SUPPLEMENTARY MATERIAL

IDENTIFYING PATIENTS WITH ATRIAL FIBRILLATION IN ADMINISTRATIVE DATA:

EXPANDED PAPER

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Abstract

Background: Identifying patients with atrial fibrillation (AF) using administrative data is important for epidemiologic and outcomes research. Although administrative data covers large populations, it is necessary to assess their validity in identifying AF patients.

Methods: We used Ontario family physician electronic medical records from the **E**lectronic **M**edical **R**ecord **A**dministrative data **L**inked **D**atabase (EMRALD) as a reference standard to assess the accuracy of administrative data algorithms in identifying patients with AF. From a random sample of 7500 adult patients, patients with AF as recorded in family physician records were identified.

Results: The optimal algorithm consisted of *ANY* of: hospitalization or an emergency room code for AF *OR* prescription for an AF specific antiarrhythmic *OR* billing code for cardioversion, *OR* prescription for an anticoagulant that was accompanied by a physician billing code for arrhythmia. The algorithm sensitivity was 80.7% (95% CI:75.1-86.3), specificity 99.1% (95% CI:98.9-99.3), positive predictive value 71.1% (95% CI:65.1-77.1), negative predictive value 99.5% (95% CI:99.3-99.7). This algorithm, applied to the Ontario population, resulted in a calculated increase in AF prevalence from 1.68% to 2.36% over the years 2000-2014. Anticoagulation rates for AF patients increased from 53% in 2011 to 60% in 2014. Amongst AF patients on anticoagulants, novel oral anticoagulant (NOAC) utilization increased from <5% in 2011 to over 50% in 2014.

Conclusions: Identifying patients with AF can be done using administrative data, and the algorithm can be used to assess trends in disease burden over time and patterns of care in large populations.

Keywords: atrial fibrillation, administrative data, electronic medical records

Introduction

Atrial fibrillation (AF) is the most prevalent heart rhythm disorder, particularly among the elderly.[1] AF markedly increases the risk for stroke, can decrease quality of life via associated symptoms, and contributes to the development of other cardiac diseases such as heart failure. With the aging of the population, AF has become an increasingly important public health issue, due to substantial implications for both patient outcomes and health care costs.[1] AF is estimated to affect 1 to 2% of the Canadian population, which translates to approximately 350,000 Canadians living with AF; however, such estimates seem to be mainly based on extrapolation of study results from cross sectional assessments, predominantly in other countries. There is a pressing need for more up to date, accurate, population-level data that can be widely applied to enable ongoing monitoring of AF epidemiology, quality of care, and complications.

A systematic review examining AF from electronic medical data found that previous AF validation studies mostly used older data, assessed populations that might not be representative of the general population, and had a disproportionate focus on inpatient data.[2] Studies that rely only on a diagnosis of AF in the hospital discharge record may miss many patients with AF that receive ambulatory medical care**.** In Canada, claims for in- and out-patient clinic visits and procedures are routinely captured. In Ontario specifically, physician billing claims for visits and procedures as covered by OHIP (Ontario Health Insurance Plan) are captured, as well as medication prescriptions for all residents 65 years and older and several low-income coverage support programs. Linking these data sources could aid in garnering a more accurate portrait of AF epidemiology in Ontario, which could act as a template for similar assessments in other Canadian provinces.[3,4] However, some drawbacks of routinely collected health data, usually collected for the purpose of billing or utilization rather than research, could substantially limit its accuracy and value. For example, there are no specific billing codes to capture AF in the outpatient setting; the physician billing code used for AF is a general arrhythmia code. Although hospitalization data have codes specific to AF, many AF cases could be missed by

using hospital data only as patients are often initially diagnosed and managed in the outpatient setting. Furthermore not all AF patients receive treatment with medications and medications used in the treatment of AF such as anticoagulants and rate and rhythm control medications have other indications as well. Electronic medical record (EMR)-based databases contain more detailed information than administrative data, but these are only representative of the health region or clinics where the EMR is used. Therefore, while routinely collected health data in Canada provide a promising resource for AF epidemiology monitoring, their accuracy should be well validated before acting upon the results.

The purpose of our study was to assess the accuracy of using administrative data to capture patients with AF in order to be able to determine AF disease burden and patterns of care over time and in large populations.

METHODS

Setting and design

The **E**lectronic **M**edical **R**ecord **A**dministrative data **L**inked **D**atabase (EMRALD) held at the Institute for Clinical Evaluative Sciences (ICES) was used as the reference standard for the diagnosis of AF. EMRALD consists of all clinically relevant information (including the cumulative patient profile, clinical encounters, laboratory test results, diagnostic test results, specialist consultation letters and discharge summaries) contained in the family physician patient chart of volunteering family physicians in Ontario using PS Suite®EMR.[5] EMRALD provides an opportunity to access the detailed clinical information contained in family physician EMRs and link the patients to administrative data thereby providing a reference standard for validating administrative data algorithms to identify patients with disease conditions.[6-9]

The data used in this validation study was extracted between June and November 2011. Patients in this database are similar to those in the Ontario population in terms of age and sex, with a slight over-representation of young adult women and slight underrepresentation of young adult males, typical of the types of patients who go to see primary care physicians.[10] EMRALD physicians have an age and sex distribution similar to that of Ontario physicians, with similar years of experience in practice.[10] At the time of the study the data in EMRALD were contributed by 83 primary care physicians who had been using their EMR for at least 2 years and whose data met quality and completeness standards.[10]

Developing the EMRALD cohort (reference standard)

A random sample of 7,500 adult patients aged 20 years or older as of December 31, 2010 was drawn from 73,014 adult patients of EMRALD physicians. Patients were included if they had a valid health card number and date of birth, were rostered to an EMRALD participating physician, and had at least one visit recorded in the EMR, one year before the data was extracted.

Using the criteria provided in an abstraction manual created with input from family physicians (KT, NI) and a cardiologist (PD), six trained chart abstractors were instructed to read the entire EMR patient record and to classify the cumulative patient profile (CPP) and each free text entry of the patient as: AF was ruled out, “possibly” having AF, “definitely” having AF; no mention of AF in the chart. (see Supplemental Appendix S1 for chart abstraction manual AF definitions).

