



## Original Contribution

# Neighborhood Determinants of 2009 Pandemic A/H1N1 Influenza Vaccination in Montreal, Quebec, Canada

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Neighborhood-level analyses of influenza vaccination can identify the characteristics of vulnerable neighborhoods, which can inform public health strategy for future pandemics. In this study, the authors analyzed rates of 2009 pandemic A/H1N1 influenza vaccination in Montreal, Quebec, Canada, using individual-level vaccination records from a vaccination registry with census, survey, and administrative data to estimate the population at risk. The neighborhood socioeconomic and demographic determinants of vaccination were identified using Bayesian ecologic logistic regression, with random effects to account for spatial autocorrelation. A total of 918,773 (49.9%) Montreal residents were vaccinated against pandemic A/H1N1 influenza from October 22, 2009, through April 8, 2010. Coverage was greatest among females, children under age 5 years, and health-care workers. Neighborhood vaccine coverage ranged from 33.6% to 71.0%. Neighborhoods with high percentages of immigrants (per 5% increase, odds ratio = 0.90, 95% credible interval: 0.86, 0.95) and material deprivation (per 1-unit increase in deprivation score, odds ratio = 0.93, 95% credible interval: 0.88, 0.98) had lower vaccine coverage. Half of the Montreal population was vaccinated; however, considerable heterogeneity in coverage was observed between neighborhoods and subgroups. In future vaccination campaigns, neighborhoods that are materially deprived or have high percentages of immigrants may benefit from focused interventions.

immunization; influenza, human; pandemics

Abbreviations: CCHS, Canadian Community Health Survey; CI, credible interval; ICD-9, *International Classification of Diseases*, Ninth Revision; NPHS, National Population Health Survey; OR, odds ratio.

On April 23, 2009, Mexican public health officials reported the first case of 2009 A/H1N1 influenza virus (1). The same day, 7 cases were reported in the United States, and 3 days later, the first case in Canada was announced (1). During the following months, the virus spread throughout the world. On June 11, 2009, with a total of 30,000 confirmed cases reported in 74 countries, the World Health Organization declared the beginning of the first influenza pandemic of the 21st century (2).

The first case of 2009 A/H1N1 influenza virus in Quebec, Canada, was confirmed on April 30, 2009, in Montreal (3). From August 30, 2009, to October 7, 2010, the number of laboratory-confirmed cases in Quebec

totaled 10,889, with 2,492 hospitalized cases and 83 deaths (4). Among these, 14% of hospitalized cases and 14% of deaths occurred in Montreal (4). To prevent infection and protect susceptible populations from severe disease, Quebec health authorities launched a mass pandemic influenza vaccination campaign on October 26, 2009.

A number of studies have examined the determinants of pandemic influenza vaccination in the general population (5–13), but only 2 used a vaccination registry (5, 10). The remainder used surveys (6–9, 11–13), which can be susceptible to selection bias and various biases associated with self-reporting, such as social desirability bias. As a result, surveys tend to overestimate coverage in comparison with

registries or other methods that collect vaccination data at the point of care (5, 12, 14, 15).

Using registries to assess vaccine coverage requires a method for estimating the at-risk population. Published methods have varied in terms of complexity and accuracy (5, 10, 15–19). Estimating precise denominators is important in order to avoid potential bias in coverage estimates (5). Standard denominator estimation methods that are reliable, are valid, and can be rapidly applied are needed.

Few studies examining the determinants of pandemic influenza vaccination have reported regional coverage estimates (5, 6). Geographic variation was noted in these studies but was not investigated further. Understanding the reasons for this heterogeneity may help to elucidate the barriers and determinants of pandemic influenza vaccination. Furthermore, understanding local determinants of vaccination is beneficial from a public health perspective, because health services are delivered locally.

The objectives of this study were: 1) to estimate by Montreal neighborhood the population of priority groups for which pandemic A/H1N1 influenza vaccination was recommended; 2) to describe pandemic influenza vaccine coverage in Montreal by sex, age group, priority group, date of vaccination, and neighborhood using a vaccination registry; and 3) to identify the neighborhood socioeconomic and demographic determinants of pandemic influenza vaccination in Montreal in the total population and among priority groups.

## MATERIALS AND METHODS

### Setting

Montreal is the most populated city in the Canadian province of Quebec and is its economic capital, with a population of 1,854,442, representing 25% of the provincial population in 2006 (20). The Public Health Department of the Health and Social Services Agency of Montreal divided the Island of Montreal into 111 neighborhoods by aggregating the 522 census tracts, which are small statistical areas with 2,500–8,000 persons (21), in a way that attempted to maintain within-neighborhood homogeneity with respect to sociodemographic factors (22).

The pandemic influenza vaccination campaign in Montreal began on October 26, 2009, during the peak of the second wave. The vaccines were administered free of charge in priority sequence (see Web Table 1 (<http://aje.oxfordjournals.org/>)) at 19 mass vaccination clinics located throughout the island. Following the closure of these clinics on December 18, 2009, people could obtain the vaccine at local community health centers. Throughout the campaign, federal and provincial authorities conducted extensive media campaigns informing the public of the benefits of vaccination.

### Study design

We conducted an ecologic study to identify the neighborhood determinants of pandemic influenza vaccination. The study population included all residents of the Island of

Montreal aged 6 months or older. This study was approved by the McGill University institutional review board. Use of the vaccination registry data was approved by the Quebec Information Access Commission.

