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Original Article

A Frailty Index to Predict Mortality, Resource Utilization and Costs in Patients Undergoing Coronary Artery Bypass Graft Surgery in Ontario

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ABSTRACT

Background: People living with frailty are vulnerable to poor outcomes and incur higher health care costs after coronary artery bypass graft (CABG) surgery. Frailty-defining instruments for population-level research in the CABG setting have not been established. The objectives of the study were to develop a preoperative frailty index for CABG (pFI-C) surgery using Ontario administrative data; assess pFI-C suitability in predicting clinical and economic outcomes; and compare pFI-C predictive capabilities with other indices.

Methods: A retrospective cohort study was conducted using health administrative data of 50,682 CABG patients. The pFI-C comprised 27 frailty-related health deficits. Associations between index scores and

RÉSUMÉ

Contexte : Les personnes dont l'état de santé est fragilisé sont susceptibles de connaître des issues défavorables et de générer des coûts plus élevés pour le système de santé après un pontage aortocoronarien. Aucun instrument n'a été établi pour définir la fragilité dans la recherche populationnelle en contexte de pontage aortocoronarien. Les objectifs de l'étude étaient les suivants : 1) concevoir un indice de fragilité préopératoire en vue d'un pontage aortocoronarien (*preoperative frailty index for CABG surgery*, pFI-C) en utilisant des données administratives de l'Ontario; 2) évaluer la capacité de cet indice à prédire les issues cliniques et économiques; et 3) comparer la valeur prédictive de cet indice avec celle d'autres indices.

Frailty is defined as a state of reduced reserve resulting from the accumulation of age- and illness-related deficits across multiple systems.[1-3] Individuals living with frailty are more vulnerable to unfavourable health events including morbidity, mortality, falls, and disability[4] and are also limited in their ability to regain physiological homeostasis after encountering stressful exposures such as surgery.[5] Although related, comorbidity and frailty are distinct concepts; the former refers to the presence of specific medical, physical, or neuropsychiatric conditions, whereas the latter considers the accumulation of multidimensional deficits, both related to comorbidities and to other similar but distinct dimensions, resulting in vulnerability.[1] Although frailty and comorbidity may overlap, they may also exist independently, resulting in the creation of distinct assessment tools for frailty and comorbidity.[1,6]

Coronary artery bypass graft (CABG) surgery is a common procedure in Ontario, with approximately 8000 of these procedures performed annually. Both age and comorbidity levels of patients having CABG surgery have increased over the past 15 years,[7] underscoring the need to conduct population-level research on predictors of health outcomes and resource utilization among CABG patients. Up to 60% of older adults undergoing cardiac surgery have been identified with frailty,[5] and CABG patients with frailty incur greater direct and indirect health care costs.[8] A recent meta-analysis of studies assessing postcardiac surgery outcomes showed that

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mortality, resource use and health care costs (2022 Canadian dollars [CAD]) were assessed using multivariable regression models. Capabilities of the pFI-C in predicting mortality were evaluated using concordance statistics; goodness of fit of the models was assessed using Akakie Information Criterion.

Results: As assessed by the pFI-C, 22% of the cohort lived with frailty. The pFI-C score was strongly associated with mortality per 10% increase (odds ratio [OR], 3.04; 95% confidence interval [CI], [2.83,3.27]), and was significantly associated with resource utilization and costs. The predictive performances of the pFI-C, Charlson, and Elixhauser indices and Johns Hopkins Aggregated Diagnostic Groups were similar, and mortality models containing the pFI-C had a concordance (C)-statistic of 0.784. Cost models containing the pFI-C showed the best fit.

Conclusions: The pFI-C is predictive of mortality and associated with resource utilization and costs during the year following CABG. This index could aid in identifying a subgroup of high-risk CABG patients who could benefit from targeted perioperative health care interventions.

Méthodologie : Une étude de cohorte rétrospective a été menée à partir de données médico-administratives portant sur 50 682 patients ayant subi un pontage aortocoronarien. Le pFI-C comprenait 27 déficits de santé liés à la fragilité. Des liens entre les scores de l'indice et la mortalité, l'utilisation des ressources et les coûts de soins de santé (en $ CA de 2022) ont été évalués à l'aide de modèles de régression multivariable. La capacité du pFI-C à prédire la mortalité a été évaluée à l'aide de la statistique de concordance; la qualité de l'ajustement des modèles a été évaluée en fonction du critère d'information d'Akaike.