Among the 242 patients who were documented as “definitely having AF” and 23 patients documented as “possibly having AF”, charts were re-reviewed by a family physician (NI) in consultation with a cardiologist (PD) to correct errors in classification. Upon re-review there were 192 patients classified as “definitely” having AF, 55 patients “possibly” having AF, 10 patients AF was ruled out and 8 patients did not have AF. Patients with a final classification of “definitely has AF” were used as the reference standard against which the various administrative data algorithms were compared. Only patients with

persistent, or paroxysmal AF were included in the reference standard as having AF; those who had documentation of transient AF (e.g. post-operative AF not present on any follow up investigations or progress notes) were not included.

Administrative data sources

Acute hospitalizations and emergency department visits were identified using the Canadian Institute for Health Information Discharge Abstract Database (CIHI-DAD) starting in 1988, the National Ambulatory Care Reporting System (NACRS) starting in 2000, the Ontario Health Insurance Database (OHIP) starting in 1991 and the Ontario Drug Benefit (ODB) database starting in 1990. These databases contain detailed diagnostic and procedural information for Canadians and have been extensively validated in Ontario.[11] Hospital visits containing a diagnosis of AF were identified using the International Classification of Diseases, 9th Edition (ICD-9) codes prior to 2002 (427.31 Atrial Fibrillation, 427.32 Atrial Flutter) and the International Classification of Diseases, 10th Edition, Canada (ICD-10-CA) codes subsequently (I48 Atrial Fibrillation and Flutter). The Ontario Health Insurance Plan (OHIP) physician billing database captures approximately 98% of the physician billings in the province of Ontario[12] and includes a procedure code accompanied by a diagnostic code. The OHIP diagnostic code for AF (427 paroxysmal tachycardia, atrial or ventricular flutter or fibrillation, cardiac arrest, other arrhythmias) was included. Given the ambiguous nature of AF diagnostic codes in the OHIP physician billing database, OHIP procedure codes for cardioversion (electrical and/or chemical; Z437) and medications related to AF were tested as well.

Oral medications potentially used for the ongoing management of AF were identified and categorized into three distinct groups, as follows: A) oral anticoagulants: warfarin, apixaban, dabigatran, rivaroxaban, B) rate control medications, calcium channel blockers: verapamil, diltiazem, beta blockers: acebutolol, atenolol, bisoprolol, carvedilol, labetalol, metoprolol, nadolol, nebivolol,

propranolol, and other: digoxin, and C) rhythm control medications: propafone, flecainide, dronedarone, sotalol and amiodarone.

Patients who had medications dispensed were identified using the ODB database; however, ODB only includes medications for residents of Ontario aged 65 years and older, or those on social assistance or Trillium Drug Plan for low income individuals. Therefore we also tested the OHIP billing code (G271) for anticoagulation management, which can be billed on a monthly basis by physicians monitoring warfarin dosing, as a proxy to identify patients not on ODB who were taking warfarin. Using anticoagulants alone to identify patients with AF is not specific, given that anticoagulants are indicated in other conditions. Therefore we tested qualifying anticoagulants to indicate AF by removing patients who were using anticoagulants for other indications (see below) , or by requiring the patient to also have taken a rate control medication, or by requiring the patient to also have a billing code for arrhythmia within one year of the prescription. Other indications for anticoagulants were identified as follows: a previous history of 1) a pulmonary embolus (ICD-9 4151 and ICD-10-CA I260, I269 codes in CIHI or NACRS) 2) a deep vein thrombosis (ICD-9 45111, 45119 and ICD-10-CA I802 in CIHI or NACRS), or 3) a mechanical heart valve replacement (using the Canadian Classification of Diagnostic, Therapeutic, and Surgical Procedures (CCP) codes 4723, 4725, 4727, 4729 prior to 2002 and the Canadian Classification of Health Interventions (CCI) codes 1HS90LACF, 1HT90LACF, 1HU90LACF, 1HU90PNCF, 1HV90LACF, 1HV90LACFA, 1HV90LACFL, 1HV90LACFN, 1HV90WJCFN). Rate control medications were not tested on their own as they have many other indications for use, but rhythm control drugs alone were examined to denote AF, as the great majority of use is for AF, with the exception of amiodarone which is also utilized for ventricular arrhythmias. Thus, patients who were on amiodarone who had a history of an implantation of an internal cardioverter/defibrillator (as identified using CCP codes 4974 or CCI codes 1HZ53GRFS, 1HZ53HAFS, 1HZ53LAFS, 1HZ53SYFS), were not included.

Testing the accuracy of administrative data algorithms

Multiple algorithms using administrative data were tested, which varied according to both the administrative data sources used and the timeframe of the assessment. For algorithms that included multiple physician billings, a 30 day separation between billings was required. For algorithms using physician billing codes we also assessed the impact of requiring the billing codes to be by a cardiologist, internist or cardio/thoracic or cardiac surgeon. Last, we confined our reference standard to just those 66 years of age and over and applied the same algorithms, to see if the use of more complete medication information improved the accuracy of our algorithms.

For each algorithm, comprehensive statistics were computed: sensitivity, specificity, positive predictive value, negative predictive value, Youden index (J = sensitivity + specificity – 1), and kappa (κ, metric that compares observed accuracy to expected accuracy, i.e. random chance), each with their 95% confidence interval (CI).

Once the optimal algorithm was identified, all false-positive and false-negative cases resulting from this algorithm were reviewed and the reasons for misclassification were identified.

Application of the algorithms to the Ontario population

The optimal algorithms were applied to the entire province of Ontario, starting from the initial availability of data. The initial years served as a 'run-in' period. We calculated the crude, and the age and sex standardized (to the Census 1991 population), annual (fiscal year) incidence and prevalence of AF. Incident date was considered the date by which the patient qualified as having AF as per the algorithm rules. All incident and prevalent cases were carried forward to the next fiscal year, unless the patient died or moved out of province.

Assessing anticoagulation rates as measured in EMR data and in administrative data

Last we assessed proportion of use of oral anticoagulants, as measured in the EMR from the patients determined via chart abstraction to have AF, and in administrative data through ODB. We included both warfarin and the novel oral anticoagulants (NOACs): apixaban, rivaroxaban, and dabigatran. For AF patients in our EMRALD reference standard, we looked in the one year prior to the date the data was extracted in 2011 for an anticoagulant prescription recorded in the EMR. We also looked in the ODB during the same time period, but allowed for an additional month past the data extraction date, to allow for a lag time between medication prescription as recorded in the EMR and dispensing as recorded in ODB. Patients who were prescribed or dispensed both warfarin and a NOAC were classified as being on whichever type was most recently prescribed or dispensed.

