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Preoperative clinical diagnostic accuracy of heart failure among patients undergoing major noncardiac surgery: a single-centre prospective observational analysis

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Abstract

Background: Reliable diagnosis of heart failure during preoperative evaluation is important for perioperative management and long-term care. We aimed to quantify preoperative heart failure diagnostic accuracy and explore characteristics of patients with heart failure misdiagnoses.

Methods: We performed an observational cohort study of adults undergoing major noncardiac surgery at an academic hospital between 2015 and 2019. A preoperative clinical diagnosis of heart failure was defined using keywords from the history and clinical examination or administrative documentation. Across stratified subsamples of cases with and without clinically diagnosed heart failure, health records were intensively reviewed by an expert panel to develop an adjudicated heart failure reference standard using diagnostic criteria congruent with consensus guidelines. We calculated agreement among experts, and analysed performance of clinically diagnosed heart failure compared with the adjudicated reference standard.

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Authors' contributions

Concept: MRM

Design of the work: JRG, HJ, MRM

Analyses performed: JRG

Statistical analyses: RBC

Querying and curation of the cohort studied: HJ

All authors were involved in the interpretation of data, revisions to the work for important intellectual content, and final approval of the version to be published, and agreed to accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.bjao.2022.100113.

Results: Across 40 555 major noncardiac procedures, a stratified subsample of 511 patients was reviewed by the expert panel. The prevalence of heart failure was 9.1% based on clinically diagnosed compared with 13.3% (95% confidence interval [CI], 10.3–16.2%) estimated by the expert panel. Overall agreement and inter-rater reliability (kappa) among heart failure experts were 95% and 0.79, respectively. Based upon expert adjudication, heart failure was clinically diagnosed with an accuracy of 92.8% (90.6–95.1%), sensitivity 57.4% (53.1–61.7%), specificity 98.3% (97.1–99.4%), positive predictive value 83.5% (80.3–86.8%), and negative predictive value 93.8% (91.7–95.9%).

Conclusions: Limitations exist to the preoperative clinical diagnosis of heart failure, with nearly half of cases undiagnosed preoperatively. Considering the risks of undiagnosed heart failure, efforts to improve preoperative heart failure diagnoses are warranted.

Keywords

cardiac risk assessment; diagnostic accuracy; electronic health record; heart failure; noncardiac surgery; observational study; preoperative evaluation

Heart failure is among the greatest risk factors for adverse events after noncardiac surgery, and is independently associated with major complications,[1,2] longer postoperative hospital stays,[3] more frequent readmissions,[4] and higher postoperative mortality.[5] Despite advances in heart failure therapies, timely and accurate diagnosis of heart failure remains challenged by the heterogeneity of clinical presentations and course of the disease.[6] Among studies of hospitalised patients and outpatients, 25–40% of patients with sufficient electronic health record documentation to define heart failure do not have an established diagnosis of heart failure.[7,8] Taken together, these studies suggest that an accurate preoperative diagnosis of heart failure – if leading to improved perioperative management and earlier initiation of guideline-directed medical therapies proven to reduce mortality – potentially carries substantial public health impact for the more than 300 million noncardiac surgical procedures performed annually worldwide.[9]

During the preoperative surgical evaluation, a wealth of health data (e.g. comprehensive history and clinical examination, laboratory test results, cardiovascular system investigations) are routinely collected, and represent an opportunity for enhanced diagnosis of heart failure. This importance is underscored by findings showing that among patients with heart failure detected by rule-based electronic health record algorithms, a failure to diagnose and document heart failure preoperatively is associated with increased length of stay and mortality.[10] Although identifying heart failure preoperatively has the potential to improve outcomes after noncardiac surgery, data are lacking as to the accuracy of heart failure diagnoses by clinicians during preoperative evaluations.

To characterise the accuracy of clinical diagnoses of heart failure in the preoperative setting, we performed an observational cohort study. The aims of this study were to (1) compare the quality of heart failure diagnoses documented preoperatively to those established through expert adjudication; and (2) explore characteristics of patients with heart failure misdiagnoses.

Methods

We obtained institutional review board approval (HUM00143523, University of Michigan, August 8, 2018) for this observational study and patient consent was waived. We followed the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) guidelines in conducting this study.[11] An *a priori* study protocol was approved within a peer-review forum[12] and registered before analysis.[13] Data were extracted from the Multicenter Perioperative Outcomes Group (MPOG) electronic anaesthesiology database, our hospital enterprise electronic health record, and a web-based survey tool (Supplementary Methods S1).[14–16] To enable transparency and reproducibility, data were processed using pre-computed, publicly available, universal perioperative electronic health record phenotype algorithms.[17]

Study design

We conducted an observational analysis of adult patients >40 yr old undergoing index major noncardiac surgical procedures at our quaternary academic medical centre from 1 August 2015 to 31 May 2019. Major noncardiac surgical procedures were defined as those performed under general anaesthesia for >60 min with a Centers for Medicare & Medicaid Services anaesthesiology base unit value >4 (i.e. procedures excluding those with lowest relative value units, such as cataract operations, endoscopies, or skin biopsies). We excluded cardiac surgical procedures as undiagnosed heart failure would be unexpected in this population because of extensive preoperative cardiac evaluation and potential use of intraoperative testing for heart failure (e.g. echocardiography). Additional cases were excluded for similar reasons, and patients with preoperative mechanical circulatory support, inotrope infusions, mechanical ventilation, history of heart or lung transplant, or ASA 5 or 6 physical status classification.

Among cases meeting inclusion criteria, statistically balanced random subsamples of patients with and without a clinical diagnosis of heart failure (described later) were selected for expert review and inclusion in the final analytic dataset. The subset of patients without a preoperative clinical diagnosis of heart failure was further stratified into: (1) *high probability* patients, defined as those patients lacking a preoperative clinical diagnosis but then developing a clinical diagnosis within 365 days postoperatively and (2) *low probability* patients, defined as all other patients. To maximise the value of heart failure expert adjudication, patients with a *high probability* of preoperative heart failure were oversampled; importantly, post-stratification weights were retained in order to determine performance characteristics of preoperative clinical diagnoses of heart failure across the full study cohort. Post-stratification weights were determined by the total number of patients in each subsample: (1) no clinical diagnosis of heart failure/high probability; (2) no clinical diagnosis of heart failure/low probability; and (3) clinical heart failure diagnosis.

Heart failure diagnosis adjudication – expert panel intensive review

To develop a reference standard of patients with and without heart failure, a subset of cases meeting inclusion criteria underwent adjudication via intensive manual review by a clinician panel of heart failure experts (four cardiologists, five cardiac anaesthesiologists, and nine

intensivists). All cases were adjudicated by at least two experts; in cases of disagreement, a third expert determined the diagnosis. Before reviews, all experts completed an online training module (Supplementary Methods S2) and underwent calibration on a practice set of patients upon which they received feedback.

To ensure rigorous review before determining an adjudicated heart failure diagnosis, experts completed web-based surveys for determining a heart failure diagnosis (Supplementary Methods S3) with survey time tracked, audited, and attested to by each expert. Experts were required to document all *available* relevant preoperative cardiac imaging findings (e.g. left ventricular ejection fraction, diastolic function) and all positive/negative mentions (or missingness) of all heart failure signs and symptoms comprising prior established criteria and consensus guidelines for the diagnosis of heart failure.[18–20] Reviewers documented all available diagnostic data for heart failure within the survey, and each reviewer's adjudicated diagnosis of heart failure was based upon their expert judgement in congruence with consensus guidelines and consistent with clinical practice. In addition, reviewers provided their diagnostic certainty (Supplementary Fig. S4).