Résultats : Selon l'évaluation par le pFI-C, 22 % de la cohorte vivait avec une fragilité. Le score de l'indice était fortement corrélé à la mortalité par tranche d'augmentation de 10 % (rapport de cotes de 3,04; intervalle de confiance à 95 % de 2,83 à 3,27) et était corrélé de manière significative à l'utilisation des ressources et aux coûts. La valeur prédictive du pFI-C, des indices de Charlson et Elixhauser, et de Johns Hopkins Aggregated Diagnostic Groups était similaire, et les modèles de mortalité contenant le pFI-C affichaient une valeur statistique C de 0,784. Les modèles de coûts contenant le pFI-C affichaient le meilleur ajustement.

Conclusions : Le pFI-C est un facteur prédictif de mortalité et est corrélé à l'utilisation des ressources et aux coûts engagés durant l'année qui suit un pontage aortocoronarien. Cet indice pourrait faciliter la détection d'un sous-groupe de patients subissant un pontage aortocoronarien et présentant un risque élevé qui pourraient bénéficier de soins périopératoires ciblés.

individuals with frailty have 2 times greater risk of perioperative mortality and 1.8 times greater risk of longer hospital stay than patients without frailty.[9] Individuals living with frailty also are more likely to incur higher costs than nonfrail patients[8]; therefore, measures incorporating frailty applied to population-level data may aid in the prediction of resource utilization and costs in the CABG setting.

Frailty status can be measured by clinical assessments using established instruments including the Clinical Frailty Scale, Fried Phenotype, and others.[10–13] However, when investigating the impact of frailty on postsurgical outcomes, prospective clinical data are often unavailable, and thus defining frailty through assessing the accumulation of multiple deficits is most feasible in studies using administrative data.[14] Using population-level data of noncardiac surgery patients, McIsaac et al.[14] created and validated a preoperative frailty index (pFI) of multiple deficits and subsequently applied the index to assess days alive at home after cardiac surgery in patients living with frailty.[15] However, this index was not created using a cardiac surgery population, and some health conditions especially relevant in the cardiac surgery setting, such as ischemic heart disease and valvular heart disease, were not included. Other claims-based frailty indices have been developed using administrative patient data (including the commonly used Hospital Frailty Risk Score [HFRS][16] and the interRAI tool[17]); however, these instruments feature limitations, including poor correlation of the HFRS with clinical frailty assessment[18] and limited availability of interRAI assessments in population-level data for all patients in various surgical and disease contexts. Accordingly, no instrument has become the gold standard for use in population-level research.[19–22] Furthermore, neither the pFI nor commonly used comorbidity indices that incorporate measures of frailty have been investigated in predicting surgical health care costs and hospital-related resource utilization in the cardiac surgery setting.[23] The overall goals of this study are to develop a pFI-C for the CABG surgery setting using Ontario administrative data; to assess the suitability of the pFI-C in predicting mortality, resource utilization, and costs in cardiac surgery; and to compare the predictive capabilities of the pFI-C to other established indices.

Methods

Design and data sources

A retrospective cohort study was conducted using standardized, population-level, routinely collected anonymized administrative databases from the Institute for Clinical Evaluative Sciences (ICES) in Ontario, Canada (https://www.ices.on.ca/). ICES is an independent, nonprofit research institute whose legal status under Ontario's health information privacy law allows it to collect and analyze health care and demographic data, without consent, for health system evaluation and improvement. In Ontario, residents receive publicly funded health care, and essential medical services are covered by the Ontario Health Insurance Plan (OHIP). Approval for this study was granted by Health Sciences and Affiliated Teaching Hospitals Research Ethics Board at Queen's University. The Cardiac Care Network of Ontario (CCN) database was used to identify patients and cardiovascular disease characteristics. An analyst at ICES then applied inclusion/exclusion criteria (discussed here) to these patient data. CCN data were linked deterministically to other ICES databases (Supplemental Table S1). These datasets were linked using unique encoded identifiers and analyzed at ICES.

Study population

This cohort included patients 18 years of age or older who underwent isolated CABG surgery in Ontario hospitals between April 1, 2008, and March 31, 2017. The date of first cardiac surgery was considered the index date, and eligible patients were followed for 1 year postoperatively with respect to mortality, resource utilization, and health-care expenditures (discussed in the following section). A 1-year follow-up period has been previously used to evaluate indices in predicting postoperative mortality[6,14] as well as to evaluate resource utilization and costs in the CABG setting.[24] Patients were included if data were available for sex, age, height, and weight and if patients were eligible for OHIP coverage during the entire study period. A lookback period of 2 years before the index date was considered to obtain patient comorbidity data except for data on chronic pulmonary disease, Parkinson disease, and chronic renal disease, for which lifetime history was obtained. Non-Ontario residents, individuals of unknown residence, and patients whose comorbidity data were unavailable within the lookback periods were excluded (Supplemental Fig. S1).

