificate or less	4.9 (3.1–6.6) <sup>a</sup>	<b>2.62 (1.47–4.69)</b>	<b>0.001</b>	<b>1.99 (1.02–3.91)</b>	<b>0.044</b>
Post-secondary	1.7 (1.0–2.5) <sup>a</sup>	0.92 (0.49–1.72)	0.782	0.79 (0.43–1.48)	0.465
University graduate	1.9 (1.1–2.7) <sup>a</sup>	Reference		Reference	
Total household income					
0 – \$39,999	3.5 (1.9–5.1) <sup>a</sup>	<b>2.14 (1.10–4.14)</b>	<b>0.024</b>	1.75 (0.84–3.67)	0.137
\$40,000 – \$59,999	3.6 (1.6–5.5) <sup>a</sup>	2.15 (1.00–4.65)	0.051	1.88 (0.84–4.22)	0.125
\$60,000 – \$79,999	3.1 (1.6–4.6) <sup>a</sup>	1.88 (0.95–3.73)	0.070	1.90 (0.93–3.89)	0.080
\$80,000 or more	1.7 (0.9–2.4) <sup>a</sup>	Reference		Reference	
Marital status of responding parent					
Married / common law	2.5 (1.8–3.2)	Reference			
Single/widowed/divorced/separated	3.3 (1.4–5.2) <sup>a</sup>	1.34 (0.68–2.66)	0.399		
Responding parent born outside Canada					
No	2.7 (2.0–3.5)	Reference			
Yes	2.4 (1.1–3.7) <sup>a</sup>	0.89 (0.46–1.71)	0.718		

Source: Childhood National Immunization Coverage Survey, 2013

All rates and odds ratios are weighted.

The analysis includes 127 children never vaccinated and 5350 children who had received at least one vaccine (total 5477).

<sup>a</sup>Use with caution; coefficient of variation between 16.6% and 33.3%.

<sup>b</sup>Adjusted for all other variables for whom ORs are shown in this column.

**Table 2.** Reasons for which Canadian children have not received any vaccine by the age of 2 y.

Reason	Weighted % (95% CI)
Concerns about safety of vaccines	56.4 (44.7–68.2)
Too many immunizations required	13.5 (6.3–20.7) <sup>c</sup>
Vaccines are not effective	10.3 (3.7–17.0) <sup>c</sup>
Philosophical and religious reasons <sup>a</sup>	32.8 (21.3–44.2) <sup>c</sup>
Other <sup>b</sup>	38.4 (26.5–50.2)

Source: Childhood National Immunization Coverage Survey, 2013.

This analysis includes 125 children who had received no vaccine at the time of the survey, and whose parent or guardian responded to a question on the reasons for this. Multiple reasons were allowed.

<sup>a</sup>Philosophical and religious reasons were 2 separate answers that were grouped afterwards because of a small number of respondent in the “religious” reason.

<sup>b</sup>Created by grouping “no access to health care,” “did not know how to access health care services,” “immune system not able to handle vaccines,” “forgot,” and “other” because of small numbers of respondents.

<sup>c</sup>Use with caution; coefficient of variation between 16.6% and 33.3%.

Almost one-quarter of children had not received the recommended 4 doses of pertussis-containing vaccine by their second birthday (23.6%, 95% CI 21.6–25.7). Approximately 4.7% had received zero doses of pertussis vaccine (95% CI 3.8–5.6). The proportion of children under-vaccinated against pertussis (including those with zero doses) was significantly higher in the Prairies, British Columbia, and the territories compared the Atlantic Region, the region with the smallest proportion of children incompletely vaccinated. Incomplete vaccination for pertussis was also associated with children being born outside Canada (aOR 3.10, 95% CI 1.73–5.58); with responding parent

having a high school diploma, a trade certificate or less education (aOR 1.92, 95% CI 1.41–2.62) compared with university graduation; and with household income between \$40,000 and \$59,999 (aOR 1.47; 95% CI 1.04–2.07) or lower than \$40,000 (aOR 1.58, 95% CI 1.13–2.22) compared with \$80,000 or more (Table 5). Again, a sensitivity analysis conducted by restricting the above-mentioned analysis on pertussis-containing vaccine to children for whom information was obtained from immunization providers and to those children never-vaccinated yielded similar patterns (data not shown).