Heart failure definitions – adjudicated diagnosis *vs* clinical diagnosis

To maximise diagnostic agreement across *adjudicated* diagnoses, experts specifically evaluated for American College of Cardiology/American Heart Association (ACC/AHA) guidelines chronic Stage C heart failure (structural heart disease with prior or current symptoms of heart failure) or Stage D heart failure (advanced heart failure). Consistent with guideline recommendations, Stage B heart failure, or structural heart disease in the absence of current or prior symptoms of heart failure, was specifically adjudicated as *not* heart failure.[19] The date of surgery, before the operation, was used as the reference time point for the adjudicated heart failure diagnosis.

Conversely, a preoperative *clinical* diagnosis of heart failure was defined as either (1) positive mention (structured data or unstructured free text confirmed via manual review) of heart failure (Stage C, D, or unspecified) within the anaesthesia preoperative history and clinical examination, or (2) an International Classification of Diseases (ICD) diagnosis code for heart failure (Supplementary Table S5). Also, we performed a sensitivity analysis in which the clinical diagnosis of heart failure additionally included any patient with a preoperative left ventricular ejection fraction ≤40%, a diagnosis code for cardiomegaly or hypertrophic cardiomyopathy. This analysis was designed to account for patients with ACC/AHA Stage B heart failure, a group with a high likelihood of receiving a heart failure diagnosis preoperatively.

Primary outcome – heart failure clinical diagnosis accuracy

We defined the primary outcome as an accurate preoperative clinical diagnosis of heart failure (true positive or true negative) as compared with the adjudicated heart failure reference standard. Clinical diagnostic accuracy was calculated as (true positive + true negative)/(true positive + true negative + false positive + false negative).

Missing or invalid data

Outlier values were treated as missing if outside of valid ranges described in MPOG phenotype specifications.[17] Variables with >10% missing data were excluded from analyses, with the exception of preoperative left ventricular ejection fraction and diastolic dysfunction, which were each classified as categorical variables including 'missing'.

Statistical analysis

Descriptive statistics were calculated for all perioperative variables, and graphical assessments for normality, symmetry, and potential outliers were performed. Variables showing standardised differences larger than 0.2 in absolute value were considered significant, comparing patients with accurate heart failure diagnoses to those with misdiagnoses. To characterise the validity of the adjudicated heart failure reference standard, the percentage absolute agreement and inter-rater agreement, computed as Cohen's kappa statistic, were used.

Accuracy, sensitivity, specificity, positive predictive value, and negative predictive value of preoperative clinical heart failure diagnoses were calculated using the adjudicated heart failure diagnosis as a reference standard and adjusting for post-stratification weights of each subset reviewed (i.e. number of patients with: (1) a clinical diagnosis of heart failure, (2) no clinical diagnosis of heart failure and *high probability* patient, and (3) no clinical diagnosis of heart failure and *low probability* patient). Statistical analyses were performed using SAS version 9.4 (SAS Institute, Inc., Cary, NC, USA).

Sample size calculation

Among patients adjudicated through expert panel review, for a minimum acceptable kappa of 0.70, expected kappa of 0.80, proportion of adjudicated heart failure diagnoses of 50%, significance level α=0.05 and study power (1–β) of 0.80, a sample of 401 adjudicated patients was required.[21] Among patients in the full study cohort, for an expected sensitivity of 75%, specificity of 95%, baseline heart failure prevalence of 5.5%,[22] acceptable error of 5.0%, and significance level α=0.05, a sample of 5,239 full study cohort patients was required.[23]

Results

Among 55 170 adult noncardiac surgical procedures queried, 40 555 met inclusion criteria (Supplementary Fig. S6). Within this full cohort, 3698 cases (9.1%) had a clinical diagnosis of heart failure. Among 36 857 (90.9%) patients *without* clinical heart failure, 264 (0.7% of full cohort) developed clinical heart failure within 365 days postoperatively (*high probability* patients), whereas 36 593 (90.2% of full cohort) remained free of clinically diagnosed heart failure (*low probability* patients). These groups (3698 with clinical heart failure diagnosis; 36 593 with no clinical heart failure diagnosis/low probability; and 264 with no clinical heart failure diagnosis/high probability) determined post-stratification weights as discussed later. Within each group, balanced subsamples of 237 patients with a clinical diagnosis of heart failure and 274 patients without a clinical diagnosis of heart failure (composed of 76 *high*

probability and 198 *low probability* patients) underwent heart failure expert panel review, totalling 511 patients (Fig. 1).

Heart failure expert reviews

During heart failure expert review, median and inter-quartile range (IQR) active review times for each patient were 28 and 19–41 min, respectively. There was agreement among experts (independent of certainty level) for 458 of 511 of patients (90%) with an inter-rater reliability (kappa) of 0.79 (95% confidence interval [CI], 0.74–0.84; Tables 1 and 2). After accounting for post-stratification weights of each subsample used for expert review, estimated reviewer agreement for the full cohort was 95% (94–97%).

Patient baseline characteristics

Baseline characteristics of the full cohort and patients undergoing heart failure expert adjudication are presented in Tables 3 and 4. Data missingness was <10% for all variables in the adjudicated cohort. Overall, the full cohort had a median age of 62 yr (IQR 53–70), 49% were female, and 87% were Caucasian. Among expert-adjudicated patients, the median age was 64 yr (IQR 56–73), 41% were female, and 87% were Caucasian.

Study outcomes – performance of clinically diagnosed heart failure

After expert review, 39 of 237 cases *with* a clinical heart failure diagnosis (16%) were determined not to have heart failure (false positives), and 34 of 274 cases *without* preoperative heart failure documentation (12%) were determined to have heart failure (false negatives) (Table 5). After accounting for post-stratification weights and the baseline prevalence of clinically diagnosed heart failure (9.1%), the true prevalence of heart failure across the overall surgical cohort was estimated to be significantly higher at 13.3% (95% CI, 10.3–16.2%).

Using the adjudicated diagnosis of heart failure as a reference standard and adjusting for post-stratification weights of subsets reviewed, the estimated accuracy of the preoperative clinical diagnosis of heart failure was 92.8% (95% CI, 90.6–95.1%). In addition, the estimated sensitivity of clinically diagnosed heart failure was 57.4% (53.1–61.7%), specificity 98.3% (97.1–99.4%), positive predictive value 83.5% (80.3–86.8%), and negative predictive value 93.8% (91.7–95.9%).

The 13.3% of patients with an adjudicated diagnosis of heart failure (true positives + false negatives) was composed of 7.6% (5.3–9.9%) *with* a clinical diagnosis (true positives) and 5.7% (3.7–7.7%) *without* a clinical diagnosis (false negatives). Thus, almost half (i.e. 42.6% [38.3–46.9%]) of patients with heart failure preoperatively were undiagnosed by clinicians (1–sensitivity). Compared with patients *with* a clinical diagnosis of heart failure (true positives), those *without* a clinical diagnosis (false negatives) were more commonly younger and female; had higher left ventricular ejection fractions, less diastolic dysfunction, fewer comorbidities, lower BMIs, lower haemoglobin A1c concentrations and international normalised ratio coagulation assays, higher platelet counts, and lower ASA physical status classifications; and more frequently underwent trauma surgery (Table 6).

