Factors Associated With Postoperative High-Sensitivity Cardiac Troponin T Elevation After Thoracic Surgery: A Single-Centre Retrospective Cohort Study

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AIM: To examine perioperative factors associated with postoperative high-sensitivity cardiac troponin T (hs-cTnT) elevation after thoracic surgery.

METHODS: This single-centre retrospective cohort study screened 588 consecutive records of patients who underwent thoracic surgery between June 2020 and June 2023, counting only the first eligible operation for each patient. After the exclusion of 128 records, all 460 eligible patients were included in the analysis. The outcome was defined as any hs-cTnT value ≥0.014 µg/L (14 ng/L) on postoperative day 1, 3, or 5. Eleven variables were entered simultaneously into a binary logistic regression model, with surgical method represented by indicator variables. Age was entered in years, and its odds ratio (OR) was expressed per 10-year increase; other continuous variables were analysed in their original units.

RESULTS: Postoperative hs-cTnT elevation occurred in 155 of 460 patients (33.7%). In the multivariable model, age (OR 1.80, 95% CI 1.23–2.63), procedure type (wedge resection: OR 4.47, 95% CI 1.57–12.71; segmentectomy/lobectomy: OR 5.52, 95% CI 2.04–14.96; oesophageal surgery: OR 27.96, 95% CI 5.50–142.27; each compared with other thoracic procedures), operation duration (OR 1.53 per hour, 95% CI 1.21–1.93), preoperative creatinine (OR 1.021 per µmol/L, 95% CI 1.007–1.035), preoperative potassium (OR 3.59 per mmol/L, 95% CI 1.84–7.02), and pre-existing atrial fibrillation (OR 5.56, 95% CI 1.84–16.83) were associated with the outcome. Postoperative day-1 haemoglobin showed an inverse association that did not reach statistical significance (OR 0.972 per g/L, 95% CI 0.942–1.002; $p = 0.069$), and the inverse association with ejection fraction was also not significant (OR 0.905 per %, 95% CI 0.772–1.060; $p = 0.216$).

CONCLUSIONS: Older age, procedure type, longer operation duration, higher preoperative creatinine, higher preoperative potassium, and pre-existing atrial fibrillation were associated with postoperative hs-cTnT elevation after multivariable adjustment. These associations do not establish causality or constitute a validated prediction model; rather, they generate hypotheses for the prospective evaluation of postoperative monitoring strategies.

Keywords: thoracic surgery; high-sensitivity cardiac troponin T; postoperative troponin elevation; retrospective cohort; risk factors

Introduction

Postoperative cardiac troponin elevation is frequently detected after non-cardiac surgery and has important prognostic implications. A systematic review reported a pooled incidence of myocardial injury after non-cardiac surgery (MINS) of 17.9%, although the reported frequency varied substantially according to the study population, type of surgery, cardiac troponin assay, sampling schedule, surveillance strategy, and diagnostic definition [1]. Large prospective cohorts have demonstrated graded associations between postoperative troponin concentrations and 30-day mortality [2,3]. Many affected patients do not experience typical ischaemic symptoms, which may be absent or masked by analgesia and other postoperative complaints [2,3]. Clinically relevant troponin elevation may therefore remain unrecognised when testing is restricted to patients with overt symptoms.

Myocardial injury after non-cardiac surgery is generally distinguished from an isolated laboratory abnormality by considering whether cardiac troponin exceeds the assay-specific upper reference limit and whether the elevation is attributable to a presumed ischaemic mechanism [4]. Troponin elevation alone is not synonymous with perioperative myocardial infarction; interpretation also depends on the likely mechanism, clinical presentation, and available electrocardiographic or imaging findings. Non-ischaemic perioperative conditions may also increase troponin concentrations, making precise terminology important. Contemporary perioperative guidance therefore emphasises cardio-

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vascular risk assessment, appropriate postoperative evaluation, and selective biomarker surveillance in patients considered to be at increased risk [4,5]. In the present study, the endpoint was defined by a postoperative high-sensitivity cardiac troponin T (hs-cTnT) value at or above the assay threshold. Because the underlying mechanism was not formally adjudicated, the more conservative term "postoperative hs-cTnT elevation" is used consistently throughout the manuscript.

