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ORIGINAL RESEARCH

Use of a Clinical Electrocardiographic Database to Enhance Atrial Fibrillation/Atrial Flutter Identification Algorithms Based on Administrative Data

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BACKGROUND: Administrative data have limited sensitivity for case finding of atrial fibrillation/atrial flutter (AF/AFL). Linkage with clinical repositories of interpreted ECGs may enhance diagnostic yield of AF/AFL.

METHODS AND RESULTS: We retrieved 369 ECGs from the institutional Marquette Universal System for Electrocardiography (MUSE) repository as validation samples, with rhythm coded as AF (n=49), AFL (n=50), or other competing rhythm diagnoses (n=270). With blinded, duplicate review of ECGs as the reference comparison, we compared multiple MUSE coding definitions for identifying AF/AFL. We tested the agreement between MUSE diagnosis and reference comparison, and calculated the sensitivity and specificity. Using a data set linking clinical registries, administrative data, and the MUSE repository (n=11 662), we assessed the incremental diagnostic yield of AF/AFL by incorporating ECG data to administrative data-based algorithms. The agreement between MUSE diagnosis and reference comparison depended on the coding definitions applied, with the Cohen κ ranging from 0.57 to 0.75. Sensitivity ranged from 60.6% to 79.1%, and specificity ranged from 93.2% to 98.0%. A coding definition with AF/AFL appearing in the first 3 ECG statements had the highest sensitivity (79.1%), with little loss of specificity (94.5%). Compared with the algorithms with only administrative data, incorporating ECG data increased the diagnostic yield of preexisting AF/AFL by 14.5% and incident AF/AFL by 7.5% to 16.1%.

CONCLUSIONS: Routine ECG interpretation using MUSE coding is highly specific and moderately sensitive for AF/AFL detection. Inclusion of MUSE ECG data in AF/AFL case identification algorithms can identify cases missed using administrative data-based algorithms alone.

Key Words: administrative data ■ ECG ■ atrial fibrillation ■ atrial flutter ■ identification algorithm

Atrial fibrillation (AF) and atrial flutter (AFL) are the most commonly encountered sustained tachyarrhythmias.[1] AF/AFL is a powerful adverse prognostic marker for long-term morbidity from congestive heart failure, stroke, and other thromboembolic events, as well as for increased mortality.[2] As its incidence and prevalence increase, AF/AFL has become a critical public health issue in many countries.[3,4]

Accurate case identification is a critical step in efforts to understand trends in the incidence, prevalence, and outcomes of patients with AF/AFL. Administrative data are frequently used for this purpose, but with well-recognized limitations.[5,6] These include generic issues, such as differences in coding criteria across institutions, changes in diagnostic criteria or coding system over time, and limited

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CLINICAL PERSPECTIVE

What Is New?

- Routine ECG interpretation using Marquette Universal System for Electrocardiography coding is highly specific and moderately sensitive for atrial fibrillation/atrial flutter detection.
- Inclusion of Marquette Universal System for Electrocardiography ECG data in atrial fibrillation/atrial flutter case identification algorithms can identify cases missed using administrative data-based algorithms alone.

What Are the Clinical Implications?

- Our findings provide evidence that incorporation of ECG data may increase the accuracy of surveillance for atrial fibrillation/atrial flutter within populations.

Nonstandard Abbreviations and Acronyms

AFL	atrial flutter
APPROACH	Alberta Provincial Project for Outcomes Assessment in Coronary Heart Disease
MUSE	Marquette Universal System for Electrocardiography

granularity in clinical detail. In addition, AF/AFL poses specific challenges in ascertainment because of its often-transient nature and varied locale of presentation (ie, emergency department [ED] and physician's office). Together, these issues limit sensitivity of health administrative data for AF/AFL case finding.[7] Combining multiple sources of data can improve diagnostic yield. In a validation study conducted in Ontario, Canada, Tu et al reported that the sensitivity for AF identification ranged from <45% using only hospitalization data to 84.6% when using an algorithm combining hospitalization, ED visits, physician billings, prescriptions for anticoagulant and/or rhythm control medications, and electrical cardioversion.[5]

