Using Ontario Health Insurance Plan physician billing claims to ascertain individual influenza immunization status: An updated validation study

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Keywords: Influenza immunization; Validation; Physician billings

Abbreviations: OHIP=Ontario Health Insurance Plan; CCHS=Canadian Community Health Survey; ICES=Institute for Clinical Evaluative Sciences; PPV=positive predictive value; NPV=negative predictive value; CIHI=Canadian Institute for Health Information; DAD=Discharge Abstract Database;

NACRS=National Ambulatory Care Reporting System; SDS=Same Day Surgery; CORR=Canadian Organ Replacement Register; ORRS=Ontario Renal Reporting System; ODD=Ontario Diabetes Database; OCR=Ontario Cancer Registry; OMID=Ontario Myocardial Infarction Database; COPD=Chronic Obstructive Pulmonary Disease; ODB=Ontario Drug Benefits; CHF=Congestive Heart Failure; HIV=Human Immunodeficiency Virus

Abstract word count: 2504~~8~~

Manuscript word count: 2543~~336~~

Abstract

Background

Due to the absence of an immunization registry in Ontario, administrative data are currently the best available data source to ascertain population-based individual-level influenza immunization status. Our objective was to validate physician billing claims for influenza immunization in the Ontario Health Insurance Plan database against the Canadian Community Health Survey.

Methods

We used self-reported seasonal influenza immunization status of Ontario residents surveyed between 2007 and 2009 as the reference standard. The survey responses were linked to physician claims database records to validate billing codes for influenza immunization. We calculated sensitivity, specificity, positive predictive value, and negative predictive value with 95% confidence intervals. We stratified the data by a number of covariates and comorbidities to determine stratum-specific performance characteristics. We used these estimates to adjust ~~recent~~ an estimate~~s~~ of influenza vaccine effectiveness for the 2010-11 influenza season.

Results

For the 47,301 individuals included in the analysis, the sensitivity for the billing codes was 49.8% (95%CI 49.0%-50.5%), specificity 95.7% (95%CI 95.5%-96.0%), positive predictive value 88.4% (95%CI 87.8%-89.0%), and negative predictive value 74.5% (95%CI 74.0%-74.9%). Performance measures were optimized in those ≥65 years of age, particularly those with comorbidities.

Interpretation

Although administrative data have limitations for ascertaining influenza immunization status, due to the high positive predictive value they are well suited for self-controlled study designs which are often used to assess vaccine safety. For studies of coverage and effectiveness, restricting the cohort to those aged ≥65 years will minimize misclassification bias. Performance characteristics from this study can be used to mitigate misclassification bias ~~in future studies~~.

Introduction

Influenza continues to pose a major public health burden in Canada. It is estimated that 5–10% of the population has a symptomatic influenza infection annually.(1) Since 2000, the province of Ontario has offered free influenza vaccines to the entire population aged ≥6 months through a variety of settings, including physician offices, community-based public health clinics, healthcare facilities, workplaces, schools, and pharmacies. However, the absence of a comprehensive immunization registry that captures influenza vaccines delivered in all settings has hindered efforts to evaluate the influenza immunization program in terms of vaccine safety, effectiveness, and coverage.

We previously validated physician billing claims for influenza immunization submitted to the Ontario Health Insurance Plan (OHIP) against self-reported influenza immunization from the Canadian Community Health Survey (CCHS) cycle 1.1, conducted in 2000–01.(2) We found high specificity (97%) and positive predictive value (PPV; 91%), moderately high negative predictive value (NPV; 79%), but lower sensitivity (56%). Sensitivity was higher for adults aged ≥65 years and individuals who reported having chronic medical conditions. Previous studies have found self-reported immunization status to be valid.(3–10) The low sensitivity of physician billing claims is partially explained by individuals receiving influenza vaccines outside of physician offices.(2) The objective of this study was to update the previous validation with more recent data, and to estimate performance measures of OHIP billing claims for individuals with a more comprehensive (and more rigorously ascertained) list of risk factors for serious influenza infections.

Methods

Study population and setting

This study included Ontario residents who responded to the CCHS between 1 January 2007 and 30 September 2009 and agreed to have their survey data linked with provincial health administrative data. These datasets were linked using unique encoded identifiers and analyzed at the Institute for Clinical

Evaluative Sciences (ICES). We excluded those surveyed on 1 October 2009 or later because two vaccines were used during the 2009–10 influenza season (the monovalent pandemic A/H1N1 vaccine and the trivalent seasonal influenza vaccine) and we were unable to differentiate between them using the OHIP data because the same billing codes were used for both vaccines. Data from more recent cycles of CCHS were not yet available in linked format at ICES at the times of manuscript submission in January 2016. This study was approved by the institutional review board at Sunnybrook Health Sciences Centre, Toronto, Canada.

Data Sources

Canadian Community Health Survey

The CCHS is a national cross-sectional survey that collects health-related information on individuals aged ≥12 years through telephone and in-person interviews. The first three iterations in 2000–01 (CCHS 1.1), 2003 (CCHS 2.1), and 2005 (CCHS 3.1) were biennial surveys of approximately 130,000 respondents. In 2007, Statistics Canada changed the survey design so that data would be collected from approximately 65,000 respondents annually. The survey excludes persons residing on aboriginal settlements, full-time members of the Canadian armed forces, and institutionalized individuals (less than 3% of total population). Details of the survey methodology have been described elsewhere.(11) The response rates for the 2007–08 and 2009–10 cycles were 77.6%, and 73.2%, respectively. The linkage rate between CCHS and ICES data was 83%.

Ontario Health Insurance Plan

The OHIP database contains billing information from approximately 94% of Ontario's physicians.(12) It excludes those not paid through fee-for-service methods. OHIP provides virtually the entire Ontario population with universal insurance coverage for physician services and hospital care, excluding new provincial residents during their initial three months.