## Discussion

CNICS is the largest nationally representative coverage survey ever conducted in Canada, and permitted the first examination at a national level of unvaccinated children with sufficient statistical power to explore potential predictors of this important outcome. Despite universal access to free childhood vaccines in Canada, regional variation and socioeconomic inequalities in vaccine uptake were still observed for each outcome under study.

The proportion of never-vaccinated children at 2 y of age in CNICS 2013, 2.7%, was much higher than the 0.7% measured the same year in the United States by the National Immunization Survey (NIS).<sup>11</sup> The way this outcome was measured in both surveys was similar; however, methodological differences in other aspects of the survey (sampling frame) or patterns of response may explain in part this difference in results. For

**Table 3.** Determinants of non-vaccination for measles in Canadian 2-year-old children, 2013.

	% with 0 dose of measles vaccine (95% CI)	unadjusted OR (95% CI)	p	adjusted <sup>c</sup> OR (95% CI)	p
Sex					
Female	10.3 (8.3–12.3)	Reference			
Male	10.3 (8.4–12.2)	1.00 (0.74–1.36)	0.992		
Region					
Atlantic	9.1 (7.3–10.9)	1.30 (0.82–2.05)	0.263	1.23 (0.77–1.97)	0.395
Quebec	9.4 (7.0–11.7)	1.34 (0.84–2.16)	0.222	1.27 (0.78–2.07)	0.337
Ontario	7.2 (4.6–9.7) <sup>a</sup>	Reference		Reference	
Prairies	16.6 (13.8–19.5)	<b>2.58 (1.66–4.03)</b>	<b>&lt;0.001</b>	<b>2.66 (1.69–4.20)</b>	<b>&lt;0.001</b>
British Columbia	13.1 (9.4–16.9)	<b>1.96 (1.16–3.32)</b>	<b>0.012</b>	<b>2.06 (1.20–3.54)</b>	<b>0.009</b>
Territories	16.5 (13.7–19.3)	<b>2.56 (1.63–4.04)</b>	<b>&lt;0.001</b>	<b>2.49 (1.55–3.99)</b>	<b>&lt;0.001</b>
Born outside Canada					
No	10.2 (8.8–11.6)	Reference			
Yes	– <sup>b</sup>	1.47 (0.65–3.36)	0.356		
Education					
High school, trade certificate or less	16.7 (13.3–20.1)	<b>2.42 (1.69–3.45)</b>	<b>&lt;0.001</b>	<b>1.86 (1.26–2.76)</b>	<b>0.002</b>
Post-secondary	8.2 (6.1–10.2)	1.07 (0.74–1.56)	0.724	0.94 (0.64–1.38)	0.749
University graduate	7.7 (5.9–9.5)	Reference		Reference	
Total household income					
0 – \$39,999	12.8 (9.5–16.2)	<b>1.84 (1.26–2.68)</b>	<b>0.002</b>	1.34 (0.87–2.06)	0.191
\$40,000 – \$59,999	14.0 (9.6–18.5)	<b>2.04 (1.30–3.18)</b>	<b>0.002</b>	<b>1.70 (1.06–2.72)</b>	<b>0.027</b>
\$60,000 – \$79,999	10.9 (7.6–14.2)	<b>1.52 (1.01–2.31)</b>	<b>0.047</b>	1.47 (0.95–2.27)	0.086
\$80,000 or more	7.4 (5.9–9.0)	Reference		Reference	
Marital status of responding parent					
Married / common law	9.1 (7.8–10.5)	Reference		Reference	
Single/widowed/divorced/separated	16.3 (11.1–21.4)	<b>1.93 (1.25–2.97)</b>	<b>0.003</b>	<b>1.63 (1.01–2.61)</b>	<b>0.043</b>
Responding parent born outside Canada					
No	10.3 (8.8–11.9)	Reference			
Yes	9.5 (6.9–12.0)	0.91 (0.64–1.28)	0.578		

Source: Childhood National Immunization Coverage Survey, 2013.

