An age-independent hospital record-based frailty score correlates with adverse outcomes after heart surgery and increased health care costs

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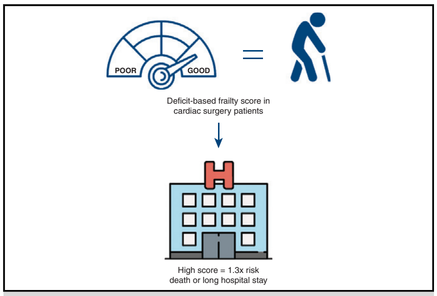
ABSTRACT

Background: Globally, an increasing number of vulnerable or frail patients are undergoing cardiac surgery. However, large-scale frailty data are often limited by the need for time-consuming frailty assessments. This study aimed to (1) create a retrospective registry-based frailty score (FS), (2) determine its effect on outcomes and age, and (3) health care costs.

Methods: Retrospective data were obtained from the New Brunswick Heart Centre registry for all cardiac surgery patients between 2012 and 2017. A 20-point FS was created using available binary risk variables. The primary outcomes of interest most relevant to vulnerable patients were prolonged hospitalization, failure to be discharged home, and hospitalization bed cost. Composite outcome of prolonged hospitalization (>8 days) and/or non-home discharge were analyzed using multivariate analysis.

Results: A total of 3463 patients (mean age, 66 ± 10 years) were included in the final analysis. Tercile-based FSs were: low (0-4; n = 856), medium (5-7; n = 1709), high (≥8; n = 898). In unadjusted data, frail patients were older with more comorbidities. High FS patients had greater risks of prolonged hospitalization (median 7 vs 5 days; $P < .001$), lower home-discharge rates (51% vs 83%; $P < .001$), higher 30-day readmission rates (18% vs 10%; $P < .001$), and increased 30-day mortality rates (≤0.7% [low], >0.7% to ≤1.2% [medium], and >1.2% to 4.8% [high]; $P < .001$). After statistical adjustment, the FS was an independent predictor of composite outcome (odds ratio, 1.3: 95% CI, 1.26-1.35), and increased hospital bed costs.

Conclusions: A registry-based FS can be used to identify vulnerable or frail patients undergoing cardiac surgery and was associated with poor outcomes independent of age. This highlights that although frailty defined by increased vulnerability is often associated with older age, it is not a surrogate for aging, thereby having important implications in reducing health system costs and efforts to provide streamlined care to the most vulnerable. (JTCVS Open 2021;8:491-502)



A retrospective, hospital record-based frailty score for cardiac surgery patients correlates with the outcomes of prolonged stay post surgery and mortality. Increasing frailty in cardiac surgery patients leads to progressively worse outcomes.

CENTRAL MESSAGE

Frailty is not limited to older patients. Registry-based frailty screening can be used to risk-stratify patients regarding outcomes. Pre-cardiac surgery frailty-reducing interventions can thus improve outcomes.

PERSPECTIVE

Assessing frailty retrospectively using existing registry data can be used for cardiac surgery patients to help identify groups of patients (independent of age) who might benefit the most from prehab to reduce frailty (exercise, nutrition, cognitive training, social connection, etc) and improve outcomes including prolonged stay, discharge disposition, and hospitalization costs after cardiac surgery.

See Commentary on page 503.

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The project was jointly funded through a Catalyst Grant by the Canadian Frailty Network and New Brunswick Health Research Foundation, grant CAT 2018-13.

Information on the IMPART Investigator Team Canada is available online (https://impart.team).

Received for publication Dec 10, 2020; accepted for publication Oct 19, 2021; available ahead of print Nov 20, 2021.

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https://doi.org/10.1016/j.xjon.2021.10.018

Abbreviations and Acronyms

EuroSCORE	= European System for Cardiac Operative Risk Evaluation
FS	= frailty score
ICU	= intensive care unit
LOS	= length of stay
NBHC	= New Brunswick Heart Centre
REB	= research ethics board
STS	= Society of Thoracic Surgeons

▶ Video clip is available online.

There is a growing need for more cardiac surgical interventions, particularly for our aging population[1] living with some degree of vulnerability or frailty.[2] Current estimates suggest that >10% of all cardiac surgeries are performed in frail adults and frailty is an independent predictor of use of increased health care resources.[2,3]

The consequences of an increasingly frail population on cardiac surgery outcomes or Canadian health care resources have not been fully examined. In particular, only a limited number of studies have assessed frailty using available cardiac surgery registries.[4,5] This knowledge gap might, in part, be due to ongoing debates on the tools used to assess frailty and whether data registries capture sufficient data on all patients. The current literature suggests that frailty is generally defined using 2 approaches: the Fried phenotypic model (most commonly used) and the Rockwood cumulative deficit model.[6,7] The phenotypic model, developed in the late 1990s, has focused on physical frailty and remains widely known and often thought of when surgeons think of patients being frail. Recent improvements to the phenotypic model have tried to add (eg, multidimensional) other domains like cognitive, emotional factors, and comorbidities in addition to physical frailty to address existing limitations.[8-10] Although debate exists on optimal assessment, widely used frailty measures are often labor-intensive, mostly prospective, require the physical presence of the patient, and cannot be obtained retrospectively. In contrast, a deficit-based electronic frailty score (FS) can be created using clinical and/or laboratory records using retrospective data that are often readily available in standard care,[11] This latter approach, to the best of our knowledge, has not been used in large Canadian cardiac surgical populations.

