Association between heart failure and perioperative outcomes in patients undergoing non-cardiac surgery

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Aims

Heart failure (HF) affects ~5.7 million US adults and many of these patients develop non-cardiac disease that requires surgery. The aim of this study was to determine perioperative outcomes associated with HF in a large cohort of patients undergoing in-hospital non-cardiac surgery.

Methods and results

Adults ≥18 years old undergoing non-cardiac surgery between 2012 and 2014 were identified using the Healthcare Cost and Utilization Project National Inpatient Sample. Patients with HF were identified by ICD-9 diagnosis codes. The primary outcome was all-cause in-hospital mortality. Multivariable logistic regression models were used to estimate associations between HF and outcomes. A total of 21 560 996 surgical hospitalizations were identified, of which 1 063 405 (4.9%) had a diagnosis of HF. Among hospitalizations with HF, 4.7% had acute HF, 11.3% had acute on chronic HF, 27.8% had chronic HF, and 56.2% had an indeterminate diagnosis code that did not specify temporality. In-hospital perioperative mortality was more common among patients with any diagnosis of HF compared to those without HF [4.8% vs. 0.78%, $P < 0.001$; adjusted odds ratio (aOR) 2.15, 95% confidence interval (CI) 2.09–2.22], and the association between HF and mortality was greatest at small and non-teaching hospitals. Acute HF without chronic HF was associated with 8.0% mortality. Among patients with a chronic HF diagnosis, perioperative mortality was greater in those with acute on chronic HF compared to chronic HF alone (7.8% vs. 3.9%, $P < 0.001$; aOR 1.78, 95% CI 1.67–1.90).

Conclusion

In patients hospitalized for non-cardiac surgery, HF was common and was associated with increased risk of perioperative mortality. The greatest risks were in patients with acute HF.

Keywords

Heart failure • Mortality • Outcomes • Perioperative • Surgery

Introduction

Heart failure (HF) affects nearly 5.7 million adults in the USA, and many patients with HF develop non-cardiac disease that ultimately requires surgical management.^{1,2} Heart failure is recognized to be associated with an increased risk of complications after non-cardiac surgery, but the clinical application of prior estimates of associations

between HF and perioperative outcomes is limited by several methodologic considerations, including use of small or highly selected study populations (such as predominantly male cohorts from Veterans Affairs hospitals or elderly populations from Medicare data), heterogeneous definitions of HF, and use of datasets representing an earlier era of perioperative management and cardiovascular care.^{3–7} Few prior studies stratified associations between HF and

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outcomes by surgery type. Consequently, the prevalence of HF in patients undergoing non-cardiac surgery in the contemporary era is not well-established, and perioperative cardiovascular outcomes associated with HF remain uncertain. To address the limitations of prior studies, the aim of the present study was to determine the prevalence of HF and associated outcomes in a large, diverse, contemporary nationwide cohort of patients undergoing in-hospital non-cardiac surgery in the USA.

Methods

Patients

Adults ≥ 18 years old undergoing non-cardiac surgery between 2012 and 2014 were identified using the Agency for Healthcare Research and Quality (AHRQ) Healthcare Cost and Utilization Project's National Inpatient Sample (NIS). The NIS includes data from a 20% stratified sample of discharges from all participating community hospitals in the USA and represents the largest all-payer database in the USA. Patients were eligible for inclusion if they had a principal *International Classification of Diseases, Ninth Revision* (ICD-9) procedure code for a major therapeutic operating room procedure (HCUP Procedure Class 4) during the hospital admission, as previously described.⁸ Principal Clinical Classifications Software (CCS) procedure codes were used to stratify operating room procedures by surgical subtype. Hospitalizations for bone marrow transplantation, ophthalmologic surgery, radiation therapy, dental surgery, cardiac procedures and surgery, cardiac transplantation, and non-operating room procedures were excluded. The remaining patients were clustered by major surgical subtype into the following groups: endocrine, general, genitourinary, gynaecologic, neurosurgery, obstetric, orthopaedic, otolaryngology, skin and breast, thoracic, non-cardiac solid organ transplant, and vascular surgery. Patients with HF were identified by any ICD-9 diagnosis code for one or more of the following: 402.x1, 404.x1, 404.x3, or 428.x (Supplementary material online, Table S1). This approach has been validated in the American Heart Association Heart Failure-GWTG registry and administrative databases.⁹ Other clinical covariates were defined using ICD-9 codes and AHRQ comorbidity measures.

