

Original Article

# Development of Acute Myocardial Infarction Mortality and Readmission Models for Public Reporting on Hospital Performance in Canada

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## ABSTRACT

**Background:** Given changes in the care and outcomes of acute myocardial infarction (AMI) patients over the past several decades, we sought to develop prediction models that could be used to generate accurate risk-adjusted mortality and readmission outcomes for hospitals in current practice across Canada.

Acute myocardial infarction (AMI) is one of the most common causes of morbidity and mortality across Canada.<sup>1</sup> Each year, more than 70,000 patients with AMI are admitted to Canadian hospitals.<sup>2</sup> Of these, approximately 5000 patients die within 30 days of hospitalization, and about 10% to 15% are readmitted within 30 days of their initial AMI.<sup>2,3</sup> Outcomes after AMI in Canadian hospitals

## RÉSUMÉ

**Contexte :** Compte tenu des changements apportés au cours des dernières décennies aux soins des patients ayant subi un infarctus aigu du myocarde (IAM) et aux issues d'un tel événement, nous avons voulu élaborer des modèles prédictifs pouvant servir à calculer de façon précise les résultats relatifs à la mortalité et aux réadmissions,

have been publicly reported by the Canadian Institute for Health Information (CIHI) for close to 2 decades to identify hospitals with suboptimal outcomes and assist in creating and monitoring quality improvement efforts.<sup>4-8</sup> Accurately profiling hospital performance regarding patient outcomes depends on selecting appropriate patients for reporting, and implementing accurate risk-adjustment

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**Ethics Statement:** The use of Ontario data in this project was authorized under section 45 of Ontario's Personal Health Information Protection Act, which does not require review by a research ethics board. The use of national data also does not require review by a research ethics board.

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See page 1058 for disclosure information.

**Methods:** A Canadian national expert panel was convened to define appropriate AMI patients for reporting and develop prediction models. Preliminary candidate variable evaluation was conducted using Ontario patients hospitalized with a most responsible diagnosis of AMI from April 1, 2015 to March 31, 2018. National data from the Canadian Institute for Health Information was used to develop AMI prediction models. The main outcomes were 30-day all-cause in-hospital mortality and 30-day urgent all-cause readmission. Discrimination of these models (measured by c-statistics) was compared with that of existing Canadian Institute for Health Information models in the same study cohort.

**Results:** The AMI mortality model was assessed in 54,240 Ontario AMI patients and 153,523 AMI patients across Canada. We observed a 30-day in-hospital mortality rate of 6.3%, and a 30-day all-cause urgent readmission rate of 10.7% in Canada. The final Canadian AMI mortality model included 12 variables and had a c-statistic of 0.834. For readmission, the model had 13 variables and a c-statistic of 0.679. Discrimination of the new AMI models had higher c-statistics compared with existing models (c-statistic 0.814 for mortality; 0.673 for readmission).

**Conclusions:** In this national collaboration, we developed mortality and readmission models that are suitable for profiling performance of hospitals treating AMI patients in Canada.

ajustés selon les risques, pour les hôpitaux dans la pratique actuelle au Canada.

**Méthodologie :** Un groupe national d'experts canadiens a été mis sur pied et a reçu le mandat de définir les critères appropriés applicables aux patients ayant subi un IAM aux fins de déclaration des cas et d'élaborer des modèles prédictifs. L'évaluation préliminaire des variables proposées a été effectuée à partir de patients hospitalisés en Ontario entre le 1<sup>er</sup> avril 2015 et le 31 mars 2018 chez lesquels l'IAM était le diagnostic principal à l'origine de l'hospitalisation. Les données à l'échelle nationale de l'Institut canadien d'information sur la santé (ICIS) ont été utilisées pour élaborer des modèles prédictifs d'IAM. Les deux principales issues évaluées étaient la mortalité hospitalière toutes causes confondues à 30 jours et la réadmission urgente toutes causes confondues à 30 jours. Le pouvoir discriminant de ces modèles (mesuré par la statistique C) a été comparé à celui des modèles existants de l'ICIS dans la même cohorte de l'étude.

**Résultats :** Le modèle de mortalité par IAM a été évalué auprès de patients ayant subi un IAM, dont 54 240 en Ontario et 153 523 dans l'ensemble du Canada. Nous avons observé un taux de mortalité hospitalière à 30 jours de 6,3 % et un taux de réadmission urgente à 30 jours toutes causes confondues de 10,7 % au Canada. Le modèle canadien final de prédiction de la mortalité par IAM était constitué de 12 variables et avait une statistique C de 0,834. Pour la réadmission, le modèle comportait 13 variables et présentait une statistique C de 0,679. Le pouvoir discriminant des nouveaux modèles d'IAM présentait une statistique C supérieure à celle des modèles existants (statistique C de 0,814 pour la mortalité et de 0,673 pour la réadmission).