### Data sources

**Vaccination data.** Vaccination data were recorded at the point of care throughout the campaign and subsequently entered into a central registry, which was established in 2009 for the sole purpose of collecting pandemic influenza vaccination data in Quebec. We obtained records of vaccination from the National Public Health Institute of Quebec for all persons vaccinated on the Island of Montreal. For our study, we obtained age group, sex, date of vaccination, census tract of residence, and self-reported priority group status (health-care workers, the chronically ill, pregnant women) for each vaccinated person. We restricted our analysis to residents of the Island of Montreal.

**Health-care utilization data.** We obtained data on health-care utilization from 2 administrative databases, Régie de l'assurance maladie du Québec (RAMQ) and Maintenance et exploitation des données pour l'étude de la clientèle hospitalière (MED-ECHO), to estimate the number of pregnant women. These databases contain information on physician services and hospitalizations, respectively, for all Quebec residents. Previous studies have used these databases to identify pregnant women (23–25). Data on mother's age, census tract of residence, and *International Classification of Diseases*, Ninth Revision (ICD-9), diagnostic codes were provided for each record.

**Census data.** We obtained 2006 Census data from Statistics Canada to estimate the distribution of the population by age and sex, the number of health-care workers, and covariates (percentage of immigrants, material and social deprivation).

**Survey data.** We obtained survey data from the 2007/2008 Canadian Community Health Survey (CCHS) and the 1998/1999 National Population Health Survey (NPHS) to estimate numbers of persons with chronic illnesses. These national, population-based surveys collect data related to the health and sociodemographic characteristics of the Canadian population. We used the Public Use Microdata Files, which contain anonymized individual-level data on sex, age group, the presence of chronic conditions, and geographic region.

### Estimation of denominators

Unlike surveys, which capture numerator and denominator data from survey respondents, registries collect only numerator data. We sought to estimate the denominator (in other words, the population of Montreal) by age, sex, and priority group status for the entire city and by neighborhood. Data on priority groups by Montreal neighborhood are not readily available. Consequently, we employed several previously developed data sources and methods to estimate the required denominators.

**Population count.** We used 2006 Census data as an approximation of the population in 2009. We obtained counts

for each age-sex stratum for each census tract on the Island of Montreal.

**Pregnant women.** We identified pregnant women using health-care utilization data and the ICD-9 codes listed in Web Table 2 (26). These codes were developed for the Canadian Chronic Disease Surveillance System to exclude women with gestational diabetes and pregnancy-induced hypertension when estimating the prevalence and incidence of diabetes in the Canadian population (26, 27). These codes describe pregnancy-related procedures and outcomes.

To determine the number of pregnant women in each neighborhood during the study period, we identified women with at least one ICD-9 code from the set during the 2006 calendar year. Women with multiple codes were considered only once. Previous studies used yearly estimates to determine the number of pregnant women during pandemic or seasonal influenza seasons (10, 28, 29).

**Chronic illness.** The CCHS and NPHS defined the presence of a chronic condition as a long-term condition that had lasted or was expected to last 6 months or more and that had been diagnosed by a health professional (30, 31). People who reported having asthma, diabetes, heart disease, cancer, effects of stroke, or chronic bronchitis/emphysema were considered to have a chronic illness for which influenza vaccination is recommended. These variables have been described previously (32, 33).

We calculated the proportion of persons with one or more chronic conditions by age group, region, and year (Web Table 3). Estimates were calculated and reported according to Statistics Canada guidelines (34). Proportions for children under 19 years of age were calculated using the NPHS for Quebec, since the CCHS is restricted to persons aged 12 years or older and NPHS estimates for Montreal were too unstable. This method slightly underestimated the proportion of children with a chronic illness in Montreal, but the difference was not statistically significant (Web Table 4).

To estimate the population of persons under age 65 years with a chronic illness, we applied the age-specific proportions to the corresponding age distribution of each neighborhood. We then totaled the stratum-specific numbers. This method of denominator estimation has been described previously (35, 36).

**Health-care workers.** To estimate the number of health-care workers, we used the 2006 Census variable that

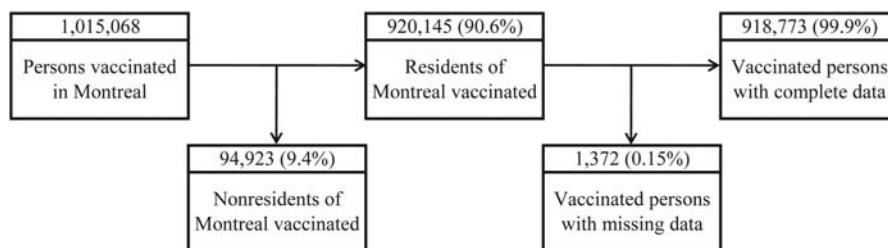
described the type of work performed at the person's place of employment (21). A health-care worker was defined as someone who identified his or her industry as "health care and social assistance." This definition includes health-care workers like physicians and nurses as well as non-health-care workers, such as administrative personnel, and has been used previously (14–17, 37–41).

## Covariates

The independent variables included in this study were determined from a literature review on the determinants of pandemic influenza vaccination (42). The socioeconomic and demographic determinants identified previously as significant predictors of pandemic influenza vaccination are: age, sex, priority group status, ethnicity/immigration status, education, occupation, income, and number of children/people living in the household. Rather than include all variables in the analysis, we used indices of material and social deprivation and percentage of immigrants, as these variables encompass the categories mentioned above and avoid potential problems of interpretation due to multicollinearity.