Development of the pFI for CABG surgery

A list of potential variables (mapped to the concept of multidimensional deficits) were selected a priori, using expert consensus and refined using cohort characteristics (age and deficit prevalence), in accordance with established guidelines by Searle et al.[25] Health deficits were considered for inclusion in the pFI-C based on common conditions in older people, and those especially relevant in the cardiac surgery setting (Supplemental Table S2).[2,26] Potential deficits indicating vulnerability (vs diseases captured in the International Classification of Diseases [ICD] system) included nutritional inadequacy, history of falls, home oxygen use, residence in long-term care, and poor mobility. Also included were certain Aggregated Diagnostic Groups (ADGs) from the Johns Hopkins Adjusted Clinical Groups (ACG) system, which captures all diseases in the ICD system and assigns every disease to 1 of 32 ADGs (broad categories such as "ear nose and throat" and "psychosocial"), in which diseases in each ADG are comparable with regard to disease duration, severity, and etiology.[27] The pFI-C was therefore designed to include multiple conditions that are not reflected in traditional comorbidity indices.[14]

As per guidelines,[25] to be included in the index, deficits must (1) be associated with health; (2) increase in prevalence as age increases; not saturate during early years (eg, presbyopia); (3) and represent a wide range of systems (eg, not all related to cognition).[25] These selection criteria were applied to health deficits identified in the administrative data for our CABG surgery cohort. Specifically, (2) and (3) were evaluated by qualitatively examining plots of cohort age distribution vs deficit prevalence for each candidate variable (plots not shown). Using this approach, we identified a final subset of 27 health deficits for the pFI-C (Table 1).

In the pFI-C, each health deficit was a binary variable (in which 1 represented the presence and 0 the absence of a condition), unless the deficit was included in an ADG. In this case, the deficit was assigned 0 to represent its absence from an ADG and 0.5 or 1 to represent the presence of the deficit in an ADG with minor symptoms or major symptoms, respectively.[14] ADGs incorporated into the index were as follows: dermatologic conditions; ear, nose, and throat conditions; eye disease; and injury. The sum of all health deficits was divided by the total number of deficits in the index to compute a final continuous pFI-C score for each patient. For the purposes of bivariate analysis only, a threshold of 0.2 on the frailty index was chosen a priori to classify patients as having (vs not having) frailty, consistent with thresholds used in other population-level studies.[12,25,28,29] All selection and recording of deficits occurred before the construction of the index and before statistical analyses.

Table 1. Composition of preoperative frailty index modified for coronary artery bypass graft surgery

Health deficits	
Anemia	Heart valve disease
Arrhythmia	Hemiparesis
Cancer malignancy	History of falls
Cerebrovascular disease	Home oxygen
Chronic obstructive pulmonary disease	Hypertension
Congestive heart failure	Incontinence of urine
Chronic pulmonary disease	Injury*
Chronic renal disease	Ischemic heart disease
Decubitus ulcer	Residence in long-term care
Dementia	Poor mobility
Dermatologic*	Parkinson's disease
Diabetes	Peripheral vascular disease
Ear, nose, throat*	Rheumatic disease
Eye disease*	

*Aggregated Diagnostic Groups (ADGs) from the Johns Hopkins Adjusted Clinical Groups (ACG) system, in which diseases in each ADG are comparable with regard to disease duration, severity, and etiology.

Exposure

The main exposure was pFI-C score. In addition, patient scores on established comorbidity indices were determined. Three indices were examined: Charlson and weighted Elixhauser comorbidity indices, and all 32 ADGs (as described earlier). The Charlson index is diagnosis based and has been adapted for use with ICD codes and administrative health records. The index contains 17 morbidities, which are weighted and summed to obtain a patient summary comorbidity score.[23,30] The Elixhauser comorbidity index contains 30 weighted conditions, for which a summary score is calculated.[31,32]

Data from Canadian Institute of Health Information (CIHI)-Discharge Abstract Database (DAD) were used to calculate the Charlson and Elixhauser comorbidity scores, and both OHIP database and CIHI-DAD were used along with the Johns Hopkins ACG case-mix software (version 10) to classify patients according to the 32 ADGs. Covariate data on patient age, sex, neighbourhood income quintile, and procedure urgency were also identified.