Outcomes

The primary outcome was all-cause in-hospital death during the index hospital admission for non-cardiac surgery. Secondary outcomes included myocardial infarction (MI), acute ischaemic stroke, acute pulmonary embolism, and cardiac arrest. Myocardial infarction was defined based on ICD-9 diagnosis code for acute ST-segment elevation MI (ICD-9 diagnosis codes 410.01 to 410.61, 410.81, and 410.91) and non-ST-segment elevation MI (ICD-9 diagnosis code 410.71), as previously described.⁸ Acute ischaemic stroke was defined by ICD-9 diagnosis codes 433.x, 434.x, 436.x, 437.0, and 437.1.¹⁰ Other in-hospital outcomes, including acute pulmonary embolism and cardiac arrest, were also identified based on relevant ICD-9 codes.

Statistical analysis

Continuous variables were reported as means with the standard error of measurement and compared using linear regression. Categorical variables were reported as proportions and compared by χ^2 tests. Multivariable logistic regression models were used to estimate odds ratios adjusted for patient demographics, cardiovascular risk factors, and comorbidities. Covariates for adjustment included age, sex, race/ethnicity, tobacco use, obesity, hypertension, hyperlipidaemia, diabetes, coronary artery disease (CAD), history of percutaneous coronary intervention (PCI) or coronary

artery bypass grafting, peripheral artery disease, atrial fibrillation or atrial flutter, valvular disease, prior venous thromboembolism, prior stroke, chronic kidney disease, end-stage renal disease, malignancy, anaemia, drug and alcohol abuse, coagulopathy, rheumatoid arthritis and collagen vascular disease, elective hospital admission, and type of non-cardiac surgery.

To confirm the validity of the overall study findings, we examined the associations between HF and outcomes by surgery subtype. We performed subgroup analyses by sex, and by hospital location, teaching status, and bed size, as defined by AHRQ.¹¹ We also performed sensitivity analyses excluding women undergoing low-risk obstetric surgical procedures during the study period, and excluding patients undergoing urgent or emergent surgeries. To evaluate the risk of acute decompensated HF in the perioperative period among patients with an established diagnosis of chronic HF, we performed a sensitivity analysis including only those patients who were assigned one or more diagnosis codes for chronic HF (Supplementary material online, Table S1).

Sampling weights were applied to determine national incidence estimates, including pre-specified clustering and strata throughout the analysis, unless otherwise noted. Statistical analyses were performed using SPSS 25 (IBM SPSS Statistics, Armonk, NY, USA). Two-sided P -values < 0.05 were considered to be statistically significant. The NIS is a publicly available, de-identified dataset, and the study was exempt from institutional board review.

Results

Perioperative outcomes

A total of 21 560 996 hospitalizations for non-cardiac surgery were identified between 2012 and 2014, of which 1 063 405 (4.9%) had a diagnosis of HF during the hospitalization. This corresponds to $\sim 350\,000$ surgical hospitalizations in the USA each year. Among hospitalizations with documented HF, 4.7% reported acute decompensated HF alone, 27.8% reported acute on chronic HF, 11.3% reported chronic HF, and 56.2% reported an indeterminate ICD-9 diagnosis code for HF that did not specify the temporality of the HF diagnosis. Patients who were hospitalized for non-cardiac surgery with any diagnosis of HF were older (71.8 vs. 53.7 years, $P < 0.001$), less likely to be women (50.5% vs. 64.0%, $P < 0.001$), and had a greater burden of cardiovascular risk factors and comorbidities compared with patients without HF undergoing non-cardiac surgery (Table 1). Patients with HF were more likely to undergo vascular and orthopaedic surgery during the index hospitalization than patients without HF (Table 1).

Overall, in-hospital perioperative mortality occurred in 1.0% of patients undergoing surgery. Mortality was greater among patients with any diagnosis of HF compared with those without HF [4.8% vs. 0.78%, $P < 0.001$; adjusted odds ratio (aOR) 2.15, 95% confidence interval (CI) 2.09–2.22]. Risks of perioperative mortality in patients with and without HF are shown by subtype of non-cardiac surgery in Figure 1. Heart failure was associated with increased in-hospital mortality in all surgical subtypes, with the greatest odds of mortality during hospitalization for orthopaedic surgery (aOR 7.05, 95% CI 6.82–7.29). A diagnosis of HF was associated with in-hospital mortality in both men (aOR 2.36, 95% CI 2.28–2.43) and women (aOR 2.1, 95% CI 2.01–2.2). Heart failure was also associated with mortality in all subgroups stratified by region, location, teaching hospital status, and bed size, however, the association between HF and perioperative

Table 1 Characteristics of patients with and without heart failure undergoing non-cardiac surgery