Conversely, the estimated 86.7% of patients *without* an adjudicated diagnosis of heart failure (true negatives + false positives) was composed of 85.2% (82.1–88.3%) *without* a clinical diagnosis (true negatives) and 1.5% (0.4–2.6%) *with* a clinical diagnosis (false positives). This corresponded to 1.7% (0.6–2.9%) of patients being incorrectly diagnosed as having heart failure by clinicians. Compared with patients *without* a clinical diagnosis of heart failure (true negatives), patients *with* a clinical diagnosis (false positives) were older; had more cardiovascular comorbidities, lower left ventricular ejection fractions, less diastolic dysfunction, higher BMIs, higher ASA physical status classifications; and more frequently underwent thoracic, trauma, or vascular surgery.

Sensitivity analysis

In a sensitivity analysis in which clinically diagnosed heart failure was expanded to include patients with a preoperative left ventricular ejection fraction ≤40%, irrespective of the presence of a heart failure diagnosis, or had a diagnosis code for cardiomegaly or hypertrophic cardiomyopathy, 315 additional patients were identified (7.8% of total patients with clinically diagnosed heart failure, n=4013). Heart failure diagnostic accuracy improved to 94.4% (95% CI, 92.4–96.4%), sensitivity to 67.7% (63.7–71.8%), and negative predictive value to 95.7% (93.9–97.4%). Conversely, a decrease was observed in specificity 98.0% (96.8–99.2%) and positive predictive value 82.6% (79.3–85.9%). Characteristics of patients with accurate diagnoses *vs* misdiagnoses related to heart failure were similar to the primary analysis.

Discussion

To understand the accuracy of heart failure diagnosed clinically during the preoperative surgical evaluation, we performed this observational cohort study which used a panel of heart failure experts to perform intensive chart reviews of older adults undergoing major noncardiac surgeries. We report five major findings.

First, the estimated true baseline prevalence of adjudicated heart failure in patients presenting for major noncardiac surgery under general anaesthesia was 13.3% based upon an expert panel review with high diagnostic agreement (95%). Compared with previous studies examining heart failure in surgical populations,[22,24] this prevalence of heart failure in our cohort was substantially higher. The higher prevalence was likely attributable to (1) our study inclusion criteria and large academic medical centre setting, favouring older patients with more comorbid conditions undergoing major non-outpatient surgeries; and (2) shortcomings to clinical diagnostic sensitivity of heart failure in previous studies, as later discussed.

Second, the prevalence of preoperative clinical diagnoses of heart failure (9.1%) underestimated the true baseline prevalence. Under-recognition of heart failure highlights that clinical diagnoses primarily lack diagnostic sensitivity rather than specificity; this finding is consistent with previous literature.[8,22,25] Based on the clinical diagnostic sensitivity of heart failure in our study, nearly half of patients with adjudicated heart failure were missed during their preoperative evaluation. Given that heart failure remains one of the most significant risk factors for morbidity and mortality after noncardiac surgery[1 2 5] and

leads to substantially increased healthcare costs[3] and readmissions,[4] our findings highlight missed opportunities for early recognition, preoperative optimisation, and surgical risk reduction (e.g. avoidance of volume overload,[26] additional haemodynamic monitoring,[27] and anaesthetic medication adjustments[28,29]) among patients with undiagnosed heart failure. Furthermore, early diagnosis has the potential to improve the longitudinal health trajectories of patients with heart failure, irrespective of short-term surgical outcomes, through timely initiation of guideline-directed medical therapy.

Third, compared with 'true positive' patients with both a clinical and adjudicated diagnosis of heart failure, 'false negative' patients without a clinical diagnosis of heart failure, yet with an adjudicated diagnosis, had fewer markers of poor health and were more likely to be female. The lack of markers for poor health was not likely attributable to incomplete medical documentation (e.g. failure to document other comorbidities), as we also observed this trend for electronic health record characteristics that were collected and recorded in an automated fashion (e.g. routine preoperative laboratory values). Rather, differences between 'false negative' and 'true positive' patients were potentially explained by a lower index of clinical suspicion for heart failure in these patients. The increased likelihood of being female may be explained by 'false negative' patients tending to be younger, with heart failure known to develop at a later age in females[30]; however, additional under-recognised inequities in heart failure diagnosis[31] may also explain this finding.

Fourth, compared with 'true negative' patients who lacked both a clinical and adjudicated diagnosis of heart failure, 'false positive' patients with a clinical diagnosis of heart failure, yet without an adjudicated diagnosis, more commonly had additional markers of poor health. Similar to the previous finding, this may be explained by the association between these negative health markers and heart failure, raising clinical suspicion for the disease.

Finally, whereas the overall diagnostic accuracy for clinical heart failure was high (92.8%), the sensitivity (57.4%) was lower than that of previous studies which reported sensitivities ranging from 70% to 90%.[8 25] This difference, which was also observed in our sensitivity analysis, was likely not attributable to limitations in ascertainment of clinical diagnoses within the electronic health record. To the contrary, our clinical diagnosis definition included diagnosis codes and keywords within the preoperative history and clinical examination which biased towards greater sensitivity compared with prior studies restricted to administrative data. Rather, the difference may be explained by the rigour of chart review through an expert consensus-adjudicated reference standard with reviewer training, calibration, and auditing. Such findings may have important implications for perioperative epidemiological studies and prediction models not using expert adjudication and therefore relying on complete and accurate heart failure clinical documentation.[32–34]

Study limitations

Our study has several important limitations. First, the study was performed at a single academic medical centre among primarily Caucasian patients. Although the full cohort included a large population across a wide range of surgical procedures with validated variables, the cohort adjudicated by heart failure experts focused on a relatively smaller number of patients. This trade-off between data quantity and quality favoured the lower

number of high-quality reviews, potentially offering unique insights compared with larger studies using less well-defined schema for identifying patients with heart failure. Second, the study was observational in nature. As such, heart failure expert reviewers only had access to the electronic health record data, rather than an in-person evaluation with each patient reviewed. Such limitations were mitigated through the use of a consensus panel of two or three experts rather than a single reviewer, and an ability to review electronic health record data up to 365 days after surgery (with sequelae such as prolonged hospitalisations or readmissions occasionally influencing an expert's adjudicated *preoperative* diagnosis of heart failure). This limitation was further explored through quantification of expert diagnostic certainty. Third, whereas the study defined a clinical diagnosis of heart failure from multiple data sources, the diagnosis relied upon electronic health record documentation and did not necessarily equate to the perioperative care team's awareness of heart failure. Nevertheless, failure to document a clinical diagnosis of heart failure by the perioperative care team remains an important finding, given the increased risk of postoperative complications,[10] and may have downstream consequences for clinicians later involved in the care of such patients.

Conclusions and next steps

We describe a heart failure clinical diagnostic accuracy of 92.8% for older patients undergoing major noncardiac surgical procedures at a single academic medical centre. Among the 13.3% of patients in this cohort who were projected to have heart failure by the expert panel, almost one-half of diagnoses were missed during preoperative evaluation. Given the substantial health risks posed by undiagnosed heart failure on postoperative outcomes and long-term health trajectories, our findings may represent a call to action for improved preoperative clinical diagnosis of heart failure.