Outcomes

Mortality and length of stay during initial hospitalization were documented, as well as mortality in the year after index surgery date. Resources used during 1-year postdischarge included the number of hospitalizations, emergency department visits, outpatient physician visits, home care visits, nursing home admissions, same-day surgeries, laboratory claims, long-term care episodes, as well as number of episodes reported by the Continuing Care Reporting System, National Rehabilitation Reporting System, and Ontario Mental Health Reporting System. One-year postoperative health care costs included those related to physician visits, hospitalizations, emergency department visits, National Ambulatory Care Reporting System (NACRS) dialysis visits, rehabilitation, same-day surgeries, NACRS cancer clinics, complex continuing care, long-term care, inpatient mental health, home care, nonphysician billings, laboratory claims, drugs, and all OHIP fee-for-service visits. Costs associated with short episodes of care (mean duration less than 60 days) were estimated from the National Ambulatory Care Reporting System. Similarly, hospital admission costs were estimated from the CIHI-DAD, using the Resource Intensity Weight (RIW) method. Under this method, each patient is evaluated on their average use of hospital resources (eg, administration and equipment), and assigned a corresponding RIW value.[33] All health care cost data were adjusted for inflation and presented in 2022 CAD based on annual Consumer Price Index (CPI) from Statistics Canada (http://www.statcan.gc.ca).

Statistical analysis

Descriptive statistics were used to present cohort characteristics and health service utilization patterns. The proportion of total health care costs attributed to each category of service was calculated. Analysis of variance (ANOVA), Kruskal-Wallis, and χ^2 tests were performed to examine unadjusted associations between frailty and patient characteristics. Multivariable regression models were used to assess health care expenditures, resource utilization, and mortality of CABG patients. A baseline regression model consisted of 4 variables: age, sex, neighbourhood income quintile, and procedure urgency. Because comorbidities lie on the causal pathway between frailty and patient outcomes,[1,14] clinical characteristics were not included in the baseline regression models to ensure that the incremental value of the frailty index could be assessed. The adjusted regression model included the baseline set of predictors plus each of the 4 comorbidity/frailty indices individually: Charlson, Elixhauser, ADGs, and the pFI-C. All indices were parameterized as linear continuous variables in regression models except for the models containing 32 binary ADGs. Cost per day was transformed using Box-Cox transformation before fitted in a linear model because it was not normally distributed. Count data for resource utilization was modelled with Poisson or negative binomial distributions, depending on the fit. Mortality was modelled using logistic regression. Likelihood ratio test (LRT) was used to determine if including an index significantly improved outcome predictions compared with base case, and Wald test was used to determine index significance in a given model. Akaike information criterion (AIC) was used to compare each comorbidity/frailty index on their modelling of cost and resource utilization, in which a lower AIC indicated better goodness of fit.[34] To determine discriminative performance of each model (ie, if patients with higher mortality had higher risk predictions than patients who had lower mortality), concordance (C)-statistics were used to compare baseline and adjusted models in logistic regressions; C-statistics < 0.7 represented low discriminative performance, 0.7 to 0.8 represented acceptable performance, and > 0.8 represented high performance.[6] Subjects with missing records on criteria of an index were excluded from the analysis of that index only. All statistical analyses were performed on SAS 9.4 Windows edition (SAS, Inc, Cary, North Carolina, USA).

Results

Baseline profile

A total of 50,682 OHIP-eligible patients receiving CABG surgery between 2008 and 2017 were included, with 28% classified as urgent, 30% semiurgent, and 42% elective; 38% of the cohort was older than 70 years of age. Details of baseline demographics of the study population are shown in Table 2.

Frailty, comorbidity and outcomes

The mean pFI-C score was 0.15 (standard deviation [SD]: 0.06), with 11,157 (22.0%) of patients considered as living with frailty (pFI-C > 0.2). Of those with frailty, the mean pFI-C score was 0.24 (SD 0.038), and the maximum score was 0.48. Frailty (pFI-C > 0.2) was significantly higher in female patients (ANOVA P value: < 0.001). The mean Charlson comorbidity score was 1.9 (SD: 1.6), and the mean Elixhauser score was 4.2 (SD: 5.7). The proportion of patients flagged for each ADG is presented in Supplemental Table S3. The mortality rates during initial hospitalization and 1-year postindex surgery were 2.0% and 4.1%, respectively, and 0.2% died on the day of surgery. Female patients had significantly higher mortality than male patients during initial hospitalization (3.2% vs 1.7%, respectively), and 1-year postdischarge (6.2% vs 3.6%, respectively) (χ^2 P value < 0.001 for both time points). The average hospital length of stay between initial surgery and discharge was 8.5 days (SD: 10.4), and 24.7% of patients were readmitted to hospital within 1 year of discharge. The breakdown of postoperative resource utilization is listed in Supplemental Table S4.