Evidence specific to thoracic surgery remains relatively limited. Thoracic procedures may produce substantial physiological stress through changes in ventilation and oxygenation, haemodynamic fluctuation, inflammation, postoperative pain, and the interaction of surgery with pre-existing cardiopulmonary disease. These factors may influence myocardial oxygen supply and demand and contribute to variation in postoperative cardiac biomarker concentrations. Recent observational work has linked perioperative high-sensitivity troponin concentrations with severe postoperative complications after lung resection, supporting further investigation in this population [6]. Previous thoracic surgery cohorts, using differing eligibility criteria and biomarker protocols, have reported associations between renal and procedure-related factors and postoperative troponin elevation or myocardial injury after non-cardiac surgery [7,8,9]. Much of the remaining evidence derives from mixed non-cardiac surgical cohorts [1,10]. The present study provides complementary evidence from a mixed thoracic-surgery cohort restricted to patients with a preoperative hs-cTnT concentration below 14 ng/L and with measurements on postoperative days 1, 3 and 5. It examines adjusted associations across four procedure categories, including oesophageal surgery, and evaluates routinely recorded perioperative variables such as preoperative potassium and pre-existing atrial fibrillation.

Methods

Study Design and Reporting

This was a single-centre retrospective observational cohort study based on consecutive electronic records of patients who underwent thoracic surgery at the Department of Cardiothoracic Surgery, The Central Hospital of Xiaogan, between June 2020 and June 2023. Only the first eligible operation was retained for each patient. The report was structured with reference to the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement [11].

Participants

Consecutive electronic records were screened for complete perioperative clinical and laboratory information, including preoperative hs-cTnT, postoperative hs-cTnT on days 1, 3, and 5, and perioperative N-terminal pro-B-type natriuretic peptide (NT-proBNP). When a patient underwent more than one thoracic operation during the study period, only the first eligible operation was counted. Patients with documented coronary artery disease, previous myocardial infarction, decompensated heart failure, or severe valvular disease (collectively regarded as a clinically significant history of heart disease) were excluded, as were those with previous thoracic or cardiac-related surgery or incomplete required records. Stable pre-existing atrial fibrillation and non-severe aortic or mitral regurgitation were not exclusion criteria in the absence of the listed conditions, because they were not considered to constitute decompensated or severe heart disease. In addition, records with a preoperative hs-cTnT concentration ≥14 ng/L (n = 28) or with documented sepsis, pulmonary embolism, or acute decompensated heart failure at the time of surgery (n = 11) were excluded during screening, and a further 33 records were excluded because of incomplete key perioperative data.

Of 588 screened records, 128 were excluded: 39 because of a documented history of heart disease, 17 because of previous thoracic or cardiac-related surgery, and 72 for the following exclusion reasons (28 with a preoperative hs-cTnT concentration ≥14 ng/L, 11 with documented sepsis, pulmonary embolism, or acute decompensated heart failure at the time of surgery, and 33 with incomplete key perioperative data). All remaining 460 patients were included in the primary analysis. Because this was an association study rather than a prediction-model study, the cohort was not randomly split into development and validation subsets (Fig. 1).

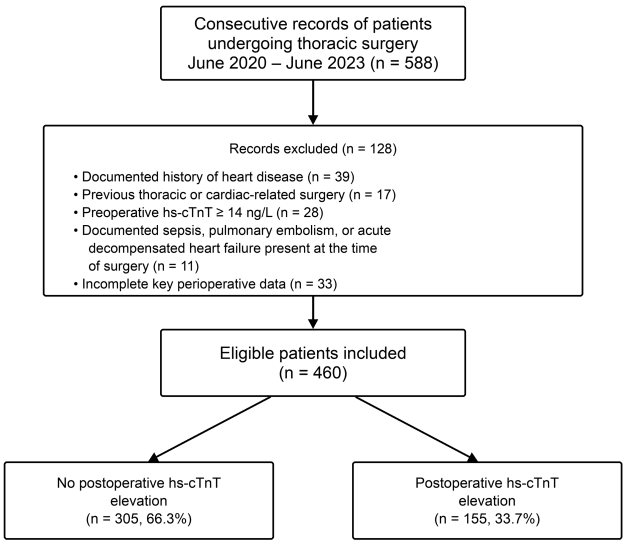


Fig. 1. Participant flow diagram. Outcome: any hs-cTnT ≥0.014 µg/L (14 ng/L) on postoperative day 1, 3, or 5. All 460 patients were included in the primary analysis. hs-cTnT, high-sensitivity cardiac troponin T.