Frailty can be defined as an accumulation of deficits, and with age, people are more likely to accumulate deficits.[12] Health deficits can be any health variable whose riskier state increases with age and is associated with mortality.[13] When present, the deficit is coded as "1" and as "0" if absent; the sum of deficits yields the final deficit-based frailty risk score.[11] What is unique about this approach is that we provide a rationale for using a simple deficit counting approach in which all deficits are considered equal. This unique approach of quantifying frailty has been well-validated by others and defined as an accumulation of health deficits but not explored in a large cardiac surgical population.[11,12] This approach of counting multiple deficits to obtain a frailty index or an FS has been shown to often be a more sensitive predictor of adverse outcomes than standard measures of frailty as originally proposed by Fried and colleagues.[14] Although awareness of the potential effect of frailty on cardiac surgery has improved in recent years, frailty measurement has not become standard of care or resulted in the specific implementation of strategies to help these patients, particularly in their home transition or length of hospitalization (ie, the know it, use it concept for informed decision-making).[2] Lastly, although frail cardiac surgery patients have been shown to incur greater hospital costs,[15] the incremental relationship between both remains unknown. In the present study, we tested a novel approach to creating a retrospective, hospital registry-derived, deficit-based frailty assessment in patients who had cardiac surgery at the New Brunswick Heart Centre (NBHC) and tried to determine its utility in predicting outcomes and health care costs.

METHODS

Study Population

All patients who underwent cardiac surgery at the NBHC between 2012 and 2017 were included in the study (coronary artery bypass graft, valve, and others using a sternotomy or thoracotomy). Transcatheter aortic valve replacement procedures and emergent surgery (immediate surgery) were excluded from the study. The NBHC is the only tertiary care hospital for cardiovascular diseases in the province of New Brunswick, Canada. Joint research ethics approval was provided by Horizon Health Network research ethics board (REB# 2018-2686, dated December 5, 2018) and the University of New Brunswick (REB# 005-2019). Because the study was retrospective and did not involve direct patient interaction, requirement of informed written consent from the study participants was waived by the REBs. Data were obtained from the NBHC Cardiac Surgery Database, a detailed clinical registry that prospectively collects pre-, intra-, and postoperative data on all cardiac surgery patients in New Brunswick.

Variable Selection and FS

The FS was determined from a previously described deficit-based approach using a data registry.[11] Twenty-one baseline clinical deficits were identified across several domains for creating the FS, including demographic characteristics, clinical condition and comorbidities, cardiac status and risk factors, and medications (Table E1).[16] The sex of patients was defined on the basis of self-report. The variables were converted into a binary score of 0 or 1 on the basis of variable-specific cutoffs and added to determine the initial age-inclusive 21-point FS. Patients were segregated into 3 groups on the basis of FS terciles as low (0-4), medium (5-7) and high (≥8).

The primary outcome of interest was a composite of prolonged hospitalization (>8 days, because the median length of stay [LOS] for all patients at our institution for frail patients was 7 days with an interquartile range of 6-8) and non-home discharge (transfer to another department within Saint John Regional Hospital: other service, to another hospital, other institution), and mortality. Secondary in-hospital outcomes included mortality and complications such as infection, neurologic, and cardiovascular. Outcomes after discharge included hospital readmission and mortality within 30 days of surgery.

Models with and without the variable "age" provided similar findings (data not shown). Therefore, in the final FS and analyses, age was removed to create the 20-point age-excluded FS instead of the initial 21-point FS. This approach was used to better determine outcomes in potentially vulnerable patients, independent of age. The mathematical basis for creating our deficit-based FS has been previously described in which all variables are considered equal, which is different than traditional risk scores like the Society of Thoracic Surgeons (STS) or European System for Cardiac Operative Risk Evaluation (EuroSCORE), which use weighted variables (coefficient from logistic regression).[13]

Cost Estimation

Average costs of hospital beds were provided by NBHC cost estimates (2019). The average cost is approximately $2856 per day in an intensive care unit (ICU) bed and $1293 per day in a general bed. We used the cost of total bed-days (ICU + general) as a measure of the increased cost to the health care system imposed by frailty in cardiac surgery patients using linear regression adjusted for age and sex.

Statistical Analysis

Categorical variables were reported as number of observations and percentages. Continuous variables were summarized with mean and standard deviation for parametric tests; and median and interquartile range for nonparametric tests. Comparisons between the FS terciles were made using χ^2, Fisher exact test, 1-way analysis of variance, and Kruskal–Wallis test, as appropriate. Patient survival was analyzed using Kaplan–Meier survival analysis and compared using Cox regression and log rank test.

The isolated effect of FS on the primary outcome was determined using multivariable logistic regression modeling, adjusted for age and biological sex. The sex-based analysis and data were reported in accordance with the Sex and Gender Equity in Research reporting guidelines.[17] All data analysis was performed using R version 3.6.2 (R Core Foundation) and GraphPad Prism 6 (GraphPad Software Inc).

TABLE 1. Baseline characteristics for all patients (N = 3463) who underwent cardiac surgery between 2012 and 2017 at New Brunswick Heart Centre

Characteristic	Value
Demographic	
Age ≥ 70 y	1359 (39.2)
Mean age ± SD, years	66 ± 10
Female sex	791 (22.8)
BMI ≥35	452 (13.1)
Smoking history	2228 (64.3)
Diabetes	1145 (33.1)
Hypertension	2463 (71.1)
CVD	414 (12.0)
PVD	400 (11.6)
Renal insufficiency	140 (4.0)
COPD	356 (10.3)
Heart function	
LVEF <40%	382 (11.0)
Surgery	
Previous CV surgery	120 (3.5)
Urgent status	1858 (53.7)
Procedure	
CABG	2122 (61.3)
Valve	404 (11.7)
CABG and valve	448 (12.9)
Other with or without CABG and with or without valve	489 (14.1)
Mean CPB time (range), minutes	98 (78-127)
Mean XC time (range), minutes	73 (55-100)
Other	
Atrial fibrillation	497 (14.4)
Dyslipidemia	2547 (73.5)
Recent MI within ≤21 d	971 (28.0)

Data are presented as n (%) except where otherwise noted. *SD*, Standard deviation; *BMI*, body mass index; *CVD*, cardiovascular disease; *PVD*, peripheral vascular disease; *COPD*, chronic obstructive pulmonary disease; *LVEF*, left ventricle ejection fraction; *CV*, cardiovascular; *CABG*, coronary artery bypass graft; *CPB*, cardiopulmonary bypass; *XC*, cross-clamp; *MI*, myocardial infarction.