Definitions

Influenza immunization status from CCHS

Respondents were asked, "Have you ever had a flu shot?" Those who responded affirmatively were asked, "When did you have your last flu shot?" Respondents specifying they had received a flu shot within the last 12 months were then asked which month, and if they answered the current month they were asked, "Was that this year or last year?" We classified the following individuals who reported receiving a flu shot within the last 12 months as immunized: 1) those whose month of immunization differed from the month of interview; and 2) those whose month of immunization matched the month of interview, and it was this year. Since the questionnaire did not ascertain the exact date of flu shot receipt, individuals whose month of immunization matched the month of interview, but it was last year, may have received their influenza vaccine more than 365 days prior. For these specific individuals, we classified individuals whose interview occurred during the first 15 days of the month as having been immunized and those interviewed after the first 15 days of the month as not immunized. We conducted a sensitivity analysis restricting the survey dates from 1 February to 31 August of each year in order to minimize the risk of immunization year misclassification for those surveyed during influenza immunization campaign periods in Ontario (usually September to January).

Influenza immunization status from OHIP

To identify influenza immunization status in the OHIP database, we used the billing codes for immunization with influenza vaccines, G590 (influenza immunization plus visit) and G591 (influenza immunization only). We also included the tracking code Q130 (influenza vaccine tracking code), which is used when a patient has been immunized elsewhere. Physicians belonging to certain remuneration plans receive financial incentives for attaining pre□specified targets for influenza immunization of their patients aged ≥65 years, and all three codes are included in the numerator for those calculations. Using

the CCHS interview date as the reference date, we considered the presence of any of the influenza immunization codes over the previous 365 days to be active immunization.

Other Definitions

We ascertained neighbourhood income quintile using residential postal codes, and defined rural residence as community size <10,000 residents. Having a regular physician was determined from the CCHS question, "Do you have a regular medical doctor?" We evaluated individuals for the presence of a number of potential risk factors for serious influenza infections, including chronic cardiovascular diseases (congestive heart failure, history of acute myocardial infarction or acute ischemic stroke, and hypertension), chronic respiratory diseases (asthma and chronic obstructive pulmonary disease), diabetes, chronic kidney disease, cancer, immunosuppression (resulting from infection with human immunodeficiency virus or from immunosuppressive therapies), dementia, morbid obesity (body mass index >40 calculated from the height and weight provided in the CCHS survey), and pregnancy (derived from the MOMBABY database). Most of these conditions were defined using previously validated algorithms applied to administrative datasets housed at ICES, including the OHIP database, the Canadian Institute for Health Information (CIHI) Discharge Abstract Database (DAD), the CIHI National Ambulatory Care Reporting System (NACRS), the CIHI Same Day Surgery (SDS) database, the Canadian Organ Replacement Register (CORR), the Ontario Renal Reporting System (ORRS), the Ontario Diabetes Database (ODD), the Ontario Cancer Registry (OCR), the Ontario Myocardial Infarction Database (OMID), the Chronic Obstructive Pulmonary Disease (COPD) database, the Ontario Drug Benefits (ODB) database, the Ontario Congestive Heart Failure (CHF) database, and the Ontario Human Immunodeficiency Virus (HIV) database.(13–28) These databases and the definitions used are described in the appendix tables e1 and e2.

Statistical analysis

We set self-reported influenza immunization status from the CCHS as the reference standard. We calculated performance measures (sensitivity, specificity, PPV, and NPV) with 95% confidence limits for OHIP physician billing claims for influenza immunization. We stratified the results by survey cycle, age group, sex, rural versus urban residence, having a regular physician, and presence of risk factors for serious influenza infections. We further stratified some of these groups by age (<65 years versus ≥65 years). Statistical analyses were conducted using SAS Enterprise Guide 6.1 (SAS Institute Inc., Cary, NC).

Application example

To illustrate the applicability of these results, we used the values for sensitivity and specificity to correct the bias arising from misclassification of influenza immunization status based on OHIP physician billing claims. We~~by~~ apply~~i~~ed~~ng~~ a SAS macro developed by Fox *et al.*(29) to results from a previous ~~influenza vaccine effectiveness~~ study by Kwong *et al.* that assessed vaccine effectiveness against laboratory-confirmed influenza hospitalizations amongst older adults during the 2010-11 influenza season.(30) This macro uses a probabilistic method for conducting a sensitivity analysis using individual-level data. Using the overall ~~and incorporates the~~ sensitivity and specificity from this study's results for influenza immunization status in Ontario individuals aged ≥65 years, we calculated vaccine effectiveness~~of the misclassified variable to produce odds ratio estimates that are~~ corrected for ~~the~~ misclassification ~~bias~~of the exposure variable (i.e., influenza immunization).(29) We assumed the bias was non-differential (i.e., that the exposure bias was not related to the outcome). ~~Statistical analyses were conducted using SAS Enterprise Guide 6.1 (SAS Institute Inc., Cary, NC).~~

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Results

There were 48,426 survey responses, with 1,122 excluded for either refusal or an inability to answer the influenza vaccine question and 3 excluded with invalid birthdates, leaving 47,301 Ontarians included in

the analysis (Table 1). Based on CCHS survey results, approximately 40% of these individuals reported being immunized against influenza, ranging from less than 25% in those aged <50 years to 68% of those aged ≥65 years. Immunization coverage was higher among females, older adults, those with a regular physician, and those with risk factors for serious influenza infection, except for pregnancy.