Variables	Heart failure		P-value
	Yes (n = 1 063 405)	No (n = 20 497 591)	
Age (years) (SEM)	71.84 (0.07)	53.67 (0.05)	<0.001
Female sex	536 465 (50.5%)	13 120 240 (64.0%)	<0.001
Race/ethnicity			<0.001
White, non-Hispanic	753 830 (70.9%)	13 724 966 (67.0%)	
Black, non-Hispanic	150 150 (14.1%)	2 317 241 (11.3%)	
Hispanic	58 755 (5.5%)	2 028 960 (9.9%)	
Other	42 970 (4.0%)	1 216 045 (5.9%)	
Missing/unknown	57 700 (5.4%)	1 210 379 (5.9%)	
Tobacco (current or former)	288 385 (27.1%)	4 743 465 (23.1%)	<0.001
Obesity	195 050 (18.3%)	3 085 116 (15.1%)	<0.001
Hypertension	845 750 (79.5%)	9 006 466 (43.9%)	<0.001
Dyslipidaemia	484 460 (45.6%)	5 162 010 (25.2%)	<0.001
Diabetes mellitus	483 860 (45.5%)	3 599 440 (17.6%)	<0.001
Coronary artery disease	543 420 (51.1%)	2 116 445 (10.3%)	<0.001
Previous PCI	104 485 (9.8%)	574 625 (2.8%)	<0.001
Previous CABG	140 770 (13.2%)	522 420 (2.6%)	<0.001
Atrial fibrillation or flutter	384 645 (36.2%)	1 075 175 (5.3%)	<0.001
Prior venous thromboembolism	48 935 (4.6%)	472 470 (2.3%)	<0.001
Prior cerebrovascular accident	93 250 (8.8%)	626 030 (3.1%)	<0.001
Chronic kidney disease	398 940 (37.5%)	1 263 330 (6.2%)	<0.001
End-stage renal disease	124 375 (11.7%)	334 760 (1.6%)	<0.001
Peripheral artery disease	221 595 (20.8%)	992 795 (4.8%)	<0.001
Valvular disease	153 240 (14.4%)	481 395 (2.4%)	<0.001
Chronic pulmonary disease	351 935 (33.1%)	2 751 920 (13.4%)	<0.001
Malignancy	60 795 (5.7%)	790 900 (3.9%)	<0.001
Anaemia	348 210 (32.7%)	2 969 585 (14.5%)	<0.001
Drug abuse	17 515 (1.7%)	404 655 (2.0%)	<0.001
Alcohol abuse	28 055 (2.6%)	454 235 (2.2%)	<0.001
Coagulopathy	91 950 (8.7%)	636 975 (3.1%)	<0.001
Arthritis/collagen vascular disease	43 275 (4.1%)	513 720 (2.5%)	<0.001
Hospital characteristics			
Teaching hospital	635 150 (59.7%)	12 074 952 (58.9%)	0.004
Hospital size			<0.001
Small	138 995 (15.2%)	3 123 233 (13.1%)	
Medium	286 500 (27.1%)	5 549 958 (26.9%)	
Large	637 910 (57.7%)	11 824 399 (60.0%)	
Surgery subtype			
General	216 265 (20.3%)	4 098 750 (20.0%)	0.003
Endocrine	5 570 (0.52%)	166 110 (0.81%)	<0.001
Genitourinary	51 020 (4.8%)	1 063 135 (5.2%)	<0.001
Gynaecology	10 105 (0.95%)	1 026 095 (5.2%)	<0.001
Neurosurgery	34 650 (3.3%)	1 011 275 (4.9%)	<0.001
Obstetric	2 510 (0.24%)	3 480 710 (17.0%)	<0.001
Orthopaedics	428 195 (40.3%)	7 179 961 (35.0%)	<0.001
Otolaryngology	6325 (0.59%)	188 615 (0.92%)	<0.001
Skin/breast	56 820 (5.3%)	608 390 (3.0%)	<0.001
Thoracic	29 295 (2.8%)	340 750 (1.7%)	<0.001
Transplant	3315 (0.3%)	59 440 (0.29%)	0.113
Vascular	219 335 (20.6%)	1 274 360 (6.2%)	<0.001

Figure 1 In-hospital mortality by non-cardiac surgical subtype in patients with and without a diagnosis of heart failure.

Figure 2 Adjusted odds of mortality associated with a diagnosis of heart failure, stratified by hospital size (A) and hospital teaching status (B).

mortality was greatest at small (aOR 5.55, 95 CI 5.24–5.89) and non-teaching (aOR 4.11, 95 CI 3.98–4.24) hospitals (Figure 2).

