Gastrointestinal Complications and Laparotomy after Cardiac Surgery: A Retrospective Cohort Study

Ann. Ital. Chir., 2025 96, 3: 409–420
https://doi.org/10.62713/aic.3819

Thomas French[1,2], Dimitrios Damaskos[2], Darja Clinch[2], Charilaos-Panagiotis Koutsogiannidis[1]

[1]Department of Cardiothoracic Surgery, Royal Infirmary of Edinburgh, EH16 4SA Edinburgh, UK
[2]Department of General Surgery, Royal Infirmary of Edinburgh, EH16 4SA Edinburgh, UK

AIM: Gastrointestinal (GI) complications following cardiac surgery are infrequent, but associated with high rates of postoperative mortality. The aim of our study was to identify risk factors predisposing patients to GI complications following cardiac surgery and describe the outcomes of patients suffering a GI complication.

METHODS: This was a retrospective cohort study of 6769 consecutive patients undergoing cardiac surgeries (at least one of coronary artery bypass grafting (CABG), aortic valve replacement, mitral valve replacement, or surgery on thoracic aorta) at a single Scottish centre between 1 January 2015 and 27 September 2023. Cohort demographics, intra-operative details and postoperative outcomes were compared between patients who did and who did not experience a gastrointestinal GI complication.

RESULTS: Patients who experienced a GI complication had greater rates of thirty-day mortality (14.4% vs 2.4%, $p < 0.001$) and in-hospital mortality (6.8% vs 1.1%, $p < 0.001$) compared with those who did not. We identified previous percutaneous coronary intervention (PCI) (Odds ratio (OR) 2.27 [1.24–4.17], $p = 0.007$) and combined cardiac surgery (OR 1.67 [1.02–2.74], $p = 0.043$) as two risk factors for developing a GI complication, in addition to several previously identified risk factors (postoperative atrial fibrillation, postoperative vascular complication, use of pre-operative inotropes and increased age).

CONCLUSIONS: GI complications frequently occur in elderly, co-morbid patients and in conjunction with other complications. Particularly lethal are mesenteric ischemia, GI bleeding, and small bowel obstruction. Extra caution should be observed in the patient group undergoing more than one cardiac procedure or those with a prior history of coronary artery disease. Prompt emergency laparotomy is a potentially life-saving intervention in promptly diagnosed patients, but confers a high risk of intra-operative and thirty-day mortality.

Keywords: gastrointestinal complications; cardiac surgery; laparotomy; mesenteric ischemia

Introduction

Cardiac surgeries comprise a high risk group of surgical procedures with an estimated all-cause postoperative mortality rate of 2.9% at one year [1]. Patients who develop a gastrointestinal (GI) tract complication in the immediate postoperative period are particularly at risk, suffering from estimated mortality rates as high as 89.7% [2–4]. Incidence of GI tract complications is measured consistently between 0.8% and 2.9% of all patients undergoing cardiac surgery [3,5,6].

Observed mortality and GI complication incidence varies considerably from one study to the next. This variance stems from a lack of a common consensus on what constitutes a 'GI complication' across different studies.

A postoperative GI complication might constitute a bleed such as a bleeding peptic ulcer, an infection such as cholecystitis, or an embolic event. Similar incidence of individual complications is observed across most studies in the literature. GI bleeds are comparatively common complications—accounting for roughly 35% of all complications. Ischaemic complications such as mesenteric ischemia occur at lower frequencies (incidence around 0.16% after cardiac surgery), and rates of infective complications vary by infective type-clostridium difficile infections being common (3%), and hepatobiliary complications such as cholecystitis (0.11%) or pancreatitis (0.13%) being relatively rare [7–9].

Although the mortality of different GI complications varies by complication type, there exists some evidence to suggest that having suffered a GI complication of any type negatively influences likelihood of survival in both the immediate postoperative period and up to three years post-operation [10,11].

Some effort has been made to identify risk factors for development of a GI complication after cardiac surgery. However, variance in the definition of what constitutes a postoperative GI complication, failure to account for operation type or number of procedures, and poor or ill-

Submitted: 21 October 2024 Revised: 6 December 2024 Accepted: 2 January 2025 Published: 10 March 2025
Correspondence to: Thomas French, Department of Cardiothoracic Surgery, Royal Infirmary of Edinburgh, EH16 4SA Edinburgh, UK; Department of General Surgery, Royal Infirmary of Edinburgh, EH16 4SA Edinburgh, UK (e-mail: thomfren12@gmail.com).

suited methods of choosing confounding variables in predictive regression modelling have impeded understanding of which patients develop a postoperative GI complication, and whether this influences long-term mortality. There exists a lack of consensus, also, as to whether patients within this cohort should be managed surgically or conservatively.

Previously identified risk factors for postoperative GI complication include increasing age, smoking status, preoperative inotropic support, New York Heart Association (NYHA) class III–IV symptoms, diabetes, prolonged cardiopulmonary bypass duration postoperative renal failure, postoperative atrial fibrillation, postoperative vascular complications and postoperative pneumonia [12]. As the majority of these risk factors manifest in the postoperative period, we sought to determine if any additional preoperative risk factors might predict the risk of a postoperative GI complication.

Successfully identifying known risk factors as a patient prior to a planned operation could prompt discussion of alternative treatment modes or appropriate risk mitigation strategies at an earlier stage in treatment. In addition to the presence of known systemic disease, we included several risk factors for cardiovascular disease in our regression modelling, hypothesising that one or several of these factors might predict for GI disease broadly.

Known cardiovascular disease may serve as an indicator of undiagnosed abdominal aortic disease - heavy calcification, atheromatous plaques and a compromised abdominal blood supply may predispose to ischaemic complications such as mesenteric ischemia or ischaemic colitis.