We also examined the proportion of patients with AF that were dispensed an anticoagulant in the province of Ontario using our two most accurate administrative data algorithms. We applied one algorithm that included medications to identify AF patients and one that did not, to assess the extent of bias in anticoagulation rates that might be produced using a case identification algorithm that included anticoagulants. We looked for anticoagulants in ODB being dispensed fiscal year 2011 for all patients that were prevalent at the start of the year and for patients who became incident in that year we looked in the one year forward from the incident date to determine anticoagulant rates and types. Similarly we looked in the administrative data in fiscal year 2014 to assess changes in rates and types of anticoagulants prescribed.

All datasets were linked using unique encoded identifiers and all measures were calculated using the binomial approximation method and analyses were conducted using SAS version 9.2 (SAS Institute, Cary, NC) at the Institute for Clinical Evaluative Sciences (ICES). This study received ethics approval from the Sunnybrook Research Ethics Board.

RESULTS

In the EMRALD cohort of adult patients, 192 (2.6%) of the patients had AF. The average age of the EMRALD cohort was 49.2 years (SD = 16.7 years) and the average age of the patients with AF was 74.1 years (SD = 11.6 years). Of the patients age 66 years and over in the EMRALD cohort, there were 149 (11.3%) patients with AF.

As expected, restricting the analysis to hospitalization data only identified less than half of the patients with AF (86 of 192). The addition of emergency room data to the hospitalization data identified less than 60% of all the cases (114 of 192). Adding a physician billing claim detected over 90% of the cases (177 OF 192), but resulted in an inordinate number of false positives (699). Requiring more than 1 physician billing claim increased the positive predictive value but even when requiring 5 physician billing claims the positive predictive value only reached 80% and resulted in a substantially decreased sensitivity (28%). Requiring the billing claims to be from a cardiovascular related specialist led to a small improvement in positive predictive value (75%), but at the expense of sensitivity (23%). Conversely, increasing the time frame allowed for multiple billing claims generally resulted in a similar decrease in positive predictive value as the sensitivity increased. Specificity and negative predictive value was high (>98%) for all algorithms. Using hospitalizations or ER visits with recorded presence of a diagnosis of AF and physician billings for arrhythmia, an algorithm of a hospitalization *or* emergency room record *or* four physician billing claims in 1 year provided the best balance of sensitivity and positive predictive value, at a rate of 70.8% for both, while providing the same prevalence estimate for AF as our reference standard. (see Supplemental Table S1)

The anticoagulant management fee did not identify many more patients with AF compared to simply using the anticoagulants themselves (122 patients using anticoagulants alone compared to 138 patients using anticoagulant or warfarin management fee of 196 AF patients), and it substantially increased the number of false positives (from 107 to 189). In terms of identifying the indication for patients to be on warfarin we found that requiring either a hospitalization code for AF or a physician

billing code for arrhythmia (sensitivity 66.1%, positive predictive value 68.6%) was more accurate than attempting to remove patients with other indications for anticoagulants (sensitivity 69.3%, positive predictive value 48.4%).

Not surprisingly, using rhythm control medications to identify patients with AF was not helpful, as only 19 (9.9%) of AF patients were prescribed a rhythm control medication. Among the 192 AF patients 30 (15.6%) underwent cardioversion. We found that qualifying the patients with cardioversion with an arrhythmia physician billing code or a hospitalization code for AF resulted in a small reduction in false positives (17 vs 12) compared to using only an arrhythmia physician billing code for qualification. Adding AF related medications or cardioversion to a hospitalization code or emergency room visit resulted in improving the sensitivity by 20% (from to 59.4% to 80.7%), with a less than 10% reduction in positive predictive value (from 79.7% to 71.1%). Adding on physician billing codes resulted in a similar increase in sensitivity (from 80.7% to 83.9%) as a decrease in positive predictive value (from 71.1% to 66.3%). An algorithm of one hospitalization, *or* an emergency room visit, *or* AF related medications, *or* cardioversion and did not include physician billing codes, maximized positive predictive value (71.1%) with little sacrifice of sensitivity (80.7%). (see Supplemental Table S2).

Sensitivity and Discrepancy Analyses

When we confined the reference standard to only those age 66 or older we found the algorithms performed similarly as in the adult population, with a slight increase in positive predictive value (see Supplemental Table S3).

When we examined the reasons for false positives, using the algorithm containing hospitalization or emergency room visit, or AF related medications, or cardioversion, <=12/63 (<20%) (exact numbers not reported due to small cell size regulation) did not have any mention of AF in the EMR chart, <= 5/63 (<10%) were not well populated EMR charts, 16/63 (25.4%) had their administrative data codes

prior to the commencement of the EMR chart and 19/63 (30.2%) had some documentation of AF but did not meet our criteria for definitive presence of AF. Therefore 51/63 (81%) of the false positives we found may have been true positives that just were not captured in our reference standard. We found that of the false positives only 12/63 (19%) had other arrhythmias and represented truly confirmed administrative data false positives. Of the false negatives <=5/37 (<16%) (exact number not reported due to small cell size regulation) had paroxysmal AF and the rest had documented AF as per our criteria for chronic AF but did not have sufficient administrative data evidence of AF.

Incidence and Prevalence

When the top performing algorithms were applied to the entire province of Ontario we found that the estimated annual age and sex standardized prevalence (Supplemental Figure S1) and incidence (Supplemental Figure S2) for the algorithm that included medications and cardioversion, and the algorithm that included physician billings was less than 1% and less than 0.5% higher, respectively, than just using hospitalizations or emergency room visits. Regardless of the algorithm applied we found a consistent increase in prevalence over the last decade and a half, with a highest adult prevalence estimate of 1.68% in 2000 to 2.36% in 2014. Incidence was relatively flat using all the algorithms except for the algorithm using medications and cardioversion, which demonstrated a slight increase in incidence in the last 3 years and ranged from a low of 2.48/1000 in 2008 to a high of 2.95/1000 in 2012.

Anticoagulation Rates

We found that approximately two thirds of the patients with AF in our 2011 EMRALD cohort were on anticoagulants, with over 90% of those patients being prescribed warfarin rather than a NOAC (Supplemental Table S4). These rates were similar when measured in the administrative data compared to the EMR data (64.1% vs. 68.3% amongst the elderly (Supplemental Table S4)). When we compared the anticoagulation rates of patients with AF across the province using our top two

algorithms (one that included anticoagulants to identify AF patients and one that did not), we found that anticoagulation rates and proportion of warfarin to NOAC use was similar regardless of the algorithm used. In 2011 a little over half the patients filled a prescription for an anticoagulant and less than 5% of the patients on anticoagulants were on a NOAC. We noted a 7% increase (53.8% to 60.8%) in the overall anticoagulation rates in 2014 compared to 2011, with an increase in the proportion of anticoagulated patients filling a prescription for a NOAC from <5% to over half (51.4%) of the patients on anticoagulants filling a prescription for a NOAC in 2014.