The combined sensitivity for influenza OHIP billing codes was 49.8% (95%CI 49.0%–50.5%), specificity 95.7% (95%CI 95.5%–96.0%), positive predictive value 88.4% (95%CI 87.8%–89.0%), and negative predictive value 74.5% (95%CI 74.0%–74.9%) (Table 2). The sensitivity ranged from 20.3% in adolescents (12–17 years) to 68.9% in those aged ≥65 years, whereas specificity was high for those <65 years of age (≥96.0%) and declined to 82.7% for those aged ≥65 years. Similarly, PPV increased with age whereas~~ile~~ NPV decreased.

Having access to a regular physician substantially improved the sensitivity of OHIP influenza vaccine billing codes, but with some decrease in specificity. The validity of the OHIP influenza immunization codes was fairly consistent across a variety of influenza risk factors, as long as the cohort was restricted to those ≥65 years of age. For chronic conditions, the sensitivity ranged from 68.9% to 74.3% and dropped to 60.5% in those without any comorbidities. The specificity ranged from 73.8% to 90.0%. The sensitivity decreased for all conditions to 40.4%–57.4% in those <65 years of age, but remained significantly higher than for younger individuals without any comorbidities (29.1%). The specificity was high across all comorbid conditions in the younger cohort. The PPV was high for all groups except those aged 12–17 years.

In the sensitivity analysis restricting to those who were surveyed between February and August, the overall PPV increased from 88.4% to 93.2% and the specificity increased marginally from 95.7% to 97.5% (Table 3). The improvements in both specificity and PPV were seen in all subgroups. Results for individuals aged <65 years who have risk factors for serious influenza infection are not presented due to the presence of numerous small cells (i.e., cell size <6 individuals).

We incorporated our results into a misclassification bias adjustment sensitivity analysis to demonstrate the utility of these results when using administrative data for ascertaining individual-level influenza immunization status for vaccine effectiveness studies. ~~In our analysis accounting for the misclassification bias from using OHIP physician billing claims to ascertain influenza immunization status in Ontario, W~~we inputted a sensitivity of 68.6% and a specificity of 89.9% (from Table 3). Figure 1 shows a significant underestimation of influenza vaccine effectiveness for the 2010-11 season before adjusting for the misclassification of immunization status. ~~and observed an increase in V~~vaccine effectiveness increased from 42% (95%CI 29%-53%) to 68% (95%CI 61%-78%) after the adjustment~~, suggesting a significant underestimation of vaccine effectiveness in the original study (Figure)~~.

Interpretation

We found that OHIP billing claims had only moderate performance characteristics to correctly identify influenza immunization status in Ontario, compared to self-report. For children and adults <65 years of age, the sensitivity was under 50%, but specificity was greater than 90%. Among those aged ≥65 years, the sensitivity was 70%, but with 83% specificity. The sensitivity was generally higher for those with comorbid conditions and those with a regular physician. These subpopulations had the most accurate OHIP influenza immunization billing claims. The performance characteristics were better when restricting to CCHS respondents who were surveyed between February and August, suggesting the presence of some misclassification by influenza season when including CCHS respondents surveyed during months that influenza vaccines are generally given.

There are a number of potential explanations for the low sensitivity of OHIP billing claims. A significant minority of individuals are immunized outside of physician offices and we would not expect their immunizations to be captured in health administrative data, despite the existence of an influenza vaccine tracking code. These include persons immunized at workplaces, schools, or public health clinics. In 2012, pharmacists began providing immunizations and these are captured in the ODB

database, which may improve the performance of Ontario administrative data during subsequent years. In addition, remuneration per immunization is low (ranging from $0.68 to $9.60 depending on the family practice funding model), possibly resulting in missed billings.

The lower specificity in the elderly population is more difficult to explain. It is possible that proportionally more elderly individuals forget while responding to the CCHS that they had received the influenza immunization that year. However, previous studies have found self-reported influenza immunization status to be reasonably ~~accurate~~valid.(3-9) Alternatively, billing errors or medical fraud could explain a proportion of the false positive results.

This study has a few limitations. The CCHS excludes children younger than 12 years and institutionalized seniors. These are important high-risk groups to study and it is unfortunate that we are unable to quantify the validity of influenza immunization in these groups. However, our study does characterize the validity of influenza immunization, as captured by administrative data, in virtually all other high-risk groups. We ~~utilized~~ used ~~survey~~ self-report ~~responses~~ as the reference ~~performance~~ standard in this analysis, and while verification of responses ~~accuracy~~ was not possible.~~,~~ ~~previous studies have shown population surveys~~ eight prior validation studies comparing self-report to medical records suggest that sensitivity of self-report is high (86%-100%) and both specificity and PPV are more variable, but are generally lower (38%-98% and 62%-96%, respectively).-(3-10) However, the specificity and PPV of self-report may be artificially reduced when using medical records as the reference standard if individuals can receive influenza immunization through alternative vaccine providers (e.g., workplaces, pharmacies) ~~in ascertaining influenza immunization status to accurate.(3-6)~~

This study updates the performance characteristics from our previous study,(2) with a much larger sample size, more recent iterations of the CCHS, and a far more extensive list of risk factors for serious influenza infection defined using validated methods. We quantified the sensitivity, specificity, PPV, and NPV across a variety of variables including multiple high-risk influenza groups. These results can be used to ~~adjust~~ correct for underascertainment of vaccine coverage levels at the aggregate level,

and to account for misclassification bias of ~~influenza~~ immunization status at the individual level (e.g., in studies of influenza vaccine effectiveness). We demonstrated the importance of quantifying misclassification bias, with significant underestimation of influenza vaccine effectiveness when utilizing OHIP physician billing claims data to ascertain influenza immunization status. Non-differential misclassification is generally expected to bias results toward the null hypothesis and thus underestimate effect sizes. However, this may not always be true; therefore it is important to quantify the degree of systematic error in observational studies.(29) In addition, the high PPV and specificity suggests the database can accurately identify those truly immunized, allowing these data to be used to study influenza vaccine safety using self-controlled study designs.(31)

In the absence of an immunization registry in Ontario, administrative data represent the best available data source to study influenza vaccines on a population level. However, we fully support the creation of an immunization registry in Ontario to permit optimal evaluations of our publicly funded immunization programs, particularly since immunizations given at public health and workplace clinics are not captured by physician billing claims data. Despite the limitations of administrative data, the results of this study ~~identifies important limitations of this data source, but~~ will enable adjustments for systematic error in future studies.