To determine whether improved preoperative clinical diagnoses of heart failure may lead to improved perioperative care, postoperative outcomes, and long-term patient health trajectories, several future studies may be pursued as next steps. These include studies exploring potential associations between heart failure misdiagnoses and heart failure-related intraoperative practice patterns such as fluid balance, haemodynamic management, anaesthetic techniques, and invasive monitoring; and similar studies exploring postoperative outcomes such as complications (e.g. acute kidney injury, pulmonary complications), hospital length of stay, and heart failure-related readmissions. Should differences in intraoperative heart failure-related practice patterns and postoperative outcomes be observed among patients with heart failure misdiagnoses, subsequent prospective interventional studies seeking to reduce preoperative misdiagnosis of heart failure are warranted. These may include studies which explore the impact of electronic health record-based preoperative screening algorithms for heart failure, with an emphasis on 'false-negative' and 'false-positive' patients identified in this study, and studies which explore the impact of goal-directed heart failure-related perioperative management strategies among commonly misdiagnosed patients.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Declaration of interest

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Appendix 1.

Group non-author collaborators – Michigan Congestive Heart Failure Investigators (PubMed-indexed): Graciela B. Mentz, Senior statistician; Brahmajee K. Nallamothu, Professor; Francis D. Pagani, Professor; Donald S. Likosky, Professor; Thomas M. Cascino, Clinical instructor.

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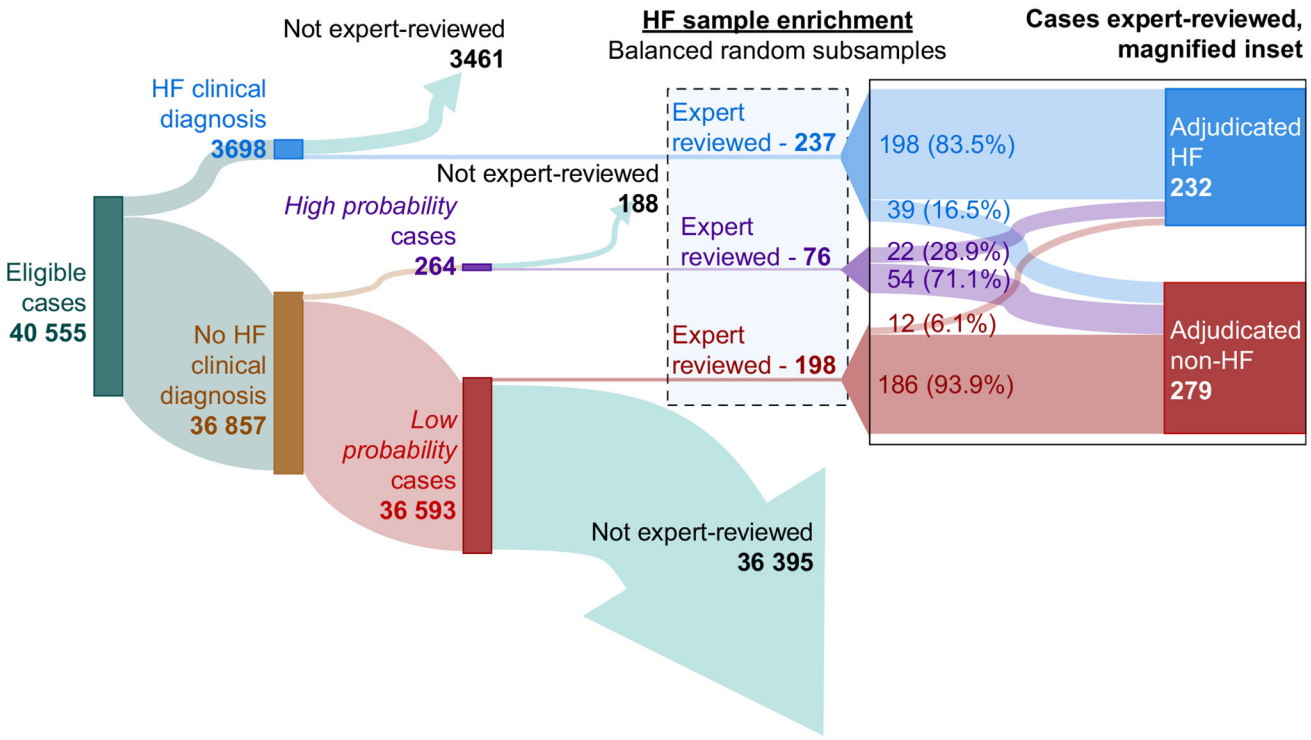

Fig 1.

Preoperative heart failure (HF) clinical diagnosis and expert adjudication Sankey diagram.

Table 1

Inter-rater agreement of heart failure adjudicated diagnosis among heart failure experts: binary assessment of heart failure.

		Expert X	
		No heart failure	**Heart failure**
Expert Y	**No heart failure**	252 (49%)	–
	Heart failure	53 (10%)	206 (40%)

Table 2

Inter-rater agreement of heart failure adjudicated diagnosis among heart failure experts: ordinal assessment of heart failure (HF) with certainty levels.

		Expert X					
		Definitely no HF (<5%)	**Probably no HF (5–15%)**	**Possibly no HF (16–49%)**	**Possibly HF (50–79%)**	**Probably HF (80–95%)**	**Definitely HF (>95%)**
Expert Y	Definitely no HF (<5%)	119 (23.2%)	–	–	–	–	–
	Probably no HF (5–15%)	75 (14.7%)	31 (6.1%)	–	–	–	–
	Possibly no HF (16–49%)	12 (2.3%)	14 (2.7%)	1 (0.2%)	–	–	–
	Possibly HF (50–79%)	7 (1.4%)	16 (3.1%)	3 (0.6%)	4 (0.8%)	–	–
	Probably HF (80–95%)	3 (0.6%)	10 (2.0%)	1 (0.2%)	11 (2.2%)	9 (1.8%)	–
	Definitely HF (>95%)	2 (0.4%)	8 (1.6%)	3 (0.6%)	13 (2.5%)	32 (6.3%)	137 (26.8%)

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Table 3

Characteristics of the full cohort (*n*=40 555) and bivariate analyses of patients with and without a clinical diagnosis of heart failure.