The average annual total postoperative cost to the health care system for this cohort was $101,530,000 CAD, and median 1-year cost of postoperative care per patient was $9969 (interquartile range [IQR]: $6806-$19,442). Median costs incurred by those living with frailty were significantly higher than those without frailty ($17,313 vs $9,018, respectively) (Kruskal-Wallis test P value < 0.0001). Inpatient hospitalization costs, including index hospitalization and subsequent readmissions, comprised the greatest proportion of total costs incurred by CABG patients, followed by the summed cost of all OHIP fee-for-service visits (Fig. 1; see Supplemental Table S5 for per patient costs).

Predictive performance of the pFI-C

The pFI-C score significantly improved predictions of mortality, resource utilization, and costs compared with the baseline set of predictors (LRT, $P = < 0.001$). Baseline models showed acceptable discriminative performance for mortality assessed during initial stay and 1-year postindex surgery (C-statistic: 0.756 and 0.719, respectively); incorporating the pFI-C into models improved discrimination for

Table 2. Baseline demographics of 50,682 coronary artery bypass graft patients in Ontario from 2008 to 2017, separated by frailty status*

	Nonfrail	Frail
Baseline variable	Percentage	Percentage
Age at index		
18-49	7.1	1.6
50-59	23.6	9.4
60-69	37.4	30.0
70-79	25.8	43.7
80-89	6.1	15.1
$\geq$ 90	0.1	0.2
Sex		
Male	81.1	72.4
Neighbourhood income quintile		
1	18.7	21.4
2	20.1	21.5
3	20.4	20.1
4	20.9	19.1
5	19.9	17.9
Number of coronary bypass grafts		
1	4.2	6.6
2	16.8	18.5
3	42.0	43.3
4	27.3	24.2
5	7.5	5.5
$\geq$ 6	2.2	1.9
Procedure urgency		
Urgent	25.6	36.6
Semiurgent	30.4	28.8
Elective	44.0	34.6
Mortality		
Inpatient	1.1	5.2
One-year postindex surgery	2.3	10.3
Baseline variable	Mean (SD)	Mean (SD)
Creatinine concentration (μmol/L)	92.8 (56.2)	122.4 (121.7)
Height (cm)	170.2 (9.6)	168.8 (9.8)
Weight (kg)†	83.1 (17.4)	83.1 (18.8)
Body mass index (kg.cm^{-2})	28.6 (5.4)	29.1 (6.0)
Charlson index score	1.5 (1.3)	3.2 (1.8)
Elixhauser index score	2.7 (4.4)	9.4 (6.8)
Initial length of stay (days)	7.1 (6.9)	13.5 (17.3)
ED visits	1.08 (1.9)	1.8 (2.7)
Total readmissions	0.3 (0.7)	0.7 (1.2)
Median (IQR) 1-year postoperative costs (2022 CAD)	9018 (6451-15,586)	17,313 (9616-37,327)

Note: P value < 0.001 for all bivariate associations from ANOVA, χ^2, or Kruskal-Wallis tests.

ANOVA, analysis of variance; ED, emergency department; IQR, interquartile range; SD, standard deviation.

* pFI-C score > 0.2 indicated frailty.

† P value > 0.05.

inpatient and 1-year mortality (C-statistic: 0.815 and 0.784, respectively) (Table 3, Supplemental Fig. S2 for receiver operating characteristic curves). A 0.1-unit increase in pFI-C score produced an odds ratio of 2.92 (95% confidence interval [CI], 2.64,3.23) and 3.04 (95% CI, 2.83,3.27) for death during initial hospitalization and 1-year postindex surgery, respectively. The pFI-C score was also significantly associated with length of stay during initial hospitalization, postoperative emergency department admissions, readmissions, and postoperative costs (Wald test, $P < 0.0001$ for all outcomes). Models incorporating pFI-C score had better fit than models with only baseline characteristics, as indicated by the lower AIC values for all resource utilization and cost outcomes. Cost models containing the pFI-C showed the best fit compared with those containing comorbidity indices (Table 4).

Predictive performance of established indices

Incorporating the Elixhauser index in regression models resulted in high discriminative performance for mortality during initial hospitalization and 1-year post-discharge (C-statistic 0.846 and 0.804, respectively) (Table 3). Each comorbidity index was significantly associated with initial hospital length of stay, emergency department admissions, total readmissions and health care costs (Wald test, $P < 0.0001$ for all indices and outcomes). All indices showed similar performance when modelling resource utilization and costs (Table 4). Models with ADGs showed marginally better fit when modelling initial hospital length of stay and emergency department admissions than other indices. The Charlson index, when used in models predicting number of readmissions, showed marginally better fit compared with other models.