Additionally, patients having suffered a prior myocardial infarction (MI) are likely to be prescribed dual antiplatelet therapy, predisposing them to gastric and duodenal ulcers through reduced prostaglandin synthesis, inhibition of platelet aggregation and suppression of platelet-derived growth factor [13].

We also examined operation-specific characteristics such as number of procedures, time in theatre, and operation urgency, hypothesising that operations involving procedures on multiple sites, or procedures of greater urgency might incur GI complications such as stress ulcers and paralytic ileus.

We aimed to test these hypotheses by describing the outcomes from a single cohort of cardiac surgery patients who have sustained a GI complication, compare mortality rates between different complications, and perform regression analysis to identify individual patient risk-factors that predispose to GI complication. Patients with identified risk-factors may then benefit from risk-mitigating treatment measures such as routine postoperative abdominal imaging, regular blood testing or early surgical intervention. Secondary aims of the study were to describe and discuss outcomes in the subset of patients requiring emergency laparotomy for a GI complication.

Materials and Methods

Study Design

This retrospective cohort study examined data from 6901 operations on 6769 consecutive patients who underwent elective or emergency cardiac surgery at the Royal Infirmary of Edinburgh between the 1 January 2015 and 27 September 2023. Patients that met the criteria were identified by a search of the hospital's national cardiothoracic audit archives. Within this group, 118 patients were identified who suffered 123 gastro-intestinal complications in the period from surgery to discharge.

Setting

For patients undergoing elective cardiac surgery, demographic data were recorded in a pre-operative clinic one to six months prior to the booked surgery date.

All patients had demographic, biochemical and imaging details recorded following discharge or death, along with intra-operative details (such as length of operation and time on the cardiopulmonary bypass circuit) and postoperative details (such as complications suffered and length of stay in hospital).

Participants were followed up and database updated in a 6–8 week postoperative clinic. The audit database was updated with date of death following confirmation from the relevant health authority up until the study endpoint (27 September 2023).

Participants

Inclusion criteria were adult patients undergoing at least one of the following surgeries: coronary artery bypass grafting (CABG), aortic valve repair or replacement, mitral valve repair or replacement, or surgery on the thoracic aorta. Exclusion criteria included patients undergoing an unlisted cardiac operation, or those undergoing a concomitant procedure performed on ten or fewer patients within the cohort (tricuspid repair, pulmonary valve repair, aneurysmectomy or pericardiectomy).

Variables and Measurements

In the pre-operative clinic, data was collected detailing demographic characteristics such as age, sex, smoking status, body-mass-index (BMI), diabetic status, neurological status, and pulmonary disease status. Cardiac surgery specific confounders that were measured at baseline included left ventricular ejection fraction (LVEF), angina status according to the Canadian Cardiovascular Society (CCS) [14], dyspnoea status according to New York Heart Association (NYHA) rating [15], pre-operative heart rhythm based on a hospital echocardiogram tracing, presence of extracardiac arteriopathy, the presence of a previous myocardial infarction (MI) were collected. Additive EuroSCORE was used as a composite measure of cardiac surgery risk [16].

Following the operation, details such as operational urgency, use of pre-operative intra-aortic balloon pump, in-

otropes or pre-operative ventilation were recorded. Operations were assigned an 'operation weighting' according to the EuroSCORE risk stratification. In ascending order of risk, operations were classified into either 'Isolated CABG', 'Isolated non-CABG', 'Two procedures', or 'Three or more procedures'. Intra-operative details such as operation time-length, time spent on the cardiopulmonary bypass, primary incision type and time spent under aortic cross-clamping were measured.

Postoperative complication categories included 'heart failure', referring to new onset left or right ventricle systolic dysfunction after surgery, pneumonia requiring antibiotics, new onset atrial fibrillation, postoperative arrhythmia requiring permanent pacemaker (PPM) implantation, or postoperative vascular complication. International Classification of Diseases, tenth revision (ICD-10) codes, including a definition for 'postoperative vascular complication' can be found in **Supplementary Tables 1,2**.

The primary outcome in all patients was the development of a GI complication prior to discharge from the hospital. Definition of a GI complication for the purposes of this study included a postoperative diagnosis of one of the following conditions: mesenteric ischemia, small bowel obstruction, GI bleed, viscus perforation, infective colitis, ileus, transaminitis, infective gastroenteritis, cholecystitis or pancreatitis. Where one of the aforementioned complications led to a viscus perforation, such as in small bowel obstruction, the complication was coded as 'viscus perforation'. ICD-10 codes for the above complications are available in **Supplementary Table 3**.

Secondary outcomes included all-cause mortality, thirty-day mortality, and length of time from development of symptoms to imaging.

Patient data were collected in advance of the study for the purposes of the National Adult Cardiac Surgery Audit (NASCA). As this was a retrospective review, meeting the criteria for a service evaluation study, Research Ethics Committee (REC) approval was exempted by the NHS Lothian health board. This study was conducted in accordance with the Declaration of Helsinki. Since this is an anonymised, retrospective analysis and does not pose any risk or impact to the patients, informed consent is not required.

Statistical Methods

Baseline demographic characteristics and intra-operative details were compared between patients who experienced a GI complication following surgery and those who did not. Distributions were assessed visually via means of histograms. A two-tailed *t*-test, CHI-square test or Mann-Whitney-U test was used to compare between-group differences depending on data distribution. Chi-square tests involving one degree of freedom or five or less observed outcomes were adjusted with Yates' continuity correction. Categorical data are represented as absolute values and group percentages, continuous data are represented as group mean and 95% confidence intervals or median and interquartile range as appropriate.

Univariate logistic regression was determined to investigate potential risk factors for development of GI complication after surgery. Adjusted regression coefficients were obtained by adjusting for pre-specified, previously identified risk factors, including age greater than 80, smoking status, use of pre-operative inotropes, NYHA class, cardiopulmonary bypass time >150 minutes, postoperative atrial fibrillation, postoperative heart failure and postoperative vascular complication [17].