All rates and odds ratios are weighted.

The analysis includes 409 children never vaccinated against measles and 3490 children who had received at least one dose of measles vaccine (total 3899).

<sup>a</sup>Use with caution; coefficient of variation between 16.6% and 33.3%;

<sup>b</sup>Suppressed due to coefficient of variation > 33.3%.

<sup>c</sup>Adjusted for all other variables for whom ORs are shown in this column.

**Table 4.** Determinants of non-vaccination for measles in Canadian 2-year-old children, 2013: sensitivity analysis.

	unadjusted OR (95% CI)	p	adjusted <sup>a</sup> OR (95% CI)	p
Sex				
Female	Reference			
Male	1.33 (0.86–2.06)	0.198		
Region				
Atlantic	1.19 (0.54–2.63)	0.664	1.06 (0.45–2.46)	0.900
Quebec	1.33 (0.60–2.98)	0.482	1.12 (0.48–2.63)	0.793
Ontario	Reference		Reference	
Prairies	<b>3.77 (1.79–7.91)</b>	<b>0.000</b>	<b>3.64 (1.67–7.94)</b>	<b>0.001</b>
British Columbia	<b>2.52 (1.04–6.11)</b>	<b>0.040</b>	2.43 (0.97–6.07)	0.058
Territories	<b>3.40 (1.63–7.09)</b>	<b>0.001</b>	<b>2.94 (1.29–6.68)</b>	<b>0.010</b>
Born outside Canada				
No	Reference			
Yes	0.49 (0.13–1.88)	0.300		
Education				
High school, trade certificate or less	<b>4.56 (2.75–7.57)</b>	<b>0.000</b>	<b>3.05 (1.67–5.55)</b>	<b>0.000</b>
Post-secondary	1.20 (0.71–2.05)	0.492	0.98 (0.57–1.68)	0.928
University graduate	Reference		Reference	
Total household income				
0 – \$39,999	<b>3.39 (1.89–6.08)</b>	<b>0.000</b>	<b>2.35 (1.18–4.66)</b>	<b>0.015</b>
\$40,000 – \$59,999	<b>2.95 (1.53–5.70)</b>	<b>0.001</b>	<b>2.12 (1.03–4.36)</b>	<b>0.041</b>
\$60,000 – \$79,999	<b>1.91 (1.05–3.48)</b>	<b>0.034</b>	1.88 (0.98–3.61)	0.059
\$80,000 or more	Reference		Reference	
Marital status of responding parent				
Married / common law	Reference		Reference	
Single/widowed/divorced/separated	1.86 (0.97–3.57)	0.061	1.38 (0.65–2.93)	0.395
Responding parent born outside Canada				
No	Reference			
Yes	0.91 (0.54–1.56)	0.744		

Source: Childhood National Immunization Coverage Survey, 2013.

All rates and odds ratios are weighted.

The analysis was restricted to children who had not received any vaccine (n = 126) and those for whom immunization information was obtained from vaccine providers who had immunized them (n = 1796). Children whose respondent was not a parent (biologic or adoptive) were excluded from this analysis.

<sup>a</sup>Adjusted for all other variables for whom ORs are shown in this column.