Variable	Full cohort (*n*=40,555)	Clinical HF diagnosis (*n*=3,698)	No clinical HF diagnosis (*n*=36,857)	Standardised difference
Age (yr)	62 (12)	68 (120)	61 (11)	0.59
Surgical duration (min)	218 (126)	223 (126)	217 (126)	0.05
Height (cm)	170 (11)	171 (11)	170 (11)	0.06
Weight (kg)	87 (23)	90 (25)	87 (23)	0.15
BMI (kg m^{-2})	30 (7)	31 (8)	30 (7)	0.13
Baseline MAP (mm Hg)	97 (13)	96 (15)	97 (13)	−0.11
Baseline heart rate (beats min^{-1})	75 (14)	75 (15)	75 (14)	−0.01
Baseline ventilatory frequency (bpm)	17 (2)	17 (2)	17 (2)	0.19
Baseline SpO_2 (%)	97 (2)	96 (2)	97 (2)	−0.17
Preoperative EGFR (L min^{-1} 1.73 m^{-2})	80 (24)	64 (28)	81 (23)	−0.68
Preoperative glucose (mg dl^{-1})	108 (35)	118 (43)	107 (34)	0.29
Preoperative haemoglobin (g dl^{-1})	13.3 (2)	12.2 (2.2)	13.4 (1.9)	−0.56
Preoperative platelet count (K μl^{-1})	245 (81)	225 (87)	247 (80)	−0.26
Preoperative sodium level (mEq L^{-1})	140 (3)	139 (4)	140 (3)	−0.26
Sex				
Male	20667 (51.0)	2201 (59.5)	18466 (50.1)	0.19
Female	19886 (49.0)	1497 (40.5)	18389 (49.9)	
Race				
Asian or Pacific Islander	903 (2.2)	63 (1.7)	840 (2.3)	0.15
Black, not of Hispanic origin	2918 (7.2)	392 (10.6)	2526 (6.9)	
Unknown/Other	1503 (3.7)	105 (2.8)	1398 (3.8)	
White, not of Hispanic origin	35231 (86.9)	3138 (84.9)	32093 (87.1)	
ASA physical status classification				
1	765 (1.9)	2 (0.1)	763 (2.1)	1.14
2	15417 (38)	167 (4.5)	15250 (41.4)	
3	22639 (55.9)	2758 (74.6)	19881 (54)	
4	1709 (4.2)	768 (20.8)	941 (2.6)	
Emergent surgery				

Variable	Full cohort (*n*=40,555)	Clinical HF diagnosis (*n*=3,698)	No clinical HF diagnosis (*n*=36,857)	Standardised difference
Emergent	2580 (6.4)	420 (11.4)	2160 (5.9)	0.20
Primary procedural service				
General	7253 (17.9)	550 (14.9)	6703 (18.2)	0.52
Otolaryngology	5666 (14)	395 (10.7)	5271 (14.3)	
Urology	4905 (12.1)	359 (9.7)	4546 (12.3)	
Orthopaedics	4570 (11.3)	451 (12.2)	4119 (11.2)	
Neurosurgery	4124 (10.2)	278 (7.5)	3846 (10.4)	
Thoracic	2409 (5.9)	238 (6.4)	2171 (5.9)	
Trauma	1953 (4.8)	253 (6.8)	1700 (4.6)	
Obstetrics/gynaecology	1707 (4.2)	91 (2.5)	1616 (4.4)	
Vascular	1622 (4)	416 (11.3)	1206 (3.3)	
Plastics	1596 (3.9)	59 (1.6)	1537 (4.2)	
Ophthalmology	1568 (3.9)	124 (3.4)	1444 (3.9)	
Oral/maxillofacial	1484 (3.7)	117 (3.2)	1367 (3.7)	
Transplant	1067 (2.6)	201 (5.4)	866 (2.4)	
Dentistry	334 (0.8)	20 (0.5)	314 (0.9)	
Other/Unknown	297 (0.7)	146 (4)	151 (0.4)	
Comorbidities				
Hypertension	22225 (54.8)	3142 (85)	19083 (51.8)	0.76
Cancer	14643 (36.1)	1195 (32.3)	13448 (36.5)	−0.09
Diabetes	7980 (19.7)	1442 (39)	6538 (17.7)	0.49
Chronic pulmonary disease	7868 (19.4)	1240 (33.5)	6628 (18)	0.36
Cardiac arrhythmia	7565 (18.7)	1856 (50.2)	5709 (15.5)	0.80
Hypothyroidism	5366 (13.2)	646 (17.5)	4720 (12.8)	0.13
Renal failure	5054 (12.5)	1436 (38.8)	3618 (9.8)	0.72
Coronary artery disease	4414 (10.9)	1544 (41.8)	2870 (7.8)	0.86
Peripheral vascular disorders	3194 (7.9)	1058 (28.6)	2136 (5.8)	0.63
Liver disease	2594 (6.4)	388 (10.5)	2206 (6)	0.16
Coagulopathy	2054 (5.1)	476 (12.9)	1578 (4.3)	0.31
Valvular disease	1721 (4.2)	695 (18.8)	1026 (2.8)	0.53
Pulmonary circulation disorders	1476 (3.6)	610 (16.5)	866 (2.4)	0.5

Variable	Full cohort (*n*=40,555)	Clinical HF diagnosis (*n*=3,698)	No clinical HF diagnosis (*n*=36,857)	Standardised difference
Cerebrovascular disease	1374 (3.4)	295 (8)	1079 (2.9)	−0.86
Year of surgery				
2015	4727 (11.7)	441 (11.9)	4286 (11.6)	0.04
2016	10361 (25.6)	923 (25)	9438 (25.6)	
2017	10541 (26)	933 (25.2)	9608 (26.1)	
2018	10616 (26.2)	967 (26.2)	9649 (26.2)	
2019	4310 (10.6)	434 (11.7)	3876 (10.5)	
Home medications[*]				
BL110 – Anticoagulants	3765 (9.3)	1086 (29.4)	2679 (7.3)	0.60
BL117 – Platelet aggregation inhibitors	1542 (3.8)	434 (11.7)	1108 (3)	0.34
CN101 – Opioids	4400 (10.9)	538 (14.6)	3862 (10.5)	0.12
CN103 – Non-opioid analgesics	21490 (53)	2811 (76)	18679 (50.7)	0.54
CV100 – Beta blockers	11159 (27.5)	2517 (68.1)	8642 (23.5)	1.00
CV150 – Alpha blockers	3524 (8.7)	528 (14.3)	2996 (8.1)	0.20
CV200 – Calcium channel blockers	7062 (17.4)	1007 (27.2)	6055 (16.4)	0.26
CV250 – Anti-anginals	1812 (4.5)	656 (17.7)	1156 (3.1)	0.49
CV300 – Anti-arrhythmics	2219 (5.5)	474 (12.8)	1745 (4.7)	0.29
CV350 – Anti-lipaemics	15850 (39.1)	2344 (63.4)	13506 (36.6)	0.56
CV701 – Thiazide diuretics	6661 (16.4)	548 (14.8)	6113 (16.6)	−0.05
CV702 – Loop diuretics	3216 (7.9)	1471 (39.8)	1745 (4.7)	0.93
CV704 – Potassium-sparing diuretics	1860 (4.6)	496 (13.4)	1364 (3.7)	0.35
CV800 – ACE inhibitors	8713 (21.5)	1121 (30.3)	7592 (20.6)	0.22
CV805 – Angiotensin II inhibitors	4832 (11.9)	695 (18.8)	4137 (11.2)	0.21
HS851 – Thyroid supplements	6397 (15.8)	718 (19.4)	5679 (15.4)	0.11
RE102 – Inhaled bronchodilators	6377 (15.7)	915 (24.7)	5462 (14.8)	0.25
Lowest preoperative left ventricular ejection fraction				
Hyperdynamic (≥70%)	14 (2.7)	3 (1.3)	11 (4)	−1.89
Missing or normal (50–69%)	290 (56.8)	54 (22.8)	236 (86.1)	
Mild dysfunction (40–49%)	46 (9)	29 (12.2)	17 (6.2)	
Moderate dysfunction (30–39%)	72 (14.1)	64 (27)	8 (2.9)	
Severe dysfunction (<30%)	89 (17.4)	87 (36.7)	2 (0.7)	

Variable	Full cohort (*n*=40,555)	Clinical HF diagnosis (*n*=3,698)	No clinical HF diagnosis (*n*=36,857)	Standardised difference
Preoperative diastolic dysfunction				
Normal or missing	287 (56.2)	66 (27.9)	221 (80.7)	−1.25
Present (any grade)	224 (43.8)	171 (72.2)	53 (19.3)	

Data are reported in the form of mean (standard deviation for quantitative variables and *n* [%] for categorical variables.