Total cumulative survival was compared with the log-rank test, and adjusted hazard ratios were calculated via multivariable cox regression.

Cox proportional hazards regression was used to investigate the relationship between postoperative GI complication and all-cause mortality in the period from operation to study follow-up endpoint.

Missing data was considered to be missing completely at random. Variables with less than 20% missing data were imputed. Mode imputation was used for categorical variables, and median imputation for continuous variables. Sensitivity analyses were conducted (**Supplementary Tables 4,5**) including only patients for whom no data were missing.

A *p*-value of 0.05 or less was considered statistically significant for all tests.

Statistical analysis was performed with *R* statistical software (version 4.3.2; R foundation for statistical computing, Vienna, Austria).

Results

Complication Type and Thirty-Day Mortality

The total incidence of postoperative GI complication was 1.74%.

GI bleed was the most common postoperative GI complication, accounting for 39% (47) of the total. Mechanical bowel complications were also comparatively common: ileus, small bowel obstruction and viscus perforation accounting for a combined 29% (35) of the total. Infective complications and ischaemic complications were relatively infrequent (Fig. 1).

Patients experiencing mesenteric ischemia experienced the highest rates of thirty-day mortality (88.9%), whilst no thirty-day mortality was observed in complication groups of gastroenteritis, transaminitis, small bowel obstruction, ischaemic colitis, cholecystitis or pancreatitis (Fig. 2) (**Supplementary Figs. 1,2,3**).

Patient Demographics

Patient demographics are presented in Table 1. Patients that suffered a GI complication had a higher median age ($p < 0.001$). They were less likely to have an abnormal pre-operative heart rhythm ($p = 0.009$), have a reduced left ven-

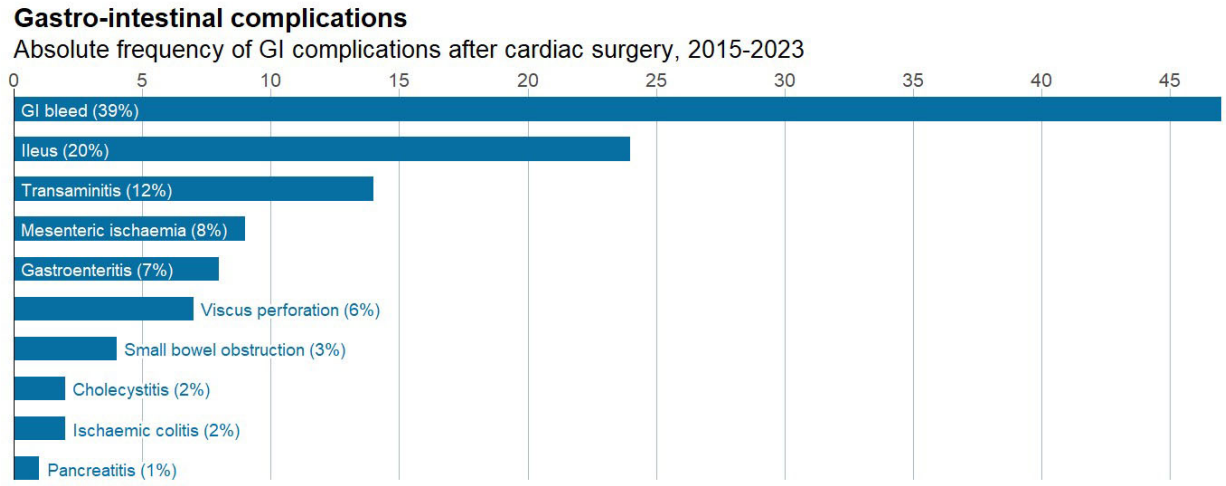

Fig. 1. Absolute frequency of GI complications after cardiac surgery, 2015–2023. GI, gastrointestinal.

