Comparison of Cardiac Surgery Mortality Reports Using Administrative Versus Clinical Data Sources

Cedric Manlhiot, PhD; Vivek Rao, MD, PhD; Barry Rubin, MD, PhD; Douglas S. Lee, MD, PhD

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Address Correspondence to: Douglas S. Lee, MD, PhD
Peter Munk Cardiac Centre at University Health Network
Senior Scientist, Institute for Clinical Evaluative Sciences
Associate Professor of Medicine, University of Toronto

From the Peter Munk Cardiac Centre at University Health Network (CM, VR, BR, DSL), Division of Cardiac Surgery (CM, VR), Division of Vascular Surgery (BR), Division of Caridiology (DSL), and the Institute for Clinical Evaluative Sciences (DSL), University of Toronto (CM, VR, BR, DSL).

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ABSTRACT

Background: Quality of care outcomes for coronary artery bypass surgery (CABG) patients are increasingly being reported using either administrative data or clinical registries. However, the impact of data type on accuracy of outcomes reporting has not been fully examined.

Methods: Two different risk adjustment models, from administrative-only (CIHI Cardiac Care Quality Indicator [CCQI]) and clinical data (Society of Thoracic Surgeons [STS]) were tested on cardiac operations from a single centre between 2013-2016 (N=1,635). Primary outcome was in-hospital mortality within 30 days of the operation. Model performance was established by comparing predicted and observed mortality, model calibration and handling of critical covariates.

Results: Observed mortality was 1.96% which was similar to STS predicted mortality (1.96%) but significantly above CCQI predicted mortality (1.03%). Despite both models having similar c-statistics (0.756 CCQI; 0.758 STS), the CCQI model showed significant underestimation of probability of mortality at the higher end of the risk spectrum. There was significant miscalibration of risk associated with seven covariates: NYHA class IV, congestive heart failure, ejection fraction <20%, atrial fibrillation, acute coronary insufficiency, cardiac compromise (shock, myocardial infarction <24 hours, intra-aortic balloon pump, cardiac resuscitation or pre-procedure circulatory support) and creatinine ≥100mg/dL. Together, these factors accounted for 84% of the difference in predicted mortality between CCQI and STS models.

Interpretation: Risk prediction using administrative data underestimated mortality risk, potentially inflating observed to predicted mortality ratios at hospitals with patients who are more ill. Caution is warranted when hospital outcomes reports of CABG surgery are based on administrative data alone.

ABBREVIATIONS

AVR	Aortic valve replacement
CABG	Coronary artery bypass grafting
CCQI	Cardiac Care Quality Indicator
CI	Confidence interval
CIHI	Canadian Institute for Health Information
CL	Confidence limits
NYHA	New York Heart Association
STS	Society of Thoracic Surgeons
UHN	University Health Network

BACKGROUND

Reporting the outcomes of cardiac surgical procedures to hospitals and providers is common practice in many jurisdictions. However, release of cardiac surgical outcomes to the lay public has been debated.[1] One of the important factors to be considered in both private and public release of report cards is the accuracy of risk adjustment, because hospitals may have a different case mix.[2] Specifically some hospitals, such as tertiary or quaternary referral centers, may provide surgery to high risk patients, whereas other centers may have a patient mix that is overall lower risk than the former.[3] In order to level the playing field, risk adjustment models have been utilized to account for the differences in patient acuity.

Reporting of surgical care quality can be performed using administrative claims data or clinical databases. Clinical databases designed to evaluate care quality are costly and require greater effort to collect.[4] While administrative claims data were not originally designed for evaluating surgical quality of care, they are routinely collected and inexpensive.[5,6] Consequently, the reporting of surgical outcomes using administrative data sources has expanded. Furthermore, they have evolved from institutional reporting to public release of their analyses.

Comparisons of administrative and clinical data sources and the risk adjustment methods that are employed using these types of sources have been performed. However, the reasons for the potential differences between administrative and clinical surgical outcomes reports have not been elucidated. In this study, we examined two methods for risk adjustment for cardiac surgical outcomes reports from the Canadian Institute for Health Information (CIHI) and the Society of Thoracic Surgeons (STS). The CIHI Cardiac Care Quality Indicators Report (CCQI) uses an administrative database and covariates that are available in the data. In contrast, the STS risk adjustment model is a clinical model that incorporates may more variables of a clinical nature. In this study, we compared the CIHI and STS models in the same cohort of patients undergoing cardiac surgery at a tertiary-quaternary care hospital. We hypothesized that while there would be similar model discrimination, the CIHI model would not account for patients with high risk characteristics in comparison to clinically-derived models.