**Table 5.** Determinants of incomplete vaccination for pertussis in Canadian 2-year-old children, 2013.

	% with <4 dose of pertussis vaccine (95% CI)	unadjusted OR (95% CI)	p	adjusted <sup>a</sup> OR (95% CI)	p
Sex					
Female	22.0 (19.2–24.9)	Reference			
Male	25.1 (22.2–28.0)	1.19 (0.94–1.49)	0.141		
Region					
Atlantic	21.2 (18.6–23.7)	Reference		Reference	
Quebec	21.2 (17.8–24.7)	1.00 (0.78–1.30)	0.978	0.95 (0.73–1.23)	0.687
Ontario	21.6 (17.3–25.9)	1.02 (0.76–1.38)	0.871	1.04 (0.76–1.41)	0.821
Prairies	29.0 (25.7–32.4)	<b>1.52 (1.22–1.91)</b>	<b>&lt;0.001</b>	<b>1.55 (1.22–1.96)</b>	<b>&lt;0.001</b>
British Columbia	28.8 (23.7–33.9)	<b>1.51 (1.13–2.01)</b>	<b>0.005</b>	<b>1.56 (1.15–2.12)</b>	<b>0.004</b>
Territories	35.0 (31.4–38.7)	<b>2.01 (1.61–2.51)</b>	<b>&lt;0.001</b>	<b>1.99 (1.57–2.53)</b>	<b>&lt;0.001</b>
Born outside Canada					
No	22.7 (20.6–24.7)	Reference		Reference	
Yes	48.6 (34.7–62.5)	3.23 (1.81–5.75)	<b>&lt;0.001</b>	3.10 (1.73–5.58)	<b>&lt;0.001</b>
Education					
High school, trade certificate or less	32.9 (28.4–37.5)	<b>2.18 (1.65–2.89)</b>	<b>&lt;0.001</b>	<b>1.92 (1.41–2.62)</b>	<b>&lt;0.001</b>
Post-secondary	22.8 (19.3–26.3)	1.31 (1.00–1.72)	0.051	1.26 (0.96–1.66)	0.100
University graduate	18.4 (15.5–21.3)	Reference		Reference	
Total household income					
0 – \$39,999	32.8 (27.3–38.2)	<b>2.08 (1.55–2.81)</b>	<b>&lt;0.001</b>	<b>1.58 (1.13–2.22)</b>	<b>0.007</b>
\$40,000 – \$59,999	28.9 (23.1–34.6)	<b>1.74 (1.25–2.40)</b>	<b>0.001</b>	<b>1.47 (1.04–2.07)</b>	<b>0.029</b>
\$60,000 – \$79,999	21.5 (16.9–26.1)	1.17 (0.85–1.60)	0.330	1.08 (0.78–1.50)	0.644
\$80,000 or more	18.9 (16.4–21.5)	Reference		Reference	
Marital status of responding parent					
Married / common law	22.5 (20.3–24.6)	Reference			
Single/widowed/divorced/separated	31.4 (24.7–38.1)	<b>1.58 (1.13–2.21)</b>	<b>0.008</b>		
Responding parent born outside Canada					
No	23.0 (20.7–25.2)	Reference			
Yes	24.7 (20.6–28.8)	1.10 (0.86–1.41)	0.447		

Source: Childhood National Immunization Coverage Survey, 2013.

All rates and odds ratios are weighted.

The analysis includes 2973 children who had received at least 4 doses of pertussis-containing vaccine and 926 children who had received 3 doses or less (total 3899)

<sup>a</sup>Adjusted for all other variables for whom ORs are shown in this column.

instance, parents of never-vaccinated children may have been more likely to participate in CNICS than in NIS.

The socio-demographic characteristics of never-vaccinated children and those not vaccinated for measles or incompletely vaccinated for pertussis were quite similar. It is important to note that the sample of children not vaccinated at all ( $n = 127$ ) was much smaller than the sample of children never vaccinated for measles ( $n = 409$ ) and incompletely vaccinated for pertussis ( $n = 926$ ), thus limiting our ability to detect significant differences between categories of independent variables. Thus, lack of statistical power may be the reason that, in multivariate analysis, income did not remain a significant determinant of total non-vaccination.