Outcome Definition

Serum hs-cTnT was measured using the Elecsys Troponin T hs assay (product batch: 827211, Roche Diagnostics, Mannheim, Germany) by electrochemiluminescence immunoassay on a cobas e 601 analyser (Roche 601, Roche). Results were reported in µg/L. The laboratory 99th-percentile upper reference limit was 0.014 µg/L (14 ng/L). The binary outcome was defined as any hs-cTnT concentration at or above this threshold on postoperative day 1, 3, or 5; patients with all three postoperative measurements below the threshold were classified as not having the outcome. All included patients had a preoperative hs-cTnT concentration below 14 ng/L. Because formal event-adjudication records were not retained, the endpoint is reported as postoperative hs-cTnT elevation rather than myocardial injury after non-cardiac surgery. At the screening stage, records with documented sepsis, pulmonary embolism, or acute decompensated heart failure present at the time of surgery were excluded, but non-ischaemic conditions that developed during the postoperative period were not identified or excluded on a case-by-case basis.

Variables

The extracted variables comprised age, sex, hypertension, diabetes, chronic obstructive pulmonary disease (COPD), preoperative discomfort symptoms (palpitations, chest tightness, shortness of breath, and fatigue), surgical method, operation duration, perioperative white blood cell (WBC) count, haemoglobin (Hb), platelet (PLT) count, albumin, creatinine, potassium, cholesterol, triglycerides, NT-proBNP, electrocardiographic (ECG) findings, and ejection fraction (EF). Hypertension was identified based on blood pressure measurements, with systolic blood pressure ≥140 mmHg or diastolic blood pressure ≥90 mmHg. Diabetes was identified based on the following criteria: random blood glucose ≥11.1 mmol/L, fasting blood glucose ≥7.0 mmol/L, 2-hour post-OGTT blood glucose ≥11.1 mmol/L, or glycated haemoglobin (HbA1c) ≥6.5%. COPD was identified based on clinical symptoms, including cough, excessive sputum production, and dyspnoea lasting for more than 3 months, together with pulmonary function test results showing a post-bronchodilator FEV1/FVC ratio <0.70. Preoperative discomfort symptoms were defined according to the symptoms documented in the patients' preoperative medical records. Preoperative discomfort symptoms were defined according to the symptoms documented in the patients' preoperative medical records. Laboratory variables were extracted at the time points recorded in the hospital information system. WBC, Hb and PLT were available at four time points: a preoperative baseline obtained during the routine preoperative work-up, and postoperative days 1, 3 and 5. NT-proBNP was available at the preoperative baseline and on postoperative day 1. NT-proBNP was measured using the Roche cobas e 601 analyser (reagent batch number: 938886). Each time point was treated as a separate variable. Albumin, creatinine, potassium, cholesterol and triglycerides were taken from the single biochemistry panel obtained on admission, before surgery, and one value per patient was analysed; these measurements therefore preceded the entire outcome ascertainment window. ECG findings were obtained from the preoperative 12-lead ECG, while EF was determined using the biplane modified Simpson's method on preoperative transthoracic echocardiography. The presence and severity of aortic and mitral regurgitation were also assessed using preoperative transthoracic echocardiography. ECG abnormalities, including conduction block, atrial fibrillation, sinus tachycardia, sinus bradycardia, and T-wave abnormalities, were identified based on the recorded preoperative ECG findings. Surgical procedures were analysed as four nominal categories: wedge resection, segmentectomy/lobectomy, oesophageal surgery and other thoracic procedure. The grouping reflected the operative case mix in this cohort, in which pulmonary nodules were the most frequent indication, and distinguished wedge resection from segmentectomy or lobectomy, from oesophageal operations, and from the remaining procedures. The reference category comprised mediastinal tumour resection (n = 64), resection of a chest wall abscess (n = 4), thoracic sympathectomy for palmar hyperhidrosis (n = 4), and incision and drainage of a mediastinal cold abscess (n = 2). These categories describe procedure type and were not treated as a validated scale of operative complexity or invasiveness. Atrial fibrillation was defined as a documented pre-existing diagnosis or atrial fibrillation detected on the preoperative 12-lead ECG; postoperative new-onset atrial fibrillation was not included.