**Deprivation indices.** Indices of material and social deprivation were constructed by Pampalon and Raymond (43) in Quebec to estimate an individual's socioeconomic status by using the person's neighborhood-level socioeconomic status as a proxy (44). Each index is composed of 3 census variables that are intended to reflect the deprivation of individuals in the area relative to the overall population being studied. "Material deprivation" measures the lack of access to goods and services and includes 3 variables: the proportion of persons lacking a high school diploma, the employment-to-population ratio, and the average income. "Social deprivation" measures the lack of social support and involvement and includes 3 variables: the proportion of persons living alone, the proportion of persons separated, divorced, or widowed, and the proportion of single-parent families. These indices have been used extensively to examine socioeconomic determinants of health in Quebec (45–50).

We obtained the deprivation quintile for each dissemination area, the smallest geographic area for which census data are available, in Montreal (21). Because each neighborhood comprises several dissemination areas, we calculated the neighborhood deprivation score, a continuous



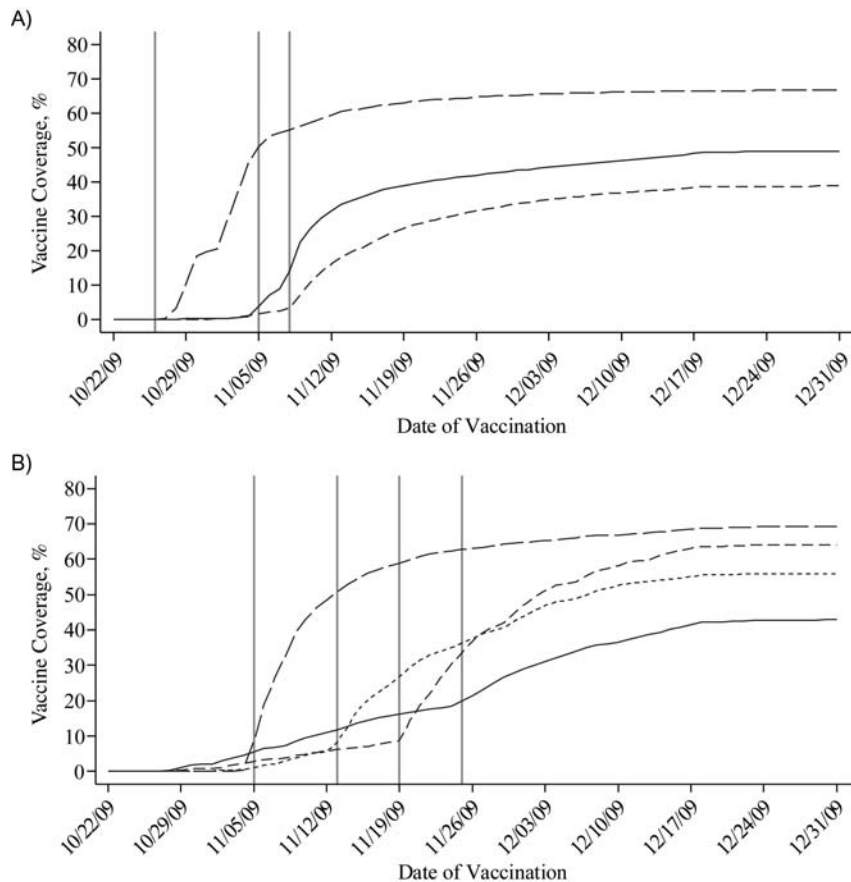
**Figure 1.** Distribution of vaccinations in Montreal, Quebec, Canada, during the 2009 pandemic A/H1N1 influenza outbreak, and vaccinations among Montreal residents included in the current study, October 2009–April 2010.

**Table 1.** Characteristics of the Population, Overall and by Neighborhood ( $n = 111$ ), and Pandemic A/H1N1 Influenza Vaccine Coverage, Montreal, Quebec, Canada, October 2009–April 2010