RESULTS

Comorbidities Significantly Increased With Increasing Frailty Terciles

We assessed data on a total of 3463 patients who underwent cardiac surgery at NBHC (2012-2017) as a 5-year collective evaluation of the potential to define a retrospective FS. In the study population, 39.2% of the patients were aged ≥70 years, 22.8% were female, and 74.7% belonged to New York Heart Association functional classification III-IV (Table 1).

The 21-point FS demonstrated a bell-shaped distribution curve with the median FS of 6 (Figure 1). Male and female sex were present across all FS classifications. No patient had a FS beyond 15. When divided into FS terciles, patients were classified as low (n = 856; 24.7%), medium (n = 1709; 49.4%), and high (n = 898; 25.9%) frailty. At baseline, increasing frailty terciles were associated with increasing age and comorbidities, with those having a higher FS more likely to undergo urgent, combined surgeries, and longer cardiopulmonary bypass and cross-clamp times (Table 2). Sex was not associated with increasing frailty.

Unadjusted Outcomes Significantly Increased Across Frailty Tercile

The percentage of patients with prolonged hospitalization (median LOS, ≥8 days) significantly increased from low to high frailty groups (16.7% vs 52.4%; $P < .001$). Similarly, highly frail patients were less likely to be discharged home, compared with low-frailty patients, with a significant percentage of highly frail patients being discharged to other institutions (7.4% vs 28%; $P < .001$).

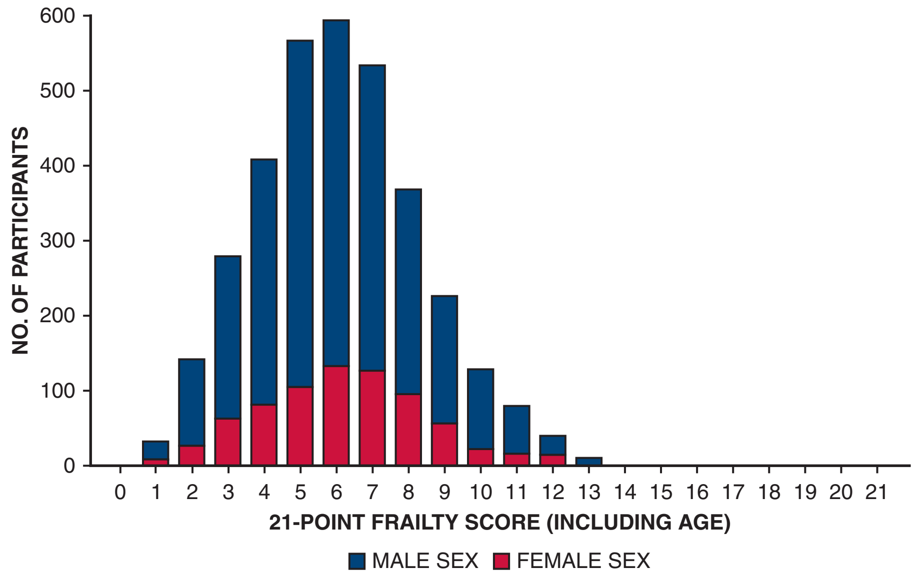


FIGURE 1. Distribution of the patients in the different age-inclusive frailty score (initially developed 21-point frailty score). A histogram was plotted with the number of patients in each frailty score. Male and female sex are shown for each score. Patients showed a bell-shaped distribution with most of the patients having a frailty score of 6. No patient had a frailty score beyond 15.

The overall unadjusted in-hospital mortality for the entire cohort was 1.9%. However, highly frail patients had significantly greater mortality (4.3% vs 0.7%; $P < .001$) and required longer hospitalization (median, 7 days vs 5 days; $P < .001$) compared with low-frailty patients. Similarly, postoperative complications such as infections and delirium were more common in the high frailty group. Frail patients also had a significantly higher incidence of mortality and hospital readmission within 30 days of surgery (Table 3). Because sex was not associated with increasing frailty (Table 2), male and female sex was not disaggregated when we studied outcomes. These data suggest the plausibility for forming a FS independent of age that could address comorbidity-dependent outcomes.

The FS Was Independent of Age

In an effort to validate that this FS and its association with outcomes was not too highly dependent on chronological age on the basis of the traditional view that age is associated with frailty, we calculated a FS in the absence of age. The data similarly showed a significant increase in FS (age-excluded) across the age spectrum (age <60: mean FS, 5.26; age ≥80: mean FS, 6.07; $P < .001$). We then explored this relationship by dividing patients into age groups of <60, 60 to 69, 70 to 89 and >80 years. We were able to show that higher frailty was not exclusive to older patients and could be seen in all age groups as shown in Figure 2. This 20-point scale did not alter the significance of the baseline nor outcome differences of the terciles (data not shown), thus confirming that our FS using a 20-point scale was a reasonable age-independent approach. This final 20-point, age-excluded FS was used for the remainder of the analysis.

Frailty Was Significantly Associated With Composite Outcomes

Because frail patients had a longer LOS at the hospital and had a discharge disposition other than home, we used both of these variables to construct the composite outcome (LOS ≥8 days and discharged home or not home). This composite outcome is most relevant to frail patients reflecting their loss of independence, namely hospitalization. Using a multivariable model to adjust for differences between patients, the FS was shown to be independent associated with the composite outcome (odds ratio, 1.3; 95% CI, 1.27-1.37). Additional independent predictors of the composite outcome were older age (>70 years) and female sex (Table 4).

Frail Patients Incurred Greater Hospital Costs

The total cost of recovery (ICU + general beds) was modeled as a function of frailty, age categories, and sex. Variables associated with longer LOS and non-home discharge were associated with higher costs, female patients on average cost approximately $2105 more, and age >70 years was associated with at least $1880 higher costs. A unit increase in FS was, on average, associated with a $1065 increase in total costs (Table 5). This is split approximately even between ICU bed costs and general bed costs (Table E2).