Statistical Analysis

All 460 eligible patients were included in the primary analysis. Continuous variables with approximately normal distributions (assessed by the Shapiro–Wilk test) are reported as mean ± standard deviation (SD), and group means were compared using Welch's t test; NT-proBNP, which was markedly right-skewed, is reported as median (interquartile range, IQR) and compared using the Mann–Whitney U test. Categorical variables are reported as number (percentage) and were compared using Pearson's chi-squared test without continuity correction, except that Fisher's exact test was used when an expected cell count was below 5. All tests were two-sided and $p < 0.05$ was considered statistically significant. Because 34 between-group comparisons were performed in Table 1, Benjamini–Hochberg (BH)-adjusted q values are reported alongside nominal p values, and $q < 0.05$ was regarded as significant after adjustment for multiple testing. Measurements of WBC, Hb, and PLT at each recorded time point were analysed as separate variables in the between-group comparisons; no within-patient longitudinal model was fitted, and changes over time were not formally assessed.

Table 1. Perioperative characteristics according to postoperative hs-cTnT elevation.

Variable	No hs-cTnT elevation (n = 305)	hs-cTnT elevation (n = 155)	Test statistic	*p* value	BH-adjusted q
Sex, n (%)			4.276	0.039	0.058
Male	146 (47.9%)	90 (58.1%)			
Female	159 (52.1%)	65 (41.9%)			
Hypertension	100 (32.8%)	69 (44.5%)	6.083	0.014	0.022
Diabetes	29 (9.5%)	28 (18.1%)	6.931	0.008	0.014
COPD	21 (6.9%)	8 (5.2%)	0.517	0.472	0.518
Preoperative discomfort symptoms	50 (16.4%)	57 (36.8%)	23.915	<0.001	<0.001
Surgical method, n (%)			80.649	<0.001	<0.001
Wedge resection	109 (35.7%)	33 (21.3%)			
Segmentectomy/lobectomy	125 (41.0%)	82 (52.9%)			
Oesophageal surgery	4 (1.3%)	33 (21.3%)			
Other thoracic procedure	67 (22.0%)	7 (4.5%)			
ECG conduction block	21 (6.9%)	12 (7.7%)	0.113	0.736	0.759
Atrial fibrillation	7 (2.3%)	20 (12.9%)	20.932	<0.001	<0.001
Sinus tachycardia	8 (2.6%)	8 (5.2%)	1.972	0.160	0.218
Sinus bradycardia	29 (9.5%)	16 (10.3%)	0.077	0.781	0.781
T-wave abnormalities	42 (13.8%)	33 (21.3%)	4.259	0.039	0.058
Preoperative echocardiographic findings, n (%)			22.693	<0.001	<0.001
Normal	209 (68.5%)	86 (55.5%)			
Aortic regurgitation	67 (22.0%)	29 (18.7%)			
Mitral regurgitation	21 (6.9%)	24 (15.5%)			
Aortic and mitral regurgitation	8 (2.6%)	16 (10.3%)			
Age (years)	58.02 ± 10.82	67.64 ± 7.37	–11.228	<0.001	<0.001
Operation duration (hours)	2.24 ± 1.12	3.53 ± 1.77	–8.320	<0.001	<0.001
Preoperative WBC ($\times10^9$/L)	5.84 ± 1.89	5.75 ± 1.57	0.544	0.587	0.623
Postoperative WBC, day 1 ($\times10^9$/L)	12.65 ± 3.00	12.44 ± 2.67	0.765	0.445	0.504
Postoperative WBC, day 3 ($\times10^9$/L)	8.56 ± 2.76	9.53 ± 2.58	–3.720	<0.001	<0.001
Postoperative WBC, day 5 ($\times10^9$/L)	6.98 ± 1.88	7.21 ± 2.00	–1.187	0.236	0.309
Preoperative Hb (g/L)	135.43 ± 17.04	126.52 ± 23.38	4.212	<0.001	<0.001
Postoperative Hb, day 1 (g/L)	132.36 ± 17.18	121.18 ± 17.84	6.430	<0.001	<0.001
Postoperative Hb, day 3 (g/L)	123.10 ± 17.89	114.51 ± 17.24	4.987	<0.001	<0.001
Postoperative Hb, day 5 (g/L)	130.50 ± 13.03	115.88 ± 15.92	9.875	<0.001	<0.001
Preoperative PLT ($\times10^9$/L)	206.00 ± 70.56	212.52 ± 75.78	–0.891	0.373	0.446
Postoperative PLT, day 1 ($\times10^9$/L)	203.54 ± 64.85	194.23 ± 66.96	1.426	0.155	0.218
Postoperative PLT, day 3 ($\times10^9$/L)	190.92 ± 60.78	174.11 ± 56.96	2.924	0.004	0.007
Postoperative PLT, day 5 ($\times10^9$/L)	216.57 ± 67.05	192.85 ± 53.41	4.120	<0.001	<0.001
Albumin (g/L)	36.10 ± 2.88	34.31 ± 2.85	6.333	<0.001	<0.001
Creatinine (μmol/L)	64.44 ± 15.90	84.19 ± 40.53	–5.842	<0.001	<0.001
Potassium (mmol/L)	4.21 ± 0.39	4.50 ± 0.51	–6.195	<0.001	<0.001
Total cholesterol (mmol/L)	2.90 ± 0.86	2.82 ± 0.73	1.049	0.295	0.371
Triglycerides (mmol/L)	1.29 ± 0.56	1.35 ± 0.75	–0.878	0.381	0.446
Preoperative NT-proBNP (pg/mL)	112 (76–156)	251 (183–339)	5145.0	<0.001	<0.001
Postoperative NT-proBNP, day 1 (pg/mL)	188 (137–264)	152 (110–200)	30024.0	<0.001	<0.001
Ejection fraction (%)	58.79 ± 2.39	57.70 ± 1.49	6.004	<0.001	<0.001