**Conclusions :** Dans le cadre de cette collaboration nationale, nous avons élaboré des modèles prédictifs de la mortalité et de la réadmission hospitalière qui permettent d'établir un profil des résultats obtenus par les hôpitaux traitant des patients ayant subi un IAM au Canada.

models.<sup>9,10</sup> However, current models are potentially limited, as they were developed almost 2 decades ago.<sup>5,11</sup> Changes in the management and outcomes of AMI patients that have occurred during this time are substantial enough that changes in the relationship of certain clinical characteristics with AMI outcomes may have occurred.<sup>3,12</sup> Also, many exclusion criteria that were applied in prior models are no longer appropriate. For example, AMI patients with a prior history of cancer and human immunodeficiency virus (HIV) were excluded in assessments of readmission rates in Canadian hospitals in previous reports.<sup>4</sup> With more patients with cardiovascular disease living with multiple comorbidities, noncardiovascular conditions are no longer criteria for exclusion from other public reports.<sup>13,14</sup>

Recognizing these gaps in knowledge, we assembled a multidisciplinary panel across Canada with expertise in cardiology, cardiac surgery, epidemiology, biostatistics, and other disciplines. This work was undertaken with involvement by the Canadian Cardiovascular Society (CCS) Quality Reporting Steering Committee and is endorsed by the CCS and included representatives of the CCS affiliate societies. The Canadian Institute for Health Information (CIHI) was a key partner in this initiative, given their role in generating hospital public reports across Canada. Our main objective was to develop

mortality and readmission models for AMI patients that could be used to generate risk-adjusted mortality and readmission outcomes for hospitals in current practice across Canada.

## Methods

### Data sources

Multiple administrative databases in Ontario were used to conduct the preliminary analysis that included (i) the Ontario Discharge Abstract Database from CIHI to capture comorbid conditions and hospitalizations; and (ii) the Registered Persons' Database, which contains mortality information in Ontario after hospital discharge.<sup>15</sup> These datasets were linked using unique encoded identifiers and analyzed at ICES (formerly known as the Institute for Clinical Evaluative Sciences) as in previous studies.<sup>3,15,16</sup> To develop the Canadian models, we used the national Discharge Abstract Database-Hospital Morbidity Database, which includes data from all 10 Canadian provinces and 3 territories that are combined into a single dataset at CIHI. This enabled analysis of the national cohort without the need for pooling of data from each province separately.

## AMI cohorts

The AMI study cohort in Ontario included patients aged 18 years and older, who had a most responsible diagnosis (the condition that is responsible for the greatest length of stay) of AMI from April 1, 2015 to March 31, 2018. The diagnosis of AMI was identified by International Classification of Diseases, 10th revision, Canada (ICD-10-CA) codes I21 and I22. The national study population included patients hospitalized for AMI across Canada from April 1, 2015 to March 1, 2016; from April 1, 2016 to March 1, 2017; and from April 1, 2017 to March 1, 2018. The use of 11 months of data in each fiscal year was due to the need for reporting 30-day outcomes. This practice is consistent with CIHI public reporting methodology. Identification of patients by CIHI was primarily from ICD-10-CA codes I21 and I22. A small number of patients were identified according to the Canadian Coding Standards of AMI traditionally established, using a combination of procedure and diagnostic codes to account for the variations in coding practice across the country (Supplemental Table S1).<sup>4</sup>

## Modified Delphi process

A modified Delphi technique was used to (i) develop inclusion and exclusion criteria of eligible AMI patients for reporting, and (ii) select candidate variables for mortality and readmission models.<sup>17-19</sup> Potential candidate variables for model development were initially assembled based on clinical knowledge and variables used in existing AMI models.<sup>11,13,20-24</sup> We did not consider physiological variables (e.g., heart rate or blood pressure), because they were not available in Canadian administrative databases. We also did not include treatment variables during AMI hospitalization, because the main purpose of public reporting is to identify potential care gaps that lead to outcome differences among hospitals. This list of variables was categorized using ICD-10-CA codes for model development. A similar process was previously used by our group to develop quality and outcome indicators of cardiac care in Canada.<sup>17,18</sup> Our process included several online meetings and a face-to-face meeting for the panel to discuss the potential merits and limitations of each selection, and to reconcile differences.

## Outcomes

For the AMI mortality model, 30-day in-hospital mortality was our main outcome of interest, defined as deaths that occurred during any hospitalizations within 30 days after the index AMI hospitalization. For the readmission model, our main outcome was 30-day urgent readmission, defined as an urgent admission within 30 days following discharge from the index AMI hospitalization.