In this study, we found significant socio-economic variations in the uptake of vaccines. Children of parents with lower levels of education or from lower income households were more likely to be unvaccinated or under-vaccinated. Although our findings provide a contrast with the prevailing stereotype of the North American vaccine-hesitant parent who is both affluent and highly educated, a negative association between socio-economic status and measles-containing vaccine uptake has been found in other studies. In the United Kingdom, studies linking registry data with area-level information found that living in a deprived area was negatively associated with the uptake of the measles, mumps and rubella (MMR) vaccine.<sup>12</sup> In Belgium, an immunization survey revealed that lower income was associated with higher odds of MMR non-vaccination.<sup>13</sup> Similarly, in the United States, the NIS showed a higher risk of incomplete vaccination in children of less educated mothers,<sup>9</sup> but another analysis showed that more educated parents were more likely to delay or refuse their child's immunization.<sup>14</sup>

The finding that non-vaccination for measles is associated with single-parent families is consistent with another Canadian study<sup>15</sup> and an American study<sup>9</sup> that found a higher probability of incomplete vaccination in 2-year-old children from single-parent families.

In all Canadian provinces and territories, vaccines recommended in childhood immunization schedules are publicly funded and therefore free of charge for parents. However, each of these jurisdictions has its own health system and the immunization programs and delivery systems vary greatly between them. Depending on jurisdiction, childhood vaccines can be administered primarily by public health services, by private medical clinics, or both. These differences in delivery systems may impact actual coverage or the completeness of information in parent-held records. However, analyses to test for associations between delivery systems and coverage was beyond the scope of this study.

The most common reason for children being fully unvaccinated was the parent having vaccine safety concerns. Unfortunately, we were unable to analyze the reasons for incomplete vaccination, which may be different.

This study has limitations. In CNICS, data was collected primarily from immunization records held by the child's parent or guardian, thus missing any unrecorded dose(s). Information from health care providers, meant to fill this gap, was obtained for only one third of participants. Therefore, the proportions of children not having received their measles-containing vaccine or 4 doses of pertussis-containing vaccine by their second

birthday may have been over-estimated. Moreover, the under-reporting of vaccine doses may be higher in some categories of variables of interest, potentially biasing the associations measured. For instance, children born outside Canada may have incomplete information in their Canadian immunization record as some doses received before their arrival in the country may not have been recorded. There may also be some association between socio-economic status and missing information in immunization records. This may have biased some of the associations found with non-vaccination for measles and incomplete vaccination for pertussis in this study. However, this bias is unlikely to have affected our findings in regards to children who have never been vaccinated as this information was based on parental knowledge, not on immunization records.

Finally, this study looked only at sociodemographic factors, and some factors associated with socio-economic status but not captured in this study may mediate or confound the associations between parental education and/or household income and non-vaccination or incomplete vaccination. For instance, the number of children in a family<sup>9,15</sup> having moved in previous years,<sup>16</sup> and child not having a regular family doctor or pediatrician<sup>16</sup> have been found to be negatively associated with child vaccination status.

In conclusion, despite universal access to free childhood vaccines in Canada, regional variation and socioeconomic inequalities in vaccine uptake were still observed. Further analyses are warranted to distinguish the contribution of access and vaccine hesitancy to these variations.

## Methods

CNICS 2013 was a large cross-sectional survey conducted by Statistics Canada, on behalf of the Public Health Agency of Canada, of Canadian children aged 2, 7 or 17, plus girls 12–14 y of age (for the human papillomavirus vaccine only) as of March 1, 2013. The list of children whose parent or guardian applied for the Canadian Child Tax Benefit (CCTB), which is estimated to cover 96% of Canadian children,<sup>17</sup> was used as a sampling frame. Participants were selected by random sampling with stratification by province or territory.

Respondents (children's parents or guardians) were asked if their child had ever received any immunization. Those who responded no were asked for the reasons, and those who responded yes were asked if they had an immunization record available for their child. Children with a record available were included in the coverage assessment component of CNICS, in which data was collected primarily from parent-held immunization records; parental report was not accepted. Information was collected by antigen (e.g., measles, pertussis) rather than by vaccine. Finally, to mitigate the risk of incomplete documentation, parents were asked permission for survey staff to contact health care providers who immunized the child, or health care facilities where the child was immunized. Information was collected from these providers and facilities to confirm immunization history. However, despite 90% of parents providing agreement by phone, less than half returned their signed consent form by mail, and some healthcare providers or facilities could not be reached or did not respond. At the end,



immunization data from healthcare providers and settings was obtained for only 33.1% of survey participants.