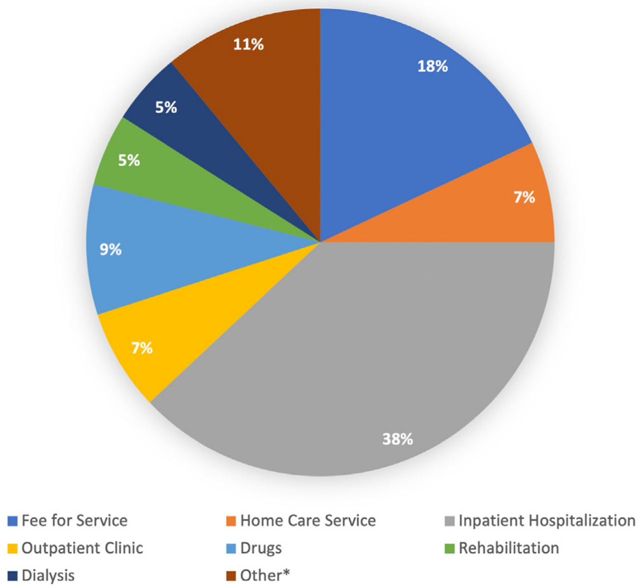

Figure 1. Proportion of total 1-year postoperative cost of Ontario coronary artery bypass graft (CABG) patients by service category. *Other cost categories shown in Supplemental Table S5.

Discussion

In this population-level cohort study, a pFI-C for CABG surgery was developed. The pFI-C was significantly positively associated with mortality during initial hospitalization, 1-year mortality, length of stay during initial hospitalization, postoperative emergency department admissions, total readmissions, and postoperative costs. In this cohort, 38% were above 70 years of age, and 79.2% were male, which is representative in age and sex of previous Canadian cardiac surgery data.[35] Incorporating the pFI-C improved mortality prediction compared with baseline characteristics (C-statistic 0.719 for baseline models and 0.784 for models using the pFI-C) and resulted in better model fit for resource use and costs. Cost models containing the pFI-C showed best fit compared with those containing a comorbidity index.

Interpretation

The results of the current study are consistent with previous research demonstrating an association between frailty and adverse postoperative outcomes.[5,9] Clegg et al.[19] used an accumulation of deficits approach to develop an electronic frailty index (eFI) using health record data in the UK, similar to the strategy used in creating the pFI-C. In the current study, all patients, regardless of frailty status, had similar body mass index (BMI) and weight; although unexpected, these results have been observed elsewhere in a cohort of noncardiac surgery patients assessed for frailty using the CFS and modified Fried Index.[10] As with the results of the current study, models predicting mortality with the eFI had acceptable discriminative performance (C-statistic 0.72).[19] The Frailty Defining Diagnosis Indicator (as defined by the Johns Hopkins ACG system) has been applied to administrative data of Ontario cardiac surgery patients,[36] and showed a postoperative mortality hazard ratio (HR) of 1.54 (95% CI, 1.49-1.59). The pFI-C showed a considerably higher 1-year postoperative mortality odds ratio (OR) of 3.04, likely because our continuous index score accounts for variation in levels of frailty, whereas the Frailty Defining Diagnosis Indicator only defines frailty with a binary outcome.[36] In the same study of Ontario patients, the HFRS (a 109-item frailty index) showed a mortality HR of 1.08 (95% CI, 1.08-1.09),[36] which is lower than our results. This discrepancy could be caused by differences in the composition of each index; the HFRS has many more conditions than the pFI-C, any of which could contribute to different results. In noncardiac surgery patients, head-to-head comparisons suggest that the pFI and HFRS provide greater discrimination and net benefit than the ACG indicator.[37] As with our cardiac surgery-specific frailty index, other disease-specific frailty indices in the cancer and trauma settings have been shown to be predictive of poor patient outcomes.[38,39] For example, the Carolina Frailty Index showed 2.36 times greater risk of mortality for cancer patients living with frailty vs those without.[38]

The scoring distribution of the current frailty index is comparable to McIsaac et al.,[14] who reported a median pFI score of 0.17 when the index was applied to a noncardiac surgery population in Ontario from 2002 to 2015. Although the average frailty index score of our cohort is lower, this may be explained by the age distribution differences among cohorts; our cohort included all patients > 18 years of age, whereas McIsaac et al. studied patients > 65 years of age. For modelling 1-year postoperative mortality, the pFI had a C-statistic value of 0.81, which outperforms our frailty index adapted for cardiac surgery.[14] This is likely, in part, because the current study only contained CABG patients, whereas