Conflicts of interest: none

Contributors: All authors contributed substantially to the conception, design, data analysis plan, and interpretation of the data. In addition, NJ performed the data analysis and KLS drafted the manuscript. All authors critically reviewed the manuscript for important intellectual content and approved the final version to be published.

Acknowledgments

This work was supported the Canadian Institutes of Health Research (CIHR) (grant no. MOP 130568). This study was also supported by the Institute for Clinical Evaluative Sciences (ICES) which is funded by annual grants from the Ontario Ministry of Health and Long Term Care (MOHLTC). KS is supported by a Fellowship Award from CIHR. JCK is supported by a New Investigator Award from CIHR and a Clinician Scientist Award from the University of Toronto DFCM. The study sponsors did not participate in: the design and conduct of the study; collection, management, analysis and interpretation of the data; preparation, review or approval of the manuscript; or the decision to submit the manuscript for publication. Parts of this material are based on data and information compiled and provided by the Canadian Institute for Health Information (CIHI) and Cancer Care Ontario (CCO). However, the analyses, conclusions, opinions and statements expressed herein are those of the authors, and not necessarily those of CIHI or CCO.

Disclaimer

The opinions, results and conclusions reported in this paper are those of the authors and are independent from the funding sources. No endorsement by ICES or MOHLTC is intended or should be inferred.

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Table 1. Demographic characteristics of the study population and percentage receiving influenza immunization within the past 12 months

	N (%)	% immunized
Total	47,301 (100.0)	39.5
CCHS cycle		
2007-2008	33,840 (71.5)	38.9
2009-2010	13,461 (28.5)	41.1
Sex		
Female	25,904 (54.8)	42.4
Male	21,397 (45.2)	36.1
Age group		
12-17 years	4,071 (8.6)	24.8
18-49 years	20,247 (42.8)	23.6
50-64 years	11,815 (25.0)	44.6
≥65 years	11,168 (23.6)	68.4
Rurality[a]		
Urban	37,406 (79.1)	39.3
Rural	9,802 (20.7)	40.4
Neighbourhood income quintile[b]		
1 (lowest)	9,342 (19.7)	40.3
2	9,402 (19.9)	39.6
3	9,467 (20.0)	39.5
4	9,568 (20.2)	38.7
5 (highest)	9,330 (19.7)	39.7
Has regular doctor		
Yes	43,110 (91.1)	41.3
No	4,191 (8.9)	21.7
Risk factors for serious influenza infections[c]		
Hypertension	13,826 (29.2)	61.7
Asthma	6,225 (13.2)	44.0
Diabetes	4,877 (10.3)	63.7
Cancer	2,572 (5.4)	64.4
Chronic obstructive pulmonary disease	1,596 (3.4)	70.5
Congestive heart failure	1,235 (2.6)	74.0
Myocardial infarction	928 (2.0)	69.6
Chronic kidney disease	886 (1.9)	68.9
Morbid obesity[d,e]	866 (1.8)	43.7
Stroke	861 (1.8)	66.0
Immunosuppression	679 (1.4)	74.7
Pregnancy[e,f]	512 (1.1)	18.0
Dementia	245 (0.5)	64.5
None of the above risk factors	25,924 (54.8)	27.3

[a] 95 missing

[b] 192 missing

[c] Percentages add up to more than 100% because individuals may have more than one risk factor

[d,e] Body mass index >40

[e,f] Date of delivery between 1 November and 1 June

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Table 2. Performance measures of Ontario Health Insurance Plan physician billing claims compared to self-reported influenza immunization using Canadian Community Health Survey data