## Statistical analysis

After obtaining a list of candidate variables for AMI mortality and readmission models from our national panel, preliminary modeling was done using Ontario data to assess the frequency of the candidate variables, examine the association of each candidate variable with our

outcomes, and determine what combination of variables could maximize discrimination abilities of the models.<sup>25,26</sup> We tested for linearity for continuous variables such as age, evaluated correlation of the candidate variables, and calculated the variance inflation factor to test for collinearity. Due to the large number of models tested with the Ontario data, we reported variables that were initially selected. Using the nationwide data, logistic regression models were used to assess the relationship of each candidate predictor variable with our outcomes of interests. In the national model, we used backward variable elimination to select variables that are significantly ( $P < 0.05$ ) associated with the outcomes.<sup>25,26</sup> Discrimination was assessed by calculating the c-statistic, also commonly known as the area under the receiver operating characteristic curve.<sup>25-28</sup> Calibration was assessed qualitatively by plotting the predicted and observed risk across the deciles of predicted risk.<sup>25-28</sup> Multi-collinearity of the variables was assessed using variance inflation factors.

Several additional analyses were performed to enhance the robustness of our results. First, we compared the discrimination ability of the mortality model in Ontario, comparing 30-day in-hospital mortality to 30-day mortality with out-of-hospital deaths. This was done to increase our understanding of the potential discrepancies in Canada's public reporting, because all deaths (in-hospital and out-of-hospital) are typically included as outcomes.<sup>14,23</sup> Second, we also examined the model properties in predicting urgent readmissions vs all readmissions (urgent and non-urgent) in Ontario. Third, we examined the prevalence of candidate comorbidities in Quebec compared with other provinces, because of the difference in how diagnostic codes are categorized. In Quebec, all secondary diagnoses are captured on the hospital discharge summary, which could result in documentation of a higher prevalence of chronic conditions compared to other jurisdictions.<sup>29</sup> Due to these differences, for candidate variables that differed in prevalence in Quebec and other provinces, we examined their association with the main outcomes and created Quebec-specific covariates for variables with a higher prevalence but a lower risk of being an outcome. Finally, we compared the discriminative ability of our developed models against that of models used by the CIHI, using the Ontario data and the national data.<sup>11,30</sup>

The use of Ontario data in this project was authorized under section 45 of Ontario's Personal Health Information Protection Act, which does not require review by a Research Ethics Board. All Ontario analyses were conducted at ICES by using SAS version 9.4 (Cary, NC). The use of national data also does not require review by a Research Ethics Board. All national analyses were conducted at CIHI using SAS Enterprise Guide 7.12 (Cary, NC).

## Results

### Revised AMI inclusion and exclusion criteria

The panel thoroughly reviewed the existing inclusion and exclusion criteria and reaffirmed the exclusion of patients with non-urgent hospitalizations. Due to frequent transfers of

AMI patients between Canadian hospitals, the panel also recommended that hospital records be linked to create a single episode of care for reporting. Additionally, the panel recommended patients be excluded who had in-hospital stays of less than 24 hours (or 1 day) or medical assistance in dying during hospitalization, who were previously included. For mortality outcomes, they reaffirmed that only the first AMI episode during the reporting year was to be considered.

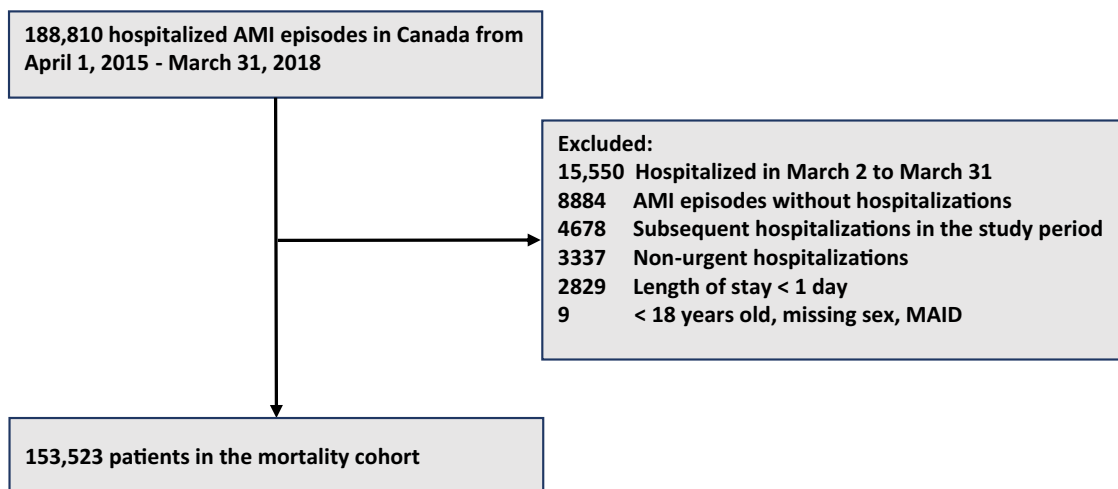
Based on the panel recommendation, those with previously excluded conditions (HIV, cancer, and trauma) and those who left the hospital against medical advice are now considered as candidates in the evaluation of AMI readmissions. In addition, although prior reports included all AMI hospitalizations for readmission reporting, we have categorized the first AMI admission as the index case, and the second as an outcome, if a patient was admitted with

2 AMI episodes within 30 days. This approach was needed so that we would not count 2 hospitalizations within 30 days as 2 index events. After 30 days from the index AMI hospitalization, another AMI hospitalization could be considered as an index hospitalization.