METHODS

Patient population and outcomes

All patients undergoing cardiac surgery at UHN during fiscal years 2013-2014 to 2015-2016 (April 1st 2013 to March 1st 2016) were considered for this study. From this patient population, 3 sub-groups of patients were identified based on the patient's primary surgical procedure: 1) isolated CABG, 2) isolated AVR and 3) combined CABG + AVR. All other types of primary operations or operations with any concomitant procedures were excluded. Repeat operations within 30 days of an index operation were also excluded. The complete details of inclusions and exclusion criteria are provided in the CCQI Indicator Library (https://www.cihi.ca/en/indicator-library). The primary outcome for this study was all-cause in-hospital mortality within 30 days of the procedure, as assessed through the Discharge Abstract Database maintained by CIHI. Ethical approval for this study was obtained from the University Health Network Research Ethics Board.

Model for risk adjustments

We compared two risk adjustment models: the STS model based on clinical data and the CIHI model, which is based on administrative data. Both models predict 30-day in-hospital mortality separately for isolated CABG, isolated AVR and combined CABG + AVR procedures. In both models, risk adjustment is done through logistic regression; the inverse logit function is used to derive the probability of outcome from the regression equations. Details of the model derivation for the CIHI model are provided in the CCQI General Methodology Notes and CCQI 2017 Indicators Technical Notes. Details of the derivation and validation of the STS models have previously been published. We used the exact methodologies described in the references listed above by CIHI and the STS to generate the predictions for 30-day in-hospital mortality after cardiac operations. CIHI directly provided the regression coefficients for each of the three risk models that they generated. Data to generate mortality probabilities with the STS methodology were obtained from the prospectively maintained divisional cardiovascular surgery database at UHN. Data to generate mortality probabilities with the CIHI methodology were obtained from our internal administrative data (the same data that is submitted to CIHI as part of mandatory reporting). CIHI directly provided the data for two of the risk factors in their model: previous cardiac surgery within 365 days and previous acute myocardial infarction, also within 365 days, given that these data were not available in the internal administrative data holdings.

