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National assessment of Canadian pandemic preparedness: Employing InFluNet to identify high-risk areas for inter-wave vaccine distribution

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ABSTRACT

Background: Influenza pandemics emerge at irregular and unpredictable intervals to cause substantial health, economic and social burdens. Optimizing health-system response is vital to mitigating the consequences of future pandemics.

Methods: We developed a mathematical model to assess the preparedness of Canadian health systems to accommodate pandemic-related increases in patient demand. We identify vulnerable areas, assess the potential of inter-wave vaccination to mitigate impacts and evaluate the association between demographic and health-system characteristics in order to identify predictors of pandemic consequences.

Results: Modelled average attack rates were 23.7–37.2% with no intervention and 2.5–6.4% with pre-vaccination. Peak acute-care demand was 7.5–19.5% of capacity with no intervention and 0.6–2.6% with pre-vaccination. The peak ICU demand was 39.3–101.8% with no intervention and 2.9–13.3% with pre-vaccination. Total mortality was 2258–7944 with no intervention and 88–472 with pre-vaccination. Regions of Southern Ontario were identified as most vulnerable to surges in patient demand. The strongest predictors of peak acute-care demand and ICU demand were acute-care bed capacity ($R = -0.8697$; $r^2 = 0.7564$) and ICU bed capacity ($R = -0.8151$; $r^2 = 0.6644$), respectively. Demographic characteristics had mild associations with predicted pandemic consequences.

Conclusion: Inter-wave vaccination provided adequate acute-care resource protection under all scenarios; ICU resource adequacy was protected under mild disease assumptions, but moderate and severe diseases caused demand to exceed expected availability in 21% and 49% of study areas, respectively. Our study informs priority vaccine distribution strategies for pandemic planning, emphasizing the need for targeted early vaccine distribution to high-risk individuals and areas.

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1. Introduction

In response to widespread global transmission of the A(H1N1) influenza virus, the World Health Organization declared a pandemic on June 11, 2009; this marked the fourth time in one hundred years that a novel influenza virus had emerged to cause significant social, economic and health burdens (Saunders-Hastings & Krewski, 2016). Influenza is an RNA virus that causes annual outbreaks of acute respiratory infections (Fiore et al., 2008). With a high mutation rate preventing substantial accumulation of natural immunity, influenza is the most deadly vaccine-preventable disease in North America (Fiore et al., 2008).

Influenza pandemics result from the emergence of new viral strains to which humans possess no appreciable immunity. This tends to be the result of a process called *antigenic shift*, wherein viral components from different sources interact and combine to form a new viral genotype; if this strain can transmit easily between human hosts and results in illness, a pandemic may emerge. The combined burden of the past four occurrences — the Spanish flu (1918), Asian flu (1957), Hong Kong flu (1968) and Swine flu (2009) — amount to tens of millions of infections, hospitalizations and deaths (Saunders-Hastings & Krewski, 2016). In each case, the pandemic evolved in multiple successive waves, with the second often being more severe than the first (Saunders-Hastings & Krewski, 2016).

Of particular concern in pandemic situations is the expected surge in patient demand, and the resulting strain on hospital-resource capacity. Hospitals tend to rely on just-in-time resource supply, and have limited surge capacity (Saunders-Hastings, Reisman, & Krewski, 2016). Sudden increases in patient demand could quickly overwhelm hospital capacity, leading to dangerous disruptions in service delivery (Oshitani, Kamigaki, & Suzuki, 2008). A key component of pandemic planning must therefore be the identification and support of vulnerable health systems in order to protect hospital-resource adequacy.

Vaccination has been identified as the most cost-effective method of containing pandemic influenza transmission and mitigating its associated burdens (Yang et al., 2009). However, the production, development and distribution of a new pandemic vaccine could take up to six months, therefore making it may unavailable to affect the first wave of a pandemic (Longini, Halloran, Nizam, & Yang, 2004). However, strategic allocation of a limited pandemic vaccine supply during the inter-wave period could help mitigate the threat of a problematic second wave. While an important component of this effort will be the targeting of high-risk individuals, strategic allocation should also involve the targeting of individuals within health systems at greatest risk of being overwhelmed by surges in patient demand.

In this article, we present the findings of modelling simulations for each Canadian Census Metropolitan Area (CMA). Using InFluNet — a mathematical model developed to predict the evolution and impacts of a pandemic influenza outbreak — we project the possible second-wave pandemic burden for each location under various vaccination and disease severity assumptions. Across six health outcomes, we identify areas at greatest risk from an influenza pandemic and identify high-priority areas for inter-wave vaccine allocation. While of particular relevance to Canadian contexts, this research also provides valuable insights for international pandemic preparedness by evaluating on the characteristics of demographic and health-system profiles that underlie regional pandemic influenza vulnerability.

2. Methods

The present study relied on InFluNet — a validated differential equation model developed by the authors — to conduct its model simulations. Below, we provide a brief summary of its underlying assumptions and how it was employed to identify vulnerable Canadian hospital systems.

2.1. Social contact

InFluNet stratifies the population by age according to the following five groups: infant (0–4), child (5–18), young adult (19–29), adult (30–64) and senior (65 and over). Individuals interact in the household, school or workplace (depending on age) and community, for twelve, eight, and four hours each day, respectively. Individuals will interact preferentially within

Table 1
Average number of daily contacts by age group per person per day (Del Valle et al., 2007).

	Infant	Child	Young adult	Adult	Senior	Total
Infant	0.9511	3.5509	1.6740	4.8698	0.6594	11.7052
Child	1.2237	7.3670	1.6153	3.5244	0.6363	14.3668
Young adult	0.6096	1.7070	6.7059	12.1926	1.3209	22.5359
Adult	0.6195	1.3010	4.2591	12.6380	1.4094	20.2271
Senior	0.3498	0.9794	1.9239	5.8766	2.1827	11.3124