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Association of frailty with days alive at home after cardiac surgery: a population-based cohort study

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Abstract

Background: Frailty is a geriatric syndrome that leaves people vulnerable to adverse outcomes. In cardiac surgery, minimal data describe associations between frailty and patient-centred outcomes. Our objective was to estimate the association between frailty and days alive at home after cardiac surgery.

Methods: We conducted a population-based cohort study using linked health administrative data in the Canadian province of Ontario. All individuals >65 yr at the time of cardiac surgery were assigned a frailty score using a validated frailty index. Days alive and at home in the 30 and 365 days after surgery were calculated. The unadjusted and adjusted associations between frailty and days alive at home were calculated.

Results: We identified 61 389 patients from 2009 to 2015. Frailty was associated with reduced days at home within 30 days (adjusted ratio of means for every 10% increase in frailty=0.79; 95% confidence interval [CI], 0.78–0.81; $P<0.0001$) and 365 days (adjusted ratio of means for every 10% increase in frailty=0.92; 95% CI, 0.91–0.93; $P<0.0001$) of surgery. Results were consistent in sensitivity analyses (5.0 fewer days alive at home [95% CI, 4.8–5.2] within 30 days and 9.0 fewer days alive at home [95% CI, 8.7–9.2] within 365 days after surgery).

Conclusion: Frailty is associated with a reduction in days alive at home after major cardiac surgery. This information should be considered in prognostic discussions before surgery and in care planning for vulnerable older patient groups. Days alive at home may be a useful outcome for routine measurement in quality, reporting, and studies using routinely collected data.

Keywords: cardiac surgery; complications; epidemiology; frailty; length of stay; patient-centred outcomes

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Editor's key points

- Complications after most types of surgery are variably detected and reported; some are not apparent until after hospital discharge.
- Readmission is an indicator of poor care and adverse patient outcome.
- The number of days alive and at home in the first 30 days after surgery is an important patient-centred outcome.
- This study evaluated the effect of frailty on these outcome metrics.

Frailty is a geriatric syndrome resulting from age- and disease-related deficits that accumulate across multiple domains.[1,2] As the cardiac surgical population continues to age,[3] frailty has emerged as an important risk factor that must be considered in surgical decision making. When patients have frailty before cardiac surgery, their risk of major adverse cardiac events are increased at least 1.5-fold, and patients are less likely to have adequate functional recovery.[4–6] However, significant limitations preclude widespread generalisability and clinical applicability of these data.

A variety of approaches exist to measuring frailty; however, little agreement exists regarding an optimal frailty instrument. Agreement does exist that frailty measurement should be operationalised using a multidimensional approach,[7] which is most often done using either the frailty phenotype or the accumulating deficits frailty index approach.[8,9] Current perioperative data suggest that neither approach is superior, and both have been used in studying surgical patients.[10] In cardiac surgery, studies typically define frailty using single domain instruments (e.g. physical performance only) or frailty proxies, such as disability or sarcopenia, which are understood to be related, but distinct, concepts from frailty.[4,11] Furthermore, little data exist evaluating the association of valid, multidimensional frailty measures with long-term and patient-centred outcomes.[4,12] Specifically, most studies are limited to data collected in hospital or across the first postoperative month. Furthermore, most studies have focused on mortality. Although mortality is a high-priority outcome for patients and the healthcare system, older people also strongly value independence after surgery and wish to return home as soon as safely possible.[13,14] The association of multidimensional frailty with patient-centred outcomes after cardiac surgery has not been well described.[4,15] Days alive at home is a validated patient-centred outcome that can be accurately measured in health administrative data that reflects the combined impacts of survival, length of stay (LoS), readmissions, and non-home discharge.[16,17] Therefore, population-based studies that define frailty with a robust multidimensional instrument and that capture long-term patient-centred outcomes, such as days alive at home, are needed to inform care planning and surgical decision making.

To address these important knowledge gaps, we undertook a population-based study of older people having common major cardiac surgical procedures with the primary objective of estimating the association of frailty, identified using a validated multidimensional frailty index,[18,19] with days alive at home after surgery. Our secondary objective was to understand what intermediate outcomes may mediate the association between frailty and days alive at home.