Discussion

We found that patients with AF could be identified with a reasonable degree of accuracy using administrative data. This accuracy is comparable to our previous studies assessing the validity of administrative data to identify patients with epilepsy[7] or parkinsonism,[9] but not as accurate as conditions such as diabetes,[13] hypertension,[14] and multiple sclerosis.[8] It is interesting to note that the algorithm that included a hospitalization, or an emergency room visit or 4 physician billing codes per year had the same number of false positives as false negatives and therefore provided a prevalence exactly the same as our EMRALD cohort prevalence. This suggests that administrative data algorithms may be highly accurate in estimating AF prevalence and incidence over large populations.

A Swedish study conducted from 2004 to 2010 found an AF prevalence of 3.0%.[15] This higher prevalence than what we found may be explained by their definition of AF, which included a single episode such as AF that occurred peri-operatively, or because they had an ECG database available. In our study 89% of patients had an electrocardiogram or Holter recorded at some point in their EMR record, but only 46% of these patients had an electrocardiogram or Holter showing AF. Although our AF prevalence in 2008 was only a little lower than that found in a German study, their incidence was almost double what we found.[16] However their methods for identifying incident cases included no previous physician billing codes in only a one year period (i.e. if a patient had a physician visit that was

primarily for AF 18 months prior they would still be included as an incident case of AF), and they only required two physician billing codes separated by at least 3 months. In comparison, our methods for identifying incident cases had at least a nine year 'wash out' period and required at least four physician billing codes to meet criteria for inclusion as having AF.

Given that our rate of anticoagulant use was similar as measured in EMRALD compared to administrative data on the same cohort of patients, it appears that either data source would be suitable to use to measure rates of anticoagulation and types of anticoagulants used. Using administrative data in 2011, anticoagulation rates amongst AF patients was higher in EMRALD (64.1%) compared to anticoagulation rates amongst AF patients in the general population (53.8%). Our prevalence and anticoagulation rates in EMRALD were also higher than that measured amongst primary care practices in England (using EMR data).[17] It is possible that our participating physicians are more likely to prescribe anticoagulants as indicated by guidelines than other primary care physicians, and may be better at detecting and treating AF patients, though we were only able to delineate prescriptions for anticoagulants in EMRALD and unable to determine adherence to medications. Our anticoagulation rate as measured in administrative data is in keeping with previously published rates,[18] whereby only about half of the patients with AF are on anticoagulants.[19] However, our finding of increasing prevalence and anticoagulation rates over time is consistent with what has been seen in the UK.[20]

Although the accuracy of our optimal algorithms were at the lower end of positive predictive value and mid-range for sensitivity compared to other studies identifying AF patients from electronic medical data,[2] the methods used here may be more generalizable than that used in other studies. The use of primary care EMRs as a reference standard is likely a less biased source than using registry data, as it is more reflective of the general population. However, there are some limitations to our reference standard. First, we were only able to identify those patients with AF who were recognized by physicians, and it is possible that there were additional patients in our EMRALD cohort that have AF

that has not yet been detected, or where the diagnosis was not recorded in the EMR. Second, our medication data in Ontario is more complete for patients age 65 years and over, than for those who are younger. Thus our anticoagulation rates may be underestimated, in particular with NOACs, as they require a limited use code for prescribing. It is possible that patients were on these medications but paid for them through private drug plans or out of pocket and therefore would not be captured in our Ontario Drug Benefit database. However our trends in the decrease of warfarin and the increase in NOACs for AF patients are in keeping with Canadian and provincial trends recently reported using pharmacy data not dependent on Ontario Drug Benefit qualification.[21] Third, although most of our patients had a Holter or electrocardiogram in their EMR chart, less than half of those patients had these tests showing AF and we were unable to delineate the temporality of the tests in relation to the initial diagnosis. The average duration of follow-up in our EMR charts was approximately 5 years and it is possible that some of our patients were diagnosed prior to the start of their EMR record and did not have completely up to date EMR records. Last, determining the appropriateness of the use of anticoagulants and any contraindications to anticoagulants was beyond the scope of this study and is difficult to ascertain in administrative data, or even within EMRs in an automated fashion.

This validation work will allow for future studies wishing to use administrative data to measure changes in AF detection or treatment in large populations or over time, and has the potential to be applied in other provinces across Canada that have similar administrative databases.

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Supplemental Table S1 Administrative data algorithms for adults using hospitalization, emergency room records and/or physician billings