*Classified by Veterans Administration National Drug Formulary Categories.

EGFR, estimated glomerular filtration rate; HF, heart failure.

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Table 4

Characteristics of the adjudicated cohort (*n*=511) and bivariate analyses of patients with and without an adjudicated diagnosis of heart failure (HF).

Variable	All adjudicated patients (*n*=511)	Adjudicated HF diagnosis (*n*=232)	No adjudicated HF diagnosis (*n*=279)	Standardised difference
Age (yr)	64 (12)	67 (11)	67 (11)	−0.39
Surgical duration (min)	233 (131)	230 (120)	230 (120)	0.05
Height (cm)	171 (10)	172 (10)	172 (10)	−0.26
Weight (kg)	84 (23)	86 (24)	86 (24)	−0.18
BMI (kg m^{-2})	29 (7)	29 (7)	29 (7)	−0.08
Baseline MAP (mm Hg)	94 (15)	92 (16)	92 (16)	0.16
Baseline heart rate (beats min^{-1})	76 (15)	79 (16)	79 (16)	−0.30
Baseline ventilatory frequency (bpm)	17 (2)	17 (3)	17 (3)	−0.17
Baseline SpO_2 (%)	97 (3)	96 (3)	96 (3)	0.22
Preoperative EGFR (L min^{-1} 1.73 m^{-2})	72 (29)	64 (29)	64 (29)	0.52
Preoperative glucose (mg dl^{-1})	112 (37)	119 (44)	119 (44)	−0.34
Preoperative haemoglobin (g dl^{-1})	12.2 (2.4)	11.7 (2.5)	11.7 (2.5)	0.38
Preoperative platelet count (K μl^{-1})	234 (103)	217 (93)	217 (93)	0.33
Preoperative sodium level (mEq L^{-1})	139 (4)	139 (4)	139 (4)	0.33
Sex				
Male	300 (58.7)	158 (68.1)	142 (50.9)	0.36
Female	211 (41.3)	74 (31.9)	137 (49.1)	
Race				
Asian or Pacific Islander	7 (1.4)	4 (1.7)	3 (1.1)	0.34
Black, not of Hispanic origin	48 (9.4)	34 (14.7)	14 (5.0)	
Unknown/Other	13 (2.5)	5 (2.2)	8 (2.9)	
White, not of Hispanic origin	443 (86.7)	189 (81.5)	254 (91)	
ASA physical status classification				
1	5 (1.0)	1 (0.4)	4 (1.4)	1.19
2	102 (20.0)	9 (3.9)	93 (33.3)	
3	304 (59.5)	133 (57.3)	171 (61.3)	
4	100 (19.6)	89 (38.4)	11 (3.9)	
Emergent surgery				

Variable	All adjudicated patients (*n*=511)	Adjudicated HF diagnosis (*n*=232)	No adjudicated HF diagnosis (*n*=279)	Standardised difference
Emergent	61 (11.9)	37 (16.0)	24 (8.6)	0.23
Primary procedural service				
General	69 (13.5)	25 (10.8)	44 (15.8)	0.78
Vascular	60 (11.7)	48 (20.7)	12 (4.3)	
Neurosurgery	53 (10.4)	11 (4.7)	42 (15.1)	
Orthopaedics	52 (10.2)	26 (11.2)	26 (9.3)	
Urology	46 (9.0)	17 (7.3)	29 (10.4)	
Otolaryngology	42 (8.2)	14 (6.0)	28 (10.0)	
Other/unknown	42 (8.2)	25 (10.8)	17 (6.1)	
Trauma	35 (6.9)	24 (10.3)	11 (3.9)	
Thoracic	33 (6.5)	13 (5.6)	20 (7.2)	
Transplant	23 (4.5)	12 (5.2)	11 (3.9)	
Oral/maxillofacial	16 (3.1)	5 (2.2)	11 (3.9)	
Obstetrics/gynaecology	15 (2.9)	7 (3.0)	8 (2.9)	
Plastics	13 (2.5)	2 (0.9)	11 (3.9)	
Ophthalmology	9 (1.8)	2 (0.9)	7 (2.5)	
Dentistry	3 (0.6)	1 (0.4)	2 (0.7)	
Comorbidities				
Hypertension	345 (67.5)	201 (86.6)	144 (51.6)	−0.82
Cancer	157 (30.7)	63 (27.2)	94 (33.7)	0.14
Diabetes	154 (30.1)	99 (42.7)	55 (19.7)	−0.51
Chronic pulmonary disease	143 (28.0)	87 (37.5)	56 (20.1)	−0.39
Cardiac arrhythmia	235 (46.0)	143 (61.6)	92 (33.0)	−0.60
Hypothyroidism	95 (18.6)	51 (22.0)	44 (15.8)	−0.16
Renal failure	160 (31.3)	107 (46.1)	53 (19.0)	−0.60
Coronary artery disease	180 (35.2)	130 (56.0)	50 (17.9)	0.88
Peripheral vascular disorders	150 (29.4)	119 (51.3)	31 (11.1)	−0.96
Liver disease	65 (12.7)	34 (14.7)	31 (11.1)	−0.11
Coagulopathy	71 (13.9)	45 (19.4)	26 (9.3)	−0.29
Valvular disease	99 (19.4)	77 (33.2)	22 (7.9)	−0.66
Pulmonary circulation disorders	89 (17.4)	70 (30.2)	19 (6.8)	−0.63

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Variable	All adjudicated patients (*n*=511)	Adjudicated HF diagnosis (*n*=232)	No adjudicated HF diagnosis (*n*=279)	Standardised difference
Cerebrovascular disease	37 (7.3)	24 (10.5)	13 (4.7)	−0.22
Year of surgery				
2015	84 (16.4)	31 (13.4)	53 (19)	0.18
2016	169 (33.1)	78 (33.6)	91 (32.6)	
2017	170 (33.3)	84 (36.2)	86 (30.8)	
2018	70 (13.7)	32 (13.8)	38 (13.6)	
2019	18 (3.5)	7 (3.0)	11 (3.9)	
Home medications *				
BL110 – Anticoagulants	135 (26.4)	86 (37.1)	49 (17.6)	−0.45
BL117 – Platelet aggregation inhibitors	40 (7.8)	31 (13.4)	9 (3.2)	−0.37
CN101 – Opioids	67 (13.1)	27 (11.6)	40 (14.3)	0.08
CN103 – Non-opioid analgesics	328 (64.2)	177 (76.3)	151 (54.1)	−0.48
CV100 – Beta blockers	268 (52.4)	181 (78)	87 (31.2)	−1.07
CV150 – Alpha blockers	46 (9.0)	29 (12.5)	17 (6.1)	−0.22
CV200 – Calcium channel blockers	83 (16.2)	37 (16.0)	46 (16.5)	0.01
CV250 – Anti-anginals	51 (10.0)	41 (17.7)	10 (3.6)	−0.47
CV300 – Anti-arrhythmics	62 (12.1)	39 (16.8)	23 (8.2)	−0.26
CV350 – Anti-lipaemics	246 (48.1)	140 (60.3)	106 (38.0)	−0.46
CV701 – Thiazide diuretics	51 (10.0)	22 (9.5)	29 (10.4)	0.03
CV702 – Loop diuretics	123 (24.1)	104 (44.8)	19 (6.8)	−0.96
CV704 – Potassium-sparing diuretics	57 (11.2)	47 (20.3)	10 (3.6)	−0.53
CV800 – ACE inhibitors	130 (25.4)	88 (37.9)	42 (15.1)	−0.54
CV805 – Angiotensin II inhibitors	65 (12.7)	32 (13.8)	33 (11.8)	−0.06
HS851 – Thyroid supplements	94 (18.4)	46 (19.8)	48 (17.2)	−0.07
RE102 – Inhaled bronchodilators	86 (16.8)	45 (19.4)	41 (14.7)	−0.13
Lowest preoperative left ventricular ejection fraction				
Hyperdynamic (≥70%)	14 (2.7)		12 (4.3)	2.27
Missing or normal (50–69%)	290 (56.8)		248 (88.9)	
Mild dysfunction (40–49%)	46 (9)		9 (3.2)	
Moderate dysfunction (30–39%)	72 (14.1)		5 (1.8)	
Severe dysfunction (<30%)	89 (17.4)		5 (1.8)	