Characteristic	Overall					Neighborhood, % of Total Population					
	Study Population		Vaccinated Persons			Minimum	Quartile 1	Median	Mean	Quartile 3	Maximum
	No.	%	No.	% <sup>a</sup>	95% CI						
Total population	1,842,897		918,773	49.9	49.8, 50.0	1,958	10,099	15,734	16,603	20,543	62,963
Sex											
Female	956,342	51.9	501,300	52.4	52.3, 52.5	39.0	51.1	52.2	51.7	53.3	56.6
Male	886,555	48.1	417,473	47.1	47.0, 47.2	43.4	46.7	47.8	48.3	48.9	61.0
Age group, years											
0.5–4	84,452	4.6	59,077	70.0	69.6, 70.3	2.1	4.0	4.5	4.5	5.1	8.0
5–19	292,950	15.9	164,333	56.1	55.9, 56.3	6.9	13.1	16.2	16.1	18.7	24.9
20–64	1,179,125	64.0	510,447	43.3	43.2, 43.4	48.2	59.9	62.6	63.9	66.6	81.7
≥65	286,370	15.5	184,916	64.6	64.4, 64.7	7.1	12.0	15.1	15.4	18.3	32.3
Priority group											
Health-care workers <sup>b</sup> (by sex)	103,490	5.6	69,086	66.8	66.5, 67.0	2.3	4.9	5.7	5.6	6.5	8.4
Female	77,935	75.3	48,388	62.1	61.7, 62.4	54.3	72.8	76.8	76.0	80.7	100.0
Male	25,555	24.7	20,698	81.0	80.5, 81.5	0.0	19.3	23.2	24.0	27.2	45.7
Pregnant women <sup>c</sup> (by age, years)	19,490	1.1	9,622	49.4	48.7, 50.1	0.5	0.9	1.0	1.1	1.2	2.5
<20	399	2.0	160	40.1	35.4, 45.0	0.0	0.8	1.6	2.1	3.2	13.3
20–44	17,095	87.7	8,985	52.6	51.8, 53.3	68.3	84.0	87.7	86.8	90.2	95.7
≥45	1,996	10.2	477	23.9	22.1, 25.8	1.8	7.7	10.1	11.1	14.1	31.7
Chronically ill aged <65 years <sup>d</sup> (by age, years)	240,830	13.1	93,724	38.9	38.7, 39.1	11.3	12.7	13.1	13.1	13.6	15.1
<20	41,475	17.2	13,697	33.0	32.6, 33.5	7.3	14.6	17.5	17.3	20.4	25.6
20–39	58,856	24.4	16,628	28.3	27.9, 28.6	12.7	20.1	22.7	23.8	26.4	43.3
40–64	140,499	58.3	63,399	45.1	44.9, 45.4	47.6	55.8	59.4	58.9	62.6	68.4
Neighborhood characteristic											
Immigrants	137,762	7.5				1.1	4.1	6.2	7.0	8.4	21.9
Material deprivation score <sup>e</sup>						1.0	2.1	3.2	3.0	3.9	5.0
Social deprivation score <sup>e</sup>						1.1	2.9	3.6	3.5	4.1	4.9

Abbreviation: CI, confidence interval.

<sup>a</sup> Percent vaccinated in stratum  $i$  = number vaccinated in stratum  $i$ /number in study population in stratum  $i$  × 100.<sup>b</sup> Percentages represent percentage among health-care workers.<sup>c</sup> Percentages represent percentage among pregnant women.<sup>d</sup> Percentages represent percentage among the chronically ill aged less than 65 years.<sup>e</sup> The deprivation score, a continuous variable, was calculated by averaging the deprivation quintile values of the dissemination areas contained within the respective neighborhoods. A value of 1 represents the lowest deprivation level and a value of 5 represents the highest deprivation level.



**Figure 2.** Cumulative pandemic A/H1N1 influenza vaccine coverage in Montreal, Quebec, Canada, from October 22, 2009, to December 31, 2009, among A) designated priority groups and B) different age groups, by date of vaccination. Vertical bars indicate vaccination eligibility dates (see Web Table 1). Part A (priority groups): long-dashed line, health-care workers; solid line, pregnant women; medium-dashed line, chronically ill persons aged <65 years. Part B (age groups): long-dashed line, age 6 months–4 years; short-dashed line, age 5–19 years; solid line, age 20–64 years; medium-dashed line, age ≥65 years.

variable, by averaging the deprivation quintile values of the dissemination areas contained within the respective neighborhoods, where a value of 1 represents the lowest deprivation level and a value of 5 represents the highest deprivation level.

**Immigrants.** Using 2006 Census data, we estimated the number of immigrants in each neighborhood by including those who immigrated between 2001 and 2006. We divided the number of immigrants in each neighborhood by the total population of the neighborhood and multiplied by 100 to obtain the percentage of immigrants.

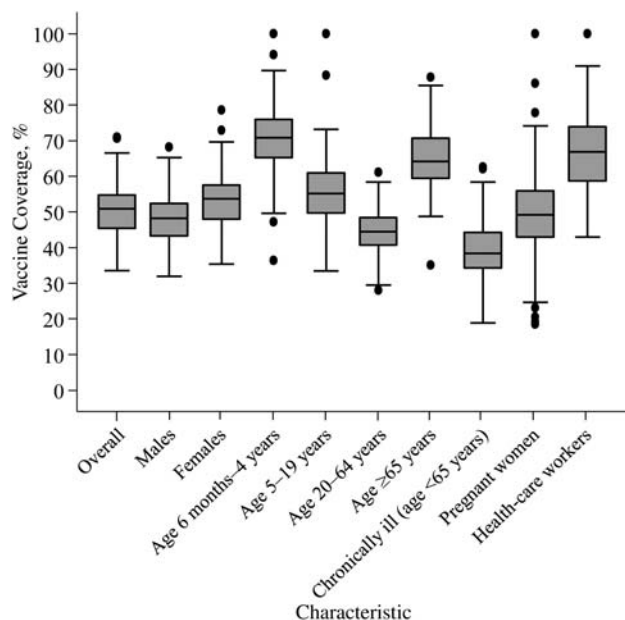
### Statistical analysis

Vaccine coverage and 95% confidence intervals were calculated overall and by sex, age group, priority group, and neighborhood. Cumulative coverage was calculated by date of vaccination among priority and age groups. Choropleth maps were constructed for the dependent variables (vaccine coverage overall and by priority group) and

independent variables (percentage of immigrants, material and social deprivation). We excluded vaccination records from census tracts where population data were suppressed (due to fewer than 40 persons in the census tract) (51, 52) and records with missing age or sex data.