Administrative data algorithm	TP	TN	FN	FP	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Youden Index	Kappa	Prevalence estimate
Single hospitalization, emergency room or physician billing codes											
1 HOSP	86	7,293	106	15	44.8(37.8-51.8)	99.8(99.7-99.9)	85.1(78.2-92.1)	98.6(98.3-98.8)	0.45	0.58	1.3%
1 ED	74	7,293	118	15	38.5(31.7-45.4)	99.8(99.7-99.9)	83.1(75.4-90.9)	98.4(98.1-98.7)	0.38	0.52	1.2%
HOSP or ED	114	7,279	78	29	59.4(52.4-66.3)	99.6(99.5-99.7)	79.7(73.1-86.3)	98.9(98.7-99.2)	0.59	0.67	1.9%
1 MD	171	6,609	21	699	89.1(84.6-93.5)	90.4(89.8-91.1)	19.7(17.0-22.3)	99.7(99.5-99.8)	0.79	0.29	11.6%
HOSP or 1 MD	177	6,606	15	702	92.2(88.4-96.0)	90.4(89.7-91.1)	20.1(17.5-22.8)	99.8(99.7-99.9)	0.83	0.30	11.7%
HOSP OR ED OR 1 MD	177	6,604	15	704	92.2(88.4-96.0)	90.4(89.7-91.0)	20.1(17.4-22.7)	99.8(99.7-99.9)	0.83	0.30	11.7%
Increasing the number of physician billing codes											
2 MD in 1 year	144	7,167	48	141	75.0(68.9-81.1)	98.1(97.8-98.4)	50.5(44.7-56.3)	99.3(99.1-99.5)	0.73	0.59	3.8%
3 MD in 1 year	103	7,244	89	64	53.6(46.6-60.7)	99.1(98.9-99.3)	61.7(54.3-69.1)	98.8(98.5-99.0)	0.53	0.56	2.2%
4 MD in 1 year	74	7,279	118	29	38.5(31.7-45.4)	99.6(99.5-99.7)	71.8(63.2-80.5)	98.4(98.1-98.7)	0.38	0.49	1.4%
5 MD in 1 year	53	7,295	139	13	27.6(21.3-33.9)	99.8(99.7-99.9)	80.3(70.7-89.9)	98.1(97.8-98.4)	0.27	0.40	0.9%
Increasing the number of years to look for multiple physician billing codes											
3 MD in 2 years	114	7,229	78	79	59.4(52.4-66.3)	98.9(98.7-99.2)	59.1(52.1-66.0)	98.9(98.7-99.2)	0.58	0.58	2.6%
3 MD in 3 years	117	7,221	75	87	60.9(54.0-67.8)	98.8(98.6-99.1)	57.4(50.6-64.1)	99.0(98.7-99.2)	0.60	0.58	2.7%
4 MD in 2 years	89	7,262	103	46	46.4(39.3-53.4)	99.4(99.2-99.6)	65.9(57.9-73.9)	98.6(98.3-98.9)	0.46	0.53	1.8%
4 MD in 3 years	95	7,254	97	54	49.5(42.4-56.6)	99.3(99.1-99.5)	63.8(56.0-71.5)	98.7(98.4-98.9)	0.49	0.55	2.0%
5 MD in 2 years	74	7,281	118	27	38.5(31.7-45.4)	99.6(99.5-99.8)	73.3(64.6-81.9)	98.4(98.1-98.7)	0.38	0.50	1.3%
Requiring the billing code to be by a specialist											
4 MD in 1 year at least 1 MD by any specialist	44	7,293	148	15	22.9(17.0-28.9)	99.8(99.7-99.9)	74.6(63.5-85.7)	98.0(97.7-98.3)	0.23	0.34	0.8%
4 MD in 2 year at least 1 MD by any specialist	59	7,277	133	31	30.7(24.2-37.3)	99.6(99.4-99.7)	65.6(55.7-75.4)	98.2(97.9-98.5)	0.30	0.41	1.2%
4 MD in 1 year at least 2 MD by any specialist	32	7,294	160	14	16.7(11.4-21.9)	99.8(99.7-99.9)	69.6(56.3-82.9)	97.9(97.5-98.2)	0.16	0.26	0.6%
4 MD in 2 year at least 2 MD by any specialist	45	7,280	147	28	23.4(17.4-29.4)	99.6(99.5-99.8)	61.6(50.5-72.8)	98.0(97.7-98.3)	0.23	0.33	1.0%
4 MD in 1 year at least 3 MD by any specialist	17	7,298	175	10	8.9(4.8-12.9)	99.9(99.8-99.9)	63.0(44.7-81.2)	97.7(97.3-98.0)	0.09	0.15	0.4%
4 MD in 2 year at least 3 MD by any specialist	30	7,284	162	24	15.6(10.5-20.8)	99.7(99.5-99.8)	55.6(42.3-68.8)	97.8(97.5-98.2)	0.15	0.24	0.7%
Combining hospital, emergency room or multiple physician billing codes											
HOSP OR ED OR 2 MD in 1 year	160	7,148	32	160	83.3(78.1-88.6)	97.8(97.5-98.1)	50.0(44.5-55.5)	99.6(99.4-99.7)	0.81	0.61	4.3%
HOSP OR ED OR 3 MD in 1 year	146	7,218	46	90	76.0(70.0-82.1)	98.8(98.5-99.0)	61.9(55.7-68.1)	99.4(99.2-99.5)	0.75	0.67	3.1%
HOSP OR ED Or 4 MD in 1 year	**136**	**7,252**	**56**	**56**	**70.8(64.4-77.3)**	**99.2(99.0-99.4)**	**70.8(64.4-77.3)**	**99.2(99.0-99.4)**	**0.70**	**0.70**	**2.6%**
HOSP OR ED or 5 MD in 1 year	130	7,267	62	41	67.7(61.1-74.3)	99.4(99.3-99.6)	76.0(69.6-82.4)	99.2(98.9-99.4)	0.67	0.71	2.3%
HOSP OR ED Or 4 MD in 2 years	142	7,236	50	72	74.0(67.8-80.2)	99.0(98.8-99.2)	66.4(60.0-72.7)	99.3(99.1-99.5)	0.73	0.69	2.9%
HOSP OR ED or 5 MD in 2 years	134	7,255	58	53	69.8(63.3-76.3)	99.3(99.1-99.5)	71.7(65.2-78.1)	99.2(99.0-99.4)	0.69	0.70	2.5%

TP=true positive, TN=true negative, FP=false positive, FN= false negative, HOSP=hospital claim, ED=emergency room visit, MD=physician billing claim
specialist=cardiologist, internist or cardio/thoracic or cardiac surgeon
total patients N=7500, average age= 49.6 years, male 42.7% atrial fibrillation patients n=192, average age= 74.5 years, male=52.6%
atrial fibrillation cohort prevalence= 2.6%

Supplemental Table S2 Administrative data algorithms for adults using hospitalization, emergency room records, physician billings, medications and/or cardioversion