Methods

Design and data source

We conducted a population-based cohort study using linked health administrative data in the Canadian province of Ontario, which has a population of more than 13 million people and provides universal health insurance coverage for hospital and physician services to all residents. Data generated by the Ontario healthcare system are collected using standardised methods and stored at the Institute for Clinical Evaluative Sciences (ICES), an independent research institute. Data at ICES are anonymised and can be deterministically linked using encrypted, patient-specific identifiers. Because all data used from this study were routinely collected and anonymised, it was legally exempt from research ethics review based on provincial privacy legislation.

Data sets used for this study included: the Discharge Abstract Database (DAD), which captures all hospitalisations and surgical procedures; the Ontario Health Insurance Plan (OHIP) database, which captures physician service claims; the National Ambulatory Care Reporting System, which captures all emergency department visits; the Continuing Care Reporting System (CCRS) which records details of long-term and respite care; the Ontario Drug Database (ODB), which captures all prescription medication claims for people 65 yr and older; and the Registered Persons Database (RPDB), which captures all death dates. The analytic data set was created and analysed by an independent analyst using data normally collected at ICES. This study is reported using appropriate guidelines.[20,21]

Cohort

All Ontario residents aged >65 yr having one of the five most common cardiac surgical procedures (isolated coronary artery bypass surgery [CABG], isolated aortic valve repair or replacement, combined CABG and aortic valve repair or replacement, combined CABG and mitral valve repair or replacement, or multivalve surgery; codes are provided in Supplementary Table S1)[22] between April 2009 (which was the date where complete data were available to identify long-term care admission and discharge dates) and March 2015 (the most recent date for which all data were complete at the time of analysis) were included. We did not include transcatheter or other minimally invasive valve implantations. Only the first procedure for each participant was included to ensure a patient-level analytic data set. We included patients having elective, urgent, and emergency surgery.

Exposure

Our exposure was frailty, operationalised using the preoperative frailty index (pFI), an accumulating deficits frailty index,[19,23] which was formatted as a continuous linear variable (as in the pFI's derivation and validation study). The pFI is a multidimensional frailty index, modelled after the original Canadian Study of Health and Ageing Frailty Index.[23] As recommended, the pFI includes 30 deficits that span multiple domains (comorbidity, sensory, cognitive, psychosocial, disability, pharmaceutical; see Table 1). It has been validated in both elective and emergency surgery settings and has been shown to be robust to missing data and variable substitution.[18] For this study, the pFI was specified exactly as was done for the original derivation. In addition to the

Table 1 Scoring rubric for frailty index. The preoperative frailty index (pFI) is calculated by adding the score for each deficit measured and dividing this number by the total number of deficits measured (i.e. 30).

Variable	Source	Points		
		0	0.5	1
Anticholinergic risk scale	ODB[a]	0	1–2	>2
Arrhythmia	Elixhauser	None		Present
Cancer	Elixhauser	None		Present
Cerebrovascular disease	Elixhauser	None		Present
Chronic obstructive pulmonary disease	COPD algorithm	None		Present
Dementia	Elixhauser	None		Present
Dental	ADG	None		Present
Dermatologic	ADG	None		Present
Diabetes mellitus	Diabetes algorithm	None		Present
Dialysis	Elixhauser	None		Present
Drug or alcohol abuse	Elixhauser	None	one	Both
Heart failure	Heart failure algorithm	None		Present
Hemiparesis	Elixhauser	None		Present
History of falls	ICD-10 code[b]	None		Present
Home oxygen	ADP	None		Present
HOMR Score	Calculated	0–21	22–55	>55
Hypertension	Hypertension algorithm	None		Present
Injury	ADG	None	minor	Major
Liver disease	Elixhauser	None		Present
Multimorbidity	Charlson score	0	1–2	>2
Myocardial Infarction	Myocardial infarction algorithm	None		Present
Peripheral vascular disease	Elixhauser	None		Present
Psychosocial (minor or stable)	ADG	None	minor/stable	Major
Resource use band 4–5	ADG	0–1	2–3	4–5
Rheumatic disease	Elixhauser	None		Present
Socioeconomic status	Census	Top 2 quintiles	middle quintile	Bottom 2 quintiles
Ear, nose, throat	ADG	None	stable	Unstable
Eye	ADG	None	stable	Unstable
Supported living environment	CCRS/HCD/LTC			
Weight loss	Elixhauser	None		Present

[a] Calculated according to methods of Rudolph and colleagues.[24]

[b] Any inpatient or emergency department record with a diagnosis code W0–W19. ADG, Aggregated Diagnosis Group; ADP, Assistive Devices Program; CCRS, Continuing Care Reporting System; COPD, chronic obstructive pulmonary disease; HCD, Home Care Database; ICD-10, International Classification of Diseases, 10th Edition; ODB, Ontario Drug Benefits Program.

continuous form, we also dichotomised frailty as present or absent based on a cut-off of >0.21 to support sensitivity analyses.