Electrocardiographic evidence is required to confirm a diagnosis of AF or AFL. The currently widespread use of electronic ECG repositories with coded ECG diagnoses therefore provides an opportunity to increase case finding in health services research. However, neither the accuracy of routine ECG interpretations of AF/AFL from an electronic repository nor the incremental diagnostic yield compared with administrative data-based algorithms has been reported. This 2-part study sought to address these knowledge gaps, by: (1) validating the accuracy of routine ECG diagnosis codes for AF/AFL from an electronic repository; and (2) estimating the incremental diagnostic yield for AF/AFL obtained by adding coded ECG data to published administrative data-based algorithms for AF/AFL ascertainment within an existing cohort.

METHODS

This study was performed within a retrospective cohort study, which was established to examine the association of cardiac rehabilitation with the incidence of incident AF in patients who underwent coronary revascularization. The study data set consisted of data sets from a provincial cardiac catheterization registry (APPROACH [Alberta Provincial Project for Outcomes Assessment in Coronary Heart Disease][8]), a city-wide cardiac rehabilitation program (TotalCardiology Rehabilitation) in Calgary, AB, Canada, Alberta provincial health administrative databases, and an Alberta local ECG repository. All data sets were linked through the use of Alberta personal health number, which uniquely identifies all residents in Alberta. The University of Calgary's Conjoint Health Research Ethics Board approved this study, including the provision to waive individual patient consent. The data that support the study findings are not available because of the privacy legislation. The analytic methods are available from the corresponding author on reasonable request.

Validation of the Accuracy of Routine ECG Coding for AF/AFL From an Electronic Repository

Study Cohort

A total of 23 200 patients were included in this validation study, whose cardiac rehabilitation referral date ranged from January 1, 1996, to March 31, 2016.

ECG Data

All hospitals and hospital-based clinics in Calgary use a common instance of the Marquette Universal System for Electrocardiography (MUSE; General Electric) for ECG recording, interpretation, and storage. ECGs are recorded with initial automated reporting using standard MUSE library statements, wherein the current rhythm diagnosis code(s) typically appear within the first 1 to 3 statements. All ECGs are then overread by a cardiologist or internist with ECG certification. If changes to diagnosis are required, the interpreting physician can use statements from the library, or make free-text entries. The physician-interpreted ECG is the version stored in the MUSE repository. In addition to storing ECG tracings,

the repository includes the coded diagnosis statements and other meta-data, such as patient identifiers, ECG date/time, and quantitative elements, such as heart rate, intervals, and axes.

Validation of MUSE-Coded AF/AFL Diagnosis

We aimed to construct a representative validation sample of rhythm diagnoses occurring in the first 3 MUSE statement positions. After randomly ordering the 140 257 ECGs in the data set, we targeted an overall sample of 400: 50 for AF, 50 for AFL, and 25 for each of 12 competing rhythm diagnoses, including sinus rhythm, narrow and wide complex tachyarrhythmias, paced rhythms, and ECGs where the rhythm was undetermined. The final sample was reduced to 369, because of insufficient occurrences of 2 diagnoses (ventricular tachycardia and multifocal atrial tachycardia) and inability to extract tracings for 2 of the selected records (1 AF and 1 undetermined rhythm).

After randomizing the order of 369 ECGs and redacting the computerized interpretations, a cardiac electrophysiologist (S.B.W.) and a cardiologist-supervised student (R.C.) independently interpretated these ECGs, using a simplified classification of AF, AFL, sinus rhythm, or "other."[9] Discrepancies between the reviewers were arbitrated by another cardiologist (R.J.H.M.), with a final consensus review for any remaining discrepancies. Using this final ECG interpretation as the reference comparison, we compared the accuracy of MUSE-based identification of AF/AFL across several definitions that required the AF/AFL diagnosis codes that appeared in either the first diagnosis statement only or any of the first 3 statements. Free-text entries were not considered.