Administrative data algorithm	TP	TN	FN	FP	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Youden Index	Simple Kappa Statistic	Prevalence estimate
Using anticoagulants											
1 anticoagulant	122	7,201	70	107	63.5(56.7-70.3)	98.5(98.3-98.8)	53.3(46.8-59.7)	99.0(98.8-99.3)	0.62	0.57	3.1%
1 warfarin management fee	115	7,177	77	131	59.9(53.0-66.8)	98.2(97.9-98.5)	46.7(40.5-53.0)	98.9(98.7-99.2)	0.58	0.51	3.3%
1 anticoagulant OR 1 warfarin management fee	138	7,119	54	189	71.9(65.5-78.2)	97.4(97.0-97.8)	42.2(36.8-47.6)	99.2(99.0-99.4)	0.69	0.52	4.4%
(1 anticoagulant OR 1 warfarin management fee) AND no PE, DVT or mechanical valve	133	7,166	59	142	69.3(62.7-75.8)	98.1(97.7-98.4)	48.4(42.5-54.3)	99.2(99.0-99.4)	0.67	0.56	3.7%
(1 anticoagulant OR 1 warfarin management fee) AND (1 HOSP OR 1 MD)	127	7,250	65	58	66.1(59.5-72.8)	99.2(99.0-99.4)	68.6(62.0-75.3)	99.1(98.9-99.3)	0.65	0.67	2.5%
(1 anticoagulant OR 1 warfarin management fee) AND 1 rate control medication	111	7,259	81	49	57.8(50.8-64.8)	99.3(99.1-99.5)	69.4(62.2-76.5)	98.9(98.7-99.1)	0.57	0.62	2.1%
(1 anticoagulant OR 1 warfarin management fee) AND ((1 HOSP OR 1 MD) OR (1 rate control medication))	136	7,225	56	83	70.8(64.4-77.3)	98.9(98.6-99.1)	62.1(55.7-68.5)	99.2(99.0-99.4)	0.70	0.65	2.9%
Adding rhythm control medication											
1 rhythm control medication	19	7,303	173	5	9.9(5.7-14.1)	99.9(99.9-100.0)	79.2(62.9-95.4)	97.7(97.3-98.0)	0.10	0.17	0.3%
((1 anticoagulant OR 1 warfarin management fee) AND 1 rate control medication) OR (1 rhythm control medication)	114	7,254	78	54	59.4(52.4-66.3)	99.3(99.1-99.5)	67.9(60.8-74.9)	98.9(98.7-99.2)	0.59	0.62	2.2%
((1 anticoagulant OR 1 warfarin management fee) AND (1 HOSP OR 1 MD)) OR 1 rhythm control medication	130	7,245	62	63	67.7(61.1-74.3)	99.1(98.9-99.3)	67.4(60.7-74.0)	99.2(98.9-99.4)	0.67	0.67	2.6%
((1 anticoagulant OR 1 warfarin management fee) AND (1 HOSP OR 1 MD)) OR ((1 anticoagulant OR 1 warfarin management fee) AND 1 rate control medication) OR 1 rhythm control	139	7,220	53	88	72.4(66.1-78.7)	98.8(98.5-99.0)	61.2(54.9-67.6)	99.3(99.1-99.5)	0.71	0.65	3.0%
Adding cardioversion											
cardioversion	30	7,291	162	17	15.6(10.5-20.8)	99.8(99.7-99.9)	63.8(50.1-77.6)	97.8(97.5-98.2)	0.15	0.24	0.6%
cardioversion AND 1 MD	30	7,296	162	12	15.6(10.5-20.8)	99.8(99.7-99.9)	71.4(57.8-85.1)	97.8(97.5-98.2)	0.15	0.25	0.6%
cardioversion AND (1 MD OR 1 HOSP)	30	7,296	162	12	15.6(10.5-20.8)	99.8(99.7-99.9)	71.4(57.8-85.1)	97.8(97.5-98.2)	0.15	0.25	0.6%
Combining hospitalization, emergency room visits, physician billings, anticoagulants, rhythm control medications and cardioversion											
1 HOSP OR 1 ED OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	**155**	**7,245**	**37**	**63**	**80.7(75.1-86.3)**	**99.1(98.9-99.3)**	**71.1(65.1-77.1)**	**99.5(99.3-99.7)**	**0.80**	**0.75**	**2.9%**
1 HOSP OR 1 ED OR (4 MD in 1 year) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	161	7,226	31	82	83.9(78.6-89.1)	98.9(98.6-99.1)	66.3(60.3-72.2)	99.6(99.4-99.7)	0.83	0.73	3.2%
1 HOSP OR 1 ED OR (4 MD in 2 years) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	164	7,213	28	95	85.4(80.4-90.4)	98.7(98.4-99.0)	63.3(57.5-69.2)	99.6(99.5-99.8)	0.84	0.72	3.5%
1 HOSP OR 1 ED OR (5 MD in 1 year) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	158	7,238	34	70	82.3(76.9-87.7)	99.0(98.8-99.3)	69.3(63.3-75.3)	99.5(99.4-99.7)	0.81	0.75	3.0%
1 HOSP OR 1 ED OR (5 MD in 2 years) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	160	7,227	32	81	83.3(78.1-88.6)	98.9(98.7-99.1)	66.4(60.4-72.4)	99.6(99.4-99.7)	0.82	0.73	3.2%

TP=true positive, TN=true negative, FP=false positive, FN= false negative, HOSP=hospital claim, ED=Emergency room visit, MD=physician billing claim, PE=pulmonary embolus, DVT=deep vein thrombosis

total patients N=7500, average age= 49.6 years, male 42.7% atrial fibrillation patients n=192, average age= 74.5 years, male=52.6%

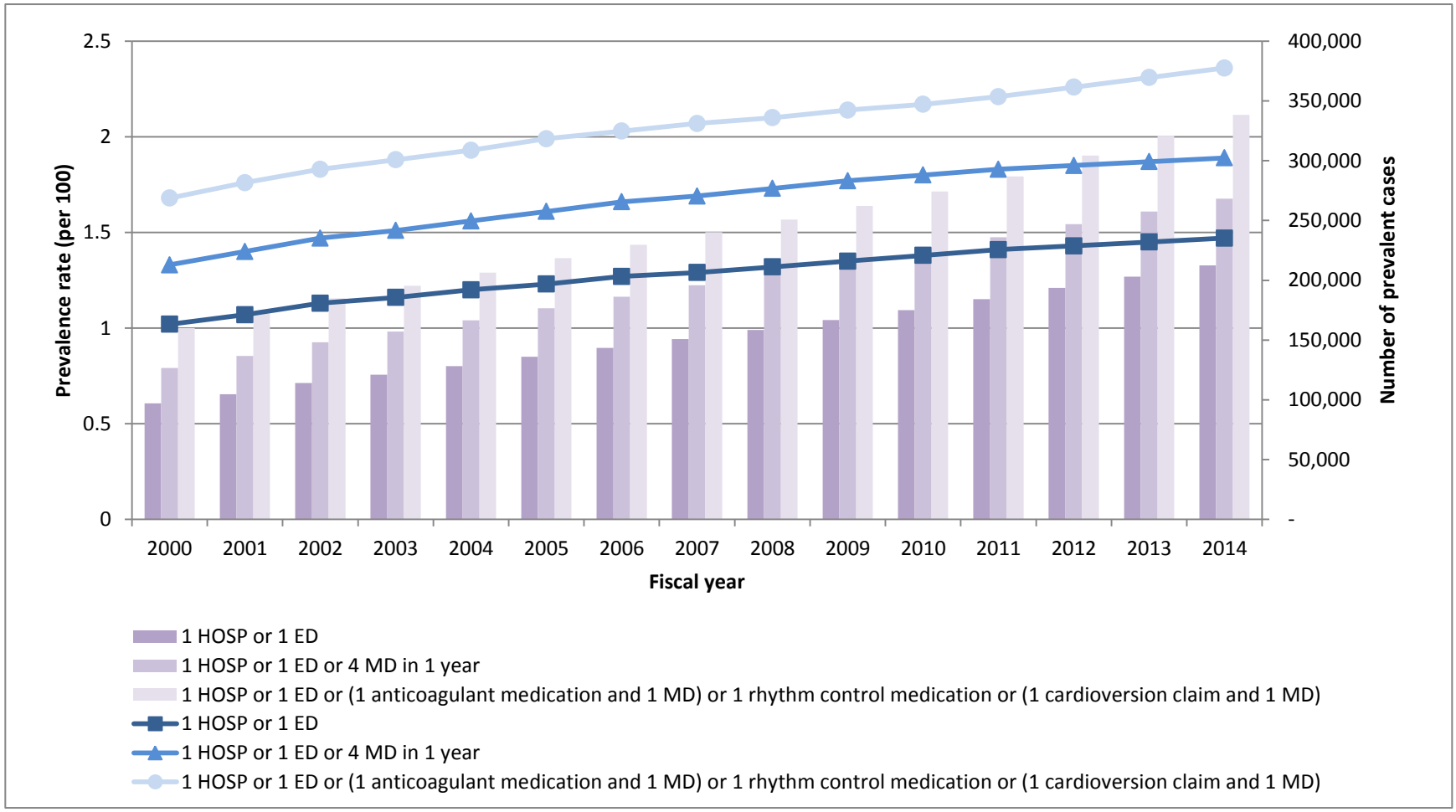
atrial fibrillation cohort prevalence= 2.6%