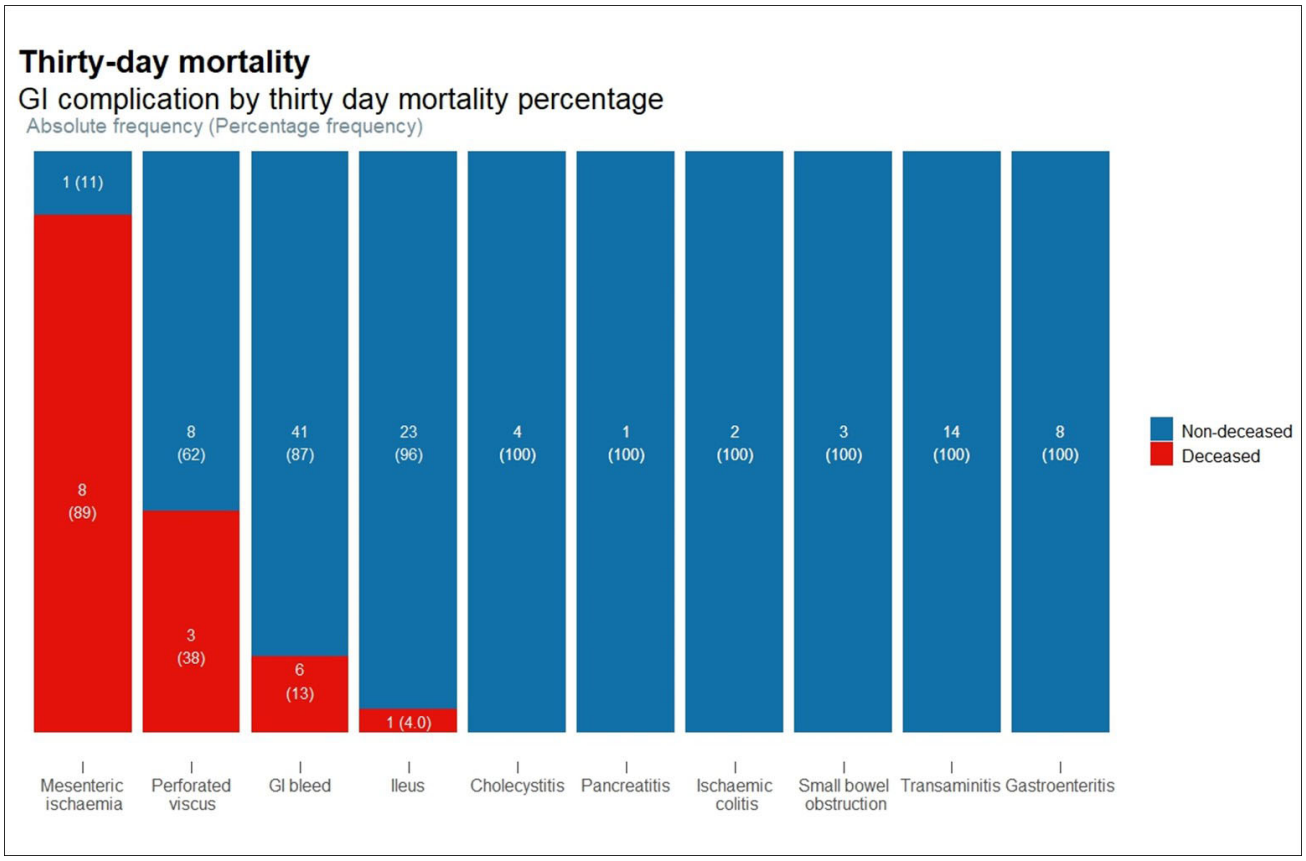

Fig. 2. GI complications after cardiac surgery by thirty-day mortality, 2015–2023.

tricle ejection fraction ($p < 0.001$), and have pre-operative neurological disease ($p = 0.003$).

Operation Type

Operation characteristics are presented in Table 2. GI complications occurred at higher proportional rates in patients undergoing combined cardiac operations ($p < 0.001$) and those of increasing urgency ($p = 0.004$) (Table 2 and Fig. 3). They occurred in the highest proportional frequency in patients undergoing operation on thoracic aorta (**Supplementary Fig. 4**).

Mortality

Patients who experienced a GI complication had greater rates of thirty-day mortality (14.4% vs 2.4%, $p < 0.001$) and in-hospital mortality (6.8% vs 1.1%, $p < 0.001$). They

Table 1. Cohort characteristics.

	No GI complication (N = 6651)	GI complication (N = 118)	Test statistic*	*p* value
Age (n = 6769)	69 [61–75]	74 [66–79]	–4.44	<0.001
BMI (n = 6757)	28.8 (23.5–34.2)	28.3 (23.4–33.3)	1.08	0.280
Sex (n = 6768)			0.56	0.453
Female	1931 (29.0%)	38 (32.2%)		
Male	4719 (71.0%)	80 (67.8%)		
Smoking status (n = 6042)			5.38	0.068
Never smoked	2668 (44.9%)	37 (34.9%)		
Ex-smoker	2443 (41.2%)	48 (45.3%)		
Current smoker	825 (13.9%)	21 (19.8%)		
Diabetic status (n = 6769)			6.02	0.111
Not diabetic	5105 (76.8%)	100 (84.7%)		
Controlled by diet	306 (4.6%)	6 (5.1%)		
Controlled by oral therapy	878 (13.2%)	7 (5.9%)		
Controlled by insulin	362 (5.4%)	5 (4.2%)		
Known pulmonary disease (n = 6633)			<0.01	1.000
No	5732 (87.9%)	100 (87.7%)		
Yes	787 (12.1%)	14 (12.3%)		
Known neurological disease (n = 6637)			8.88	0.003
No	5925 (90.9%)	96 (82.8%)		
Yes	596 (9.1%)	20 (17.2%)		
Pre-operative renal failure (n = 6758)			0.72	0.397
No	6515 (98.1%)	114 (96.6%)		
Yes	125 (1.9%)	4 (3.4%)		
Hypertension (n = 6067)			2.50	0.114
No	2188 (36.7%)	31 (29.2%)		
Yes	3773 (63.3%)	75 (70.8%)		
Abnormal pre-operative heart rhythm (n = 6446)			6.92	0.009
No	792 (12.5%)	23 (20.9%)		
Yes	5544 (87.5%)	87 (79.1%)		
LVEF (n = 5086)			21.52	<0.001
Good (LVEF >50%)	3973 (79.5%)	60 (67.4%)		
Fair	762 (15.2%)	19 (21.3%)		
Poor	241 (4.8%)	7 (7.9%)		
Very poor	21 (0.4%)	3 (3.4%)		
Dyspnoea status (n = 5985)			1.35	0.718
NYHA I	1475 (25.1%)	21 (21.6%)		
NYHA II	1681 (28.5%)	26 (26.8%)		
NYHA III	1996 (33.9%)	35 (36.1%)		
NYHA IV	736 (12.5%)	15 (15.5%)		
LMS disease (n = 6166)			0.62	0.431
No	4653 (76.8%)	81 (73.6%)		
Yes	1403 (23.2%)	29 (26.4%)		
Known coronary artery disease (n = 6272)			0.24	0.626
No	2426 (39.4%)	45 (41.7%)		
Yes	3738 (60.6%)	63 (58.3%)		
Previous MI (n = 6428)			0.12	0.725
No	4550 (72.0%)	79 (70.5%)		
Yes	1766 (28.0%)	33 (29.5%)		
Previous PCI (n = 6353)			0.87	0.351
No	5484 (87.8%)	89 (84.8%)		
Yes	764 (12.2%)	16 (15.2%)		

BMI, body-mass-index; NYHA, New York Heart Association; LMS, left main-stem disease; LVEF, left ventricle ejection fraction; MI, myocardial infarction; PCI, percutaneous coronary intervention.