To identify the neighborhood determinants of pandemic influenza vaccination, we used a Bayesian ecologic logistic regression model accounting for spatially unstructured and structured variation in vaccine coverage (53–55) (Web Appendix 1 and Web Appendix 2). Given the size of our geographic partitions, neighboring areas were defined as areas sharing a border.

We fitted our models using 3 chains, each with different initial values. To improve convergence, we centered all covariates. Convergence was assessed by means of visual inspection of Gelman-Rubin diagnostic plots. Once convergence was achieved, we conducted an additional 20,000 iterations to obtain the posterior distributions. We investigated the influence of the different choices of hyperpriors on our results through sensitivity analyses.



**Figure 3.** Box plots of neighborhood ( $n = 111$ ) pandemic A/H1N1 influenza vaccine coverage in Montreal, Quebec, Canada, by characteristic, October 2009–April 2010. Neighborhoods with greater than 100% coverage (1 neighborhood for 5- to 19-year-olds, 1 neighborhood for pregnant women, and 5 neighborhoods for health-care workers) were coded as having 100% coverage. The lines of the box represent the first quartile (Q1), the median value (Q2), and the third quartile (Q3). The box spans the interquartile range (IQR;  $Q3 - Q1$ ). The whiskers (the 2 outermost horizontal lines) represent the lower bound ( $1.5(IQR) - Q1$ ) and the upper bound ( $1.5(IQR) + Q3$ ). The dots are outliers (data points outside the upper/lower bounds).

We undertook separate analyses for the total population, pregnant women, chronically ill persons under age 65 years, and health-care workers (Web Appendix 3). The independent variables were percentage of immigrants and material and social deprivation, and the potential confounders were age group, sex, and priority group status as a percentage of the neighborhood population. The determinants of pandemic influenza vaccination were investigated using univariable and multivariable analyses. We retained all covariates in the multivariable model regardless of significance, as all of the variables are relevant from a public health perspective. We calculated univariable and multivariable odds ratios and 95% credible intervals. For 6 (1.4%) neighborhoods with proportions greater than 1, we adjusted the numerator value to equal the denominator value. To investigate the influence of changing the numerator value on our results, we conducted sensitivity analyses in which we changed the denominator to equal the numerator value and excluded the numerator value (i.e., assumed that the neighborhood's value was missing).

Data were analyzed using Stata/SE 9.2 (StataCorp LP, College Station, Texas) and WinBUGS 1.4 (Medical Research Council Biostatistics Unit, Cambridge, United

Kingdom). Maps were constructed using ArcMap 9.3 (ESRI Inc., Redlands, California).

## RESULTS

A total of 1,015,068 persons aged 6 months or older were vaccinated on the Island of Montreal during the study interval (Figure 1). We excluded 94,923 (9.4%) vaccinations of nonresidents. An additional 1,372 (0.15%) records were excluded because they were for residents of census tracts with suppressed population data ( $n = 1,339$  among 7 census tracts) or were missing age or sex data ( $n = 33$ ).

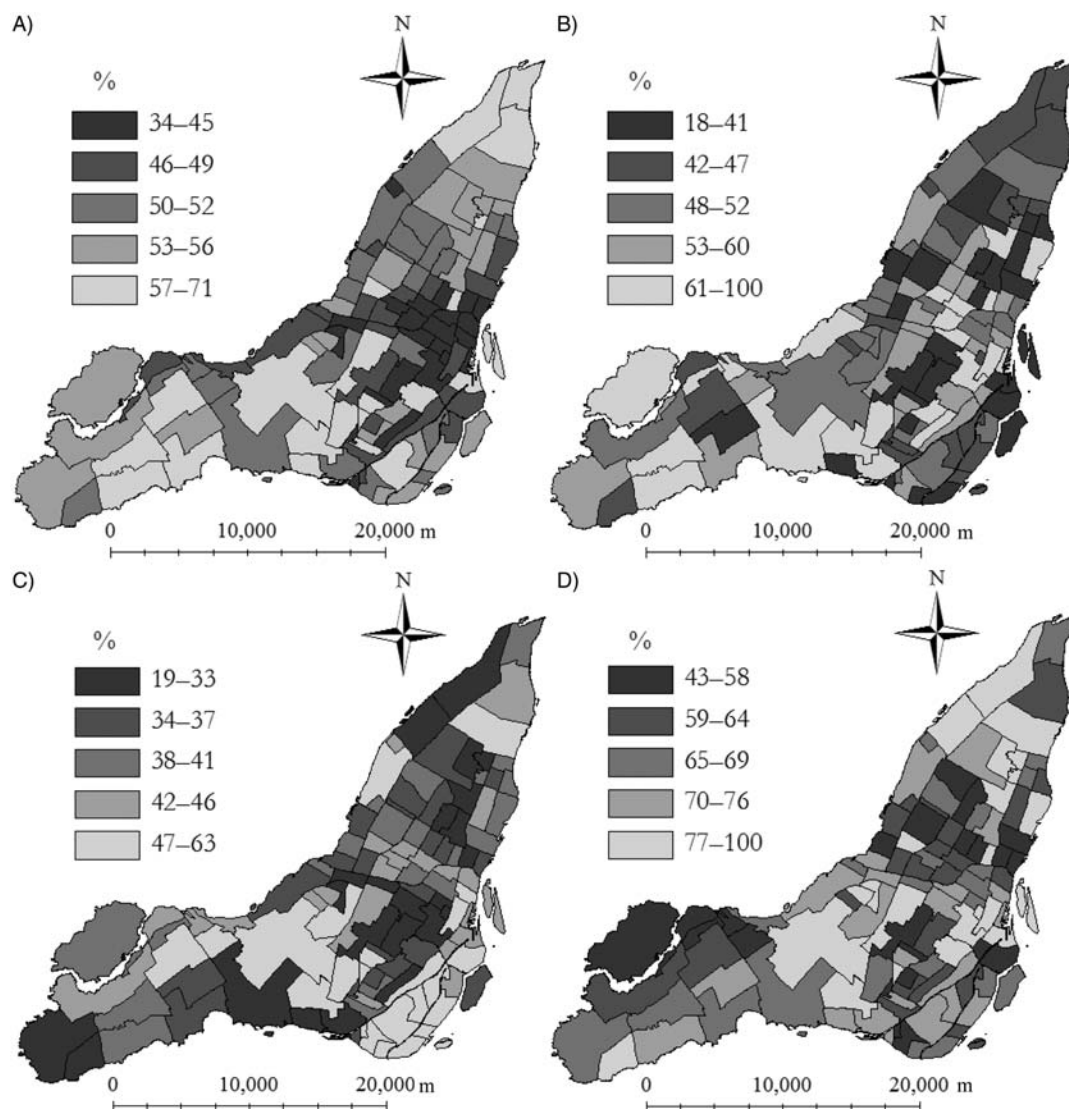
In our study population, a total of 918,773 (49.9%) Montreal residents were vaccinated against pandemic influenza during the study period (Table 1). Statistically significant differences in coverage were observed by sex, age group, and priority group. Coverage was highest among females (52.4%), children aged 6 months–4 years (70.0%), and health-care workers (66.8%).