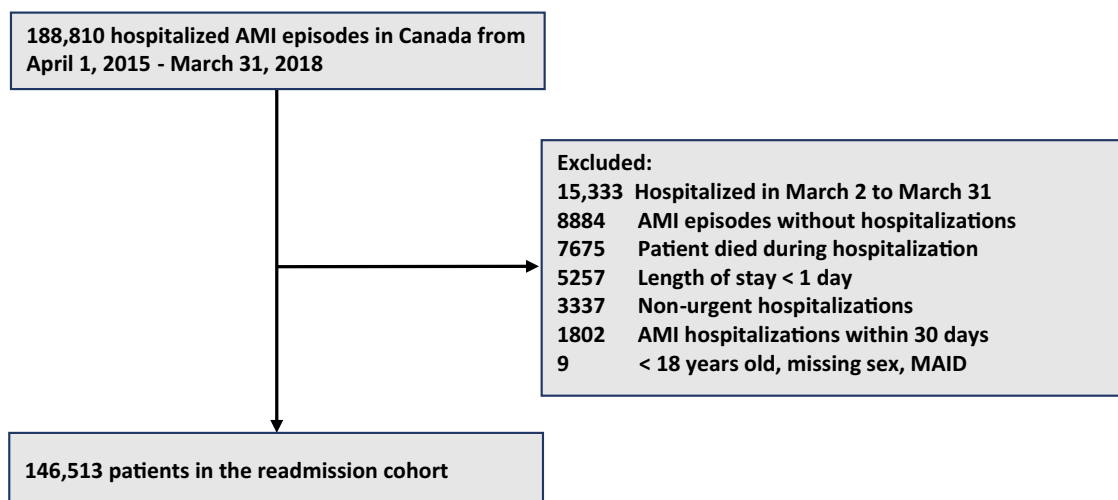
### AMI mortality model

The construction of the Ontario AMI mortality cohort is detailed in [Supplemental Figure S1](#). There were 76,222 patients hospitalized with a main diagnosis of AMI in Ontario from April 1, 2015 to March 31, 2018. After applying the exclusion criteria, 54,240 were included with a mean age of 68.3 years, and 66% were men. The 30-day in-hospital mortality rate was 6.1%, and the 30-day mortality rate including all deaths within 30 days was 6.7%. The association of the

## A Canada cohort for AMI mortality model



## B Canada cohort for AMI readmission model



**Figure 1.** Construction of the acute myocardial infarction (AMI) cohorts for mortality and readmission model development in Canada. (A) A total of 153,523 patients were included for Canada AMI mortality model development. (B) A total of 146,513 patients were included for Canada AMI readmission model development. MAID, medical assistance in dying.



**Table 1. Characteristics of the variables selected in the Canada AMI mortality model and their association with 30-day in-hospital mortality in multivariate logistic regression analysis**

Characteristic	Frequency, %	Coefficient estimate	Odds ratio	95% CI
<b>Demographics</b>				
Age, y				
18-44	3.7	Ref	Ref	Ref
45-64	36.8	0.5061	1.66	1.28-2.16
65-74	25.2	1.2687	3.56	2.74-4.61
75-84	20.5	1.9736	7.20	5.55-9.32
≥ 85	13.8	2.7611	15.82	12.21-20.50
Men	66.6	-0.1147	0.89	0.85-0.93
<b>Clinical presentation</b>				
Cardiac arrest	1.4	2.2928	9.90	8.84-11.09
STEMI	9.9	0.1566	1.17	1.08-1.27
Shock	2.2	2.7178	15.15	13.95-16.45
<b>Prior comorbidities*</b>				
Diabetes	32.1	-0.0798	0.92	0.87-0.98
Heart failure	11.6	0.1065	1.11	1.02-1.21
Quebec	16.9	0.2325	1.26	1.14-1.39
Cancer	0.7	0.6612	1.94	1.59-2.37
Quebec	4.7	0.2221	1.25	1.07-1.47
Cerebrovascular disease	0.5	1.0815	2.95	2.34-3.73
Quebec	3.5	0.1794	1.20	0.99-1.44
Renal failure	5.9	0.7402	2.10	1.95-2.26
Quebec	21.5	0.3574	1.43	1.31-1.56
Pneumonia	2.8	0.6409	1.90	1.74-2.07
<b>Modified Charlson score†</b>				
0	60.9	Ref	Ref	Ref
1	32.0	0.4001	1.49	1.40-1.59
2	7.1	0.7826	2.19	1.96-2.45

AMI, acute myocardial infarction; CI, confidence interval; Ref, reference; STEMI, ST-segment elevation myocardial infarction.