Statistical analysis

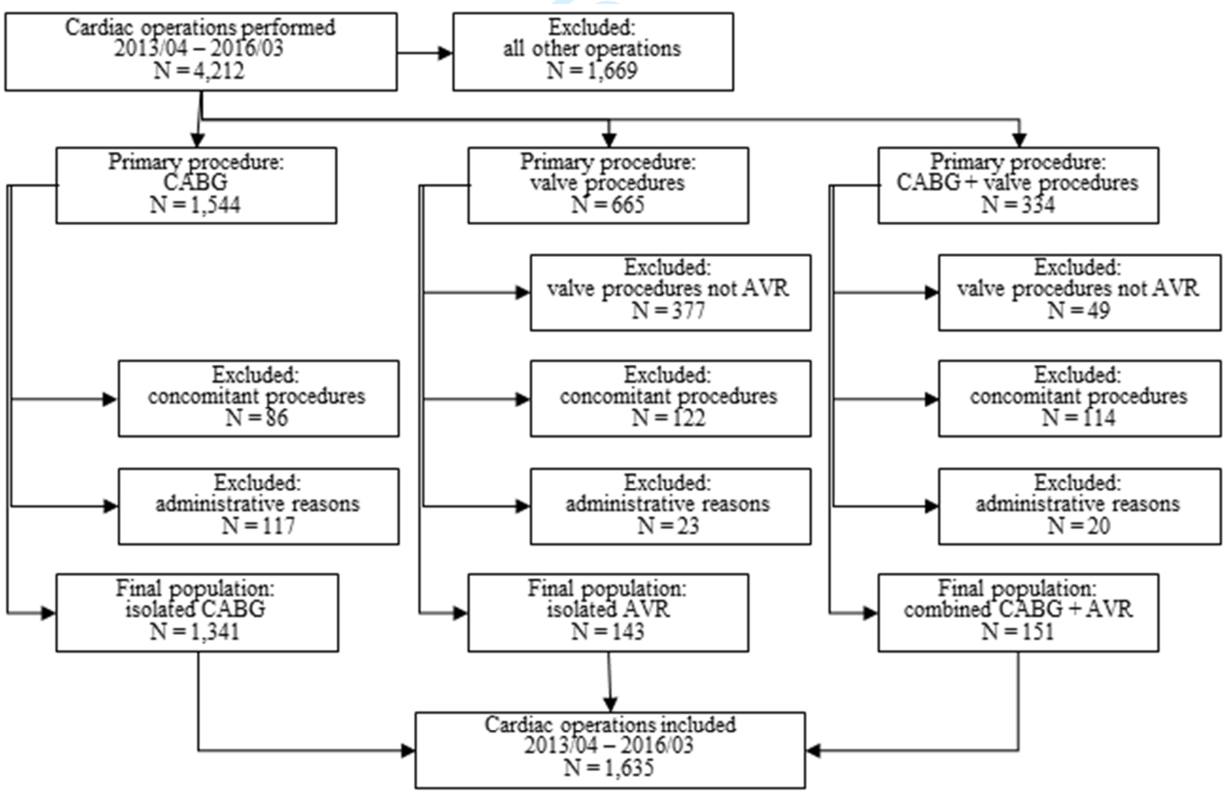
Crude mortality rates were reported as percentages and 95% confidence intervals. Differences between predicted mortality derived from the CIHI and STS risk models and the factors associated with those differences were assessed using linear regression models. To compare model performance, we compared model fit within our study population using c-statistics from logistic regression models, with in-hospital death as the outcome, and standard calibration curves constructed for both models. For both risk adjustment strategies, the observed to predicted ratio was calculated both overall and for various subgroups of patients, in order to assess any imbalance in risk adjustment. Finally, we simulated the change in the predicted number of deaths when recalibrating the CIHI model for various patient characteristics that were found to impact the risk adjustment. In order to accomplish this, we used the STS-estimated effect on mortality to estimate the recalibration coefficient and calculate the effect on predicted mortality in our patient population. All statistical analyses were done using SAS v9.4 (SAS Institute, Cary NC).

RESULTS

Patient population: inclusions and exclusions

During fiscal years 2013-2014 to 2015-2016 (Apr 1 2013 to Mar 31 2016), UHN performed 4,212 cardiac operations, including: 1,544 isolated CABG; 665 valve procedures; 334 combined CABG and valve procedures and 1,669 other cardiac operations. As per CIHI prescribed methodology for this study, patients with valve procedures other than AVR and those with concomitant procedures were excluded from this analysis. Further, a small number of procedures were excluded for administrative reasons such as mismatches in patient identifiers or date of procedures. After exclusions, a total of 1,635 cardiac procedures were left in the current analysis including: 1,341 isolated CABG; 143 isolated AVRs and 151 combined CABG and AVR procedures (**Figure 1**).

Figure 1: Patient population



Comparisons of data elements used in CIHI and STS risk adjustment models

Table 1 compares the data elements that are included in the CIHI and STS risk adjustment models. From this comparison, it is evident that the STS risk adjustment model includes greater amount of data on cardiac function and cardiac pathologies along with patient status immediately prior to the procedure. On the other hand, the CIHI risk adjustment model includes more details on non-cardiac comorbidities than the STS model.

Table 1: Comparisons of data elements in the CIHI vs. STS risk prediction models for 30-day in-hospital mortality after isolated CABG, isolated AVR and combined CABG + AVR.