Note: Data are mean ± SD, median (25th–75th percentile), or n (%). Continuous variables with approximately normal distributions were compared using Welch's *t* test; NT-proBNP was compared using the Mann–Whitney U test. Categorical variables were compared using Pearson's chi-squared test without continuity correction; Fisher's exact test was used when an expected cell count was below 5 (no such case occurred). Test statistics are *t*, χ^2, or U values. BH, Benjamini–Hochberg; COPD, chronic obstructive pulmonary disease; Hb, haemoglobin; hs-cTnT, high-sensitivity cardiac troponin T; NT-proBNP, N-terminal pro-B-type natriuretic peptide; PLT, platelet; WBC, white blood cell; ECG, electrocardiographic. WBC and PLT in $\times10^9$/L; Hb and albumin in g/L; creatinine in μmol/L; potassium, total cholesterol, and triglycerides in mmol/L; NT-proBNP in pg/mL; ejection fraction (EF) in %.

The following 11 predictor variables were entered simultaneously into a binary logistic regression model; surgical method was represented by three indicator variables, yielding 13 model terms in total: age, surgical method, operation duration, preoperative Hb, postoperative day-1 Hb, postoperative day-3 Hb, albumin, creatinine, potassium, atrial fibrillation, and EF. Surgical method was represented by three indicator variables (wedge resection, segmentectomy/lobectomy, and oesophageal surgery), with other thoracic procedures as the reference category. Age was entered in years; its odds ratio (OR) and 95% confidence interval (CI) are presented for a 10-year increase. All other continuous predictors were analysed in their recorded original units. Multicollinearity was assessed using the variance inflation factor (VIF), computed by linear regression of each predictor on the remaining predictors. Adjusted ORs, 95% CIs, and two-sided p values are reported for all model terms, including atrial fibrillation. The analyses should be regarded as exploratory; we do not claim that the variable set was prespecified in a dated protocol or statistical analysis plan.

All analyses were based on the final 460-record dataset confirmed by the authors. In this dataset, the postoperative day-5 haemoglobin level was 116 g/L. With this value, day-5 haemoglobin was lower than the preoperative value in both groups and was consistent with the serial haemoglobin trajectory. This internal consistency check was not independently verified against primary laboratory, transfusion, or fluid-administration records.

Two sensitivity analyses were performed. First, to assess sensitivity to the outcome definition, the model was refitted using day-1 hs-cTnT elevation as the outcome while the original covariate set was retained. Because the postoperative Hb terms, including day-3 Hb (recorded after the day-1 outcome), were retained, this analysis examines sensitivity to the outcome definition and does not establish temporal ordering between the covariates and the outcome. Second, to examine the influence of collinearity among serial Hb measurements, the model was refitted after exclusion of day-3 Hb. Analyses were performed using IBM SPSS Statistics (version 26.0, IBM Corp., Armonk, NY, USA).