\*Prior comorbidities are defined by pre-admission conditions recorded during the AMI hospitalization.

†Modified Charlson index included congestive heart failure, dementia, chronic pulmonary disease, rheumatologic disease, mild liver disease, diabetes with chronic complications, hemiplegia or paraplegia, renal disease, moderate or severe liver disease, autoimmune deficiency syndrome/human immunodeficiency virus (AIDS/HIV), any malignancy (including lymphoma and leukemia), and metastatic solid tumor.

selected characteristics with 30-day mortality in Ontario is shown in [Supplemental Table S2](#).

In the Canadian cohort, there were 188,810 hospitalized AMI episodes from April 1, 2015 to March 31, 2018. We first excluded AMI episodes that hospitalized in the last month of the fiscal years (15,550), cardiac procedures performed for AMI but without hospitalization (8884), subsequent episodes (4678), non-urgent hospitalizations (3337), length of stay < 1 day (2829), and missing data. After these exclusions, our final cohort included 153,523 patients ([Fig. 1A](#)). The mean age of the included Canadian AMI cohort was 68 years; 66.6% were men; 32.1% had a history of diabetes; 9.9% had an ST-segment elevation myocardial infarction; 2.2% had shock; and 1.4% had cardiac arrest ([Table 1](#)). The 30-day in-hospital mortality rate in the national cohort was 6.3%.

The final Canadian AMI mortality model included age, sex, 3 variables related to clinical presentation (cardiac arrest, ST-segment elevation myocardial infarction, shock),

6 comorbidity variables (diabetes, heart failure, prior cancer, cerebrovascular disease, renal failure, and pneumonia), and the modified Charlson comorbidity score ([Table 1](#)). Among these variables, the highest odds ratios (ORs) associated with 30-day in-hospital mortality were shock (OR 15.15, 95% confidence interval [CI] 13.95-16.45), and cardiac arrest (OR 9.90, 95% CI 8.84- 11.09). The Canadian AMI mortality model had good discrimination ability, with a c-statistic of 0.834. As shown by the expected vs observed risk deciles in [Figure 2A](#), the model was well calibrated.