	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Total	9,303	1,218	9,395	27,385	49.8 (49.0-50.5)	95.7 (95.5-96.0)	88.4 (87.8-89.0)	74.5 (74.0-74.9)
CCHS survey cycle								
2007-08	6,506	1,023	6,666	19,645	49.4 (48.5-50.2)	95.1 (94.8-95.3)	86.4 (85.6-87.2)	74.7 (74.1-75.2)
2009-10	2,797	195	2,729	7,740	50.6 (49.3-51.9)	97.5 (97.2-97.9)	93.5 (92.6-94.4)	73.9 (73.1-74.8)
Age group								
12-17 years	205	71	803	2,992	20.3 (17.9-22.8)	97.7 (97.1-98.2)	74.3 (69.1-79.4)	78.8 (77.5-80.1)
18-49 years	1,510	275	3,272	15,190	31.6 (30.3-32.9)	98.2 (98.0-98.4)	84.6 (82.9-86.3)	82.3 (81.7-82.8)
50-64 years	2,319	263	2,947	6,285	44.0 (42.7-45.4)	96.0 (95.5-96.5)	89.8 (88.6-91.0)	68.1 (67.1-69.0)
≥65 years	5,269	609	2,373	2,918	68.9 (67.9-70.0)	82.7 (81.5-84.0)	89.6 (88.9-90.4)	55.2 (53.8-56.5)
Sex								
Female	5,536	708	5,448	14,211	50.4 (49.5-51.3)	95.3 (94.9-95.6)	88.7 (87.9-89.4)	72.3 (71.7-72.9)
Male	3,767	510	3,947	13,174	48.8 (47.7-49.9)	96.3 (96.0-96.6)	88.1 (87.1-89.0)	76.9 (76.3-77.6)
Rural								
Urban	7,474	1,016	7,229	21,687	50.8 (50.0-51.6)	95.5 (95.3-95.8)	88.0 (87.3-88.7)	75.0 (74.5-75.5)
Rural	1,812	201	2,152	5,638	45.7 (44.2-47.3)	96.6 (96.1-97.0)	90.0 (88.7-91.3)	72.4 (71.4-73.4)
Has a regular doctor								
Yes (<65 years)	3,924	585	6,430	21,505	37.9 (37.0-38.8)	97.4 (97.1-97.6)	87.0 (86.0-88.0)	77.0 (76.5-77.5)
Yes (≥65 years)	5,205	600	2,229	2,632	70.0 (69.0-71.1)	81.4 (80.1-82.8)	89.7 (88.9-90.4)	54.1 (52.7-55.5)
No (<65 years)	110	24	592	2,962	15.7 (13.0-18.4)	99.2 (98.9-99.5)	82.1 (75.6-88.6)	83.3 (82.1-84.6)
No (≥65 years)	64	9	144	286	30.8 (24.5-37.0)	96.9 (95.0-98.9)	87.7 (80.1-95.2)	66.5 (62.1-71.0)
Risk factors for serious influenza (≥65y)								
Hypertension	4,012	448	1,589	1,671	71.6 (70.4-72.8)	78.9 (77.1-80.6)	90.0 (89.1-90.8)	51.3 (49.5-53.0)
Asthma	651	63	270	244	70.7 (67.7-73.6)	79.5 (75.0-84.0)	91.2 (89.1-93.3)	47.5 (43.2-51.8)
Diabetes	1,340	159	544	554	71.1 (69.1-73.2)	77.7 (74.6-80.8)	89.4 (87.8-91.0)	50.5 (47.5-53.4)
Cancer	858	81	342	359	71.5 (68.9-74.1)	81.6 (78.0-85.2)	91.4 (89.6-93.2)	51.2 (47.5-54.9)
COPD	586	55	265	234	68.9 (65.7-72.0)	81.0 (76.4-85.5)	91.4 (89.3-93.6)	46.9 (42.5-51.3)
Congestive heart failure	571	51	202	178	73.9 (70.8-77.0)	77.7 (72.3-83.1)	91.8 (89.6-94.0)	46.8 (41.8-51.9)
Myocardial infarction	329	34	130	120	71.7 (67.6-75.8)	77.9 (71.4-84.5)	90.6 (87.6-93.6)	48.0 (41.8-54.2)
Chronic kidney disease	323	36	134	116	70.7 (66.5-74.9)	76.3 (69.6-83.1)	90.0 (86.9-93.1)	46.4 (40.2-52.6)
Morbid obesity[a]	67	<6	<30	45	72.0 (62.9-81.2)	90.0 (81.7-98.3)	93.1 (87.2-98.9)	63.4 (52.2-74.6)
Stroke	334	39	124	137	72.9 (68.9-77.0)	77.8 (71.7-84.0)	89.5 (86.4-92.6)	52.5 (46.4-58.5)
Immunosuppression	337	25	133	123	71.7 (67.6-75.8)	83.1 (77.1-89.1)	93.1 (90.5-95.7)	48.0 (41.9-54.2)
Dementia	107	21	37	59	74.3 (67.2-81.4)	73.8 (64.1-83.4)	83.6 (77.2-90.0)	61.5 (51.7-71.2)
No risk factors	733	95	478	856	60.5 (57.8-63.3)	90.0 (88.1-91.9)	88.5 (86.4-90.7)	64.2 (61.6-66.7)

Risk factors for serious influenza (<65y)								
Hypertension	1,460	176	1,471	2,999	49.8 (48.0-51.6)	94.5 (93.7-95.3)	89.2 (87.7-90.7)	67.1 (65.7-68.5)
Asthma	734	87	1,084	3,092	40.4 (38.1-42.6)	97.3 (96.7-97.8)	89.4 (87.3-91.5)	74.0 (72.7-75.4)
Diabetes	649	76	572	983	53.2 (50.4-56.0)	92.8 (91.3-94.4)	89.5 (87.3-91.7)	63.2 (60.8-65.6)
Cancer	215	19	243	459	46.9 (42.4-51.5)	96.0 (94.3-97.8)	91.9 (88.4-95.4)	65.4 (61.9-68.9)
COPD	152	21	122	161	55.5 (49.6-61.4)	88.5 (83.8-93.1)	87.9 (83.0-92.7)	56.9 (51.1-62.7)
Congestive heart failure	81	11	60	81	57.4 (49.3-65.6)	88.0 (81.4-94.7)	88.0 (81.4-94.7)	57.4 (49.3-65.6)
Myocardial infarction	94	10	93	118	50.3 (43.1-57.4)	92.2 (87.5-96.8)	90.4 (84.7-96.1)	55.9 (49.2-62.6)
Chronic kidney disease	81	<6	<75	120	52.9 (45.0-60.9)	96.8 (93.7-99.9)	95.3 (90.9-99.8)	62.5 (55.7-69.3)
Morbid obesity[a]	144	27	141	411	50.5 (44.7-56.3)	93.8 (91.6-96.1)	84.2 (78.7-89.7)	74.5 (70.8-78.1)
Stroke	63	<6	<50	113	57.3 (48.0-66.5)	96.6 (93.3-99.9)	94.0 (88.4-99.7)	70.6 (63.6-77.7)
Pregnancy[b]	67	13	93	565	41.9 (34.2-49.5)	97.8 (96.5-99.0)	83.8 (75.7-91.8)	85.9 (83.2-88.5)
No risk factors	1,725	321	4,209	17,447	29.1 (27.9-30.2)	98.2 (98.0-98.4)	84.3 (82.7-85.9)	80.6 (80.0-81.1)