Results

Participant Flow and Outcome Frequency

Of the 588 consecutive records screened, 128 were excluded: 39 because of a documented history of heart disease, 17 because of previous thoracic or cardiac-related surgery, and 72 for the following exclusion reasons (28 with a preoperative hs-cTnT concentration ≥14 ng/L, 11 with documented sepsis, pulmonary embolism, or acute decompensated heart failure at the time of surgery, and 33 with incomplete key perioperative data; Fig. 1). Only the first eligible operation was counted for each patient. All remaining 460 patients were included in the primary analysis; of these, 155 (33.7%) had postoperative hs-cTnT elevation and 305 (66.3%) did not. When individual postoperative days were considered, 130 patients (28.3%) had day-1 elevation, 110 (23.9%) had day-3 elevation, and 81 (17.6%) had day-5 elevation.

Group Comparisons

Within the full cohort, 23 of 34 between-group comparisons had nominal $p < 0.05$, and 21 remained significant after BH adjustment (Table 1). Patients with postoperative hs-cTnT elevation were older and more often male; had higher frequencies of hypertension, diabetes, preoperative discomfort symptoms, atrial fibrillation, and T-wave abnormalities; showed a different distribution of surgical procedures; and had longer operation durations, lower postoperative haemoglobin concentrations, lower albumin, higher creatinine and potassium, higher preoperative NT-proBNP, and lower EF. Notably, although preoperative NT-proBNP levels were higher in the hs-cTnT elevation group than in the no hs-cTnT elevation group (251 vs 112 pg/mL), the direction of this difference was reversed on postoperative day 1 (152 vs 188 pg/mL). Atrial fibrillation was present in 7 of 305 patients without hs-cTnT elevation and 20 of 155 with hs-cTnT elevation (unadjusted OR 6.31, 95% CI 2.60–15.27; $p < 0.001$). Male sex and T-wave abnormalities were numerically more frequent in patients with hs-cTnT elevation, but their nominal associations did not remain significant after BH adjustment (q = 0.058 for both).

Multivariable Associations

In the multivariable model including all 11 variables, age, surgical method, operation duration, creatinine, potassium, and atrial fibrillation were independently associated with postoperative hs-cTnT elevation (Table 2). Age was associated with the outcome (OR 1.80 per 10-year increase, 95% CI 1.23–2.63; $p = 0.002$). Relative to other thoracic procedures, oesophageal surgery (OR 27.96, 95% CI 5.50–142.27), segmentectomy/lobectomy (OR 5.52, 95% CI 2.04–14.96), and wedge resection (OR 4.47, 95% CI 1.57–12.71; $p = 0.005$) were associated with higher odds of the outcome; the oesophageal-surgery estimate was imprecise. Longer operation duration (OR 1.53 per hour, 95% CI 1.21–1.93) and higher potassium (OR 3.59 per mmol/L, 95% CI 1.84–7.02) were likewise associated with higher odds of the outcome. Postoperative day-1 Hb showed an inverse association that did not reach statistical significance (OR 0.972 per g/L, 95% CI 0.942–1.002; $p = 0.069$). Atrial fibrillation remained independently associated with the outcome after adjustment (OR 5.56, 95% CI 1.84–16.83; $p = 0.002$). The inverse association with ejection fraction was not significant (OR 0.905 per %, 95% CI 0.772–1.060; $p = 0.216$). Preoperative Hb showed a weak positive adjusted association that was not statistically significant (OR 1.025 per g/L, 95% CI 0.999–1.052; $p = 0.060$) despite an inverse unadjusted association, a pattern that may reflect the strong correlation among serial Hb measurements; this estimate

Table 2. Multivariable logistic regression for postoperative hs-cTnT elevation.