TABLE 2. Baseline characteristics of patients in the initial age-included frailty score (21-point frailty score; N = 3463)

Characteristic	Frailty score (including age) Low (0-4), n = 856 (24.72%)	Medium (5-7), n = 1709 (49.35%)	High (8-15), n = 898 (25.93%)	*P* value
Demographic				
Age ≥70 y	175 (20.4)	666 (39.0)	518 (57.7)	**<.0001**
Mean age ± SD, years	63 ± 11	66 ± 10	70 ± 9	**<.0001**
Female sex	189 (22.1)	373 (21.8)	229 (25.5)	.09
BMI ≥35	50 (5.8)	223 (13.0)	179 (19.9)	**<.0001**
Smoking history	359 (41.9)	1148 (67.2)	721 (80.3)	**<.0001**
Diabetes	89 (10.4)	521 (30.5)	535 (59.6)	**<.0001**
Hypertension	409 (47.8)	1251 (73.2)	803 (89.4)	**<.0001**
CVD	21 (2.5)	161 (9.4)	232 (25.8)	**<.0001**
PVD	6 (0.7)	143 (8.4)	251 (28.0)	**<.0001**
Renal failure	5 (0.6)	30 (1.8)	105 (11.7)	**<.0001**
COPD	10 (1.2)	135 (7.9)	211 (23.5)	**<.0001**
Heart function				
LVEF <40%	17 (2.0)	139 (8.1)	226 (25.2)	**<.0001**
NYHA class 3-4	339 (39.6)	1382 (80.9)	865 (96.3)	**<.0001**
Surgery				
Previous CV surgery	16 (1.9)	50 (2.9)	54 (6.0)	**<.0001**
Urgent status	168 (19.6)	985 (57.6)	705 (78.5)	**<.0001**
Procedure				
CABG	505 (59.0)	1116 (65.3)	501 (55.8)	**<.0001**
Valve	195 (22.8)	213 (12.5)	81 (9.0)	
CABG and valve	32 (3.7)	178 (10.4)	194 (21.6)	
Other with or without CABG and with or without valve	124 (14.5)	202 (11.8)	122 (13.6)	
Mean CPB time (range), minutes	96 (75-121)	96 (76-122)	106 (82-145)	**<.0001**
Mean XC time (range), minutes	72 (54-96)	72 (54-95)	80 (58-112)	**<.0001**
Other				
Atrial fibrillation	42 (4.9)	195 (11.4)	260 (29.0)	**<.0001**
Dyslipidemia	475 (55.5)	1283 (75.1)	789 (87.9)	**<.0001**
Recent MI within ≤21 d	52 (6.1)	506 (29.6)	413 (46.0)	**<.0001**

Data are presented as n (%) except where otherwise noted. Patients were characterized according to frailty terciles as low, medium, and high. All baseline characteristics (other than female sex) showed a significant increase with increasing frailty. Significant *P* values are shown in bold. *SD*, Standard deviation; *BMI*, body mass index; *CVD*, cardiovascular disease; *PVD*, peripheral vascular disease; *COPD*, chronic obstructive pulmonary disease; *LVEF*, left ventricular ejection fraction; *NYHA*, New York Heart Association; *CV*, cardiovascular; *CABG*, coronary artery bypass graft; *CPB*, cardiopulmonary bypass; *XC*, cross-clamp; *MI*, myocardial infarction.

Frail Patients, Despite Greater Resource Dedication, Had a Significantly Lower Survival Rate

Patients with FS < 8 and LOS < 7 days were compared with patients having FS ≥ 8 and LOS ≥ 7 days. Although many patients had FS < 8 and LOS < 7 days (n = 1971), they incurred lower average hospital bed cost ($8081.70). In contrast, a smaller population of patients with FS ≥ 8 and LOS ≥ 7 (n = 398) incurred more than 2.5 times the average bed cost ($22,106.03). These patients also had a significantly lower survival ($P = .002$) compared with the former group (Figure 3). There was no difference in survival between male and female sex (Figure E1). Taken together, there is a distinct cost difference associated with sex, because of the composite outcome unrelated to survival outcomes. These data indicate the need to address frailty to improve patient outcomes and reduce health costs, with consideration to disaggregating sex in future studies and potential approaches to intervention (Video 1).

DISCUSSION

In the present report, we were able to show that a FS could easily be calculated retrospectively using a deficit-based approach with existing cardiac surgery registry data. This is particularly relevant, because a large registry exists for cardiac surgery patients, but the magnitude of how many patients should be considered vulnerable or frail is not well understood.[3] Hospital record-based frailty has previously been shown to be of immense value for determining vulnerability or frailty in patients retrospectively but yet to be explored in the Canadian population of cardiac surgery patients.[18,19] What is novel in our study is that we were able to validate the usefulness of the FS in showing that 25.9% (898/3463) of our cardiac surgery population could be considered most vulnerable and at greatest risk of adverse events.

We used a previously validated approach in which clinical deficits were used to quantify vulnerability or frailty

TABLE 3. Outcomes in patients with the initial age-included frailty score (21-point frailty score; N = 3463)