Estimation of the Incremental Diagnostic Yield for AF/AFL Obtained by Adding MUSE ECG Data to Administrative Data-Based Algorithms

Study Cohort and Data Sources

This analysis was performed within a subset of the validation study cohort. We only included patients meeting all of the following criteria: (1) referred to TotalCardiology Rehabilitation program between April 1, 2004, and March 31, 2015; (2) treated with percutaneous coronary intervention or coronary artery bypass grafting surgery within 1 year before cardiac rehabilitation referral; (3) no diagnosis of AF/AFL recorded within at least a 2-year look-back period (to exclude the patients with preexisting AF); and (4) alive before the start of follow-up.

The primary study outcome of AF/AFL was ascertained by linkage with provincial administrative data sources and MUSE repository. Table 1 summarized the identification definitions for AF/AFL that we applied in each data set. Hospitalization records containing a diagnosis of AF/AFL were identified from the Discharge Abstract Database using the *International Classification of Diseases, Tenth Revision* (*ICD-10*), codes I48.0, I48.1, I48.3, I48.4, and I48.9 in any diagnosis statement, with discharge dates ranging from April 1, 2002, to December 31, 2015. ED records containing a primary diagnosis of AF/AFL were identified from the Ambulatory Care Classification System Database and National Ambulatory Care Reporting System Database using the aforementioned *ICD-10* codes in the first diagnosis statement, with visit dates ranging from April 1, 2002, to March 31, 2014. Physician claim records containing a primary diagnosis of AF/AFL were identified from the Physician Claim Database using the *International Classification of Diseases, Ninth Revision* (*ICD-9*), code 427.3 in the first diagnosis statement, with claim dates ranging from April 1, 2001, to March 31, 2015. Finally, using the optimal AF/AFL identification definition from the ECG validation study, we retrieved all AF/AFL ECG records between April 1, 2006, and December 31, 2015, from the MUSE repository.

Identification Algorithms for Incident AF/AFL

We first applied 2 published algorithms to identify incident AF/AFL within administrative data: (1) 1 hospitalization or 1 ED visit or 1 physician claim; and (2) 1 hospitalization or 1 ED visit or 2 physician claims (2 physician claims between 30 and 365 days).[5,10] We then modified each algorithm to also diagnose incident AF/AFL if a single ECG record contained AF/AFL. We also attempted to exclude potential transient AF/AFL

Table 1. AF/AFL Definitions in Different Databases

Database	Content	Definition
DAD	Hospitalization	Any AF/AFL codes (I48.0, I48.1, I48.3, I48.4, or I48.9) appear in any diagnosis variables.
ACCS+NACRS	Emergency department visit	Any AF/AFL codes (I48.0, I48.1, I48.3, I48.4, or I48.9) appear in the first diagnosis variable.
PC	Physician claim	AF/AFL code (427.3) appears in the first diagnosis variable.
MUSE	ECG	AF/AFL acronym appears in any of the first 3 diagnosis variables.

ACCS indicates Ambulatory Care Classification System Database; AF, atrial fibrillation; AFL, atrial flutter; DAD, Discharge Abstract Database; MUSE, Marquette Universal System for Electrocardiography; NACRS, National Ambulatory Care Reporting System Database; and PC, Physician Claim Database.

diagnoses related to cardiac surgery, and compared a strategy of excluding all episodes that were concurrent with an admission for cardiac surgery with another one of excluding all episodes that were concurrent with an admission for cardiac surgery and in which AF/AFL were listed as postadmit diagnoses.[10]

Identification Algorithm for Preexisting AF/AFL

Patients with preexisting AF, defined as 1 hospitalization or 1 ED visit or 2 physician claims (2 physician claims between 30 and 365 days) or 1 ECG, were excluded from analysis, regardless of whether AF/AFL events were transient AF/AFL associated with cardiac surgery.