Supplemental Table S3. Administrative data algorithms for patients age 66 years and older

Administrative data algorithm	TP	TN	FN	FP	Sensitivity (%)	Specificity (%)	Positive Predictive Value (%)	Negative Predictive Value (%)	Youden Index	Simple Kappa Statistic	Prevalence estimate
Hospital, emergency room or multiple physician billing codes											
1 HOSP code	67	1,161	82	12	45.0(37.0-53.0)	99.0(98.4-99.6)	84.8(76.9-92.7)	93.4(92.0-94.8)	0.44	0.55	5.7%
HOSP or ED	88	1,152	61	21	59.1(51.2-67.0)	98.2(97.5-99.0)	80.7(73.3-88.1)	95.0(93.7-96.2)	0.57	0.65	7.9%
HOSP OR ED Or 4 MD in 1 YR	**105**	**1,144**	**44**	**29**	**70.5(63.1-77.8)**	**97.5(96.6-98.4)**	**78.4(71.4-85.3)**	**96.3(95.2-97.4)**	**0.68**	**0.71**	**9.8%**
HOSP OR ED or 5 MD in 1 YR	101	1,149	48	24	67.8(60.3-75.3)	98.0(97.1-98.8)	80.8(73.9-87.7)	96.0(94.9-97.1)	0.66	0.71	9.2%
HOSP OR ED Or 4 MD in 2 YRS	109	1,136	40	37	73.2(66.0-80.3)	96.8(95.8-97.8)	74.7(67.6-81.7)	96.6(95.6-97.6)	0.70	0.71	10.7%
HOSP OR ED or 5 MD in 2 YRS	104	1,143	45	30	69.8(62.4-77.2)	97.4(96.5-98.3)	77.6(70.6-84.7)	96.2(95.1-97.3)	0.67	0.70	9.8%
Combining hospitalization, emergency room visits, physician billings, anticoagulants, rhythm control medications and cardioversion											
1 HOSP OR 1 ED OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	**126**	**1,130**	**23**	**43**	**84.6(78.8-90.4)**	**96.3(95.3-97.4)**	**74.6(68.0-81.1)**	**98.0(97.2-98.8)**	**0.81**	**0.76**	**12.8%**
1 HOSP OR 1 ED OR (4 MD in 1 year) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	127	1,126	22	47	85.2(79.5-90.9)	96.0(94.9-97.1)	73.0(66.4-79.6)	98.1(97.3-98.9)	0.81	0.76	13.2%
1 HOSP OR 1 ED OR (4 MD in 2 years) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	128	1,119	21	54	85.9(80.3-91.5)	95.4(94.2-96.6)	70.3(63.7-77.0)	98.2(97.4-98.9)	0.81	0.74	13.8%
1 HOSP OR 1 ED OR (5 MD in 1 year) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	126	1,129	23	44	84.6(78.8-90.4)	96.2(95.2-97.3)	74.1(67.5-80.7)	98.0(97.2-98.8)	0.81	0.76	12.9%
1 HOSP OR 1 ED OR (5 MD in 2 years) OR (1 anticoagulant AND 1 MD) OR (1 rhythm control medication) OR (cardioversion AND 1 MD)	127	1,124	22	49	85.2(79.5-90.9)	95.8(94.7-97.0)	72.2(65.5-78.8)	98.1(97.3-98.9)	0.81	0.75	13.3%