* Test statistic referring to: CHI-square value for categorical data, Mann-Whitney U test standardised Z value for non-normally distributed continuous data, *t*-test value for normally distributed continuous data.

Table 2. Operation characteristics.

Operation characteristic	No GI complication (N = 6651)	GI complication (N = 118)	Test statistic*	*p* value
Operation weighting (n = 6557)			31.73	<0.001
Isolated CABG	2464 (38.3%)	28 (24.1%)		
Isolated non-CABG	2289 (35.5%)	31 (26.7%)		
Two combined cardiac procedures	1497 (23.2%)	49 (42.2%)		
Three or more combined cardiac procedures	191 (3.0%)	8 (6.9%)		
Operative priority (n = 6769)			13.34	0.004
Elective	4564 (68.6%)	78 (66.1%)		
Urgent	1924 (28.9%)	31 (26.3%)		
Emergency	152 (2.3%)	8 (6.8%)		
Salvage	11 (0.2%)	1 (0.8%)		
Pre-operative inotropes (n = 6598)			0.08	0.772
No	6418 (99.0%)	110 (98.2%)		
Yes	68 (1.0%)	2 (1.8%)		
Cross-clamp time (minutes) (n = 5517)	70 [53–94]	86 [60–110]	–3.39	<0.001
Bypass time (minutes) (n = 5545)	98 [74–127]	120 [87–164]	–3.91	<0.001

CABG, coronary artery bypass grafting.

* Test statistic referring to: CHI-square value for categorical data, Mann-Whitney U test standardized Z value for non-normally distributed continuous data, *t*-test value for normally distributed continuous data.

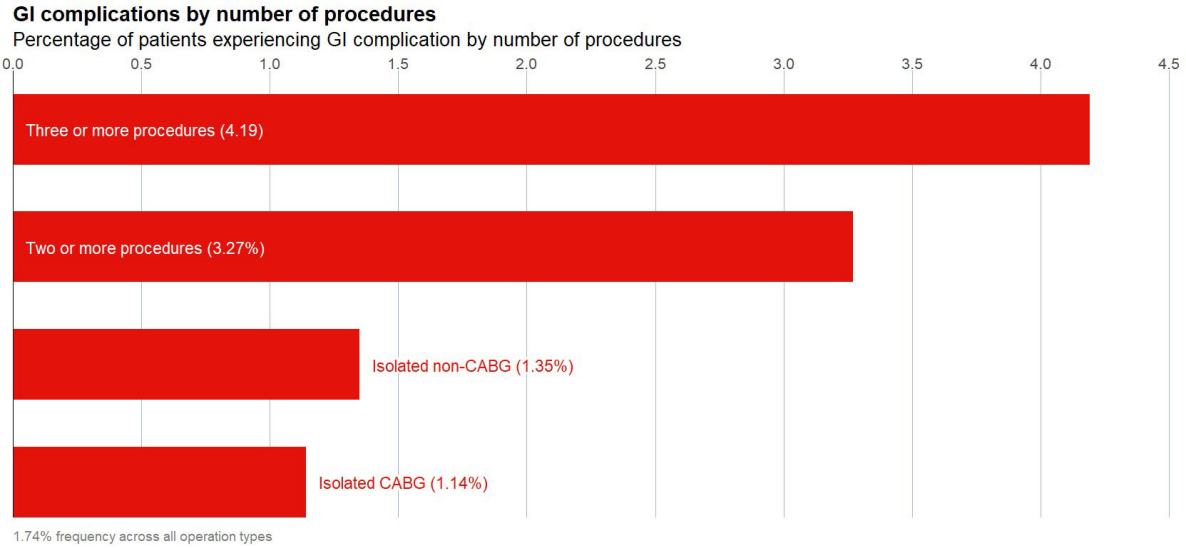

Fig. 3. GI complications after cardiac surgery by operation weighting, 2015–2023. CABG, coronary artery bypass grafting.

experienced concurrent complications such as pneumonia (43.2% vs 20.2%, $p < 0.001$), atrial fibrillation (43.2% vs 25.8%, $p < 0.001$), heart failure (3.4% vs 0.9%, $p = 0.017$) and general vascular complications (9.3% vs 2.8%, $p < 0.001$) at higher rates. They spent longer on the bypass, longer under aortic cross clamping, and spent longer in the hospital than their counterparts (12.0 vs 6.85 median days, $p < 0.001$) (Table 3).

Developing a GI complication in the postoperative period significantly predicted thirty-day mortality, even after adjusting for additive euroscore and length of patient stay (Odds ratio (OR) 7.95 [4.35–14.5], $p < 0.001$). All-cause mortality across the across the nine-year follow-up period was significantly higher for patients who suffered a GI complication (Fig. 4). However, developing a serious GI complication did not significantly predict mortality in the long-term (hazard ratio (HR) 1.22 [0.87–1.71], $p = 0.254$) after adjusting for additive euroscore and length of stay (**Supplementary Table 6**).