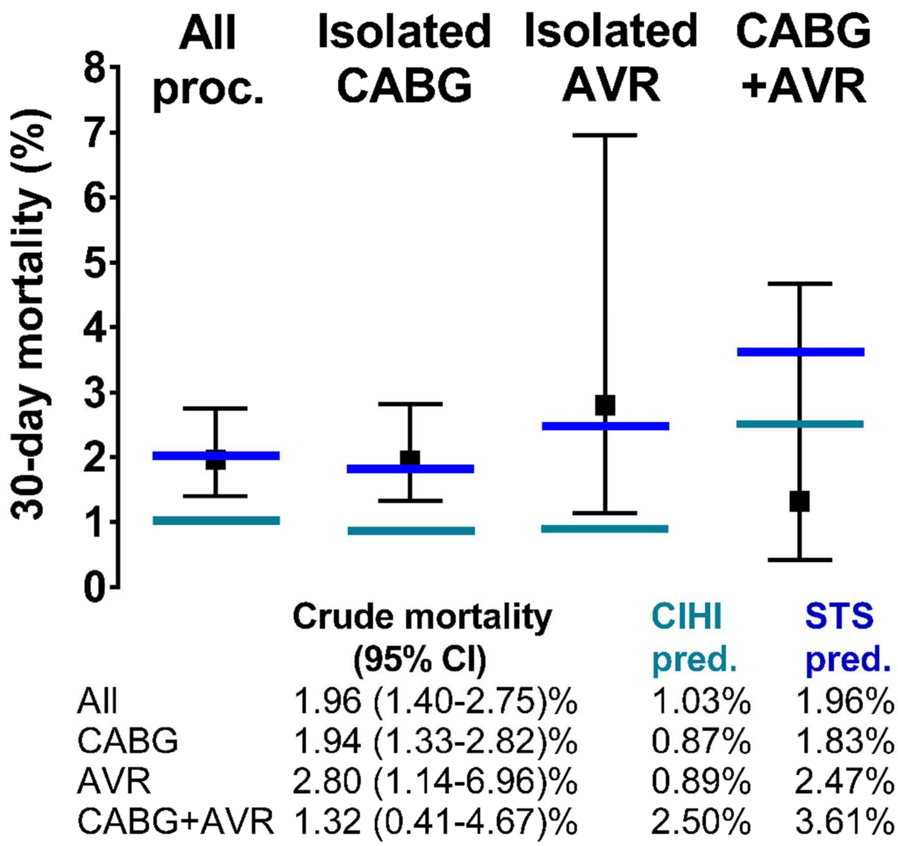
	Isolated CABG		Isolated AVR		CABG + AVR	
	STS	**CIHI**	**STS**	**CIHI**	**STS**	**CIHI**
Patient demographics						
Age	+	+	+	+	+	+
Gender	+	+	+	+	+	+
Medical history						
Previous acute myocardial infarction						
<1 day before procedure	+				+	
1-21 days before procedure	+				+	
>21 days before procedure	+				+	
<365 days before procedure		+				+
Any previous cardiac operations	+		+		+	
Previous cardiac operations within 365 days		+		+		+
Number of previous cardiac operations	+					
Previous cerebrovascular accident	+		+		+	
Cardiac and vascular morbidities						
Acute coronary syndrome	+	+				+
Ejection fraction	+		+		+	
Functional status (NYHA class)	+		+		+	
Left main disease	+		+		+	
Number of disease coronary branches	+		+		+	
Aortic valve stenosis			+			
Cardiac dysrhythmias		+		+		+
Atrial fibrillation	+		+		+	
Cerebrovascular disease	+		+	+	+	
Peripheral vascular disease	+	+				
Endocarditis			+	+		
Hypertension			+			
Non-cardiac comorbidities						
Body surface area	+		+		+	
	Isolated CABG		**Isolated AVR**		**CABG + AVR**	
	STS	**CIHI**	**STS**	**CIHI**	**STS**	**CIHI**

Acute renal failure	+	+	+	+	+	+
Charlson index						
Congestive heart failure	+	+	+	+	+	+
Dementia		+		+		+
Chronic pulmonary disease	+	+	+	+	+	+
Rheumatologic disease		+		+		+
Mild liver disease		+		+		+
Moderate or severe liver disease		+		+		+
Diabetes with organ failure	+	+	+	+	+	+
Hemiplegia or paraplegia		+		+		+
Renal disease	+	+	+	+	+	+
HIV infection		+		+		+
Primary cancer		+		+		+
Metastatic cancer		+		+		+
Procedure						
Elective vs. urgent/emergent admission	+	+	+	+	+	+
Salvage procedure (resuscitation/circulatory support)	+		+		+	
Cardiogenic shock	+	+	+	+	+	+
Intra-aortic balloon pump/inotropic support	+		+		+	
Multiple cardiac interventions in same episode	+	+			+	+