Outcomes

Our primary outcome was days alive at home in the 30 days after surgery (DAH_{30}), a patient-centred outcome that can be derived from administrative data.[16,17] To calculate each participant's DAH_{30}, we summed all days an individual was in an acute care hospital (from the DAD, index admission, or readmission for any reason at any Ontario hospital), rehabilitation facility, continuing care facility or long-term care facility (from CCRS) in the 30 days after surgery and subtracted this value from the number of days the individual was alive in the 30 day postoperative time window. Our secondary outcome was days alive at home in the 365 days after surgery (DAH_{365}); to calculate this value, we summed the total of days each participant was in any of the non-home locations of care listed previously and subtracted this sum from the number of days the individual was alive in the 365 days after surgery. To explore contributors to reduced DAH, we also captured hospital LoS, non-home discharge rates and days in long-term care, and overall survival from the DAD and RPDB.

Covariates

In addition to the variables included in the pFI, we also identified patient sex (from the DAD), age at surgery; year of surgery; whether the surgery was elective (elective DAD admission for surgery), urgent (non-elective DAD admission for surgery and surgery ≥3 days after admission), or emergent (non-elective DAD admission for surgery and surgery ≤2 days after admission); and a unique identifier for each hospital.

Analyses

All analyses were conducted using SAS 9.4 for Windows (SAS Institute Inc., Cary, NC, USA). Baseline characteristics comparing those with or without frailty (based on a cut-off of >0.21) were compared using absolute standardised differences, which, unlike *P* values, are not dependent on sample size; values >0.1 are considered to represent substantial differences.[25]

Unadjusted and multilevel, multivariable adjusted analyses were performed to estimate the association of frailty with outcomes; all adjusted models accounted for clustering of patients in hospitals using generalised estimating equation methods. Because the distributions of DAH_{30} and DAH_{365} were continuous but over-dispersed, we used generalised linear models with a log link and negative binomial response distribution.

Our postulated causal model was that comorbidity and other health deficits lead to the development of frailty, which was our exposure; therefore, as an intermediary between health deficits and adverse outcomes, we did not adjust for comorbidity as this could lead to over-adjustment bias.[26] However, multivariable models did adjust for age (fractional polynomial), sex (binary), type of surgery (as a five-level categorical variable), urgency status (three-level categorical), and year of surgery (as a restricted cubic spline with three knots), which could both be associated with frailty and outcome, but were not thought to be directly on the causal pathway preceding frailty. We also re-ran our unadjusted and adjusted primary and secondary analyses using quantile regression for the median value, as was used in the primary validation study for DAH_{30}.[16] Adjusted and unadjusted associations between frailty index score and LoS, non-home discharge, and overall survival were also calculated (using log-gamma, logistic and proportional hazards regression, respectively).

Sensitivity analyses

As frailty is often represented as a binary state, we also re-ran pre-specified unadjusted and adjusted primary and secondary outcomes with the pFI formatted as a binary variable (cut-off 0.21, as previously described[18]).

Mediation analyses

To estimate the degree to which each of LoS, discharge disposition and mortality mediated decreased DAH, we completed a causal mediation analysis using Vanderweele's counterfactual approach.[27,28] This allowed us to calculate the proportion of the DAH outcome mediated by each of these intermediary outcomes by dividing the total effect by the natural indirect effect.

Sample size and missing data

As this was a population-based study, all eligible individuals were included; no formal sample size calculation was used. There were no missing values for exposure, outcome or covariate data.

Results

We identified 61 389 older individuals having their first cardiac surgery during our study period; cohort characteristics are provided in Table 2. The mean pFI score was 0.23 (standard deviation [SD] 0.07) Individuals with pFI scores >0.21 were more

Table 2 Cohort characteristics by binary frailty status.