Vaccinations took place from October 22, 2009, through April 8, 2010. Most (95%) vaccinations occurred before December 16, 2009. Vaccine coverage rose rapidly among health-care workers, pregnant women, and young children once these groups became eligible to receive the vaccine (Figure 2). Vaccine coverage changed little after December 18, corresponding to the closure of the mass vaccination clinics.

Neighborhood vaccine coverage varied overall and by sex, age, and priority group (Figure 3). Variation in coverage by neighborhood was lowest among persons aged 20–64 years and greatest among pregnant women. The geographic distribution of vaccine coverage varied overall and by priority group (Figure 4) and age group (Web Figure 1). In the overall population, areas of low coverage were clustered in the northern and eastern neighborhoods of Montreal, coinciding with higher deprivation scores and greater percentages of immigrants (Figure 5).

Univariable analyses showed that the percentage of immigrants and material and social deprivation were negatively associated with neighborhood pandemic influenza vaccine coverage in the total population (Table 2). For priority groups, material deprivation was negatively associated with vaccine coverage, particularly among pregnant women (per 1-unit increase in deprivation score, odds ratio (OR) = 0.90, 95% credible interval (CI): 0.82, 0.98) and health-care workers (per unit increase, OR = 0.87, 95% CI: 0.73, 0.99), and percentage of immigrants was negatively associated with vaccine coverage among chronically ill persons under age 65 years (per 5% increase, OR = 0.85, 95% CI: 0.79, 0.91).

After adjusting for age, sex, and priority group status, neighborhood material deprivation and the percentage of immigrants remained negatively associated with neighborhood vaccine coverage (Table 3). After adjustment for the effects of other variables, a 1-unit increase in neighborhood material deprivation score resulted in approximately 7%, 15%, and 17% decreases in the odds of neighborhood vaccination among the total population, health-care workers, and pregnant women, respectively (Table 3). We observed 10% and 17% decreases in the odds of neighborhood vaccination for every 5% increase in neighborhood percentage of immigrants in the total population and among the



**Figure 4.** Choropleth maps of neighborhood pandemic A/H1N1 influenza vaccine coverage in Montreal, Quebec, Canada, among A) the total population, B) pregnant women, C) chronically ill persons under age 65 years, and D) health-care workers, October 2009–April 2010. Neighborhoods with greater than 100% coverage (1 neighborhood for pregnant women and 5 neighborhoods for health-care workers) were coded as having 100% coverage.

chronically ill under age 65 years, respectively, after adjusting for the effects of other variables (Table 3). There did not appear to be a statistically significant association between social deprivation and vaccine coverage in the multivariable analysis for any of the populations analyzed.