Patients with any HF diagnosis were also more likely to have other cardiovascular complications during the surgical hospitalization, including perioperative acute MI, ischaemic stroke, acute pulmonary embolism, and cardiac arrest (Table 2). Risks of perioperative cardiovascular complications associated with HF are shown in subgroups by sex, hospital size, and teaching status in [Supplementary material online, Tables S2–S4](#). Associations between HF and perioperative outcomes were also observed after excluding patients undergoing low-risk obstetric surgeries ([Supplementary material online, Table S5](#)) and after excluding patients undergoing urgent or emergent surgeries.

Acute decompensated HF without a diagnosis of chronic HF was associated with 8.0% post-operative in-hospital mortality (vs. 0.78% in those without HF, $P < 0.001$; aOR 2.79, 95 CI 2.57–3.03). In the

setting of chronic HF without documentation of acute decompensated HF, post-operative in-hospital mortality was 3.9% (vs. 0.78% in those without HF, $P < 0.001$; aOR 1.53, 95 CI 1.47–1.61). Mortality among patients without an ICD-9 diagnosis code specifying the acuity or chronicity of the HF diagnosis was 4.4%. Adjusted odds of perioperative mortality associated with HF are shown in Figure 3, grouped by acuity of the HF presentation.

Perioperative outcomes of patients with acute on chronic heart failure

Chronic HF was documented during 415 845 hospitalizations for non-cardiac surgery. Among these, a diagnosis of acute on chronic HF was reported in 120 150 (28.9%) hospitalizations. Characteristics of patients with acute on chronic HF are shown in Table 3. Patients with acute on chronic HF were more likely to have atrial fibrillation or flutter (43.5% vs. 38.5%, $P < 0.001$), chronic kidney disease (47.3% vs. 41.5%, $P < 0.001$), chronic pulmonary disease (34.4% vs. 31.7%, $P < 0.001$), peripheral artery disease (24.3% vs. 21.7%, $P < 0.001$), and valvular heart disease (18.9% vs. 15.6%, $P < 0.001$). Hospitalizations for vascular and general surgery were more common among those assigned a diagnosis of acute on chronic HF. Patients diagnosed with perioperative acute on chronic HF had higher in-hospital all-cause mortality compared to patients with chronic HF without acute decompensation (7.8% vs. 3.9%, $P < 0.001$; aOR 1.78, 95 CI 1.67–1.90). Associations between acute on chronic HF and perioperative acute MI, pulmonary embolism, and cardiac arrest were also observed (Table 4).

Discussion

In a large US database of hospital admissions, we identified a diagnosis of HF in 4.9% of hospitalizations for non-cardiac surgery. Heart failure was associated with an increased risk of perioperative morbidity and mortality. Patients with all types of HF (acute, chronic, acute on chronic, and indeterminate) had higher mortality than patients without HF. Among patients with chronic HF, the greatest risk of perioperative mortality was observed in those with a concomitant

Table 2 Frequency of perioperative major adverse cardiovascular events in patients with and without heart failure

Outcomes	Heart failure		P-value	aOR (95% CI) ^a
	Yes (n = 1 063 405)	No (n = 20 497 591)		
Death	51 235 (4.8%)	160 745 (0.78%)	<0.001	2.15 (2.09–2.22)
Acute myocardial infarction	44 325 (4.2%)	67 585 (0.33%)	<0.001	3.55 (3.41–3.69)
Acute ischaemic stroke	20 460 (1.9%)	103 595 (0.50%)	<0.001	1.39 (1.33–1.45)
Acute pulmonary embolism	23 960 (2.3%)	139 645 (0.68%)	<0.001	1.62 (1.56–1.69)
Cardiac arrest	15 480 (1.5%)	45 835 (0.22%)	<0.001	2.22 (2.10–2.35)

^aOdds ratio adjusted for age, sex, race/ethnicity, tobacco use, obesity, hypertension, hyperlipidaemia, diabetes, coronary artery disease, history of PCI, history of CABG, peripheral artery disease, atrial fibrillation or atrial flutter, COPD, CKD, ESRD, any malignancy, any anaemia, drug abuse, alcohol abuse, coagulopathy, rheumatoid arthritis or collagen vascular disease, and surgery type.

diagnosis of acute decompensated HF. The findings from the present study validate prior associations between HF and adverse perioperative outcomes. In addition, we found that HF was associated with perioperative mortality across all major surgical subtypes, with the greatest odds of mortality in orthopaedic surgery. The odds of mortality associated with HF were also greatest at small and non-teaching hospitals.