In-hospital mortality – predicted vs. actual

Of the 1,635 patients included in this study, 32 died within 30 days of the operation (crude mortality rate: 1.96%, 95% CI: 1.40-2.75%); comparison of the actual vs. predicted mortality rate for each type of operations is included in **Figure 2**. For all types of operations, crude mortality rates were either at or below STS predicted mortality rates. Conversely, isolated CABG and isolated AVR crude mortality rates were significantly higher than CIHI predicted mortality rates. For combined AVR+CABG operations, crude mortality rates were lower than either CIHI or STS predicted mortality rate, albeit not statistically significant given the small number of events.

Figure 2: Crude mortality rates vs. CIHI and STS predicted mortality rates – Crude mortality rates reported through black squares with 95% confidence interval (black error bars), CIHI predicted mortality is reported through teal bars while STS predicted mortality is reported through blue bars.

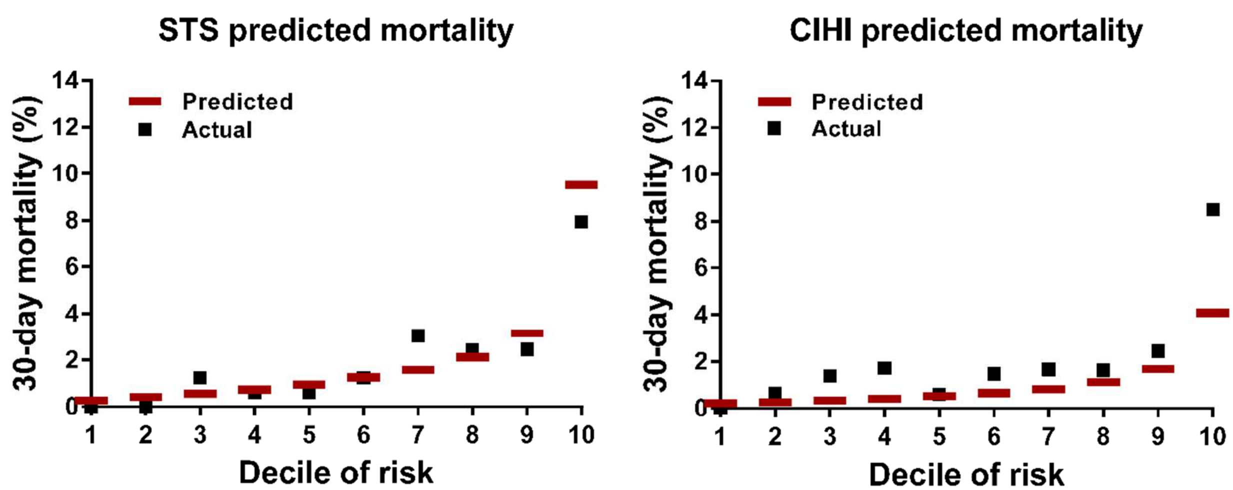


Risk model performance and calibration

Both risk prediction models had virtually identical c-statistics (0.756 for the CIHI risk model vs. 0.758 for the STS model). Despite this, the CIHI predicted mortality was significantly lower than the STS predicted mortality. The average absolute difference (CIHI – STS predicted mortality) was -1.03% (95% CL: -1.19% to -0.86%), p<0.001), and 77.3% of patients had lower predicted mortality in the CIHI vs. the STS risk model. In relative terms, the CIHI risk model underestimated the risk of mortality by an average of 23.7% (95% CL: 19.6% to 27.7%, p<0.001). The underestimation was more pronounced in patients who died within 30 days of surgery (average: -2.47% (95% CL: -5.24% to +2.92%)) vs. those who did not (-

1.00% (95% CL: -1.16% to -0.84%)), which was statistically significant (p=0.01). The underestimation of mortality risk by the CIHI compared to the STS model was more pronounced in patients at higher predicted risk, as evidenced in the calibration plots presented in **Figure 3.**

Figure 3: Calibration plots for the STS and CIHI predicted mortality models - observed vs. predicted mortality, stratified by decile of risk.