Table 3. Comparison of indices for predicting mortality rates

Model	Mortality during initial hospitalization C-statistic	Mortality during initial hospitalization OR (95% CI)	Mortality 1 year postsurgery C-statistic	Mortality 1 year postsurgery OR (95% CI)
Baseline*	0.756	—	0.719	—
Baseline + pFI-C†	0.815	2.92 (2.64,3.23)	0.784	3.04 (2.83,3.27)
Baseline + Charlson†	0.820	1.47 (1.42,1.51)	0.795	1.51 (1.48,1.55)
Baseline + Elixhauser†	0.846	1.13 (1.12,1.14)	0.804	1.13 (1.12,1.14)
Baseline + ADGs	0.840	See Supplemental Table S6	0.785	See Supplemental Table S6

Likelihood Ratio Test *P* value < 0.001 for all models with indices.

ADGs, aggregated diagnostic groups; CI, confidence interval; C-statistic, concordance statistic; pFI-C, preoperative frailty index for coronary artery bypass graft surgery; OR, odds ratio.

* Included age, sex, neighbourhood income quintile, and procedure urgency.

† pFI-C assessed per 0.1-unit increase; Charlson and Elixhauser assessed per 1 unit increase.

Table 4. Comparison of Akaike Information Criterion (AIC) for indices modelling resource utilization and costs of CABG patients

Model	AIC* values for each outcome			
	Initial length of stay	ED visits	Readmission	Cost†
Baseline‡	320,489	148,363	78,608	−63,301
Baseline + pFI-C	309,665	146,353	76,557	−70,648
Baseline + Charlson	310,657	146,938	76,541	−70,581
Baseline + Elixhauser	304,904	147,411	76,933	−68,342
Baseline + ADG	304,331	145,660	76,677	−70,373

Likelihood Ratio Test P values < 0.001 for all models.

ADG, aggregated diagnostic group; CABG, coronary artery bypass graft; ED, emergency department; pFI-C: preoperative frailty index for the CABG surgery setting.

* AIC was used (where lowest AIC indicated best model fit) because these outcome data were not binary, and therefore a C-statistic could not be computed.

† Cost models produced negative values because of how AIC is calculated; the log-likelihood of models, multiplied by 2, was consistently less than 2 times the number of model parameters.

‡ Included age, sex, neighbourhood income quintile, and procedure urgency.

McIsaac et al. had a heterogeneous population of patients undergoing various surgeries; thus, with less variance in predictor values, the expected discrimination is lower. In addition, the composition of the frailty index adapted for use in the CABG surgical setting differed from the original pFI, including health conditions especially relevant in the cardiac surgery setting such as ischemic heart disease and valvular heart disease.

The Elixhauser index showed high discriminative performance when modelling mortality; this is expected because the conditions in the Elixhauser index were specifically weighted to predict mortality in hospitalized Ontario patients,[32] whereas the pFI-C was created to identify a clinically relevant subgroup of high-risk CABG patients living with frailty. Although the pFI-C showed best fit when incorporated in cost modes, the fit of all indices contained in models assessing resource utilization and costs were similar. Numerous studies have compared the predictability and model fit of various indices in different populations, and, as in the current study, there is no consensus on which comorbidity index is superior for all outcomes.[6,40,41] Although comorbidity indices evaluated in our study showed high discrimination and model quality, the identification of individuals living with frailty using the pFI-C could be more beneficial for delivering targeted preoperative interventions than identifying patients with high risk predictions based on comorbidity. This is because frail individuals with the same pFI-C score may have more in common (and therefore benefit from similar preoperative treatment) than 2 individuals with similar risk predictions from comorbidity indices (who could be high risk for different reasons and would require distinct preoperative interventions). Future work could compare outcomes in CABG patients receiving targeted preoperative intervention as indicated by the pFI-C vs comorbidity index.

Population-level researchers aiming to build predictive models may wish to choose validated comorbidity indices for mortality and resource utilization outcomes. The pFI-C may be most useful for building predictive cost models and for researchers requiring a tool based in administrative data to identify and account for frailty in CABG surgery populations. To improve the predictive abilities of the pFI-C, future studies could incorporate additional frailty indicators in the index to gain a more thorough assessment of a patient's health status[32] and add weights to each deficit. Further research is needed to validate the pFI-C in other cardiac surgery settings.