Heart failure has been recognized as a risk factor for cardiovascular events after non-cardiac surgery for decades. In the landmark 1977 publication, Goldman *et al.*⁷ proposed a multifactorial index of perioperative cardiac risk, in which preoperative clinical markers of HF (an S3 gallop or elevation of jugular venous pressure) were associated with life-threatening cardiovascular complications and cardiac death. The Revised Cardiac Risk Index incorporated a history of congestive HF as an important preoperative risk factor.⁶ Heart failure has also been associated with perioperative morbidity and mortality in other surgical cohorts.¹² Among patients undergoing lower extremity revascularization, the odds of 30-day mortality were two-fold greater among patients with HF compared to those without HF.¹³ Similar associations were reported in patients undergoing general surgery for diverticulitis.¹⁴ Few large studies have evaluated the association between perioperative HF and outcomes. One such analysis of a Medicare database reported that older adults with HF had a substantially greater risk of operative mortality and readmission after

non-cardiac surgery than patients with CAD, or patients without cardiovascular disease.⁴ Likewise, an analysis of the American College of Surgeons National Surgical Quality Improvement Program (ACS NSQIP) database reported an association between HF and adverse outcomes including intubation, renal failure, MI, and 30-day all-cause mortality.⁵ Unfortunately, the NSQIP study only included 7582 patients with HF due to a restrictive definition that required a new HF diagnosis or signs and symptoms of HF within the 30 days prior to surgery. A Canadian population-based cohort study reported greater perioperative mortality and higher risks of rehospitalization in patients with HF undergoing non-cardiac surgery compared to those with CAD, but the study did not compare outcomes to unselected patients without HF.¹² Finally, a more recent study from the predominantly male Veterans Affairs Surgical Quality Improvement Project (VASQIP) database reported HF in 7.9% of patients undergoing non-cardiac surgery. Post-operative mortality at 90 days was 1.2% in patients without HF, and 4.9% and 10.1% in patients with asymptomatic and symptomatic HF, respectively. In the VASQIP analysis, any HF was associated with a nearly two-fold greater risk of post-operative mortality after adjustment for demographics and clinical variables.³

Consistent with prior studies, the present analysis of nationwide data from the US reports that patients with any diagnosis of HF have increased risks of perioperative mortality in all major surgical subtypes, with a particularly elevated risk in patients undergoing orthopaedic surgery. This observation may be in part due to a comparatively healthy cohort of patients without HF referred for relatively low-risk orthopaedic surgery. Although risks of perioperative morbidity and mortality were greatest among patients with acute decompensated HF, we also report substantial risk among patients with chronic HF without acute HF. Consequently, renewed efforts are necessary to mitigate the risk of adverse cardiovascular outcomes in these vulnerable cohorts.

Refined preoperative risk stratification may be necessary to identify HF patients at the greatest risk of perioperative complications. Echocardiography and cardiovascular biomarkers such as B-type natriuretic peptide may predict perioperative risk, although these modalities have not been incorporated into the latest perioperative clinical practice guidelines.^{15–21} Although guidance on the perioperative management of patients with HF is scant, deferral of elective non-cardiac surgery may be warranted to optimize preoperative

Table 3 Characteristics of patients with chronic heart failure undergoing non-cardiac surgery, with and without perioperative acute decompensated HF