Models based on administrative data are not calibrated for high-risk/high-acuity operations

The CIHI risk prediction model, based on administrative data, predicted that out of 1,635 cardiac operations, UHN would record 17 deaths within 30 days of surgery. With 32 reported deaths (26 in isolated CABG, 4 in isolated AVR and 2 in combined CABG+AVR), the observed to predicted ratio using the CIHI risk prediction model was statistically higher than expected, at 1.88. This was in sharp contrast with the STS prediction model, which predicted 34 deaths during the same period (observed to predicted ratio of 0.94, no statistical differences). In order to further explore this discrepancy, we assessed all variables included in the STS risk prediction model, to determine whether any variables were statistically associated with the observed to predicted ratio in either the CIHI or STS model; such an association would suggest an imbalance in risk adjustment. This analysis, presented in **Table 2**, shows that NYHA class IV, congestive heart failure, ejection fraction below 40%, atrial fibrillation, acute coronary insufficiency, cardiac compromise (shock, myocardial infarction within 24 hours, intra-aortic balloon pump, cardiac resuscitation or pre-procedure circulatory support) and creatinine ≥100mg/dL were most strongly associated with an imbalance in the risk adjustment in the CIHI model. Other risk factors including: age, sex, body surface area, hypertension, number of disease coronaries and previous operations, while associated with the risk of mortality in these patients, were not associated with an imbalance in risk adjustment.

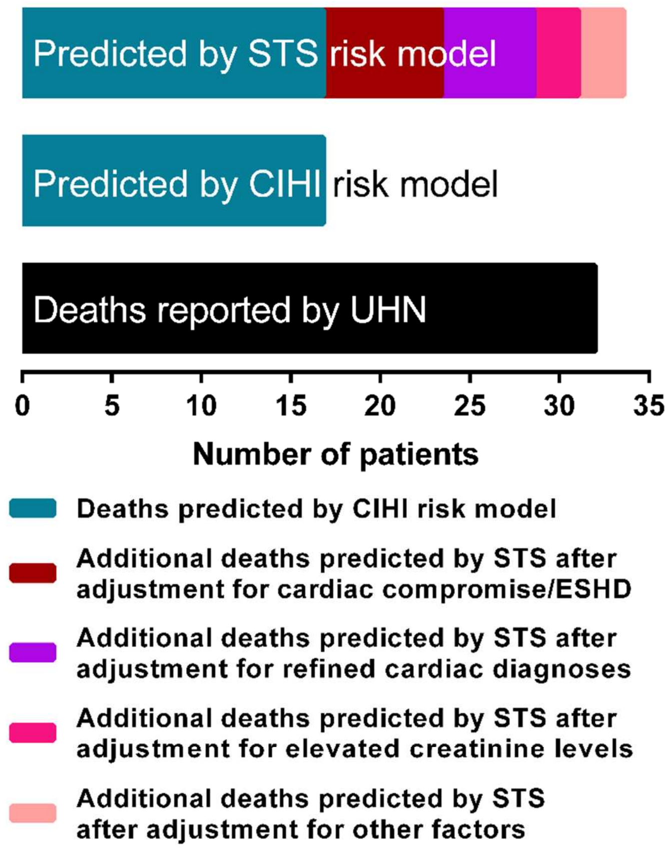
We then merged the seven risk factors identified in **Table 2** that were associated with an imbalance in risk adjustment into three risk groups: 1) cardiac compromise and end stage heart disease (ejection fraction <20% or NYHA class IV), 2) refined cardiac diagnosis (congestive heart failure, atrial fibrillation, acute coronary syndrome or myocardial infarction more than 24 hours but less than one week prior to cardiac surgery, and 3) elevated creatinine level (>100mg/dL). Starting with the number of deaths predicted by the CIHI risk model, we investigated the additional number of deaths that would be predicted if the risk model was recalibrated using the STS predicted mortality for each of these three groups sequentially. These results are presented in **Figure 4;** starting with the 17 deaths predicted by the CIHI risk model an additional 6 deaths were predicted after adjustment for cardiac compromise and end stage heart disease, 5 were predicted after refinement of the cardiac diagnoses, and 3 were predicted after accounting for an elevated creatinine level. This left 3 deaths predicted in the STS model that can only be accounted for by other factors that are not listed above, and that are not included in the CIHI risk model. Overall, 84% of the difference in predicted mortality between CIHI and STS was accounted for by 7 risk factors: NYHA class IV, congestive heart failure, ejection fraction below 20%, atrial fibrillation, acute coronary insufficiency, cardiac compromise (shock, myocardial infarction within 24 hours, intra-aortic balloon pump, cardiac resuscitation or pre-procedure circulatory support) and creatinine ≥100mg/dL.