### AMI readmission model

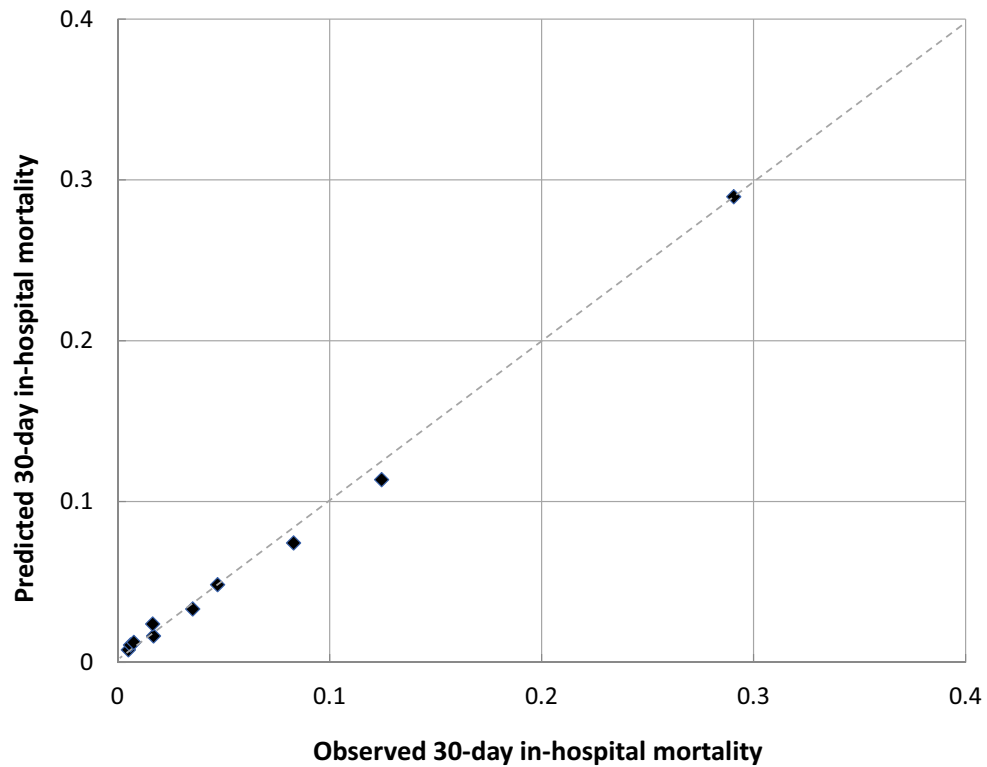
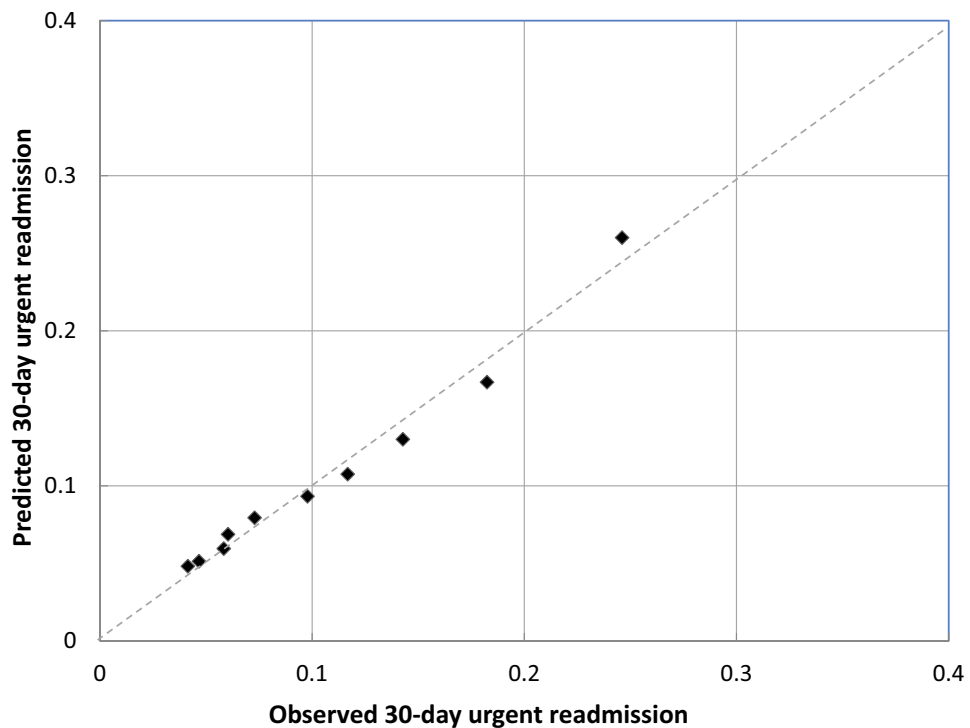
The creation of the Ontario cohort to evaluate AMI readmission models is shown in [Supplemental Figure S2](#). In Ontario, the all-cause readmission rate at 30 days was 12.2%, and among those readmitted, 10.8% had an urgent indication. [Supplemental Table S3](#) shows the characteristics and their associated odds ratios in predicting 30-day readmission.

Across Canada, after inclusion and exclusion criteria were applied, there were 146,513 AMI episodes included for the development of the readmission model. This cohort differed from the mortality cohort, in which we excluded patients who did not survive to hospital discharge (7675 patients) and 1802 patients who were admitted with AMI within 30 days of each other (second episode excluded). The 30-day readmission rate for an urgent indication, across Canada, was 10.7%. For the final readmission model, we selected 2 demographic variables (age, sex), 2 variables related to clinical presentation (ST-segment elevation myocardial infarction, shock), 7 comorbidity variables (diabetes, heart failure, prior cancer, renal failure, chronic obstructive pulmonary disease, dementia, and cardiac arrhythmia), modified Charlson comorbidity score, and having a hospitalization to an acute care hospital within 6 months ([Table 2](#)). Older age group (≥85 years) had the highest odds ratio (OR 2.27, 95% CI 2.01-2.55) in predicting 30-day readmission. None of the other factors had an odds ratio > 2. The national readmission model had a c-statistic at 0.679, and good calibration, as shown in [Figure 2B](#).

### Additional analyses

[Table 3](#) summarizes model discrimination properties of several additional analyses. The revised models had higher discrimination ability for mortality and readmission outcomes compared with the existing models in the Ontario cohort. For 30-day mortality, the c-statistic was 0.807 for the existing model vs 0.843 for the new model; the c-statistic for 30-day readmission was 0.597 in the existing model vs 0.638 for the new model. The revised models also had greater ability to discriminate in the Canadian data population for 30-day in-hospital mortality (c-statistic 0.814 [existing] vs 0.834 [new]) and 30-day urgent readmission (c-statistic 0.673 [existing] vs 0.679 [new]).