Characteristics	Frailty index >0.21 (*n*=35 270)	Frailty index <0.21 (*n*=26 119)	Absolute standardised difference[a]
Female	11 502 (32.6%)	6832 (26.2%)	0.14
Age at surgery, yr, mean (SD)	73.22 (5.20)	74.64 (5.48)	0.27
Surgery type			
CABG	19 102 (73.1%)	24 093 (68.3%)	0.11
CABG+AVR	3158 (12.1%)	5279 (15.0%)	0.08
AVR	2751 (10.5%)	3318 (9.4%)	0.04
CABG+MVR	269 (1.0%)	734 (2.1%)	0.09
Multivalve	839 (3.2%)	1846 (5.2%)	0.1
Income quintile[b]			
Lower two quantiles	16 781 (47.6%)	7155 (27.4%)	0.43
Middle quantile	7173 (20.3%)	5205 (19.9%)	0.01
Comorbidities			
Chronic obstructive pulmonary disease	17 687 (50.1%)	4725 (18.1%)	0.72
Peripheral vascular disease	4331 (12.3%)	466 (1.8%)	0.42
Arrhythmia	79 (0.2%)	0 (0.0%)	0.07
Cancer	2252 (6.4%)	381 (1.5%)	0.26
Heart failure	24 669 (69.9%)	6858 (26.3%)	0.97
Diabetes mellitus	23 892 (67.7%)	9128 (34.9%)	0.69
Dialysis	712 (2.0%)	26 (0.1%)	0.19
Drug or alcohol abuse	569 (1.6%)	80 (0.3%)	0.13
Hemiparesis	347 (1.0%)	5 (0.0%)	0.14
Hypertension	34 248 (97.1%)	23 174 (88.7%)	0.33
Myocardial Infarction	14 063 (39.9%)	3936 (15.1%)	0.58
Multimorbidity	14 286 (40.5%)	1151 (4.4%)	0.96
Rheumatic disease	482 (1.4%)	47 (0.2%)	0.14
Cerebrovascular disease	3435 (9.7%)	385 (1.5%)	0.37
Weight loss	185 (0.5%)	14 (0.1%)	0.09
Resource use quintile			
Quintile 4 or 5	34 284 (97.2%)	20 260 (77.6%)	0.62
Quintile 2 or 3	986 (2.8%)	5859 (22.4%)	0.62

[a] Values >0.1 represent a substantial difference.
[b] Represents neighbourhood income quintile based on smallest unit of census tracts; based on pre-admission Adjusted Clinical Groups Resource Utilization Bands, which stratify patients based on expected rates of in- and outpatient utilisation of healthcare services. AVR, isolated aortic valve repair; CABG, coronary artery bypass surgery; MVR, isolated mitral valve replacement or repair; SD, standard deviation.

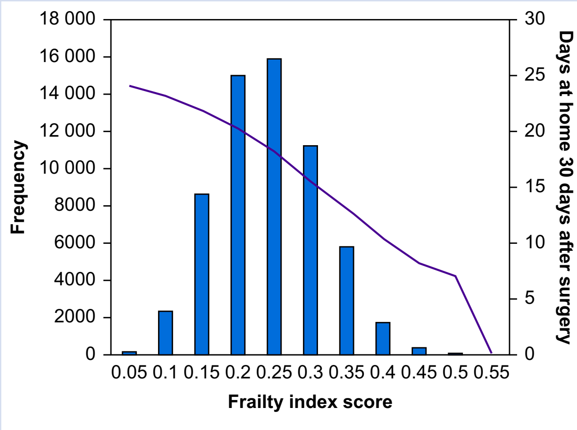

Fig 1. Distribution of frailty index scores with the corresponding number of days alive at home in the 30 days after cardiac surgery for each 0.05 point change in frailty index score. Bars represent the proportion of the cohort in each 0.05 increment of the frailty index score distribution. The line represents the number of days alive at home within 30 days of surgery.

likely to be female, older, and were more likely to have an isolated CABG.

In the 30 days after surgery the mean DAH_{30} was 18.2 (8.4) and the median was 22 days (inter-quartile range [IQR], 15–24). The mean LoS was 11.4 (16.4) days. Before adjustment, each 10% increase in the pFI was associated with a 23% (95% CI, 21–25%; $P<0.0001$) relative decrease in DAH_{30}. After covariate adjustment, each 10% increase in pFI continued to be significantly associated with a decrease in DAH_{30} (21% decrease; 95% CI, 19–22%; $P<0.0001$). Figure 1 demonstrates the association of DAH_{30} with frailty index score across the range of frailty index score values, along with the distribution of frailty index scores.