Statistical Analysis

We assessed the agreement between MUSE ECG interpretation and reviewer-validated ECG interpretation using the Cohen κ statistic. Diagnostic accuracy of MUSE ECG interpretation was assessed by calculating sensitivity, specificity, positive predictive value, and negative predictive value, using reviewer-validated ECG interpretations as reference standard. Each algorithm for identifying incident AF/AFL was applied to the study cohort. We calculated the crude incidence of AF/AFL during follow-up, and the incremental diagnostic yield achieved by adding MUSE ECG data to the administrative data-only algorithms for case identification. All statistical analyses were performed using STATA version 15.

RESULTS

Accuracy of MUSE ECG Interpretation of AF/AFL

For the 369 MUSE ECG records, the agreement between routine MUSE interpretation and reviewer-validated ECG interpretation was acceptable across the 6 definitions, with the Cohen κ statistic ranging from 0.57 to 0.75 (Table 2). Compared with the reviewer-validated ECG interpretation, the sensitivity of MUSE ECG interpretations ranged from 60.6% to 79.1% across 6 comparisons; specificity ranged from 93.2% to 98.0%; positive predictive value ranged from 57.7% to 87.9%; and negative predictive value ranged from 89.3% to 95.6%. A definition requiring AF/AFL diagnosis codes to appear in any of the first 3 statements was optimal, because it had highest sensitivity (79.1%), with little loss of specificity (94.5%).

AF Incidence and Incremental Diagnostic Yield With MUSE ECG Data

Among 23 200 patients in the validations study, 11 662 (50.3%) met all entry criteria and were included in this analysis (Figure). Incorporating MUSE ECG data increased the detection of preexisting AF/AFL by 14.5% compared with the algorithm including only administrative data.

During a median follow-up of 4.8 years, an overall AF/AFL incidence, based on administrative data alone, was 4.5% to 6.7%, depending on the definitions applied (Table 3). As expected, requiring 2 versus 1 physician claim decreased the diagnostic yield, regardless of the definition applied. Incorporating MUSE ECG data increased the relative diagnostic yield by 7.5% to 16.1% compared with the corresponding algorithms, including only administrative data. Exclusion of incident AF/AFL events associated with an admission for cardiac surgery, whether coded as a preexisting or postadmit diagnosis, had only a modest effect on estimated incidence (Table 3).

DISCUSSION

The present study was designed to validate the accuracy of routine ECG codes for AF/AFL from the MUSE ECG repository and estimate the incremental diagnostic yield for AF/AFL obtained by adding coded MUSE ECG data to administrative data-based algorithms for AF/AFL ascertainment. We found that the definition requiring codes for AF/AFL to appear in any of the first 3 diagnosis statements had the optimal balance of sensitivity and specificity for true AF/AFL.

Although the specificity of a MUSE diagnosis of AF or AFL was good regardless of the definition applied, sensitivity was low, and required combining terms for AF and AFL to be acceptable. This is perhaps surprising, given that we tested the accuracy of the final, physician-interpreted ECG diagnosis. There are at least 2 plausible explanations for the reduced sensitivity. First, in our analysis, we included only coded entries made using the MUSE statement library in first 3 positions. Including AF/AFL codes in any position resulted in unacceptably low specificity, likely because of the terms being used to specify absence of the condition when appearing later in the interpretation. Inclusion of free-text entries made by interpreting physicians would have improved the sensitivity, with unclear effects on specificity. Second, the validation sample of ECGs was deliberately enriched for competing dysrhythmias. If a true random sample of ECGs had been selected, the sensitivity and specificity of routinely coded ECG interpretation would almost certainly be improved, although the positive predictive value may have been lower because of reduced prevalence.

Using the MUSE ECG interpretations, we identified more patients with preexisting or incident AF/AFL, who would not have been previously identified using administrative data. The findings corroborate the idea of the previous work in this field, which inferred that

Table 2. Comparison of MUSE and Reviewer-Validated ECG Interpretation for the Diagnosis of AF/AFL

Position of AF/AFL Acronym	κ Value	Sensitivity, %	Specificity, %	PPV, %	NPV, %
AF in statement 1	0.66	60.6	98.0	87.8	91.3
AF in statements 1–3	0.67	63.4	97.3	84.9	91.8
AFL in statement 1	0.59	68.2	93.8	60.0	95.6
AFL in statements 1–3	0.57	68.2	93.2	57.7	95.6
AF or AFL in statement 1	0.74	75.7	95.3	87.9	89.3
AF or AFL in statements 1–3	0.75	79.1	94.5	86.7	90.9