COPD=Chronic obstructive pulmonary disease; TP=True positive; FP=False positive; FN=False negative; TN=True negative; PPV=Positive predictive value; CI=Confidence interval; NPV=Negative predictive value; CCHS=Canadian Community Health Survey

[a] Body mass index >40

[b] Date of delivery between 1 November and 1 June

Table 3. Performance measures of Ontario Health Insurance Plan physician billing claims compared to self-reported influenza immunization using Canadian Community Health Survey data, restricted to individuals surveyed between 1 February and 31 August

	TP	FP	FN	TN	Sensitivity (95% CI)	Specificity (95% CI)	PPV (95% CI)	NPV (95% CI)
Total	5,639	408	5,744	16,017	49.5 (48.6 -50.5)	97.5 (97.3-97.8)	93.2 (92.6-93.9)	73.6 (73.0 -74.2)
CCHS survey cycle								
2007-08	3,745	276	3,831	10,414	49.4 (48.3-50.6)	97.4 (97.1-97.7)	93.1 (92.4-93.9)	73.1 (72.4-73.8)
2009-10	1,894	132	1,913	5,603	49.8 (48.2-51.3)	97.7 (97.3-98.1)	93.5 (92.4-94.6)	74.5 (73.6-75.5)
Age group								
12-17 years	126	34	507	1,745	19.9 (16.8-23.0)	98.1 (97.5-98.7)	78.8 (72.4-85.1)	77.5 (75.8-79.2)
18-49 years	960	112	2,025	9,060	32.2 (30.5-33.8)	98.8 (98.6-99.0)	89.6 (87.7-91.4)	81.7 (81.0-82.5)
50-64 years	1,401	83	1,770	3,610	44.2 (42.5-45.9)	97.8 (97.3-98.2)	94.4 (93.2-95.6)	67.1 (65.8-68.4)
≥65 years	3,152	179	1,442	1,602	68.6 (67.3-70.0)	89.9 (88.6-91.3)	94.6 (93.9-95.4)	52.6 (50.9-54.4)
Sex								
Female	3,345	221	3,320	8,226	50.2 (49.0-51.4)	97.4 (97.0-97.7)	93.8 (93.0-94.6)	71.2 (70.4-72.1)
Male	2,294	187	2,424	7,791	48.6 (47.2-50.0)	97.7 (97.3-98.0)	92.5 (91.4-93.5)	76.3 (75.4-77.1)
Rural								
Urban	4,485	348	4,360	12,628	50.7 (49.7-51.7)	97.3 (97.0-97.6)	92.8 (92.1-93.5)	74.3 (73.7-75.0)
Rural	1,142	59	1,376	3,357	45.4 (43.4-47.3)	98.3 (97.8-98.7)	95.1 (93.9-96.3)	70.9 (69.6-72.2)
Has a regular doctor								
Yes (<65 years)	2,424	218	3,941	12,705	38.1 (36.9-39.3)	98.3 (98.1-98.5)	91.7 (90.7-92.8)	76.3 (75.7-77.0)
Yes (≥65 years)	3,119	176	1,349	1,441	69.8 (68.5-71.2)	89.1 (87.6-90.6)	94.7 (93.9-95.4)	51.6 (49.8-53.5)
No (<65 years)	63	11	361	1,710	14.9 (11.5-18.2)	99.4 (99.0-99.7)	85.1 (77.0-93.2)	82.6 (80.9-84.2)
No (≥65 years)	33	<6	<95	161	26.2 (18.5-33.9)	98.2 (96.1-100.0)	91.7 (82.6-100.0)	63.4 (57.5-69.3)
Risk factors for serious influenza (≥65y)								
Hypertension	2,403	121	977	896	71.0 (69.6-72.6)	88.1 (86.1-90.1)	95.2 (94.4-96.0)	47.8 (45.6-50.1)
Asthma	368	18	159	134	69.8 (65.9-73.7)	88.2 (83.0-93.3)	95.3 (93.2-97.4)	45.7 (40.0-51.4)
Diabetes	808	52	332	293	70.9 (68.2-73.5)	84.9 (81.2-88.7)	94.0 (92.4-95.5)	46.9 (43.0-50.8)
Cancer	494	19	196	186	71.6 (68.2-75.0)	90.7 (86.8-94.7)	96.3 (94.7-97.9)	48.7 (43.7-53.7)
COPD	348	11	164	128	68.0 (63.9-72.0)	92.1 (87.6-96.6)	96.9 (95.2-98.7)	43.8 (38.1-49.5)
Congestive heart failure	345	10	117	94	74.7 (70.7-78.6)	90.4 (84.7-96.1)	97.2 (95.5-98.9)	44.5 (37.8-51.3)
Myocardial infarction	204	12	78	66	72.3 (67.1-77.6)	84.6 (76.6-92.6)	94.4 (91.4-97.5)	45.8 (37.7-54.0)
Chronic kidney disease	187	10	81	69	69.8 (64.3-75.3)	87.3 (80.0-94.7)	94.9 (91.9-98.0)	46.0 (38.0-54.0)
Morbid obesity[a]	40	0	13	26	75.5 (63.9-87.1)	100.0 (100.0-100.0)	100.0(100.0-100.0)	66.7 (51.9-81.5)
Stroke	191	14	79	70	70.7 (65.3-76.2)	83.3 (75.4-91.3)	93.2 (89.7-96.6)	47.0 (39.0-55.0)
Immunosuppression	194	7	84	63	69.8 (64.4-75.2)	90.0 (83.0-97.0)	96.5 (94.0-99.0)	42.9 (34.9-50.9)
Dementia	59	11	19	31	75.6 (66.1-85.2)	73.8 (60.5-87.1)	84.3 (75.8-92.8)	62.0 (48.5-75.5)
No risk factors	415	35	276	473	60.1 (56.4-63.7)	93.1 (90.9-95.3)	92.2 (89.7-94.7)	63.2 (59.7-66.6)

COPD=Chronic obstructive pulmonary disease; TP=True positive; FP=False positive; FN=False negative; TN=True negative; PPV=Positive predictive value; CI=Confidence interval; NPV=Negative predictive value; CCHS=Canadian Community Health Survey
[a]Body mass index >40

Figure 1. ~~Crude and adjusted 2010-2011 I~~influenza ~~season~~ vaccine effectiveness estimates for the 2010-11 season, with 95% confidence intervals, from Kwong et al. (2013) before and after adjustment for misclassification bias using the validation results from this study.