When the pFI was dichotomised, participants without frailty had a mean DAH_{30} of 21.1 (SD 6.3) whereas participants with frailty had a mean DAH_{30} of 16.0 (9.1). The unadjusted association between frailty and DAH_{30} was significant (relative decrease 26%; 95% CI, 24–29%; $P<0.0001$), as was the adjusted association (relative decrease 20%; 95% CI, 19–21%; $P<0.0001$). The fully specified primary model is provided in Supplementary Table S2.

Table 4 Associations between frailty and exploratory outcomes.

Outcome	Unadjusted effect measure	Adjusted effect measure
Per 10% increase in FI		
1-yr survival	1.87 (1.76–1.98)	1.58 (1.49–1.68)
Non-home discharge	2.37 (2.29–2.47)	1.07 (1.06–1.07)
Length of stay, days	1.65 (1.64–1.67)	1.56 (1.55–1.57)

All P values <0.0001; bracketed numbers represent 95% confidence intervals; effect estimates adjusted for age, sex, urgency, procedure type (hazard ratio for survival, odds ratio for discharge, ratio of means for length of stay); FI, frailty index.

The association of frailty and DAH_{365} is provided in Table 3. Each 10% increase in the pFI was significantly associated with a decrease in DAH_{365}, as was the binary representation of frailty. Results from quantile regression are also provided in Table 3; the association between the various frailty representations and the median DAH_{30} and DAH_{365} were consistent with the negative binomial regression models. Table 4 provides associations between frailty and LoS, discharge, and survival, demonstrating strong associations between frailty index score and each exploratory outcome. Supplementary Table S3 provides rates of contributing outcomes by binary frailty status.

Mediation analyses

At 30 days after surgery, hospital LoS (49%) and non-home discharge (16%) were the major mediators of people with frailty having reduced days at home; mortality mediated only a 6% reduction. At 365 days, mortality was the major mediator (62%) of the frailty days at home association, followed by time in long-term care (40%) and LoS (22%) (note that when multiple mediators are considered, the proportion mediated can sum to >100%; therefore, it is the relative strength that should be considered).[29] Full causal mediation results are provided in Supplementary Table 4.

Discussion

In this population-based cohort study of older patients having cardiac surgery, we found that preoperative frailty status was

Table 3 Results of sensitivity analyses.

Outcome	Unadjusted		Adjusted	
	RoM	Median difference[a]	RoM	Median difference[a]
Per 10% increase in FI				
DAH_{30}	0.77 (0.75–0.79)	3.0 (3.0–3.0)	0.79 (0.78–0.81)	2.4 (2.3–2.5)
DAH_{365}	0.91 (0.91–0.92)	5.3 (5.1–5.4)	0.92 (0.91–0.93)	4.3 (4.1–4.4)
Binary frailty status				
DAH_{30}	0.74 (0.71–0.76)	6.3 (6.3–6.3)	0.80 (0.79–0.81)	5.0 (4.8–5.2)
DAH_{365}	0.91 (0.91–0.92)	11.0 (10.6–11.4)	0.93 (0.92–0.93)	9.0 (8.7–9.2)

All P values <0.0001.
[a] Number of days fewer for higher frailty group; bracketed numbers represent 95% confidence intervals. Effect estimates adjusted for age, sex, urgency, and procedure type. DAH, days alive at home; FI, frailty index; RoM, ratio of means.

strongly associated with a reduced number of days that patients were alive and at home in the month and year after surgery. Specifically, each 10% increase in frailty was associated with 20% decrease in the number of days spent at home in the month after surgery and an approximately 10% decrease in the year after surgery. Knowledge of the association between frailty status and the patient-centred days at home outcome should allow for better informed preoperative decision-making for patients and clinicians and a greater ability to plan for postoperative resources. Days at home may also serve as an important outcome for studies looking to test interventions to improve recovery after cardiac surgery for high risk older people.