In Ontario, although 30-day in-hospital mortality captured slightly fewer events (0.6%) than it would have if out-of-hospital deaths were included, the model performance was similar for models using either outcome, with c-statistics of 0.856 and 0.843, respectively. For

**A** Canadian AMI mortality model**B** Canadian AMI readmission model

**Figure 2.** Predicted and observed outcome for the Canadian acute myocardial infarction (AMI) mortality and readmission models, by decile of risk. (A) Predicted vs observed rate of events is shown for 30-day in-hospital mortality in the Canada AMI mortality model. (B) Predicted vs observed rate of events is shown for 30-day urgent readmission in the Canada AMI readmission model.

**Table 2. Characteristics of variables selected in the Canada AMI readmission model and their association with 30-day urgent readmission in multivariate logistic regression analysis**

Characteristic	Frequency, %	Coefficient estimate	Odds ratio	95% CI
<b>Demographics</b>				
Age, y				
18-44	3.8	Ref	Ref	Ref
45-64	38.1	0.0307	1.03	0.92-1.16
65-74	25.6	0.3269	1.39	1.24-1.56
75-84	20.0	0.5633	1.76	1.57-1.97
≥ 85	12.4	0.8182	2.27	2.01-2.55
Men	67.2	-0.1567	0.86	0.83-0.89
<b>Clinical presentation</b>				
STEMI	9.7	-0.0931	0.91	0.85-0.97
Shock	1.1	0.3635	1.44	1.26-1.65
<b>Prior comorbidities*</b>				
Diabetes	32.1	0.1304	1.14	1.09-1.20
Heart failure	11.7	0.1475	1.16	1.09-1.23
Cancer	1.5	0.1162	1.12	1.0-1.26
Renal failure	8.5	0.3362	1.40	1.33-1.47
COPD	5.2	0.1727	1.19	1.11-1.27
Dementia	1.5	-0.2329	0.79	0.70-0.89
Cardiac arrhythmia	10.4	0.1638	1.18	1.12-1.24
<b>Modified Charlson score<sup>†</sup></b>				
0	61.2	Ref	Ref	Ref
1	31.9	0.2923	1.34	1.27-1.41
2	6.9	0.5589	1.75	1.59-1.92
Any hospitalization in the past 6 months	12.9	0.6582	1.93	1.85-2.01

AMI, acute myocardial infarction; CI, confidence interval; COPD, chronic obstructive pulmonary disease; Ref, reference; STEMI, ST-segment elevation myocardial infarction.

\*Prior comorbidities are defined by pre-admission conditions recorded during the AMI hospitalization.

<sup>†</sup>Modified Charlson index included congestive heart failure, dementia, chronic pulmonary disease, rheumatologic disease, mild liver disease, diabetes with chronic complications, hemiplegia or paraplegia, renal disease, moderate or severe liver disease, autoimmune deficiency syndrome/human immunodeficiency virus (AIDS/HIV), any malignancy (including lymphoma and leukemia), and metastatic solid tumor.

readmission, using urgent readmission as an outcome was associated with slightly higher c-statistics (0.638 for 30-day all readmission vs 0.662 for 30-day urgent readmission).

## Discussion

Profiling hospital performance based on patient outcomes is dependent on having robust adjustment methodologies to account for patient characteristics and clinical profiles to enable fair comparisons across hospitals. Despite their importance, there has been little coordinated effort to ensure that they are updated and valid. In this study, we undertook a Canada-wide collaborative effort and included members from cardiovascular organizations and CIHI to redevelop mortality and readmission models for AMI patients hospitalized across Canada. Extensive analyses were conducted utilizing both provincial and national data. The revised Canada AMI models were found to have good discrimination and good calibration and to be suitable to generate risk-adjusted hospital outcomes in contemporary practice. Our approach of risk prediction

**Table 3. Summary of the discrimination performance of existing and revised AMI models**

Models and variables	Number of events/ number of patients (event rate, %)	C-statistic (AUC)
<b>Mortality models</b>		
Ontario cohort		
Existing CIHI variables to predict 30-day mortality (in-hospital and out-of-hospital)*	3624/54,240 (6.7)	0.807
Revised variables to predict 30-day mortality (in-hospital and out-of-hospital)		0.843
Revised variables to predict 30-day in-hospital mortality	3303/54,240 (6.1)	0.856
Canada cohort		
Existing CIHI model to predict 30-day in-hospital mortality*	9685/153,523 (6.3)	0.814
New Canadian mortality model to predict 30-day in-hospital mortality		0.834
<b>Readmission models</b>		
Ontario cohort		
Existing CIHI variables to predict 30-day readmission <sup>†</sup>	6563/53,917 (12.2)	0.597
Revised variables to predict 30-day readmission		0.638
Revised variables to predict 30-day urgent readmission	5828/53,917 (10.8)	0.662
Canada cohort		
Existing CIHI model to predict 30-day urgent readmission*	15,673/146,513 (10.7)	0.673
New Canadian 30-day readmission model to predict 30-day urgent readmission		0.679

AMI, acute myocardial infarction; AUC, area under the receiver operating characteristic curve; CIHI, Canadian Institute for Health Information.