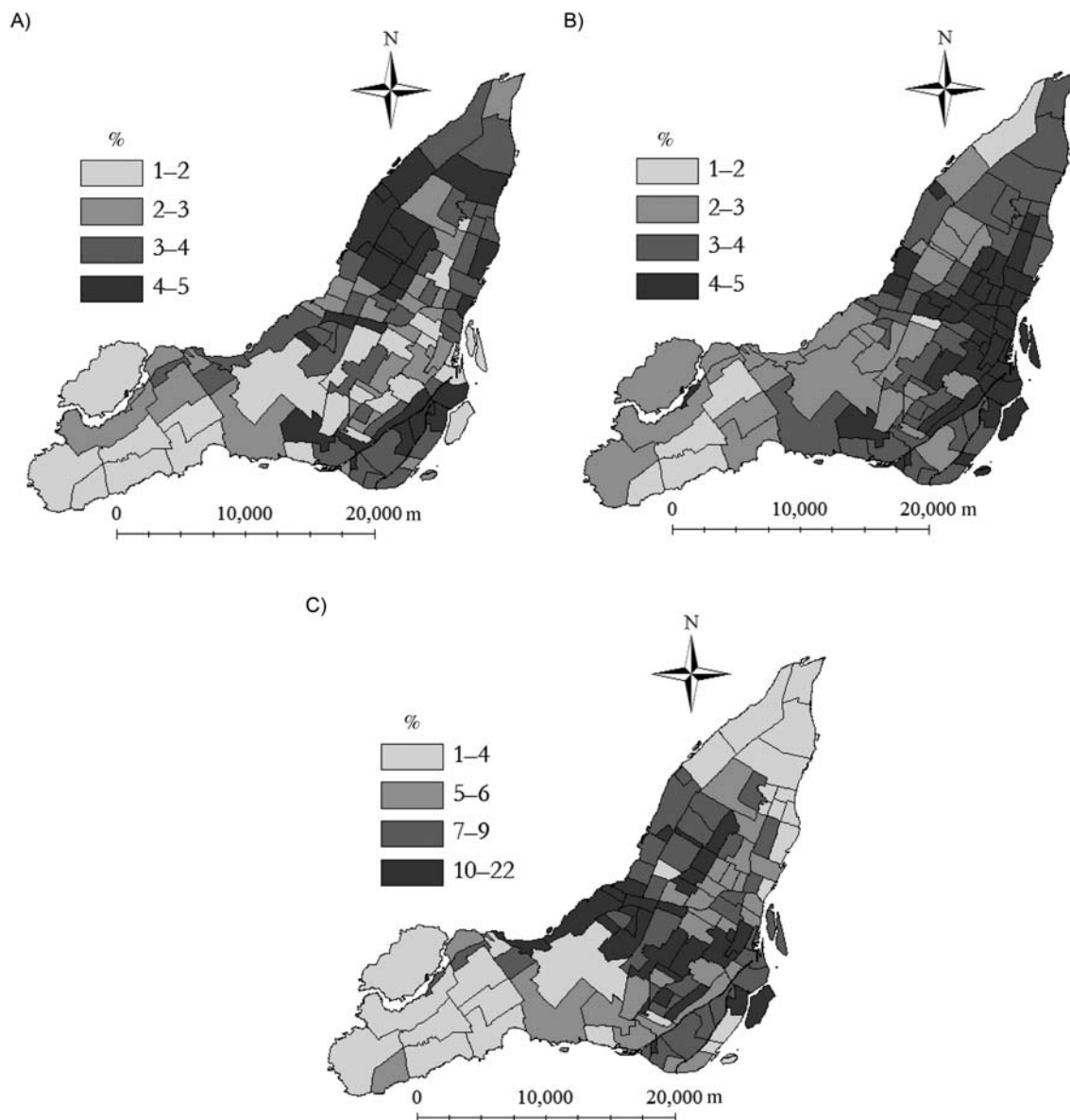
Our results were not sensitive to either the choice of hyperpriors (Web Tables 5–8) or the method used to correct data for neighborhoods with vaccine coverage greater than 100% (Web Tables 9 and 10).

## DISCUSSION

Using a population-based immunization registry to estimate events and using census, survey, and administrative

records to estimate the population at risk, we calculated pandemic influenza vaccine coverage for an urban area at a high geographic resolution. Overall pandemic influenza vaccine coverage in Montreal was 50%; however, we observed considerable variation by subgroup and geographic region. Females, younger persons, and health-care workers were more likely to receive the vaccine. We found that neighborhoods with higher percentages of immigrants and more material deprivation had lower vaccine coverage.

Neighborhoods with low vaccine coverage, particularly those with vulnerable populations, can contribute to the spread of outbreaks (56, 57). Although the vaccination campaign in Montreal was successful in vaccinating 50% of the total population, there were vulnerable



**Figure 5.** Choropleth maps of neighborhood variables included in an analysis of pandemic A/H1N1 influenza vaccination in Montreal, Quebec, Canada, 2006. A) Material deprivation; B) social deprivation; C) percentage of immigrants. For indices of deprivation, see Pampalon and Raymond (43).

subgroups with particularly low rates of vaccination. The results from this study suggest that neighborhoods with higher percentages of immigrants and material deprivation should be the focus of targeted interventions to increase vaccination during future influenza pandemics.

In this study, we employed methods of estimating vaccine coverage among neighborhoods using publicly available data. The methods described in this study can be used as a framework and can be adapted to estimate vaccine coverage in other areas. We have proposed methods for estimating the sizes of populations of pregnant women using administrative data and the chronically ill

using survey data. Depending on the data available, these methods could be adapted—for example, by applying the birth rate by age group to estimate numbers of pregnant women or by using ICD-9 codes defining chronic conditions to estimate numbers of the chronically ill. These methods could also be used together with registry data to monitor neighborhood seasonal influenza vaccine coverage in real time.

Our overall coverage estimate for Montreal is similar to a previously published estimate (50.4%) (4) and greater than estimates reported from other countries (range, 4.8%–20.3%) (7, 9, 10, 12, 13). Our results are similar to those of



**Table 2.** Neighborhood Determinants of Pandemic A/H1N1 Vaccination (Univariable Odds Ratios), Montreal, Quebec, Canada, October 2009–April 2010

Determinant	Total Population		Pregnant Women <sup>a</sup>		Chronically Ill Aged <65 Years		Health-care Workers <sup>b</sup>	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Material deprivation <sup>c</sup>	0.92	0.88, 0.96	0.90	0.82, 0.98	1.01	0.96, 1.08	0.87	0.73, 0.99
Percentage of immigrants <sup>d</sup>	0.85	0.81, 0.90	0.98	0.87, 1.09	0.85	0.79, 0.91	0.92	0.76, 1.11
Social deprivation <sup>c</sup>	0.89	0.83, 0.95	1.02	0.92, 1.14	0.97	0.89, 1.05	1.00	0.84, 1.18

Abbreviations: CI, credible interval; OR, odds ratio.