Risk Factors

Seven risk factors were identified for the development of a postoperative GI complication in this cohort. In addition to several previously identified risk factors, a history of previous percutaneous coronary intervention (PCI) (OR 2.27 [1.24–4.17], $p = 0.007$) and increased operation weighting

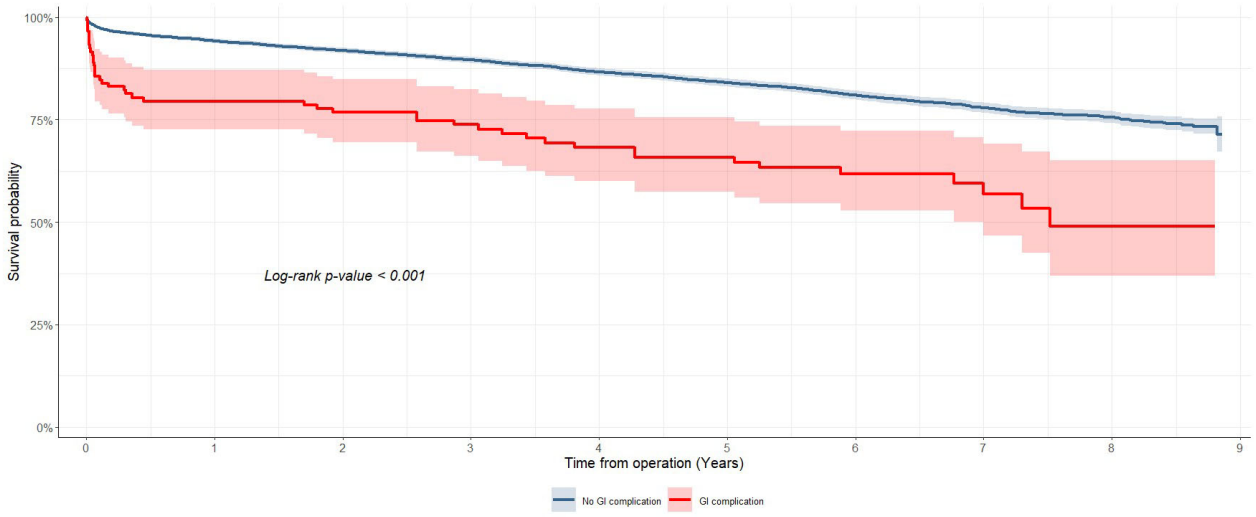

Fig. 4. Cumulative survival after cardiac surgery, 2015–2023.

Table 3. Operation outcomes.

Outcome	No GI complication (N = 6651)	GI complication (N = 118)	Test statistic*	*p* value
Thirty-day mortality (n = 6769)	160 (2.4%)	17 (14.4%)	60.95	<0.001
In-hospital mortality (n = 6711)	71 (1.1%)	8 (6.8%)	28.03	<0.001
Postoperative vascular complication (n = 6769)	184 (2.8%)	11 (9.3%)	15.54	<0.001
Postoperative heart failure (n = 6769)	57 (0.9%)	4 (3.4%)	5.73	0.017
Postoperative pneumonia (n = 6769)	1345 (20.2%)	51 (43.2%)	37.46	<0.001
Postoperative PPM (n = 6769)	89 (1.3%)	1 (0.8%)	<0.01	0.955
Postoperative AF (n = 6769)	1718 (25.8%)	51 (43.2%)	18.16	<0.001
Length of stay (days) (n = 6483)	6.85 [5.24–9.39]	12.0 [7.84–19.9]	–9.35	<0.001

PPM, permanent pacemaker; AF, atrial fibrillation.

* Test statistic referring to: CHI-square value for categorical data, Mann-Whitney U test standardised Z value for non-normally distributed continuous data, *t*-test value for normally distributed continuous data.

(OR 1.67 [1.02–2.74], $p = 0.043$) increased the likelihood of developing a postoperative GI complication (Table 4).

Laparotomy

Eight patients underwent emergency laparotomy (Table 5). The mean age of patients undergoing laparotomy was 72.5 years. The median time from cardiac surgery to onset of symptoms in this group was 7.5 days. Seven out of the eight patients underwent computed tomography (CT) imagining within 24 hours of symptom onset. Three of the patients, however, waited several days between developing symptoms and onset of surgery. Rates of mortality in the cohort undergoing laparotomy were high: intra-operative mortality was 25% and six of the eight patients died within thirty days of the laparotomy procedure.

Discussion

In line with previous literature on the topic, our data suggests that development of a GI complication in the immediate postoperative period confers a greatly increased risk of short-term mortality, independent of length of hospital stay or pre-operative risk. This is a widely reported phenomenon [3,7,18]. Development of a GI complication did not significantly impact on long term mortality when adjusting for pre-operative risk score and length of patient stay. This may reflect the fact that elderly, high-risk patients were more likely to suffer a GI complication, and that patients who suffered the most common GI complications such as ileus, UGI bleeding or gastroenteritis and survived did not experience significant functional impairment as a result of the complication.

Subgroup analysis indicated that not all GI complications are equal with regards to risk of postoperative mortality. Mesenteric ischemia, GI bleeding, and viscus perforation represent dangerous complications associated with high rates of early mortality, whilst low rates of early mortality were observed in patients suffering ileus, transient transaminitis or GI-tract infections.

Of the complications associated with a high risk of mortality, GI bleeding was the most commonly observed. The

Table 4. Adjusted odds ratios for developing a GI complication.

Characteristic	β	Standard error	Wald χ^2	Odds ratio*	Confidence interval	p value
Age greater than 80 years	1.03	0.30	11.84	2.81	1.26–5.06	<0.001
Previous PCI	0.82	0.31	7.00	2.27	1.24–4.17	0.007
Bypass time >150 minutes	0.59	0.29	4.22	1.8	1.03–3.15	0.040
Inotropes	1.62	0.76	4.52	5.06	1.14–22.5	0.033
Operation weighting						
Isolated CABG						
Isolated non-CABG	–0.21	0.26	0.64	0.81	0.49–1.35	0.422
Two procedures	0.51	0.25	4.11	1.67	1.02–2.74	0.043
Three procedures	0.70	0.48	2.10	2.01	0.78–5.15	0.147
Postoperative atrial fibrillation	0.84	0.24	12.19	2.32	1.45–3.72	<0.001
Postoperative vascular complication	1.18	0.45	6.83	3.25	1.34–7.89	<0.001

*Odds ratio obtained after adjusting for age, smoking status, inotropes, NYHA class, bypass time >150 minutes, postoperative atrial fibrillation, postoperative vascular complication and postoperative heart failure.

high incidence of GI bleeding after cardiac surgery is attributable to several factors. A high proportion of anticoagulated patients, such as those undergoing implantation of mechanical prostheses, high rates of postoperative antiplatelets that predispose both to increased bleeding and an increased risk of developing ulcers, and the development of stress ulcers are all likely contributors. Whilst the most common complication, the incidence of GI bleeding (0.69%) in this cohort falls into the lower end of the observed incidences ranges in comparable studies (0.07%–1.6%) [19,20]. This is possibly related to the fact that routine proton-pump inhibitors were prescribed in all patients receiving postoperative antiplatelet therapy at our centre.