Table 2: Factors associated with an imbalance in risk adjustment

	Proportion of patients	Observed mortality	CIHI predicted mortality	CIHI ratio observed to predicted	STS predicted mortality	STS ratio observed to predicted
New York Heart Association						
Class I-III	89.4%	1.37%	0.88%	0.64	1.62%	1.18
Class IV	10.6%	6.89%	2.24%	0.33	5.69%	0.83
Congestive heart failure						
No	82.2%	1.41%	0.89%	0.63	1.54%	1.09
Yes	17.8%	4.33%	1.73%	0.40	4.66%	1.08
Ejection fraction						
≥60%	57.2%	1.21%	0.86%	0.71	1.59%	1.31
40-59%	31.4%	2.00%	1.00%	0.50	1.89%	0.95
<40%	11.4%	5.53%	1.76%	0.32	4.77%	0.86
Atrial fibrillation						
No	94.5%	1.74%	0.82%	0.47	1.74%	1.00
Yes	5.5%	5.41%	1.88%	0.35	3.49%	0.65
Acute coronary insufficiency						
No	76.0%	1.20%	0.67%	0.56	1.32%	1.10
Yes	24.0%	4.43%	1.55%	0.35	3.37%	0.76
Cardiac compromise*						
No	96.0%	1.46%	0.94%	0.64	1.73%	1.18
Yes	4.0%	13.85%	2.98%	0.22	9.90%	0.71
Creatinine						
<100 mg/dl	72.4%	1.53%	0.92%	0.60	1.64%	1.07
≥100-149 mg/dl	21.8%	3.30%	1.33%	0.40	2.69%	0.82
≥150 mg/dl	5.8%	4.55%	1.42%	0.31	4.67%	1.03

*Salvage procedure (resuscitation/circulatory support) (2.1%), cardiogenic shock (0.6%), pre-procedure intra-aortic balloon pump (3.2%) or myocardial infarction within 24 hours of procedure (1.0%).

Figure 4: Observed vs. predicted mortality by adjusting risk models for various categories of risk factors not available in administrative data



DISCUSSION

In this study, we compared two different models for risk-adjustment of patients undergoing cardiovascular surgery procedures. These models used an approach to reporting where the predicted mortality rates are based on risk-adjusted rates, and the observed to predicted ratios of mortality are presented. We found that the results emanating from these two different risk adjustment approaches varied considerably. Using data from our institution as a case study, the CIHI-predicted model suggested higher than expected mortality, whereas the STS-predicted model suggested outcomes that were better than expected based on case mix. We found that the reason for the discrepancy between the two methods was the lack of adjustment for important indicators of disease severity that were not available from the CIHI analysis.

Prior studies have suggested that quality reports based on administrative data sources and clinical data sources differed.[7] Some prior studies using different risk adjustment methods have reported that the models employed are important contributors to the discrepancies in quality reports.[2] Others have suggested that the type of data, specifically administrative claims or clinical data sources may be the primary reason for the reported differences.[8-10] In our study, we used clinical data sources to compare the CIHI risk-adjustment model to that of the STS risk-adjustment method, and found that the differences in the models contributed to the opposite directionality of the observed to expected ratios using these two different methods. This difference was present even though the c-statistics of the CIHI and STS risk-adjustment models were comparable. The observation that risk-adjustment model performance can be suboptimal despite comparable c-statistics has been reported previously.[11,12]

Other studies have suggested that the differences between surgical report cards from administrative and clinical data sources were less marked. In a comparison of the EuroSCORE with an administrative data-based report card for CABG mortality, Ugolini found that the latter could perform adequately provided that variables accounting for clinical complexity were included, such as emergency procedures, and provided that hospital data could be linked to multiple episodes of care up to one year prior to surgery.[13] Another study reporting correlations between administrative and clinical report cards examined non-cardiac surgical procedures, but they found that the positive predictive value for identifying outlier hospitals was only 51%, while the negative predictive value was high.[14] Our study findings suggest that in light of the above, the adequacy of risk adjustment for surgical report cards may depend on the type of surgery and that administrative risk adjustment models should be rigorously compared to clinical data sources.