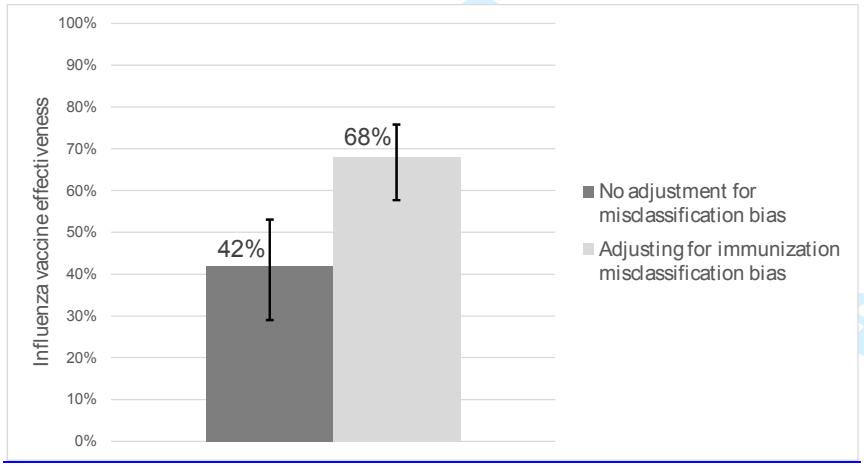

Table e1: The Institute for Clinical Evaluative Sciences databases used in this study and their descriptions

Database	Description
Ontario Health Insurance Plan (OHIP)	Contains claims data paid for by the Ontario Health Insurance Plan for most healthcare professionals in the province
Canadian Institute for Health Information Discharge Abstract Database (CIHI-DAD)	Contains patient-level data for acute, chronic, and day surgery institutions in Ontario
Canadian Institute for Health Information National Ambulatory Care Reporting System (CIHI-NACRS)	Contains patient visits to hospital and community based ambulatory care: day surgery, outpatient clinics and emergency departments
Canadian Institute for Health Information Same Day Surgery (CIHI-SDS)	Contains patient-level data for day surgery institutions in Ontario
Canadian Organ Replacement Register (CORR)	Contains activity and outcomes of vital organ transplantation and renal dialysis for donors and recipients treated in Ontario
Ontario Renal Reporting System (ORRS)	Contains data on patients with chronic kidney disease and renal dialysis
Ontario Diabetes Database (ODD)	Contains all incident cases of diabetes in Ontario
Ontario Cancer Registry (OCR)	Contains Ontario residents newly diagnosed, or died, with cancer (except non-melanoma skin cancers)
Ontario Myocardial Infarction Database (OMID)	Contains hospitalized patients with first acute myocardial infarction
Chronic Obstructive Pulmonary Disease (COPD)	Contains all Ontario patients with COPD
Ontario Drug Benefit (ODB)	Contains claims for prescription drugs received under the ODB program (most are for those ≥65 years of age)
Ontario Congestive Heart Failure (CHF) Database	Contains all Ontario individuals identified as having CHF
Ontario Human Immunodeficiency Virus (HIV) database	Contains all Ontario HIV positive patients

Table e2: Databases and codes used to define medical conditions

Medical Condition	Definition
Hypertension	Hypertension was defined as a) one hospital admission with a hypertension diagnosis, or b) an OHIP claim with a hypertension diagnosis followed within two years by either an OHIP claim or a hospital admission with a hypertension diagnosis.

Medical Condition	Definition
	CIHI-DAD, CIHI-SDS ICD-9 diagnostic codes: 401, 402, 403 404, 405 ICD-10 diagnostic codes: I10, I11, I12, I13, I15 OHIP OHIP diagnostic codes: 401, 402, 403 404, or 405
Asthma	Asthma database was used to identify patients with asthma, based on 2 or more ambulatory care visits and/or 1 or more hospitalizations.(1) OHIP OHIP diagnostic code: 493 CIHI-DAD ICD-9 diagnostic code: 493 ICD-10 diagnostic codes: J45, J46
Diabetes	ODD was used to identify patients with diabetes, based on 2 OHIP diagnostic codes or 1 OHIP service code or 1 CIHI admission within 2 years.(2) OHIP OHIP diagnostic code: 250 OHIP service codes: Q040, K029, K030, K045, K046 CIHI-DAD, CIHI-SDS ICD-9 diagnostic code: 250 ICD-10 diagnostic codes: E10, E11, E13, E14
Cancer	OCR was used to identify patients with a history of cancer diagnosed in Ontario except for non-melanoma skin cancer.(3)
Chronic obstructive pulmonary disease (COPD)	COPD database was used to identify patients with COPD, based on 3 or more ambulatory care visits and/or 1 or more hospitalizations within 2 years.(4) OHIP OHIP diagnostic codes: 491, 492, 496 CIHI-DAD ICD-9 diagnostic codes: 491, 492, 496 ICD-10 diagnostic codes: J41, J42, J43, J44