Outcome	Frailty score (including age)			*P* value
	Low (0-4), n = 856	Medium (5-7), n = 1709	High (8-15), n = 898	
Primary outcome				
LOS ≥8 d with or without DC not home	147 (16.7)	544 (31.1)	491 (52.4)	**<.0001**
DC disposition				
Home	711 (83.1)	1197 (70.0)	459 (51.1)	**<.0001**
Home EMH	72 (8.4)	201 (11.8)	132 (14.7)	
Other service	4 (0.5)	11 (0.6)	17 (1.9)	
Other institution	63 (7.4)	281 (16.4)	251 (28.0)	
Secondary outcome				
Mortality	6 (0.7)	19 (1.1)	39 (4.3)	**<.0001**
Postoperative LOS	5 (4-6)	5 (5-7)	7 (5-9)	**<.0001**
Infection				
Leg	5 (0.6)	16 (0.9)	29 (3.2)	**<.0001**
Sepsis	3 (0.4)	16 (0.9)	27 (3.0)	**<.0001**
DSW	0 (0.0)	1 (0.1)	7 (0.8)	**.0008**
SSW	9 (1.1)	36 (2.1)	32 (3.6)	**.002**
UT	6 (0.7)	30 (1.8)	26 (2.9)	**.002**
Neurologic				
Delirium	42 (4.9)	148 (8.7)	144 (16.0)	**<.0001**
Permanent stroke	6 (0.7)	20 (1.2)	14 (1.6)	.24
Transient stroke	3 (0.4)	10 (0.6)	6 (0.7)	.66
Cardiovascular				
Perioperative MI	1 (0.1)	5 (0.3)	1 (0.1)	.69
Reoperation for bleeding	11 (1.3)	18 (1.1)	16 (1.8)	.30
Atrial fibrillation (new-onset)	266 (31.1)	599 (35.0)	302 (33.6)	.13
Thirty-day outcome				
Mortality	6 (0.7)	21 (1.2)	43 (4.8)	**<.0001**
Readmission ≤30 d	80 (9.3)	177 (10.4)	136 (15.1)	**.0001**

Data are presented as n (%) except where otherwise noted. Primary outcomes (length of stay, discharge disposition), secondary outcomes (mortality, infection) and 30-day postsurgery outcomes (mortality, readmission within 30 days) significantly increased with increasing frailty. Significant *P* values are shown in bold. *LOS*, Length of stay; *DC*, discharge; *EMH*, extramural homecare; *DSW*, deep sternal wound; *SSW*, superficial sternal wound; *UT*, urinary tract; *MI*, myocardial infarction.

by creating a ratio between the number of deficits and the total number of variables examined.[20] This approach, largely on the basis of work from Rockwood and colleagues, allowed us to focus the developed FS using 20 clinical deficits that were reliably captured in the NBHC registry and on the basis of a previous study.[11] In support of our approach, the distribution of patients' FS appeared to follow a normal distribution similar to previous reports.[13] Furthermore, our findings suggest that frailty does not behave as a dichotomous variable but instead on a spectrum of severity or vulnerability.

Herein we show that the FS generated for each patient was associated with adverse outcomes independent of age using just 20-elements. This also means that we were able to observe patients with a high FS in all age groups, validating the score as expected from previous literature. Our observation reinforces the notion that frailty is not merely reflective of chronological age[21] but encompasses multiple domains.[22]

It is no surprise that patients with a higher FS had an increased risk of complications and adverse outcomes as we were able to show.[4,7,23,24] We sought in the present report to stay away from the traditional view of frailty as "old, immobile, and weak." Frailty is in fact a clinical state of increased vulnerability resulting from aging-associated decline across multiple physiologic systems.[25] This explains why frailty encompasses several domains and there are many types of variables and scoring methods that can be used to determine frailty.[26,27] Although traditional approaches to define frailty included physical and cognitive status, we have used a health deficit-based approach to calculate frailty, which has been validated by others.[11,12] What is unique about our study is that we showed that our FS is independent of age, challenging the usual assumption that frailty is largely seen in older individuals.

These findings are especially relevant, where the FS was identified as an independent predictor of the outcome of interest, prolonged hospitalization, death, non-home discharge, and consequently increased health care costs.[15] We chose this composite outcome as most relevant to frail patients, reflecting their loss of independence, namely

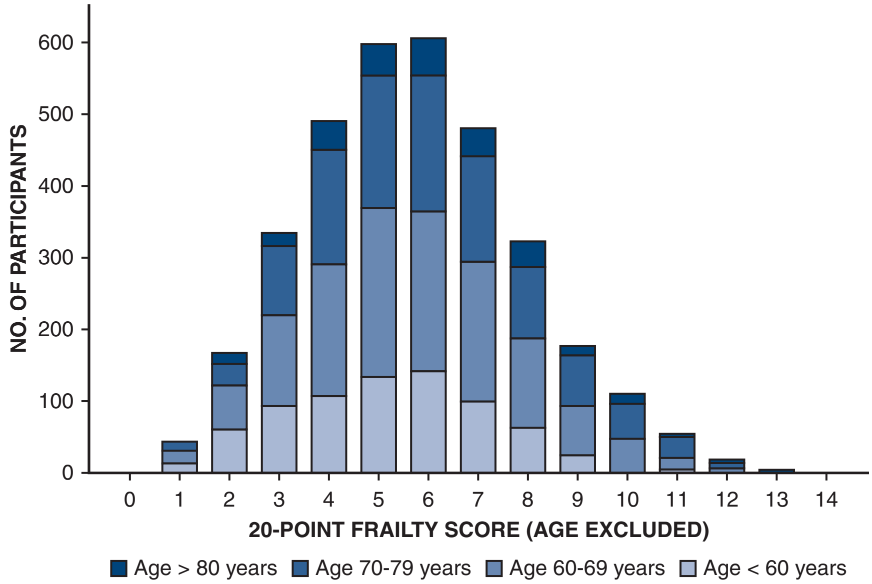


FIGURE 2. Distribution of patients of different ages in age-excluded frailty scores (final 20-point frailty score). A histogram was plotted showing the number of patients of different age groups (<60 years, 60-69 years, 70-79 years and 80 years or older) in each frailty score. Patients of all age groups were present in the different frailty scores, thereby showing that frailty was not dependent on chronological age.

hospitalization. Specifically, we identified age older than 70 years and female sex as independent predictors of composite outcome of prolonged hospitalization or non-home discharge. These findings are in line with a previous study conducted on 3826 consecutive patients who appeared for cardiac surgery between 2004 and 2007.[24] The study showed that age and female sex were independent predictors of in-hospital mortality, prolonged institutional care, and mid-term mortality. Therefore, despite our study being single-centered, we were able to capture data regarding all patients for an entire region (Provincial Center in Canada) who required cardiac surgery between the years 2012 and 2017, making our findings more generalizable. Notwithstanding, going further, a comparison of the fitness of the developed hospital record-based FS with other established methods of frailty analysis is warranted.