<sup>a</sup> For neighborhoods with coverage greater than 100% ( $n = 1$ ), the numerator value was changed to the denominator value.

<sup>b</sup> For neighborhoods with coverage greater than 100% ( $n = 5$ ), the numerator value was changed to the denominator value.

<sup>c</sup> OR for a 1-unit increase in deprivation score.

<sup>d</sup> OR for a 5% increase in percentage of immigrants.

other studies in which females (10, 17), children (5, 7, 12), and health-care workers (10, 12) were more likely to receive the vaccine.

The geographic variability we observed among population groups was partially explained by neighborhood material deprivation and the percentage of immigrants. Our results are comparable to those of other epidemiologic studies on the determinants of pandemic influenza vaccination in which ethnic origin (7, 10, 13, 18), income (18), occupation (12, 58), and education (12, 37, 59–61) predicted vaccination. A review of determinants of seasonal influenza vaccination also observed lower vaccine coverage among racial and ethnic minorities and persons living in poverty (62). Lower coverage in areas with greater percentages of immigrants may be due to barriers in access to health care, transportation, knowledge, and language (63–67). One possible reason for lower coverage in areas with more material deprivation may be poor understanding of and lower sensitivity to public health messages, leading to decreased health awareness and the adoption of fewer public health interventions (68). We observed differences

in determinants by priority group, indicating that the neighborhood factors that influence the decision to receive the vaccine probably differ by priority group.

Because of the large neighborhood variability observed, our results suggest that coverage should ideally be measured at the neighborhood level. Neighborhood estimates of coverage are essential for public health officials to make informed decisions during vaccination campaigns. Using registry data, we were able to calculate estimates of vaccine coverage at a higher geographic resolution than any estimates previously published or obtained using traditional survey methodology. However, estimating denominators for priority groups for small areas is a challenge, as data describing persons within priority groups are not readily available. Although our methods of estimation have not been validated for small areas, our results are similar to those from other studies. We observed a small percentage of observations (1.4%) with coverage over 100%. Although we cannot verify whether this finding reflects an issue with numerator data (overreported priority group status which was not consistently verified at the point of care) or

**Table 3.** Neighborhood Determinants of Pandemic A/H1N1 Vaccination (Multivariable Odds Ratios), Montreal, Quebec, Canada, October 2009–April 2010

Determinant	Total Population <sup>a</sup>		Pregnant Women <sup>b,c</sup>		Chronically Ill Aged <65 Years <sup>d</sup>		Health-Care Workers <sup>e,f</sup>	
	OR	95% CI	OR	95% CI	OR	95% CI	OR	95% CI
Material deprivation <sup>g</sup>	0.93	0.88, 0.98	0.83	0.74, 0.93	1.09	1.02, 1.17	0.85	0.70, 0.99
Percentage of immigrants <sup>h</sup>	0.90	0.86, 0.95	1.08	0.95, 1.21	0.83	0.76, 0.91	0.99	0.81, 1.22
Social deprivation <sup>g</sup>	1.00	0.94, 1.07	0.98	0.87, 1.10	0.99	0.91, 1.09	0.99	0.85, 1.17

Abbreviations: CI, credible interval; OR, odds ratio.

<sup>a</sup> Adjusted for percent female, percent aged 20–64 years, percent aged 65 years or more, percentage of pregnant women, percentage of chronically ill persons under age 65 years, and percentage of health-care workers.

<sup>b</sup> Adjusted for percentage of pregnant women aged 20–44 years and percentage of pregnant women aged 45 years or more.

<sup>c</sup> For neighborhoods with coverage greater than 100% ( $n = 1$ ), the numerator value was changed to the denominator value.

<sup>d</sup> Adjusted for percentage of chronically ill persons aged 20–39 years and percentage of chronically ill persons aged 40–64 years.

<sup>e</sup> Adjusted for percentage of female health-care workers.

<sup>f</sup> For neighborhoods with coverage greater than 100% ( $n = 5$ ), the numerator value was changed to the denominator value.

<sup>g</sup> OR for a 1-unit increase in deprivation score.

<sup>h</sup> OR for a 5% increase in percentage of immigrants.

denominator data (estimation errors leading to underestimation), our sensitivity analyses indicated that these observations did not affect our results.

There were other limitations of our study that were unrelated to our method of estimation. Our data were restricted to vaccinations that took place on the Island of Montreal among residents. We were missing 1% of vaccinations among residents that took place off the island, comprised mostly of health-care workers who were vaccinated at their off-island workplaces (information provided by the National Public Health Institute of Quebec). Because we studied the determinants of vaccination at the neighborhood level, we cannot extrapolate our findings to individuals, although our neighborhood perspective compliments the results of individual-level studies.

This study highlights the importance of measuring vaccine coverage at the neighborhood level. We have described methods for estimating at-risk populations for small areas and have identified population-level characteristics that can be used by public health officials to strategically plan for future influenza pandemics.

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