Medical Condition	Definition
Congestive heart failure (CHF)	CHF database was used to identify patients with CHF, based on 1 CIHI NACRS, CIHI-DAD, CIHI-SDS, or OHIP claim and a second claim (from either) in 1 year.(5) OHIP OHIP diagnostic code: 428 CIHI-DAD, CIHI-SDS ICD-9 diagnostic code: 428 ICD-10 diagnostic codes: I500, I501, I509
Acute myocardial infarction (AMI)	OMID was used to identify patients with a history of AMI using OHIP, CIHI-DAD, and CIHI-SDS.(6) OHIP: OHIP service codes: C132, C133, C134, C135, C136, C137, C139, C435, C602, C603, C604, C605, C606, C607, C609, C675, C002, C003, C004, C005, C006, C007, C009, C905, G297, G557, G558, G559, G400, G401, G402, G405, G406, G407, R742, R743, Z434, Z442. CIHI-DAD, CIHI-SDS CCI procedure codes: 3IS10, 3IP10, 2HZ28, 1IJ50, 1IJ57, or 1IJ76 CCP procedure codes: 4802, 4803, 4809, 4892, 4893, 4894, 4895, 4896, 4897, 4898, 4996, or 4997 ICD-9 diagnostic codes: 410, 411, 413, or 428 ICD-10 diagnostic codes: I21, I50, or I20
Chronic kidney disease (CKD)	Identifying patients with CKD(7) OHIP OHIP diagnostic codes: 403, 585 CIHI NACRS, CIHI-DAD ICD-10 diagnostic codes: E102, E112, E132, E142, I12, I13, N08, N18, N19
	Identifying patients on chronic dialysis(8) At least 2 of any of the following codes in OHIP, CIHI-DAD, or CIHI-SDS separated by at least 90 days, but less than 150 days OHIP OHIP service codes: R849, G323, G325, G326, G860, G862, G865

Medical Condition	Definition
	G863, G866, G330, G331, G332, G333, G861, G082, G083, G085, G090, G091, G092, G093, G094, G095, G096, G294, G295, G864, H540, H740 CIHI-DAD, CIHI-SDS CCI procedure codes: 5195, 6698 CCP procedure code: 1PZ21 CORR Treatment codes: 060, 111, 112, 113, 121, 122, 123, 131, 132, 133, 141, 151, 152, 211, 221, 231, 241, 242, 251, 252, 311, 312, 313, 321, 322, 323, 331, 332, 333, 413, 423, 433, 443, 453 ORRS Patients included in ORRS
	Exclusion criteria: Patients with kidney transplants(9) OHIP OHIP service codes: S435, S434 CIHI DAD CCP procedure code: 6759 CCI procedure code: 1PC85 CORR Treatment code: 171 plus one or more of Transplanted Organ Codes (1-3): 10, 11, 12, 18, 19 ORRS Type of event during patient care: Transplanted (tx)
Stroke	CIHI-DAD was used to identify patients with a history of acute ischemic stroke, based on at least one hospitalization with the most responsible diagnosis coded with one of the following codes (10): CIHI-DAD, CIHI-SDS ICD-9 diagnostic codes: 434, 436 ICD-10 diagnostic codes: I63 (excluding 163.6), I64, H34.1

Medical Condition	Definition
Immunosuppression	ACG macro was used to identify patients in OHIP, CIHI-NACRS, and CIHI-DAD(11) with any mention of immune system disorders. In addition, the following databases and definitions were used to identify patients with immunosuppression: ODB 30 days of oral corticosteroids in the past 6 months, antineoplastic use in the past 6 months, or use of another immunocompromising drug in the past 6 months CORRLINK CORRLINK is a dataset in ICES which links CORR and CIHI-DAD data. This database only includes patients that have received an organ transplant and does not include dialysis patients. HIV HIV database was used to identify patients with HIV, based on 3 physician claims in 3 years with OHIP diagnostic codes: 042, 043 or 044(12)
Dementia	1 hospitalization for dementia and/or 3 ambulatory visits for dementia, each separated by at least 30 days, within 2 years and/or 1 prescription from ODB(13) OHIP OHIP diagnostic codes: 290, 331 CIHI-DAD, CIHI-SDS ICD-10 diagnostic codes: F00, F01, F02, F03, G30 ODB 1 prescription for a cholinesterase inhibitor

CCI= Canadian Classification of Health Interventions, CCP=Canadian Classification of Procedures, ACG=Adjusted Clinical Groups®

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Table 1: Studies validating self-reported influenza immunization

Author, year	PMID	Population	Self-report	Reference	n	Sn	Sp	PPV	NPV	Kappa
Hutchison, 1989	2790635	Seniors in a group family practice, Burlington, ON	Mail	Medical records	535	93	98	96	97	88
MacDonald, 1999	10198654	Managed care organization	Mail	Medical records	237	98	71	92	91	75
MacDonald, 1999	10198654	Veteran Affairs (VA)	Mail	Medical records	195	100	79	82	100	79
Martin, 2000	10722987	>21 y, Colorado HMO	Telephone	Medical records	599	86	73	86	73	N/A
Zimmerman, 2003	12615445	>65 y, inner"city, VA, rural, suburban practices	Telephone	Medical records	819	98	38	62	94	36
Mangtani, 2007	16740194	65"84 y, United Kingdom general practices	Mail	Medical records	354	95	90	93	93	85
Skull, 2007	17499402	≥65 y, inpatients at 2 Australian hospitals	Telephone	Medical records	2980	98	56	88	91	62
Irving, 2009	19729083	All ages, Marshfield Clinic, WI	In"person	Immunization registry, medical and other records	2907	95	95	95	96	N/A
Rolnick, 2013	23806243	≥18 y, Integrated health care delivery system in MN	Telephone	Medical records	3499	93	66	66	93	56

PMID=PubMed ID; Sn=sensitivity; Sp=specificity; PPV=positive predictive value; NPV=negative predictive value