The predictive value of identifying the most vulnerable patients using a FS is further supported by the fact that it was able to identify patients likely to consume health care resources by remaining in the hospital or requiring care for extended periods, thereby resulting in increased hospital bed costs as shown previously.[15,28,29] This is not surprising, considering that increasing FS indicates a higher accumulation of comorbidities.[30] However, what is interesting about our study is that we were able to show the increase in hospital bed cost per unit increase in FS, as well as with increasing age. Additionally, highly frail patients with longer hospital stay not only incurred greater hospital bed costs but showed significantly worst survival. Because frailty is an established predictor of poor outcomes,[31,32] this FS might help identify elective cardiac surgery patients who could have better outcomes when subjected to a multidimensional pre-surgery frailty-reversal approach, such as controlled physical exercise, nutrition, social support, etc.[33-35] Furthermore, we showed that female patients have a higher hospital bed cost than men,

TABLE 4. Logistic regression: LOS ≥8 days with or without DC not home (N = 3463)

Variable	OR (95% CI)	*P* value
Frailty score (20-point, age-excluded)	1.32 (1.27-1.37)	**<.0001**
Age category		
< 60 Years	– (–)	–
60-69 Years	1.08 (0.87-1.33)	.48
70-79 Years	1.97 (1.60-2.44)	**<.0001**
80 y and older	4.36 (3.23-5.91)	**<.0001**
Female sex	1.71 (1.44-2.04)	**<.0001**

Significant *P* values are shown in bold. *OR*, Odds ratio; *CI*, confidence interval.

TABLE 5. Total cost of hospital beds (n = 3461 patients)

Variable	Cost	SE	*P* value	95% CI
FS	1065.65	86.14	**.000**	896.76-1234.54
Age 60-69	312.68	509.27	.539	−685.83 to 1311.19
Age 70-79	1879.30	531.76	**.000**	836.70-2921.90
Age 80 or older	3082.65	786.73	**.000**	1540.15-4625.15
Female sex	2105.56	457.70	**.000**	1208.18-3002.95
Constant	4061.59	611.08	.000	2863.46-5259.72

The total cost of stay included stay at intensive care unit + stay at general bed. Cost of stay increased with a unit increment in FS, in patients aged 70 years and older and in female patients. Significant *P* values are shown in bold. *SE*, Standard error; *CI*, confidence interval; *FS*, final age-excluded frailty score (20-point).

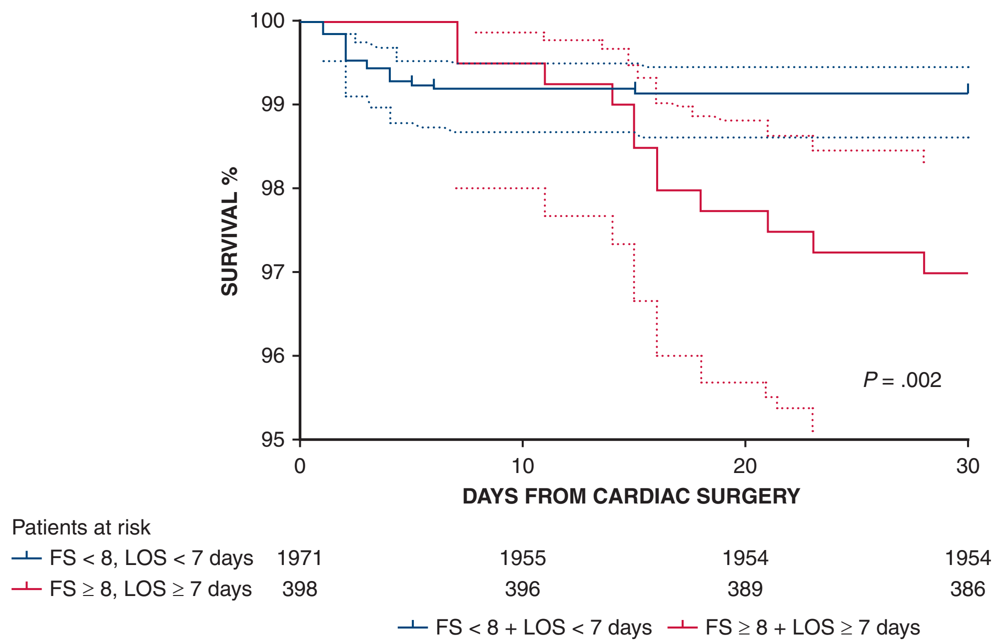


FIGURE 3. Kaplan–Meier survival analysis for 2 groups of patients, FS < 8 and LOS < 7 days versus FS $\geq$ 8 and LOS $\geq$ 7 days. A Kaplan–Meier survival analysis was plotted to understand the difference in survival of 2 groups of patients: healthier patients with lower frailty and shorter hospital stay (FS < 8 and LOS < 7 days) and sicker patients with higher frailty and longer hospital stay (FS $\geq$ 8 and LOS $\geq$ 7 days). There was marked difference in survival of the 2 groups, with the latter group of patients having worse survival. *Solid lines* represent survival, *dotted lines* represent 95% confidence interval. With univariate Cox regression, the hazard ratio was 3.50 (95% CI, 1.67-7.32; P = .002). *FS*, Frailty score (age-excluded); *LOS*, length of stay.

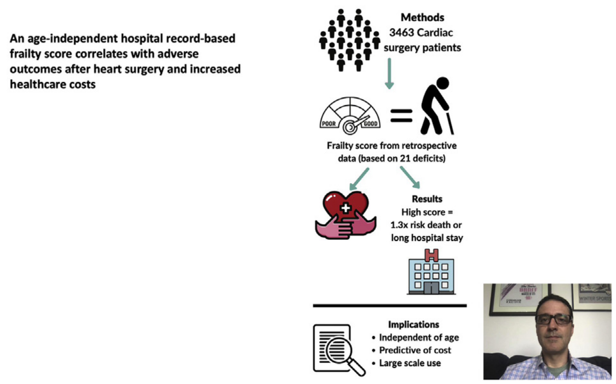
a trend previously reported,[36] and which indicates the need for sex- or gender-specific approaches in modifying cardiac surgical practices.[37] These sex differences existing in our patient cohort are not related to survival but are contingent on composite outcomes and resource utilization. This has been noted elsewhere in the literature and yet it is unclear what actions are necessary to overcome the disparity. Together, the data highlight the importance of frailty assessment not only for clinicians but also for health policy planners and governments, to better allocate resources and to do so more equitably.