Variables	Acute on chronic HF (n = 120 150)	Chronic HF without acute decompensated HF (n = 295 695)	P-value
Demographics			
Age (years) (SEM)	73.37 (0.10)	72.54 (0.07)	<0.001
Female sex	58 315 (48.5%)	143 930 (48.7%)	0.711
Race/ethnicity			<0.001
White, non-Hispanic	85 885 (71.5%)	208 890 (70.6%)	
Black, non-Hispanic	16 230 (13.5%)	41 760 (14.1%)	
Hispanic	6365 (5.3%)	14 795 (5.0%)	
Other	5115 (4.26%)	11 390 (3.9%)	
Missing/unknown	6555 (5.5%)	18 860 (6.4%)	
Comorbidities			
Tobacco (current or former)	27 900 (23.2%)	78 375 (26.5%)	<0.001
Obesity	18 835 (15.7%)	52 715 (17.8%)	<0.001
Hypertension	90 880 (75.6%)	236 470 (80.0%)	<0.001
Dyslipidaemia	50 050 (41.7%)	142 125 (48.1%)	<0.001
Diabetes mellitus	54 575 (45.4%)	137 315 (46.4%)	0.009
Coronary artery disease	63 270 (52.7%)	159 510 (53.9%)	0.001
Previous PCI	10 305 (8.6%)	31 425 (10.6%)	<0.001
Previous CABG	15 410 (12.8%)	41 455 (14.0%)	<0.001
Atrial fibrillation or flutter	52 280 (43.5%)	113 880 (38.5%)	<0.001
Prior venous thromboembolism	4170 (3.5%)	14 175 (4.8%)	<0.001
Prior cerebrovascular accident	8260 (6.9%)	26 490 (9.0%)	<0.001
Chronic kidney disease	56 805 (47.3%)	122 765 (41.5%)	<0.001
End-stage renal disease	15 265 (12.7%)	34 915 (11.8%)	<0.001
Peripheral artery disease	29 250 (24.3%)	64 050 (21.7%)	<0.001
Valvular disease	22 665 (18.9%)	46 090 (15.6%)	<0.001
Chronic pulmonary disease	41 345 (34.4%)	93 790 (31.7%)	<0.001
Malignancy	7445 (6.2%)	16 105 (5.5%)	<0.001
Anaemia	45 325 (37.7%)	95 265 (32.2%)	<0.001
Drug abuse	2015 (1.7%)	5065 (1.7%)	0.724
Alcohol abuse	3170 (2.6%)	7505 (2.5%)	0.407
Coagulopathy	14 130 (11.8%)	25 310 (8.6%)	<0.001
Arthritis/collagen vascular disease	4340 (3.6%)	11 825 (4.0%)	0.01
Surgery type			
General	25 525 (21.2%)	54 585 (18.5%)	<0.001
Endocrine	470 (0.39%)	1225 (0.41%)	0.643
Genitourinary	6090 (5.1%)	12 905 (4.4%)	<0.001
Gynaecology	630 (0.52%)	2120 (0.72%)	0.002
Neurosurgery	2700 (2.3%)	9310 (3.2%)	<0.001
Obstetric	185 (0.15%)	245 (0.08%)	0.004
Orthopaedics	38 740 (32.2%)	132 935 (45.0%)	<0.001
Otolaryngology	570 (0.47%)	1625 (0.55%)	0.17
Skin/breast	7945 (6.6%)	15 555 (5.3%)	<0.001
Thoracic	4655 (3.9%)	7450 (2.5%)	<0.001
Transplant	115 (0.10%)	590 (0.20%)	0.003
Vascular	32 525 (27.1%)	57 150 (19.3%)	<0.001

haemodynamics and ensure adequate diuresis in high-risk cohorts of patients with clinically apparent HF.^{3,13,22,23}

Hospital characteristics may impact outcomes of surgery in patients with and without HF. In this analysis, large hospitals and

teaching facilities performed a greater proportion of urgent and high-risk surgeries, and consequently, had a higher frequency of post-operative cardiovascular complications than small and non-teaching hospitals. However, we observed the greatest adjusted odds of

Table 4 Frequency of perioperative major adverse cardiovascular events in patients with chronic heart failure, with and without perioperative acute decompensated HF

Outcomes	Acute on chronic HF (n = 120 150)	Chronic HF without acute decompensated HF (n = 295 695)	P-value	aOR (95%CI) ^a
Death	9420 (7.8%)	11 515 (3.9%)	<0.001	1.78 (1.67–1.90)
Acute myocardial infarction	11 395 (9.5%)	7745 (2.6%)	<0.001	3.76 (3.50–4.05)
Acute ischaemic stroke	2975 (2.5%)	5800 (2.0%)	<0.001	1.09 (0.98–1.20)
Acute pulmonary embolism	4525 (3.8%)	5345 (1.8%)	<0.001	1.75 (1.59–1.93)
Cardiac arrest	2910 (2.4%)	3605 (1.2%)	<0.001	1.79 (1.59–2.00)

^aOdds ratio adjusted for age, sex, race/ethnicity, tobacco use, obesity, hypertension, hyperlipidaemia, diabetes, coronary artery disease, history of PCI, history of CABG, peripheral artery disease, atrial fibrillation or atrial flutter, COPD, CKD, ESRD, any malignancy, any anaemia, drug abuse, alcohol abuse, coagulopathy, rheumatoid arthritis or collagen vascular disease, and surgery type.

mortality associated with HF in smaller hospitals and non-teaching facilities. This may suggest that hospital volume, experience, and resources affect perioperative outcomes in patients with HF, a finding consistent with prior literature suggesting an overall lower risk of operative death at centres with the highest surgical volumes, and lower overall HF-associated mortality at high-volume hospitals.^{24,25} Although the systems of care underlying this observation cannot be identified using administrative data from the present analysis, large teaching hospitals may be more likely to adhere to HF process measures, perform thorough preoperative cardiovascular evaluation, institute careful perioperative haemodynamic monitoring, have improved nurse and physician staffing during the surgical hospitalization, and provide rapid access to expert cardiovascular medicine and anaesthesiology specialists than small and non-teaching hospitals.²⁶ Alternatively, this finding may simply reflect a relatively low-risk profile of surgical patients without HF at small centres and non-teaching hospitals. Still, based on the findings of this study, referral to be a large, experienced surgical centre may be preferred in patients with pre-existing or at increased risk for HF.