Less frequent than GI bleeding, but associated with a notably higher risk of mortality, was mesenteric ischemia. Mesenteric ischemia after cardiac surgery is widely recognized as the most lethal postoperative GI tract complication. Visceral hypoperfusion secondary to reduced cardiac output syndrome is the most commonly identified cause of mesenteric ischemia in this patient subgroup, followed by thrombo-embolic events. Previously identified risk factors for mesenteric ischemia include the duration of cardiopulmonary bypass, postoperative blood transfusion, use of vasopressive inotropes and use of an intra-aortic balloon pump [21]. Difficulty lies in early diagnosis, as patients are often ventilated and heavily sedated postoperatively, but serial serum lactate measurement and a low threshold for contrast enhanced triple phase computed-tomography (CT) scans can be useful tools in these complex patients.

We observed that GI complications frequently occur in conjunction with other, more common, postoperative complications such as pneumonia, atrial fibrillation, heart failure and general vascular complications, and are associated with longer hospital stays. Yadav *et al.* [22] and Viana *et al.* [23] describe similar findings. There is likely a causative link between several of these complications.

Visceral hypoperfusion secondary to pneumonia-driven sepsis or heart failure, and thrombo-embolic events as a result of atrial fibrillation or septic emboli are likely to provoke bowel ischemia or hypoperfusion and ensuing GI complications. Patients experiencing prolonged hospital stays due to postoperative ileus or GI bleeding are more likely to acquire hospital acquired pneumonia. Multiple postoperative adverse events lead to longer hospital stays, globally worsened outcomes and a corresponding increased risk of mortality.

In addition to previously identified risk factors—age, postoperative atrial fibrillation, postoperative vascular complication, pre-operative inotropes and prolonged bypass time—we identified two additional risk factors for development of a GI complication: pre-operative angioplasty and combined, rather than isolated, cardiac procedures.

The finding that a history of PCI increases the risk of suffering a postoperative GI complication in this cohort was in keeping with our hypothesis that coronary artery disease may increase the likelihood of a GI Complication. There are several potential mechanisms underlying this association. Patients having undergone prior PCI in the area surveyed are likely to have been taking dual antiplatelet therapy prior to their cardiac operation. Local best policy guidance suggests a combination of aspirin and clopidogrel following non-ST-elevation myocardial infarction (NSTEMI) or ST-elevation myocardial infarction (STEMI). Suppression of prostaglandin synthesis by antiplatelets results in reduced gastric mucosal blood supply, and development of gastric ulcers [24]. Use of cardiopulmonary bypass can induce dilutional coagulopathy or coagulopathy as a result of a systemic immune-mediated inflammatory response [25,26]. Such coagulopathies may result in GI bleeding in patients with pre-existing gastric ulcer disease.

Ensuring patients on long-term antiplatelet therapy are on an appropriate proton pump inhibitor (PPI) prior to operation, and consideration of pre-operative endoscopy in this cohort may reduce the incidence of postoperative GI bleeding.

Table 5. Laparotomy details and outcomes.

Specific complication	Imaging	Intervention	Days from surgery to onset	Days from surgery to imaging	Days from surgery to intervention	Intra-operative mortality	Thirty-day mortality	Initial cardiac operation	Additive euroscore
Mesenteric ischemia	CT	Laparotomy/extensive small and large bowel resections	1	2	2	No	Yes	Aortic valve replacement	10
Cryofibrinogenemia resulting in mesenteric ischemia	CT	Laparotomy + resection of ischaemic bowel	15	30	32	No	Yes	Aortic valve and aortic arch replacement	10
GI bleed requiring bowel resection	CT	Small bowel resection	16	16	28	No	No	Aortic arch replacement	14
Mesenteric ischemia	CT	Laparotomy – not amenable to resection	1	2	2	No	Yes	CABG + mitral valve repair	1.99
Mesenteric ischemia	CT	Laparotomy – not amenable to resection	6	6	6	Yes	Yes	CABG	8
Perforated diverticular abscess	CT	Laparotomy + hartmann's procedure	15	15	21	No	No	CABG	4
Infarcted caecum and gallbladder, perforated viscus	CT	Laparotomy/right hemi-colectomy and cholecystectomy	6	6	6	No	Yes	CABG	4
Small bowel obstruction + GI bleed	CT	Laparotomy/division of adhesions	9	9	9	Yes	Yes	CABG	0.92

CT, computed tomography.

Previous PCI predisposing patients to development of a GI complication is likely reflective of the fact that previous angioplasty serves to some degree as a measure of a patient's general vascular health. To some extent, a patient's extracoronary vessel disease can be predicted by their degree of coronary artery disease [27]. Patients with mesenteric artery or coeliac trunk stenosis will be more susceptible to thrombotic emboli or splanchnic hypoperfusion in the context of reduced cardiac output [28,29]. Both thrombotic emboli and splanchnic hypoperfusion may result in mesenteric ischemia, and poor visceral circulation may contribute to bowel wall oedema and relative hypoxia of affected bowel segments, resulting in an increased risk of paralytic ileus and more serious sequelae, such small bowel obstruction and viscus perforation [30].