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Variable	All adjudicated patients (*n*=511)	Adjudicated HF diagnosis (*n*=232)	No adjudicated HF diagnosis (*n*=279)	Standardised difference
Preoperative diastolic dysfunction				
Normal or missing	287 (56.2)		225 (80.7)	−1.29
Present (any grade)	224 (43.8)		54 (19.4)	

Data are reported in the form of mean (standard deviation for quantitative variables and n (%) for categorical variables. ACE, angiotensin-converting enzyme; EGFR, estimated glomerular filtration rate.

*Classified by Veterans Administration National Drug Formulary Categories.

Table 5

Preoperative clinical diagnosis *vs* adjudicated diagnosis of heart failure among patients undergoing expert review (*n*=511).

	Clinical diagnosis positive (*n*=237)	**Clinical diagnosis negative (*n*=274)**
Adjudicated diagnosis positive (*n*=232)	198 (True positive)	34 (False negative)
Adjudicated diagnosis negative (*n*=279)	39 (False positive)	240 (True negative)

Table 6

Characteristics of patients with correct *vs* incorrect clinical heart failure diagnoses as compared with adjudicated heart failure reference standard.

Variable	Patients with an adjudicated diagnosis of heart failure (True positives + false negatives)			Patients without an adjudicated diagnosis of heart failure (True negatives + false positives)		
	Patients with a clinical diagnosis of heart failure 'True positives' (*n*=198)	Patients without a clinical diagnosis of heart failure 'False negatives' (*n*=34)	Standardised difference	Patients without a clinical diagnosis of heart failure 'True negatives' (*n*=240)	Patients with a clinical diagnosis of heart failure 'False positives' (*n*=39)	Standardised difference
Age (yr)	67 (11)	65 (11)	−0.22	61 (12)	70 (11)	0.76
Surgical duration (min)	230 (118)	228 (135)	−0.02	237 (143)	233 (118)	−0.03
Height (cm)	173 (10)	169 (10)	−0.44	170 (10)	170 (12)	0.01
Weight (kg)	87 (23)	84 (27)	−0.12	83 (22)	80 (25)	−0.10
BMI (kg m^{-2})	29 (7)	29 (8)	0.05	29 (7)	28 (8)	−0.12
Baseline MAP (mm Hg)	91 (15)	101 (14)	0.67	95 (15)	93 (12)	−0.17
Baseline heart rate (beats min^{-1})	79 (16)	81 (14)	0.17	74 (14)	78 (18)	0.28
Baseline ventilatory frequency (bpm)	17 (2)	17 (3)	−0.14	17 (2)	17 (2)	0.23
Baseline SpO_2 (%)	96 (3)	96 (2)	−0.04	97 (2)	97 (3)	−0.17
Preoperative EGFR (L min^{-1} 1.73 m^{-2})	64 (29)	68 (32)	0.15	81 (26)	67 (32)	−0.51
Preoperative glucose (mg dl^{-1})	120 (45)	113 (34)	−0.17	106 (29)	107 (32)	0.06
Preoperative haemoglobin (g dl^{-1})	12 (2)	13 (3)	0.38	13 (2)	12 (3)	−0.40
Preoperative platelet count (K μl^{-1})	209 (86)	264 (117)	0.53	249 (99)	260 (156)	0.09
Preoperative sodium level (mEq L^{-1})	139 (4)	138 (4)	−0.05	140 (3)	140 (4)	−0.08
Sex						
Male	138 (69.7)	20 (58.8)	0.23	120 (50.0)	22 (56.4)	−0.13
Female	60 (30.3)	14 (41.2)		120 (50.0)	17 (43.6)	
Race						
Asian or Pacific Islander	4 (2.0)	0 (0)	0.31	2 (0.8)	1 (2.6)	0.29
Black, not of Hispanic origin	29 (14.7)	5 (14.7)		12 (5)	2 (5.1)	
Unknown/other	3 (1.5)	2 (5.9)		8 (3.3)	(0)	
White, not of Hispanic origin	162 (81.8)	27 (79.4)		218 (90.8)	36 (92.3)	
ASA physical status classification						
1	1 (0.5)	0 (0)	0.56	4 (1.7)	0 (0)	1.11

Variable	Patients with an adjudicated diagnosis of heart failure (True positives + false negatives)			Patients without an adjudicated diagnosis of heart failure (True negatives + false positives)		
	Patients with a clinical diagnosis of heart failure 'True positives' (*n*=198)	**Patients without a clinical diagnosis of heart failure 'False negatives' (*n*=34)**	**Standardised difference**	**Patients without a clinical diagnosis of heart failure 'True negatives' (*n*=240)**	**Patients with a clinical diagnosis of heart failure 'False positives' (*n*=39)**	**Standardised difference**
2	5 (2.5)	4 (11.8)		92 (38.3)	1 (2.6)	
3	110 (55.6)	23 (67.7)		139 (57.9)	32 (82.1)	
4	82 (41.4)	7 (20.6)		5 (2.1)	6 (15.4)	
Emergent surgery						
Emergent	30 (15.2)	7 (20.6)	0.14	17 (7.1)	7 (18.0)	0.33
Primary procedural service						
General	22 (11.1)	3 (8.8)	0.87	37 (15.4)	7 (18.0)	1.24
Vascular	43 (21.7)	5 (14.7)		9 (3.8)	3 (7.7)	
Neurosurgery	8 (4.0)	3 (8.8)		37 (15.4)	5 (12.8)	
Orthopaedics	23 (11.6)	3 (8.8)		22 (9.2)	4 (10.3)	
Urology	14 (7.1)	3 (8.8)		29 (12.1)	0 (0)	
Otolaryngology	12 (6.1)	2 (5.9)		28 (11.7)	0 (0)	
Other/unknown	25 (12.6)	0 (0)		9 (3.8)	8 (20.5)	
Trauma	17 (8.6)	7 (20.6)		8 (3.3)	3 (7.7)	
Thoracic	11 (5.6)	2 (5.9)		14 (5.8)	6 (15.4)	
Transplant	11 (5.6)	1 (2.9)		9 (3.8)	2 (5.1)	
Oral/maxillofacial	2 (1.0)	3 (8.8)		11 (4.6)	0 (0)	
Obstetrics/gynaecology	6 (3.0)	1 (2.9)		8 (3.3)	0 (0)	
Plastics	1 (0.5)	1 (2.9)		10 (4.2)	1 (2.6)	
Ophthalmology	2 (1.0)	0 (0)		7 (2.9)	0 (0)	
Dentistry	1 (0.5)	0 (0)		2 (0.8)	0 (0)	
Comorbidities						
Hypertension	174 (87.9)	27 (79.4)	−0.23	111 (46.3)	33 (84.6)	0.88
Cancer	55 (27.8)	8 (23.5)	−0.10	85 (35.4)	9 (23.1)	−0.27
Diabetes	89 (45.0)	10 (29.4)	−0.33	48 (20.0)	7 (18.0)	−0.05
Chronic pulmonary disease	74 (37.4)	13 (38.2)	0.02	44 (18.3)	12 (30.8)	0.29
Cardiac arrhythmia	126 (63.6)	17 (50.0)	−0.28	61 (25.4)	31 (79.5)	1.29
Hypothyroidism	42 (21.2)	9 (26.5)	0.12	35 (14.6)	9 (23.1)	0.22