AF indicates atrial fibrillation; AFL, atrial flutter; MUSE, Marquette Universal System for Electrocardiography; NPV, negative predictive value; and PPV, positive predictive value.

the addition of ECG data could enhance the detection of an AF population compared with only using administrative data.[6,11] However, the accuracy of platform-specific ECG coding definitions and which diagnosis definition to use have not been previously explored. In addition to detecting an overall higher number of incident or preexisting AF cases, MUSE ECG data were helpful in reclassifying some patients from incident to preexisting AF, indicating that incorporation of ECG data may increase the accuracy of surveillance for AF within populations.

This study demonstrates the feasibility of using routinely coded ECG data to enhance the identification of rhythm abnormalities in large, multicomponent secondary use data sets. Although there is some work-required data preparation, the fact that rhythm diagnoses are coded as discrete data means that linkage with other data sources is straightforward as long as a common patient identifier is used. We recently published another study using similar methods to investigate the prognostic implications of MUSE-defined ECG conduction system disturbances.[12] Because ECG is the gold standard for diagnosis of rhythm disturbances, we believe that incorporation of ECG data source should improve both case finding and accuracy compared with approaches relying only on administrative data sources. Validation of these methods in data sets from other jurisdictions is required.

Several limitations of this study need to be acknowledged. First, in administrative databases, encounter coding would not distinguish AF and AFL when both arrhythmias have been present. Therefore, in the development of identification algorithms, we needed to include codes for both AF and AFL. Second, the findings