\*Variables in the existing CIHI AMI mortality model included age, sex, and 9 additional clinical variables (diabetes with complications, cancer, cerebrovascular disease, heart failure, pulmonary edema, acute renal failure, chronic renal failure, and shock).

<sup>†</sup>Variables in the existing CIHI AMI readmission model included age, sex, chronic obstructive pulmonary disease, renal failure, diabetes with complications, heart failure, and acute hospitalization in the past 6 months.

development should be considered for adoption in other areas of medicine and surgery.

Discrimination of a prediction model indicates how well it can separate those who do vs do not have an outcome of interest.<sup>28</sup> Using c-statistics as a measure of discrimination, our Canadian AMI mortality model to predict 30-days in-hospital mortality had a c-statistic of 0.834, which represented an improvement compared with existing AMI mortality models used for public reporting, which had a c-statistic of 0.814.<sup>11</sup> Improvement in discrimination was consistently seen in the Ontario data and the national data. In the United States, risk-adjustment of AMI mortality is primarily based on the Medicare models, for which the c-statistic is 0.71 for predicting 30-day mortality in AMI patients older than 65 years.<sup>23</sup>

Hospital readmission is a topic of intense research because these episodes are frequent, costly, and associated with worse patient outcomes.<sup>31-33</sup> In 2012, the Hospital Readmission Program was initiated in the United States to impose financial penalties on hospitals if rates of 30-day readmission rates of AMI were in excess of the national average.<sup>34,35</sup> This program

was based on the Medicare AMI readmission model that included 31 variables and had a moderate *c*-statistic of 0.63.<sup>13</sup> Despite using fewer variables in our model, we were able to achieve a slightly higher *c*-statistic of 0.679 in our Canadian AMI readmission model. It is important to note that *c*-statistics of readmission models are much lower than those for mortality models in cardiac conditions because it is much harder to accurately predict which patients will be readmitted after an AMI hospitalization. Smith and colleagues performed a systematic review including 15 AMI readmission models and found a median *c*-statistic of 0.65.<sup>24</sup> Only 2 studies in the review achieved higher *c*-statistics of > 0.75, but they were based on smaller cohorts with few readmission events.<sup>24</sup>

In addition to generating statistical prediction models, creating suitable cohorts of AMI patients is also essential for the comparison of outcomes across different hospitals. One notable change in defining the mortality cohort was the exclusion of AMI patients who had a length of stay < 24 hours. This is because short AMI admissions are likely of patients who are investigated for AMI (“rule-out AMI”) rather than those diagnosed with it.<sup>36</sup> Patients who were diagnosed with AMI and died within 24 hours are still included in the mortality cohort. We also made substantial changes to the readmission cohort and expanded the cohort of interest. Previously, patients with a history of HIV, cancer, and trauma were excluded because of significant competing risks of death. Finally, although prior reports included all AMI hospitalizations for readmission reporting, we have now categorized the first AMI admission as the index case and the second as an outcome, if a patient were admitted with 2 AMI episodes within 30 days.

Several limitations of our study merit consideration. First, although it has been shown that models using clinical variables may have higher discrimination ability on an individual level compared with administrative models, we did not include potentially relevant clinical variables in our models (e.g., left ventricular ejection fraction) because they are not available in administrative databases across Canada. However, studies have demonstrated that AMI models based on clinical variables as compared to administrative variables have similar discriminative abilities when used in aggregate at the hospital level.<sup>13,14,23</sup> Second, we had to create variables specific to Quebec because of the differences in how comorbidities were captured in Quebec compared with other provinces. Third, the Canadian data were unable to capture deaths that occurred out of the hospital setting. However, we compared the discrimination using all mortality vs in-hospital mortality as outcomes in the Ontario dataset and found similar ability to predict mortality. Fourth, we were not able to evaluate cardiovascular death as an outcome because this variable was not available across Canada for public reporting. We also were not able to evaluate severity of heart failure or left ventricular ejection fraction in our models because of the lack of data. Also, although prior AMI or unstable angina was predictive of outcomes in the Ontario data, this variable was not included in the final Canadian model because patients who were admitted during the acute hospitalization could be miscoded as having prior AMI in administrative data in some provinces. Finally, we did not use hierarchical modelling to consider clustering of patients who might be readmitted several times in each fiscal year, because of its complexity to implement with data from across Canada.

## Conclusions

We have developed and validated the Canadian AMI mortality and readmission models, which can be used to publicly report the variation among hospitals across Canada. Growing interest in the public reporting of outcomes also should parallel the need to minimize variation in quality of care and optimize outcomes across all hospitals.

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### Supplementary Material

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