Being alive and in one's own home after an acute illness is an important and patient-centred outcome that has been assessed in cardiovascular medicine,[30,31] geriatric medicine,[32] and more recently in perioperative medicine and surgery.[16,17] As an outcome measure, the number of days at home reflects both the clearly stated preference of older people to maintain function and independence in the face of acute illness,[14] and summarising the collective impacts of postoperative adverse events. To date, older age, higher comorbidity score, higher ASA score, and longer surgical duration have all been associated with fewer days at home after surgery.[16,17] As a multidimensional syndrome, frailty encompasses aspects of biologic aging and comorbidity[33]; therefore, it is not surprising that older people with frailty experienced fewer days at home. The 3 day decrease in days at home in the month after surgery is similar in size to the difference attributable to being ASA score 4 *vs* 2, and is greater than the influence of a 30 yr increase in age or the presence of single high-risk comorbidity such as heart failure or stroke.[16] As demonstrated in Fig 1, an almost linear negative association existed between greater frailty and fewer days alive at home. Together, these findings highlight the substantial challenges faced by people with frailty who require cardiac surgery and the clinicians and health systems tasked with their care. Furthermore, our data support the construct validity and responsiveness of days at home, as people with frailty had increased risk of death, long LoS, and non-home discharge, all of which contributed to the significant reduction in DAH_{30} and DAH_{365}. Therefore, days at home appears to represent an important patient-centred outcome that can be routinely measured for quality assurance, reporting, and to support larger pragmatic trials with registry linkage.[29]

Although the original validation of DAH as an outcome did include cardiac surgery patients (approximately 30% of the cohort),[11] the current study represents an important opportunity to further consider the merits of DAH as an outcome in cardiac surgery, which is unique from noncardiac surgical specialties. Cardiac surgery patients tend to be older and medically complex,[3,34] and procedures place substantial physiologic demand on patients and postoperative recovery typically involves stays in critical care,[22] where loss of physical reserve, cognitive reserve, or both can occur.[35] Not surprisingly, mortality rates, LoS, and readmission rates tend to be high after cardiac surgery.[36–38] However, depending on the ascertainment window (i.e. DAH_{30} and DAH_{365}), fewer days at home values were differentially mediated by mortality *vs* time in hospital or long-term care. Within 30 days of surgery, hospital stay was the main mediator of having fewer days at home with increasing frailty, followed by discharge to long-term care; early mortality was a weak mediator. However, in the year after surgery, mortality was the major mediator of reduced DAH with increasing frailty score. This suggests that different causal pathways underlie reduced time at home in the short-*vs* long-term for people with frailty having cardiac surgery. Although mortality is an important outcome in the early postoperative period, for people with frailty, a focus on regaining function and independence appear to be key to successful transitions home. However, in the longer term, careful follow-up and support may be required to meaningfully support extended and meaningful longevity at home.

Strengths and limitations

The current study should be appraised in consideration of its strengths and limitations. As a population-based study, our findings may be generalisable to similar patients cared for in similar healthcare systems. However, generalisability to other systems, especially those featuring substantial private provision of care, cannot be determined. Our study relied upon validated and accurately ascertained exposure and outcome metrics; however, we did use health administrative data that were not initially collected for research purposes. Our data also did not contain granular physiologic measures, such as cardiac function, or physical performance measures, meaning that we were unable to specifically assess the impacts of these measures on our outcome. We also restricted our population to major surgical procedures; therefore, future research will be required to assess the impact of frailty on days at home in minimally invasive procedures, such as endovascular aortic valve repairs. Furthermore, we only studied the frailty index and its association with DAH; future research will be required to determine if similar effect sizes are found with related frailty tools (e.g. the Clinical Frailty Scale) or alternative approaches (e.g. Fried Phenotype), as different frailty assessment tools typically only have moderate agreement in terms of who is identified as having frailty.

Conclusions

In a population-based cohort study of older adults having major cardiac surgery, we found that frailty was strongly associated with a reduction in the number of days alive and spent at home in both the short and long term. Such findings should be discussed with patients and families with frailty considering cardiac surgery, whereas days at home should be considered as a relevant outcome in cardiac surgery studies using routinely collected data.

Authors' contributions

Conception: DIM, BM, AF
Study design: DIM, BM, AF, ES
Data acquisition: DIM, BM, AF, ES
Data analysis: DIM, BM, ES
Data interpretation: DIM, BM, AF, ES
Drafting of the manuscript: DIM, BM
Revision of the manuscript: DIM, BM, AF, ES
Approval of the final manuscript version: DIM, BM, AF, ES
Guarantor: DIM

Declarations of interest

The authors declare that they have no conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bja.2021.02.011.

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