We had a strong sample size but the developed FS was computed retrospectively and might be improved with additional domains used with previously shown comprehensive frailty assessments.[38] We acknowledge that this retrospective study does not have prospective frailty assessment data to compare or validate the FS data at this time. This approach is also very different than the weighted approach of the EuroSCORE and STS score used to predict mortality in cardiac surgery and we acknowledge that we could not compare our findings with these traditional scores. It is worth noting that there are several frailty metrics that currently exist and as such there is currently no established gold standard, thus making validation more difficult. Nevertheless, our findings in the present study were robust and validated using multivariable analysis.

In summary, our study highlights the fact that many patients with considerable vulnerability are at increased risk of adverse events after cardiac surgery (Figure 4). This valuable information can now better inform clinicians to identify patients who are at increased risk and could require additional health care resources or differential approaches to care flow plans. This work is critical to allow us to test, evaluate, and/or implement new approaches to help vulnerable patients recover and transition home after a major intervention like heart surgery.

Limitations

- We computed a FS retrospectively with no option to assess patients directly for traditional measures of frailty to allow direct validation. We acknowledge that our inability to compare our findings with more traditional frailty scales (Fried methods of physical frailty) or traditional cardiac surgery risk scores (STS or EuroSCORE) was a limitation. However, our method of frailty analysis was rapid, previously validated, not labor-intensive, and gave a robust assessment of frailty that was predictive of outcome.
- We acknowledge that one can never assume any model designed retrospectively can be truly "predictive" because confounders are always present, whether measured or not. The goal here was not necessarily to



VIDEO 1. An age-independent frailty score can created from the cardiac surgery registry, and this can be used to correlate with adverse outcomes after surgery and determine health care costs associated with hospitalization. Video available at: https://www.jtcvs.org/article/S2666-2736(21)00372-7/fulltext.

devise a fully predictive model, but instead to show that the frailty assessment using a FS could affect the composite outcome independent of age.
- We agree that a traditional comprehensive frailty assessment can additionally take into account other aspects such as mobility, cognition, functional independence, etc, which were not accounted for in our study.[38] However, there are currently no established standards to assess frailty, supporting the present study.

CONCLUSIONS

- Because of the yet to be defined potential that frailty is reversible, our study illustrates a method of frailty screening (that does not require time-consuming prospective frailty assessment) that can be implemented using large data sets to monitor its prevalence among aging adults who undergo cardiac surgery. This method could allow appropriate risk stratification of patients with a focus on an outcome most relevant to frail patients, namely hospitalization and prolonged care.
- Vulnerability and frailty exist along a spectrum of severity, are not limited to older patients, and can affect all patients.
- Our findings could be used as a basis to further study or identify the combination(s) of presurgical interventions to reverse frailty, such as exercise training, social support, nutrition, or other interventions that might help in reduce hospital costs and provide better outcomes after cardiac surgery.

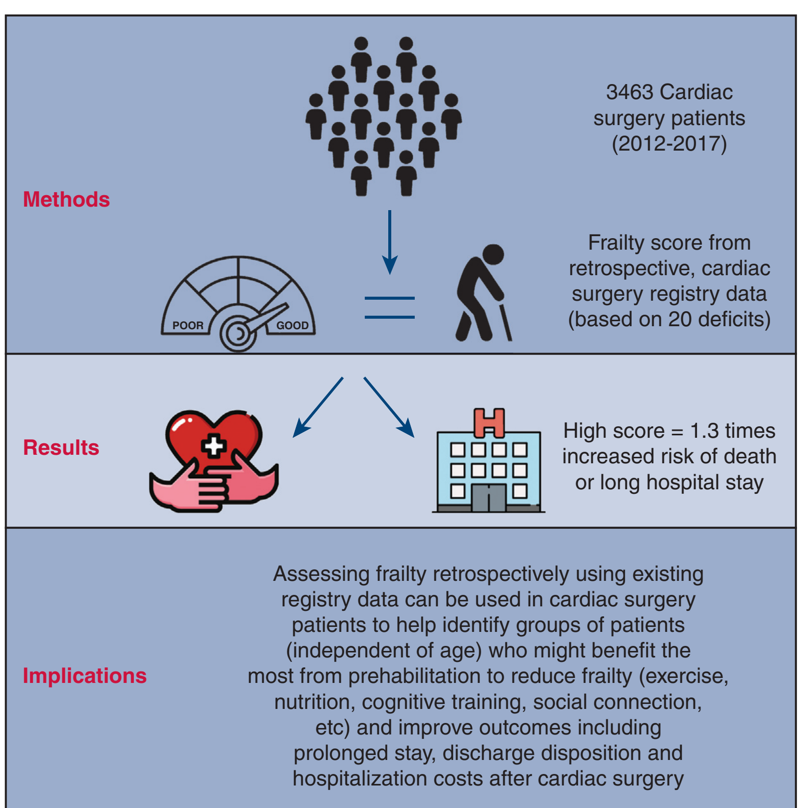


FIGURE 4. A retrospective, hospital record-based frailty score for cardiac surgery patients correlates with the outcomes of prolonged stay post-surgery, non-home discharge, mortality, and increased hospitalization costs.

Conflict of Interest Statement

The authors reported no conflicts of interest.

The *Journal* policy requires editors and reviewers to disclose conflicts of interest and to decline handling or reviewing manuscripts for which they may have a conflict of interest. The editors and reviewers of this article have no conflicts of interest.