Variable	Patients with an adjudicated diagnosis of heart failure (True positives + false negatives)			Patients without an adjudicated diagnosis of heart failure (True negatives + false positives)		
	Patients with a clinical diagnosis of heart failure 'True positives' (*n*=198)	**Patients without a clinical diagnosis of heart failure 'False negatives' (*n*=34)**	**Standardised difference**	**Patients without a clinical diagnosis of heart failure 'True negatives' (*n*=240)**	**Patients with a clinical diagnosis of heart failure 'False positives' (*n*=39)**	**Standardised difference**
Renal failure	95 (48.0)	12 (35.3)	−0.26	40 (16.7)	13 (33.3)	0.39
Coronary artery disease	115 (58.1)	15 (44.1)	0.35	33 (13.8)	17 (43.6)	0.77
Peripheral vascular disorders	108 (54.6)	11 (32.4)	−0.46	22 (9.2)	9 (23.1)	0.39
Liver disease	30 (15.2)	4 (11.8)	−0.10	27 (11.3)	4 (10.3)	−0.03
Coagulopathy	42 (21.2)	3 (8.8)	−0.35	15 (6.3)	11 (28.2)	0.61
Valvular disease	70 (35.4)	7 (20.6)	−0.33	13 (5.4)	9 (23.1)	0.52
Pulmonary circulation disorders	64 (32.3)	6 (17.7)	−0.34	15 (6.3)	4 (10.3)	0.15
Cerebrovascular disease	20 (10.3)	4 (11.8)	0.05	9 (3.8)	4 (10.5)	0.27
Year of surgery						
2015	25 (12.6)	6 (17.7)	0.22	46 (19.2)	7 (18)	0.19
2016	67 (33.8)	11 (32.4)		76 (31.7)	15 (38.5)	
2017	74 (37.4)	10 (29.4)		76 (31.7)	10 (25.6)	
2018	26 (13.1)	6 (17.7)		32 (13.3)	6 (15.4)	
2019	6 (3.0)	1 (2.9)		10 (4.2)	1 (2.6)	
Home medications[*]						
BL110 – Anticoagulants	80 (40.4)	6 (17.7)	−0.52	30 (12.5)	19 (48.7)	0.85
BL117 – Platelet aggregation inhibitors	29 (14.7)	2 (5.9)	−0.29	7 (2.9)	2 (5.1)	0.11
CN101 – Opioids	26 (13.1)	1 (2.9)	−0.38	38 (15.8)	2 (5.1)	−0.36
CN103 – Non-opioid analgesics	157 (79.3)	20 (58.8)	−0.45	122 (50.8)	29 (74.4)	0.50
CV100 – Beta blockers	159 (80.3)	22 (64.7)	−0.35	63 (26.3)	24 (61.5)	0.76
CV150 – Alpha blockers	25 (12.6)	4 (11.8)	−0.03	13 (5.4)	4 (10.3)	0.18
CV200 – Calcium channel blockers	30 (15.2)	7 (20.6)	0.14	32 (13.3)	14 (35.9)	0.54
CV250 – Anti-anginals	36 (18.2)	5 (14.7)	−0.09	8 (3.3)	2 (5.1)	0.09
CV300 – Anti-arrhythmics	35 (17.7)	4 (11.8)	−0.17	18 (7.5)	5 (12.8)	0.18
CV350 – Anti-lipaemics	121 (61.1)	19 (55.9)	−0.11	87 (36.3)	19 (48.7)	0.25
CV701 – Thiazide diuretics	17 (8.6)	5 (14.7)	0.19	23 (9.6)	6 (15.4)	0.18
CV702 – Loop diuretics	98 (49.5)	6 (17.7)	−0.72	12 (5)	7 (18)	0.41

Variable	Patients with an adjudicated diagnosis of heart failure (True positives + false negatives)			Patients without an adjudicated diagnosis of heart failure (True negatives + false positives)		
	Patients with a clinical diagnosis of heart failure 'True positives' (*n*=198)	Patients without a clinical diagnosis of heart failure 'False negatives' (*n*=34)	Standardised difference	Patients without a clinical diagnosis of heart failure 'True negatives' (*n*=240)	Patients with a clinical diagnosis of heart failure 'False positives' (*n*=39)	Standardised difference
CV704 – Potassium-sparing diuretics	46 (23.2)	1 (2.9)	−0.63	8 (3.3)	2 (5.1)	0.09
CV800 – ACE inhibitors	75 (37.9)	13 (38.2)	0.01	34 (14.2)	8 (20.5)	0.17
CV805 – Angiotensin II inhibitors	29 (14.7)	3 (8.8)	−0.18	25 (10.4)	8 (20.5)	0.28
HS851 – Thyroid supplements	36 (18.2)	10 (29.4)	0.27	41 (17.1)	7 (18)	0.02
RE102 – Inhaled bronchodilators	39 (19.7)	6 (17.7)	−0.05	34 (14.2)	7 (18)	0.10
Lowest preoperative left ventricular ejection fraction						
Hyperdynamic (≥70%)	1 (0.5)	1 (2.9)	1.14	10 (4.2)	2 (5.1)	0.84
Missing or normal (50–69%)	29 (14.7)	13 (38.2)		223 (92.9)	25 (64.1)	
Mild dysfunction (40–49%)	26 (13.1)	11 (32.4)		6 (2.5)	3 (7.7)	
Moderate dysfunction (30–39%)	60 (30.3)	7 (20.6)		1 (0.4)	4 (10.3)	
Severe dysfunction (<30%)	82 (41.4)	2 (5.9)		0 (0)	5 (12.8)	
Preoperative diastolic dysfunction						
Normal or missing	41 (20.7)	21 (61.8)	−0.92	200 (83.3)	25 (64.1)	0.45
Present (any grade)	157 (79.3)	13 (38.2)		40 (16.7)	14 (35.9)	

Data are reported in the form of mean (standard deviation for quantitative variables and *n* [%] for categorical variables. ACE, angiotensin-converting enzyme; EGFR, estimated glomerular filtration rate; HF, heart failure.

*Classified by Veterans Administration National Drug Formulary Categories.