Patients undergoing more than one procedure in an operation were at a greater risk of developing a GI complication after controlling for time on the cardiac bypass. Combined operations, which might involve operating on several valves or major blood vessels incur a substantial physiological impact on the patient, frequently require a higher volume of foreign implanted material, and are frequently associated with high mortality rates and poor outcomes [31].

Prolonged surgeries, multiple surgical sites and more implanted foreign material will result in increased sympathetic drive to the gut in the postoperative period, and systemic release of TNF-α and interleukins, resulting in abnormal wall motility and further bowel wall oedema [30]. This systemic inflammatory response also has the potential to trigger worsening coagulopathy, contributing to the likelihood of GI bleeding. Inflammation of abdominal viscera in the context of this immune response may contribute to postoperative diagnoses of acalculous cholecystitis or colitis.

Identification of risk factors and appropriate preoperative risk mitigation are important, but there will remain, in the foreseeable future, a small cohort of patients who suffer a serious GI complication after cardiac surgery, and consideration of how best to manage these patients is important.

Outcomes in patients undergoing laparotomy were poor. Two of the patients undergoing emergency postoperative laparotomy suffered intra-operative mortality, meeting the criteria outlined by Javanmard-Emamghissi *et al.* [32] for futile laparotomy, in that the operations did not provide any therapeutic benefit, but did represent a missed opportunity for palliation.

Prompt diagnosis and surgical intervention with respect to symptom onset have been associated with improved outcomes in a similar cohort [4], and it is notable that both patients surviving beyond thirty days at laparotomy underwent surgery within 24 hours of CT imaging.

Prompt emergency laparotomy is a potentially life-saving intervention in correctly diagnosed postoperative cardiac surgery patients however careful consideration should be paid to the individual circumstances, pre-operative functional status and expected prognosis. The current risk scoring tool for emergency laparotomy in the UK—namely the National Emergency Laparotomy Audit (NELA) score—is not sensitive enough in high risk cases such as mesenteric ischemia, which is the most common reason for which these patients would be considered for a laparotomy [33].

This study had several limitations. It was retrospective, rather than prospective, and causal inferences should be drawn with caution. The presence of preoperative gastrointestinal disease was not an available data item in this cohort, and it is unknown to what degree this might confound the identified risk factors.

The primary outcome lacked granularity—gastroenteritis could encompass one of several conditions, and ileus represents a spectrum of disease ranging from moderate constipation to pseudo-obstruction.

The aetiology of the gastrointestinal complications covered in this study varies, and regression analysis treating 'GI complication' as a dichotomous outcome will likely identify features that predict broadly for poor postoperative outcomes, but may miss certain, complication-specific risk factors such as the use of a balloon pump predisposing to mesenteric ischemia as a result of dislodged emboli.

Grouping complications of differing aetiology and severity, such as ileus and mesenteric ischemia together in this manner allows for identification of those factors that predict broadly for a poor postoperative outcome, specifically with regards to disease of the gastrointestinal tract in a small cohort, without risking unstable and biased regression models due to an insufficient number of outcomes compared to regression confounders. Identification of the most commonly suffered postoperative complications, and some idea of relevant risk factors, can identify priority areas of interest for future, large-cohort studies.

However, this approach may mask risk factors for individual complications. Non-significance of a measured characteristic does not suggest it is not a risk factor for an individual complication. Likewise, individual complication analysis may reveal that prior PCI and multiple cardiac procedures are risk factors for some, but not all of the complications covered in this study.

Conclusions

GI-tract complications comprise a rare but high-risk group of complications following cardiac surgery. In assessing the patient who presents with abdominal pain and altered bowel habit following surgery, consider gastrointestinal bleeding, mesenteric ischemia and small bowel obstruction. All postoperative cardiac surgery patients prescribed antiplatelet therapy should receive regular PPI therapy, and clinicians should adopt a low threshold for contrast enhanced triple phase computed-tomography (CT) scanning, particularly in patients with a prior history of vascular disease who have undergone a combined procedure.

In the preoperative stage, consideration should be given to minimally invasive alternatives to traditional cardiac surgeries when assessing older patients who have previously undergone PCI and who may be due to undergo combined cardiac surgery.

Validation of these risk factors in a series of prospective studies investigating individual GI complications will aid in the preoperative stratification of cardiac surgery patients by risk, helping clinicians to identify appropriate treatments on an individual basis.

Availability of Data and Materials

The data that support the findings of this study are available from the corresponding author upon reasonable request, and subject to our being able to satisfy local data-sharing agreements to preserve patient confidentiality.

Author Contributions

TF: conceptualization, methodology, statistical analysis, writing—original draft, writing-review, and editing. DD: conceptualization, methodology, writing—original draft, writing-review, and editing. CPK: conceptualization, writing—review and editing, data curation. DC: writing—review and editing, statistical analysis. All authors have been involved in revising it critically for important intellectual content. All authors gave final approval of the version to be published. All authors have participated sufficiently in the work to take public responsibility for appropriate portions of the content and agreed to be accountable for all aspects of the work in ensuring that questions related to its accuracy or integrity.

Ethics Approval and Consent to Participate

As this was a retrospective review, meeting the criteria for a service evaluation study, Research Ethics Committee (REC) approval was exempted by the NHS Lothian health board. This study was conducted in accordance with the Declaration of Helsinki. Since this is an anonymised, retrospective analysis and does not pose any risk or impact to the patients, informed consent is not required.

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

Dimitrios Damaskos is serving as one of the Editorial Board members of this journal. Dimitrios Damaskos had no involvement in the peer review of this article and has no access to information regarding its peer review. Other authors declare no conflict of interest.

Supplementary Material

Supplementary material associated with this article can be found, in the online version, at https://doi.org/10.62713/aic.3819.

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