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Key Words: risks, deficits, retrospective, readmission, prolonged stay

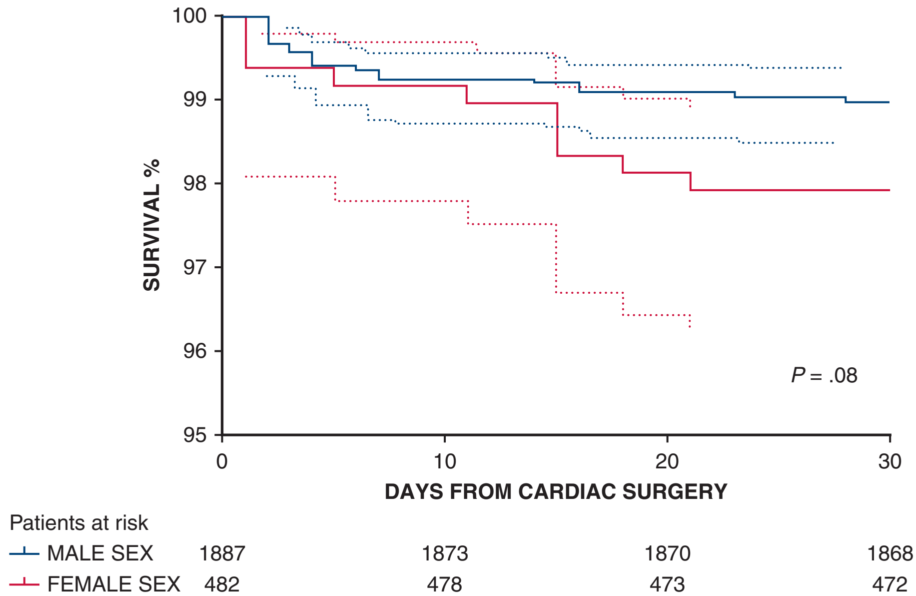

FIGURE E1. Survival for men and women. A Kaplan–Meier survival curve was plotted to understand the difference in survival between male and female sex in the cardiac surgery population between 2012 and 2017. Women had a higher mortality rate at 10 (2.1%) versus 19 (1.0%) for men ($P = .09$). Univariate Cox regression gives the hazard ratio for female (vs male) at 2.07 (95% CI, 0.96-4.45; $P = .08$). *Solid lines* represent survival, *dotted lines* represent 95% confidence interval.

TABLE E1. Variables used to construct the frailty score

No.	Variable	Inclusion criteria for deficit (1 point)
1	Age*	70 Years or older
2	Pre-CPB Hematocrit	<0.24
3	Atrial fibrillation	Present
4	CVD (TIA, stroke, or carotid stenosis)	Present
5	PVD	Present
6	Renal insufficiency	Serum creatinine > 176
7	Diabetes	Present
8	LVEF	<40%
9	CHF	Present
10	NYHA	III-IV
11	Hypertension	Present
12	COPD	Present
13	BMI	<18.5 or >34.9
14	Medications†	>3
15	Urgency (elective vs IHU vs emergent)	Urgent
16	Smoking history	Present
17	Hypercholesterolemia	Present
18	Previous CV intervention‡	Present
19	Recent MI within ≤21 d	Present
20	Procedure type§	Combined disease
21	Pulmonary hypertension	Present

Data for all variables were preoperative and available from the New Brunswick Heart Centre cardiac surgery registry. *CPB*, Cardiopulmonary bypass; *CVD*, cardiovascular disease; *TIA*, transient ischemic attack; *PVD*, peripheral vascular disease; *LVEF*, left ventricular ejection fraction; *CHF*, congestive heart failure; *NYHA*, New York Heart Association; *COPD*, chronic obstructive pulmonary disease; *BMI*, body mass index; *IHU*, in-hospital urgent; *CV*, cardiovascular; *MI*, myocardial infarction. *Age was used in the initial construction of the age-included frailty score (21-point frailty score), but was later eliminated to generate the final age-excluded frailty score (20-point frailty score). †Fourteen types of drugs were given to patients: (1) digitalis, (2) β-blocker, (3) calcium antagonist, (4) angiotensin-converting enzyme inhibitor, (5) nitroglycerin (intravenous, oral, or patch), (6) anti-arrythmia, (7) antiplatelet, (8) anticoagulant, (9) diuretic, (10) inotrope, (11) steroid, (12) cholesterol, (13) angiotensin receptor blocker, and (14) glycoprotein IIb/IIIa receptor inhibitor. ‡Previous CV intervention: surgery (any type) or percutaneous coronary intervention. §Procedure type included coronary artery bypass graft, valve, and others. More than one type of procedure was categorized as combined disease.

TABLE E2. Cost of stay at the hospital

Variable	Cost	SE	*P* value	95% CI
ICU cost				
FS	566.30	64.10	0	440.61-691.98
Age 60-69 y	−91.90	378.99	0.808	−834.96 to 651.16
Age 70-79 y	712.44	395.72	0.072	−63.43 to 1488.31
Age > 80 y	1003.43	585.46	0.087	−144.45 to 2151.31
Female sex	1171.66	340.60	0.001	503.85-1839.46
Constant	804.27	454.75	0.077	−87.34 to 1695.88
General bed cost				
FS	499.35	42.87	**0**	415.29-583.40
Age 60-69 y	404.58	253.47	0.111	−92.39 to 901.54
Age 70-79 y	1166.86	264.66	**0**	647.95-1685.77
Age >80 y	2079.22	391.56	**0**	1311.50-2846.93
Female sex	933.91	227.80	**0**	487.27-1380.55
Constant	3257.33	304.14	**0**	2661.00-3853.65

Costs included stay in ICU and general bed (total stay = stay in ICU + general bed; n = 3461 patients). Bed costs increased with unit increase in frailty score, age, and female sex. Significant *P* values are shown in bold. *SE*, Standard error; *CI*, confidence interval; *ICU*, intensive care unit; *FS*, final age-excluded frailty score (20-point frailty score).