We chose to examine incomplete vaccination separately for 2 individual antigens of interest rather than deriving a “fully vaccinated” variable based on doses received across multiple antigens, as has been done in a previous analysis using health care provider information to ascertain immunization status.<sup>18</sup> This is because of potential directional misclassification resulting from missing doses, illegible dose information or missing dates in parent-held immunization records. That is, we judged it more likely that an immunization record was missing information on doses previously administered, than to have an immunization erroneously recorded. This error would have been additive in a variable that attempted to identify those fully or partially vaccinated across multiple antigens, leading to a larger proportion of individuals misclassified on the outcome variable.

The outcomes under study were 1) total non-vaccination, i.e., children who had never received any vaccine at the time of the survey; 2) non-vaccination for measles, i.e., children having received zero doses of measles-containing vaccine by their second birthday, and 3) incomplete vaccination for pertussis, i.e., children having received fewer than 4 doses of pertussis vaccine by their second birthday. Children who had received at least one dose of any vaccine were the reference group for the total non-vaccination analysis; children not vaccinated against measles were compared with those who had received at least one dose of measles-containing-vaccine; children with fewer than 4 doses of pertussis were compared with children who had received 4 doses. Minimum ages and minimum intervals used for valid dose assessment were not considered in evaluating children in the reference groups, instead a dose counting approach to coverage was applied. However, vaccine doses had to be administered at least 28 d apart to be considered as distinct; this interval was used to ensure that doses reported by healthcare providers were not double-counted.

Independent variables under study were child’s sex, region of residence, child being born outside Canada, responding parent’s education, household income, responding parent’s marital status and responding parent being born outside Canada. For each variable, missing responses (don’t know, not stated) were grouped into a separate category. Adjacent provinces and territories of residence were grouped into regions (Atlantic: Newfoundland and Labrador, Prince Edward Island, Nova Scotia and New Brunswick; Prairies: Manitoba, Saskatchewan, and Alberta; and Territories: Nunavut, Northwest Territories, and Yukon) as the coefficients of variation for total non-vaccination estimates for some provinces and territories were too large. Canada’s largest provinces of British Columbia, Ontario and Quebec were examined individually. Imputation was done for only one variable, household income, by the nearest neighbor imputation method.<sup>19</sup>

Data were analyzed using SAS Enterprise Guide 5.1 and SAS 9.1. Weighted rates of non-vaccination and under-vaccination were calculated, and associations with socio-demographic factors were measured by simple and multiple logistic regressions. Independent variables associated with dependent variables at  $p < 0.1$  in simple regression were included in multiple regression models and kept as long as their  $p$  values remained below 0.1.

Unadjusted odds ratios (OR) and adjusted odds ratios (aOR) were calculated with 95% confidence intervals. To account for the complex survey design, standard errors and confidence intervals were estimated with the bootstrap technique.<sup>20</sup>

As a sensitivity analysis for the assessment of predictors of measles non-vaccination and pertussis incomplete vaccination, we repeated the logistic regressions by restricting the analysis to children for whom immunization information was obtained from vaccine providers who had immunized them and those who had not received any vaccine.

## Ethics

CNICS was conducted by Statistics Canada as part of its mandate to “collect, compile, analyze, abstract and publish statistical information relating to the commercial, industrial, financial, social, economic and general activities and conditions of the people of Canada,” and was not therefore considered as health research. The survey was done on a voluntary basis and data were kept confidential. Authors of this study had no access to any identifiable record.

## Disclosure of potential conflicts of interest

No potential conflicts of interest were disclosed.

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## Contributors

NLG and HG designed the study and conducted the analysis. All authors contributed to the interpretation of results. NLG drafted the manuscript, to which all authors provided input. All authors approved the final manuscript.

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