Limitations

There are a number of limitations of the present analysis. First, data were obtained from a large US administrative database and may be subject to errors in misclassification and miscoding. Second, potential clinical confounders, including laboratory values, results of cardiovascular imaging (including assessment of left ventricular ejection fraction), haemodynamic data, preoperative medications, intraoperative fluid management, and perioperative haemodynamic monitoring strategies are not reported in the NIS. Third, the sequence of diagnoses cannot be reliably established from the NIS. Consequently, the temporal relationship between acute HF diagnoses and thromboembolic complications remains uncertain. Acute HF may result as a consequence of a venous or arterial thromboembolic complication of surgery, such as MI, or from other perioperative complications, such as renal failure. Conversely, thromboembolic complications may result as a consequence of a hypercoagulable state associated with HF.^{5,14,27} Perioperative antithrombotic agents were not reported in this administrative database. Although antithrombotic agents have not been specifically studied in patients with HF undergoing non-cardiac surgery, perioperative aspirin administration was

not associated with benefit in a large randomized clinical trial.²⁸ Prospective investigations will be necessary to further evaluate this relationship. Finally, the NIS is limited to in-hospital outcomes and deaths that occurred early after discharge were not captured. Therefore, early post-operative mortality may be underestimated in the present analysis.

Conclusions

In an analysis of a large US database, 4.9% of hospitalizations for non-cardiac surgery were associated with a diagnosis of HF. Patients with HF had a high burden of thromboembolic events and an increased risk of perioperative mortality, with the greatest risks in patients who had acute decompensated HF. These findings validate observations from smaller cohorts and highlight the need for novel strategies to reduce perioperative risk in patients with a diagnosis of HF.

Supplementary material

Supplementary material is available at *European Heart Journal – Quality of Care and Clinical Outcomes* online.

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References

1. Benjamin EJ, Muntner P, Alonso A, Bittencourt MS, Callaway CW, Carson AP et al.; American Heart Association Council on Epidemiology and Prevention Statistics Committee and Stroke Statistics Subcommittee. Heart disease and