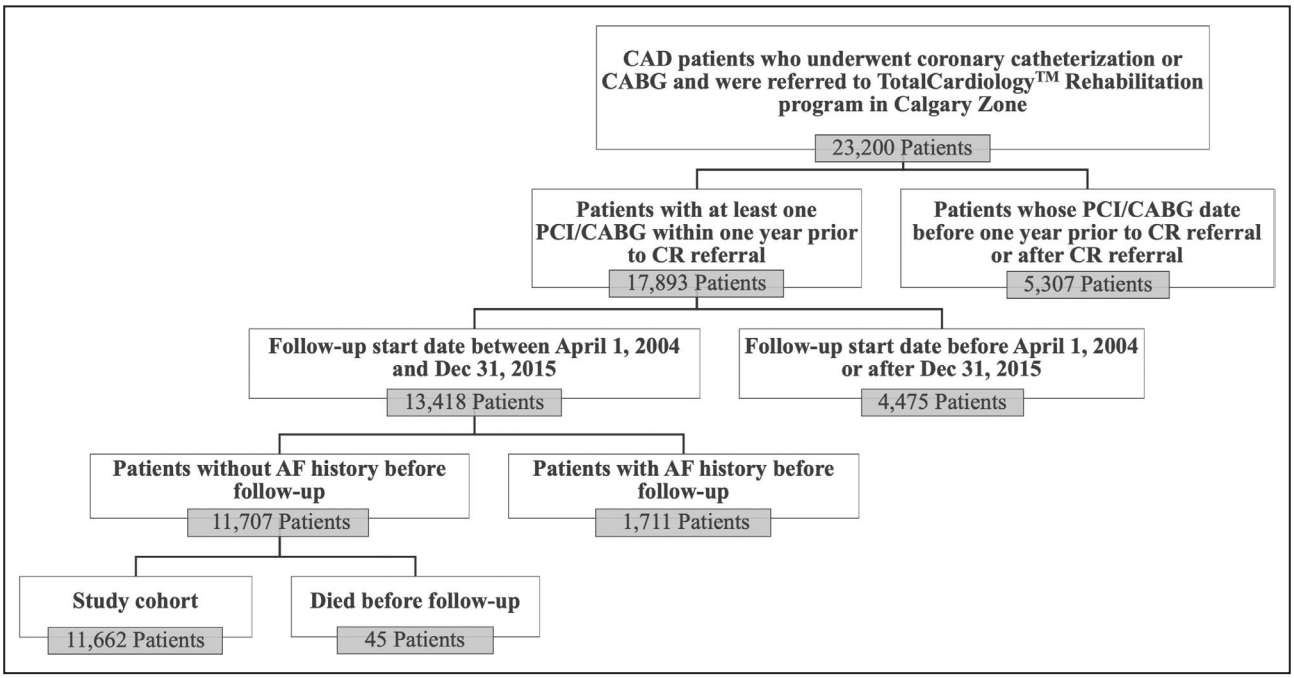

Figure. Study population derivation flowchart.
AF indicates atrial fibrillation; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CR, cardiac rehabilitation; and PCI, percutaneous coronary intervention.

Table 3. Incidence of Incident AF/AFL Identified With Different Algorithms

AF/AFL Identification Algorithms	Exclusion of Potentially Transient AF/AFL Episodes	AF Patients, n (%)	AF Patients Identified by ECG Alone, n (%)
1 Hospitalization or 1 ED or 1 PC	None	784 (6.7)	59 (7.5)
1 Hospitalization or 1 ED or 1 PC or 1 ECG		843 (7.2)	
1 Hospitalization or 1 ED or 2 PCs (2 PCs between 30 and 365 d)		556 (4.8)	77 (13.8)
1 Hospitalization or 1 ED or 2 PCs or 1 ECG (2 PCs between 30 and 365 d)		633 (5.4)	
1 Hospitalization or 1 ED or 1 PC	All episodes during hospitalization for cardiac surgery	757 (6.5)	67 (8.9)
1 Hospitalization or 1 ED or 1 PC or 1 ECG		824 (7.1)	
1 Hospitalization or 1 ED or 2 PCs (2 PCs between 30 and 365 d)		527 (4.5)	85 (16.1)
1 Hospitalization or 1 ED or 2 PCs or 1 ECG (2 PCs between 30 and 365 d)		612 (5.2)	
1 Hospitalization or 1 ED or 1 PC	All episodes during hospitalization for cardiac surgery and classified as postadmit diagnosis	765 (6.6)	65 (8.5)
1 Hospitalization or 1 ED or 1 PC or 1 ECG		830 (7.1)	
1 Hospitalization or 1 ED or 2 PCs (2 PCs between 30 and 365 d)		535 (4.6)	83 (15.5)
1 Hospitalization or 1 ED or 2 PCs or 1 ECG (2 PCs between 30 and 365 d)		618 (5.3)	

AF indicates atrial fibrillation; AFL, atrial flutter; ED, emergency department visit; and PC, physician claim.

in this study were based on MUSE ECG system, which do not necessarily apply to other vendors' ECG systems because of variance in ECG recording, interpretation, and storage. Third, we did not include data from ambulatory ECG monitoring, and free-text entries and ECG tracings were not considered for the development of MUSE AF/AFL coding definitions. Using artificial intelligence, which could automatically identify AF/AFL through text mining or image recognition, would provide greater opportunities to enhance the diagnostic yield of AF/AFL. These are important issues for future research to establish. Fourth, we acknowledge that having a student participate in ECG overreading can be viewed as a limitation. However, we believe that the risk of error resulting from this choice is minimal, as the student used a simplified classification scheme to adjudicate ECGs, and all ECGs where his coding differed from the expert cardiac electrophysiologist (S.B.W.) were arbitrated by another independent cardiologist (R.J.H.M.), with a final consensus review for any remaining discrepancies. These additional review steps ensured the reliability of our reference standard by ensuring all ECG interpretations are finalized on the basis of expert opinion.

CONCLUSIONS

Routine MUSE ECG interpretation is highly specific and moderately sensitive for identification of AF/AFL. Moreover, adding data from routine ECG interpretation to administrative data-based algorithms can significantly improve diagnostic yield where AF/AFL is an outcome.

ARTICLE INFORMATION

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Disclosures

None.

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