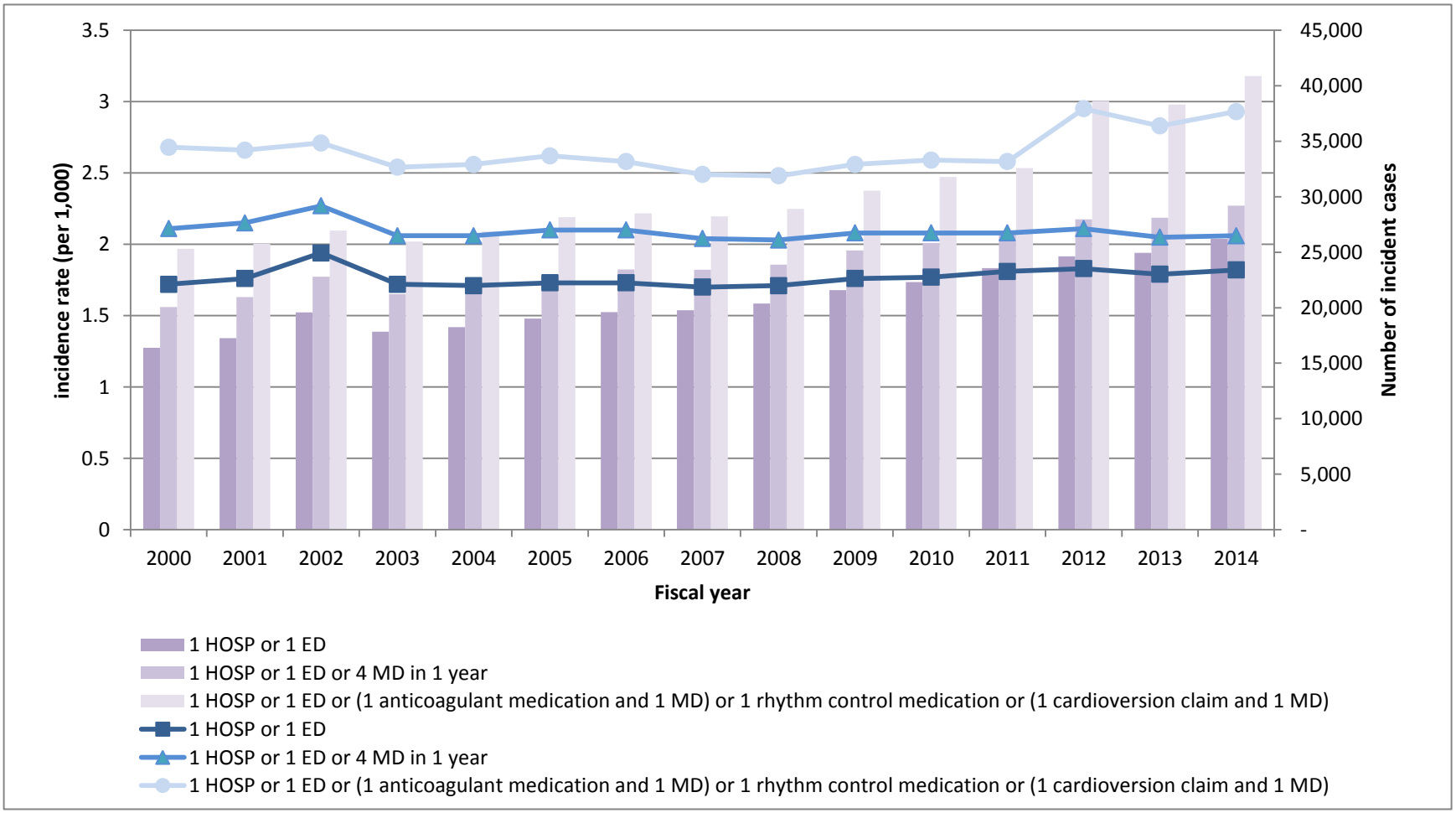
TP=true positive, TN=true negative, FP=false positive, FN= false negative, HOSP=hospital claim, ED=emergency room visit, MD=physician billing claim
Total patients N=1322, average age=75.6 years, male=45.0%, atrial fibrillation n=149, average age = 79.2 years, male= 51.0%,
atrial fibrillation cohort prevalence= 11.3%

Supplemental Figure S1 Crude and age and sex standardized atrial fibrillation prevalence per 100 adult population, 2000 - 2014.



HOSP=hospital claim, ED=emergency room visit, MD=physician billing claim
Bars represent crude numbers
Points and lines represent age and sex standardized prevalence rate

Supplemental Figure S2 Crude and age and sex standardized atrial fibrillation incidence per 1,000 adult population, 2000 - 2014.



HOSP=hospital claim, ED=emergency room visit, MD=physician billing claim
Bars represent crude numbers
Points and lines represent age and sex standardized incidence rate

Supplemental Table S4. Anticoagulation rates and types for adult patients with atrial fibrillation as identified in EMR and administrative data

	AF patients alive during anticoagulation time frame assessed	Filled a prescription for an anticoagulant	%	Filled a prescription for warfarin	%	Filled a prescription for a NOAC	%
Anticoagulation rates in 2011 as measured in the EMR							
AF patients from 7500 chart abstraction sample (*Age 20 years+)	188	118	62.8	110	93.2	8	6.8
AF patients from 7500 chart abstraction sample (*Age 66+years)	145	99	68.3	-†	<98%†	≤5†	<7†
Anticoagulation rates in 2011 as measured in administrative data							
AF patients from 7500 chart abstraction sample (*Age 66+years)	145	93	64.1	-†	<98%†	≤5†	<7†
AF in all Ontario using rule 1 HOSP or 1 ED or 4 MD in 1 year (*Age 66+years)	168,623	90,692	53.8	87,713	96.7	2,979	3.3
AF in all Ontario using rule 1 HOSP or 1 ED or (1 anticoagulant medication and 1 MD) or 1 rhythm control medication or (1 cardioversion claim and 1 MD) (*Age 66+years)	222,489	118,793	53.4	113,901	95.9	4,892	4.1
Anticoagulation rates in 2014 as measured in administrative data							
AF in all Ontario using rule 1 HOSP or 1 ED or 4 MD in 1 year (**Age 66+years)	192,374	116,880	60.8	56,749	48.6	60,131	51.4
AF in all Ontario using rule 1 HOSP or 1 ED or (1 anticoagulant medication and 1 MD) or 1 rhythm control medication or (1 cardioversion claim and 1 MD) (**Age 66+years)	262,673	157,885	60.1	74,123	46.9	83,762	53.1

* Age calculated as of Dec 31, 2010
† exact numbers suppressed due to small cell size regulation
‡ Age calculated as of Dec 31, 2013
NOAC=novel oral anticoagulant, HOSP=hospital claim, ED=emergency room visit, MD=physician billing claim

SUPPLEMENTAL APPENDIX S1.

Chart abstraction rules for identifying atrial fibrillation

ATRIAL FIBRILLATION (A FIB)

Does the patient have a history of Atrial Fibrillation (AFib)?

Data Entry:

- Select **[Def]** if there is a history of atrial fibrillation as recorded by the family physician or specialist (including interpretation of Holter monitor)
- Select **[Poss]** if AFib on ECG/EKG only
- Select **[Poss]** if 'rule out', 'R/O', '?', 'possible' or other query term precedes atrial fibrillation or its synonyms
- Select **[No]** if the diagnosis of atrial fibrillation has been ruled out

Include, select [Def]:

- Atrial Fib
- Atrial Fibrillation (A-Fib, AFib, AF)
- Auricular Fibrillation
- Chronic atrial Fibrillation
- Atrial Flutter
- Fibrillation

Exclude:

- Intermittent Atrial Tachycardia
- New Onset Atrial Tachycardia
- Multifocal Atrial Tachycardia (MAT)
- Paroxysmal Atrial Tachycardia (PAT)
- Paroxysmal supraventricular tachycardia (PSVT)
- Supraventricular Tachycardia (SVT)