- stroke statistics-2019 update: a report from the American Heart Association. *Circulation* 2019;**139**:e56–e528.
2. Smilowitz NR, Gupta N, Guo Y, Beckman JA, Bangalore S, Berger JS. Trends in cardiovascular risk factor and disease prevalence in patients undergoing noncardiac surgery. *Heart* 2018;**104**:1180–1186.
  3. Lerman BJ, Popat RA, Assimes TL, Heidenreich PA, Wren SM. Association of left ventricular ejection fraction and symptoms with mortality after elective noncardiac surgery among patients with heart failure. *JAMA* 2019;**321**:572–579.
  4. Hammill BG, Curtis LH, Bennett-Guerrero E, O'Connor CM, Jollis JG, Schulman KA et al. Impact of heart failure on patients undergoing major noncardiac surgery. *Anesthesiology* 2008;**108**:559–567.
  5. Turrentine FE, Sohn MW, Jones RS. Congestive heart failure and noncardiac operations: risk of serious morbidity, readmission, reoperation, and mortality. *J Am Coll Surg* 2016;**222**:1220–1229.
  6. Lee TH, Marcantonio ER, Mangione CM, Thomas EJ, Polanczyk CA, Cook EF et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. *Circulation* 1999;**100**:1043–1049.
  7. Goldman L, Caldera DL, Nussbaum SR, Southwick FS, Krogstad D, Murray B et al. Multifactorial index of cardiac risk in noncardiac surgical procedures. *N Engl J Med* 1977;**297**:845–850.
  8. Smilowitz NR, Gupta N, Ramakrishna H, Guo Y, Berger JS, Bangalore S. Perioperative major adverse cardiovascular and cerebrovascular events associated with noncardiac surgery. *JAMA Cardiol* 2017;**2**:181–187.
  9. Al-Khatib SM, Hellkamp AS, Fonarow GC, Mark DB, Curtis LH, Hernandez AF et al. Association between prophylactic implantable cardioverter-defibrillators and survival in patients with left ventricular ejection fraction between 30% and 35%. *JAMA* 2014;**311**:2209–2215.
  10. Brinjikji W, Rabinstein AA, Kallmes DF, Cloft HJ. Patient outcomes with endovascular embolectomy therapy for acute ischemic stroke: a study of the national inpatient sample: 2006 to 2008. *Stroke* 2011;**42**:1648–1652.
  11. NIS Description of Data Elements. *Healthcare Cost and Utilization Project (HCUP)*. Rockville, MD: Agency for Healthcare Research and Quality; 2018. www.hcup-us.ahrq.gov/db/nation/nis/nisde.jsp.
  12. van Diepen S, Bakal JA, McAlister FA, Ezekowitz JA. Mortality and readmission of patients with heart failure, atrial fibrillation, or coronary artery disease undergoing noncardiac surgery: an analysis of 38 047 patients. *Circulation* 2011;**124**:289–296.
  13. Amdur RL, Ashby B, Neville R, Tunstall A, Nguyen BN, Sidawy A. The effect of congestive heart failure on perioperative outcomes in patients undergoing lower extremity revascularization. *J Vasc Surg* 2016;**63**:1289–1295.
  14. Sheer AJ, Heckman JE, Schneider EB, Wu AW, Segal JB, Feinberg R et al. Congestive heart failure and chronic obstructive pulmonary disease predict poor surgical outcomes in older adults undergoing elective diverticulitis surgery. *Dis Colon Rectum* 2011;**54**:1430–1437.
  15. Matyal R, Hess PE, Subramaniam B, Mitchell J, Panzica PJ, Pomposelli F et al. Perioperative diastolic dysfunction during vascular surgery and its association with postoperative outcome. *J Vasc Surg* 2009;**50**:70–76.
  16. Healy KO, Waksmonski CA, Altman RK, Stetson PD, Reyentovich A, Maurer MS. Perioperative outcome and long-term mortality for heart failure patients undergoing intermediate- and high-risk noncardiac surgery: impact of left ventricular ejection fraction. *Congest Heart Fail* 2010;**16**:45–49.
  17. Upshaw J, Kiernan MS. Preoperative cardiac risk assessment for noncardiac surgery in patients with heart failure. *Curr Heart Fail Rep* 2013;**10**:147–156.
  18. Devereaux PJ, Sessler DI. Cardiac complications in patients undergoing major noncardiac surgery. *N Engl J Med* 2015;**373**:2258–2269.
  19. Dernellis J, Panaretou M. Assessment of cardiac risk before non-cardiac surgery: brain natriuretic peptide in 1590 patients. *Heart* 2006;**92**:1645–1650.
  20. Villacorta Junior H, Castro IS, Godinho M, Mattos C, Visconti R, Saud M et al. B-type natriuretic peptide is predictive of postoperative events in orthopedic surgery. *Arq Bras Cardiol* 2010;**95**:743–748.
  21. Ryding AD, Kumar S, Worthington AM, Burgess D. Prognostic value of brain natriuretic peptide in noncardiac surgery: a meta-analysis. *Anesthesiology* 2009;**111**:311–319.
  22. Flu WJ, van Kuijk JP, Hoeks SE, Kuiper R, Schouten O, Goei D et al. Prognostic implications of asymptomatic left ventricular dysfunction in patients undergoing vascular surgery. *Anesthesiology* 2010;**112**:1316–1324.
  23. Fleisher LA, Fleischmann KE, Auerbach AD, Barnason SA, Beckman JA, Bozkurt B et al. 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines. *J Am Coll Cardiol* 2014;**64**:e77–e137.
  24. Birkmeyer JD, Siewers AE, Finlayson EV, Stukel TA, Lucas FL, Batista I et al. Hospital volume and surgical mortality in the United States. *N Engl J Med* 2002;**346**:1128–1137.
  25. McAlister FA, Youngson E, van Diepen S, Ezekowitz JA, Kaul P. Influence of hospital volume on outcomes for patients with heart failure: evidence from a Canadian national cohort study. *Am Heart J* 2018;**202**:148–150.
  26. Kumbhani DJ, Fonarow GC, Heidenreich PA, Schulte PJ, Lu D, Hernandez A et al. Association between hospital volume, processes of care, and outcomes in patients admitted with heart failure: insights from get with the guidelines-heart failure. *Circulation* 2018;**137**:1661–1670.
  27. Meltzer AJ, Shrikhande G, Gallagher KA, Aiello FA, Kahn S, Connolly P et al. Heart failure is associated with reduced patency after endovascular intervention for symptomatic peripheral arterial disease. *J Vasc Surg* 2012;**55**:353–362.
  28. Devereaux PJ, Mrkobrada M, Sessler DI, Leslie K, Alonso-Coello P, Kurz A et al. Aspirin in patients undergoing noncardiac surgery. *N Engl J Med* 2014;**370**:1494–1503.