In our study, we found that there was similar overall model discrimination when CIHI was compared to STS models, with similar c-statistics. However, systematic underestimation of predicted risks in those with clinically recognized high risk features occurred in the CIHI model. Specifically, the STS model included factors such as NYHA class IV, congestive heart failure, ejection fraction below 20%, atrial fibrillation, acute coronary insufficiency, cardiac compromise (shock, myocardial infarction within 24 hours, intra-aortic balloon pump, cardiac resuscitation or pre-procedure circulatory support) and creatinine ≥100mg/dL which accounted for much of the difference between the two models. The consequences of omission of the above variables from a risk adjustment are that hospitals with a cohort that has greater abundance of these features would be more likely to have an underestimation of predicted risk. Consequently their observed to predicted ratios would be artefactually increased.

There are implications of our study that are relevant for the developers, recipients and consumers of cardiac surgery report cards. Cardiac surgical report cards should account for predictors of risk that are deemed to be clinically important, and accounting for these factors is important even though the overall model c-statistic is deemed to be acceptable. Indeed, prior studies suggested that relying on the c-statistic alone may not identify the best model for risk adjustment, supporting our assertion that the covariates in the model are also highly important.[11,12] If these high risk indicators are not accounted for, there would be little impact on hospitals that select only the lowest risk cases. However, hospitals with a greater proportion of their cases that are higher risk, such as tertiary referral centers or those that provide mechanical circulatory support would appear to underperform. This could lead to undesired effects where those who have the most potential to benefit from surgical revascularization might not be offered surgery in lieu of lower risk, and potentially healthier patients. There are also wider implications for report cards in a broader sense, particularly as they relate to administrative vs. clinical data sources. Caution is warranted when using administrative databases for inter-institutional comparisons of quality of care. Before administrative databases can be used for such purposes, careful examination of the performance of risk adjustment models, and the accuracy of coding, should be compared with clinical databases that were designed for the evaluation of care quality, to ensure that bias does not impede the validity of the results.

There were some limitations of our study. The analysis was performed only at one center, a quaternary referral center for mechanical therapies and cardiac transplantation. Thus, the analyses that we describe should be verified at other centers. We used a three year time period to perform this study. Given that patient demographics and selection criteria may change with time, the results of this analysis may be different in another time period where the surgical acuity was less severe. In alignment with our findings, if our institution had a lower risk profile during the time period analyzed, we may not have found any significant difference between the CIHI and the STS risk prediction models. The ascertainment of risk factors and comorbidities in the administrative dataset was limited to conditions documented within the index hospital admission for this analysis while the actual CIHI risk adjustment model used risk factors ascertained from all available hospital admissions. As such, our administrative dataset might underestimate the burden of comorbidities and underestimate risk of mortality. Additionally, while the STS risk adjustment models (selected variables and regression coefficients) have been validated in the United-States, it has not been re-validated in the Canadian population and as such may not completely apply to our context. Finally, the study population represents a highly selected subset of patients undergoing cardiac operations; thus the conclusions of this study might not apply for all types of cardiac operations.

In conclusion, despite similar c-statistics, cardiac surgery report cards exhibited different results using an administrative model versus a clinical model. The administrative model underestimated predicted risks in high risk surgical patients, largely because many high risk indicators were not included in the model or such variables were not available in claims data. Risk adjustment using a clinical model that adequately accounted for higher acuity of patients yielded different results, where the predicted risks were well-matched to observed mortality rates. The use of administrative models for quality reporting is cautioned, and should be considered exploratory if there are discrepancies in the results for high risk patients when compared to a clinical database that has been collected and designed for the evaluation of care quality.

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DISCLOSURES

No conflicts to declare.

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