Strengths and limitations

This study has several strengths. We developed a 27-item frailty index for CABG patients that produces a simple, easily interpretable score between 0 and 1, in which greater scores above 0.2 indicate increasingly severe levels of frailty. Although some guidelines recommend the inclusion of 30 to 40 deficits in a frailty index,[25] the clinical utility of a 23-item laboratory-based frailty index (FI-LAB) has been demonstrated in studies assessing risk of in-hospital mortality of patients with chronic obstructive pulmonary disease (COPD)[42] and 1-year mortality of hospitalized older adults.[43] Although further studies are required to investigate the feasibility of prospectively collecting pFI-C items for clinical use, its application may be practical and worthwhile; we showed the odds of dying after surgery increased 3-fold per 10% increase in pFI-C score. This could identify patients at the highest risk of postoperative mortality. Further, increasing scores on the pFI-C were positively associated with resource utilization and costs, and therefore the clinical application of our index could help evaluate targeted, preoperative interventions for high-risk patients to militate against poor cardiac surgery outcomes. This is also the first study to develop a frailty index with administrative data from a CABG surgery cohort and the first to compare comorbidity and frailty measures with regard to associations with resource utilization and health care expenditures in a large (> 50,000) cohort of cardiac surgery patients in Ontario. The use of ICES data allowed for the evaluation of the predictive performance of various comorbidity indices while controlling for baseline patient characteristics. Finally, the index was developed following well-established criteria in the literature,[25] ensuring its quality.

Limitations include the retrospective nature of administrative data so that results of the study are correlative and preclude definitive statements about causation. ICES codes, rather than ICD-10 codes, were used to capture diagnoses, which may limit the generalizability of findings to studies conducted outside of Ontario. Other indices relevant to the cardiac surgery setting, such as Euroscore II, were not compared with the pFI-C because of the lack of availability of some of the variables. The construction of the pFI-C also requires the Johns Hopkins ACG system software, which is not free for use. Furthermore, this study focused solely on the derivation of the pFI-C using recommended guidelines[25] and its associations with study outcomes; internal validation was not performed, and variance estimates were not obtained for C-statistics. Regression models containing ADGs may have been predisposed to high AIC values because of the inclusion of 32 predictor variables; however, models incorporating ADGs did not appear to suffer in terms of model fit. Finally, health care systems differ across countries, and the results of this study may not reflect health care costs incurred by cardiac surgery patients outside of Ontario, Canada.

Future directions

At the population level, the pFI-C could aid decision makers in their efforts to allocate resources to the most appropriate settings. This index could also be employed in other studies using administrative data to account for frailty in the assessment of various exposure-outcome relationships in the CABG setting. Further, the pFI-C contains cardiac surgery-specific deficits and could be compared in future studies to more general frailty indices (eg, pFI and Frailty Defining Diagnosis Indicator) or to surgical risk scores (such as Euroscore II and Society of Thoracic Surgeons [STS] score).[44] At the clinical/hospital level, the pFI-C should be studied as to its ability to identify individuals living with frailty who are high risk for adverse postoperative outcomes. Importantly, the pFI-C should also be studied for its clinical utility in evaluating targeted interventions (eg, nutritional programs associated with weight loss or gain; prehabilitation programs/physiotherapy; hormone therapy), which may pre-emptively offset subsequent health care utilization and costs.[45,46]

Conclusions

The pFI-C identified a clinically relevant subgroup of high-risk patients that is significantly associated with 1-year mortality, resource utilization, and costs within 1 year after surgery. This preliminary work using real-world data to ascertain appropriate parameters in a frailty index would also facilitate the study of targeted preoperative and postoperative interventions to reduce costs and complications in patients following CABG surgery.

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Data Availability

The dataset from this study is held securely in coded form at ICES. Although legal data sharing agreements between ICES and data providers (eg, health care organizations and government) prohibit ICES from making the dataset publicly available, access may be granted to those who meet pre-specified criteria for confidential access, available at www.ices.on.ca/DAS (e-mail: das@ices.on.ca). The full dataset creation plan and underlying analytic code are available from the authors upon request, understanding that the computer programs may rely upon coding templates or macros that are unique to ICES and are therefore either inaccessible or may require modification.

Ethics Statement

This research has adhered to the ethical guidelines established by ICES and Queen's University.

Patient Consent

The authors confirm that patient consent is not applicable to this article. ICES is a prescribed entity under Ontario's Personal Health Information Protection Act (PHIPA). Section 45 of PHIPA authorizes ICES to collect personal health information, without consent, for the purpose of analysis or compiling statistical information with respect to the management of, evaluation, or monitoring of, the allocation of resources to, or planning for all or part of the health system.

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Disclosures

The authors have no conflicts of interest to disclose.

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Supplementary Material

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