Variable	Adjusted OR	95% CI	*p* value
Age, per 10-year increase	1.802	1.232–2.634	0.002
Surgical method: wedge resection (vs other thoracic procedures)	4.471	1.573–12.706	0.005
Surgical method: segmentectomy/lobectomy (vs other thoracic procedures)	5.524	2.039–14.963	<0.001
Surgical method: oesophageal surgery (vs other thoracic procedures)	27.961	5.495–142.270	<0.001
Operation duration, per hour	1.531	1.212–1.934	<0.001
Preoperative Hb, per g/L	1.025	0.999–1.052	0.060
Postoperative Hb day 1, per g/L	0.972	0.942–1.002	0.069
Postoperative Hb day 3, per g/L	0.972	0.943–1.001	0.061
Albumin, per g/L	0.934	0.839–1.040	0.215
Creatinine, per µmol/L	1.021	1.007–1.035	0.003
Potassium, per mmol/L	3.592	1.839–7.016	<0.001
Atrial fibrillation	5.563	1.839–16.826	0.002
Ejection fraction, per %	0.905	0.772–1.060	0.216

Note: n = 460 with 155 events. All 11 variables were entered simultaneously. Surgical method was represented by three indicator variables, with other thoracic procedures as the reference category. Age was entered in years and is displayed per 10-year increase; ORs for all other continuous variables are per one recorded original-unit increase. Atrial fibrillation was coded as present versus absent. VIFs ranged from 1.05 to 4.31 (maximum for day-3 Hb), all below 10. OR, odds ratio; VIF, variance inflation factor.

should be interpreted with caution. Day-3 Hb, albumin, and the remaining variables were not significantly associated with the outcome. The maximum VIF was 4.31 (day-3 Hb), with VIF values of 3.69 and 4.23 for preoperative and day-1 Hb, respectively, all below the conventional threshold of 10.

Sensitivity Analyses

When the outcome was restricted to day-1 hs-cTnT elevation (n = 130 events), age, surgical method, operation duration, potassium, and atrial fibrillation were significantly associated with the outcome, whereas creatinine, day-1 Hb, and EF showed directionally consistent but non-significant associations (**Supplementary Table 1**). Because postoperative day-3 Hb was measured after the day-1 outcome, this sensitivity analysis was intended only to assess the robustness of associations to the alternative outcome definition and should not be interpreted as a temporally valid predictive model. When day-3 Hb was excluded from the model to address collinearity among serial Hb measurements, the day-1 Hb association became statistically significant (OR 0.957, 95% CI 0.932–0.982; $p = 0.001$).

Discussion

Postoperative hs-cTnT elevation occurred in approximately one third of the included patients. After multivariable adjustment, older age, surgical method, longer operation duration, higher creatinine, higher potassium, and atrial fibrillation were independently associated with the outcome. Postoperative day-1 Hb showed an inverse but non-significant association in the main model; a weak positive adjusted association of preoperative Hb may reflect collinearity, and EF showed a non-significant inverse association (Table 2). These findings describe perioperative associations rather than a causal sequence or validated prediction framework.

The observed frequency provides context for these associations. Postoperative hs-cTnT elevation occurred in 33.7% of the 460 included patients, which exceeds the pooled incidence of 17.9% reported across broader non-cardiac surgical populations [1], although the two estimates are not directly comparable. Thoracic surgery may impose particular cardiopulmonary stress, and recent work has linked perioperative high-sensitivity troponin concentrations with severe complications after lung resection [6]. In the day-1-outcome sensitivity analysis, age, procedure type, operation duration, potassium and pre-existing atrial fibrillation remained associated with the outcome, whereas the creatinine estimate was attenuated (OR 1.007, 95% CI 0.997–1.017). Sensitivity to the outcome definition therefore differed across variables, and the results should not be interpreted as indicating uniform robustness of all associations.

Thoracic-specific studies provide relevant, although not directly comparable, context. A previous thoracic cohort evaluated perioperative high-sensitivity troponin as a predictor of severe postoperative complications rather than as an outcome, and therefore does not report a frequency directly comparable with ours [6]. González-Tallada et al. [7] reported a MINS frequency of 27.3% (95% CI 20.8–34.5%) among 177 patients at high cardiovascular risk, defined as at least one troponin I value ≥0.04 ng/mL during the first two postoperative days without evidence of a non-ischaemic aetiology; smoking status and procedure type were independently associated with the outcome. Nandate et al. [8] reported early high-sensitivity troponin I elevation in 103 of 320 patients (32.2%), using a threshold of 26.2 ng/L and sampling on arrival in intensive care

and on the following day, with no preoperative baseline value available in that cohort; chronic renal failure, lung resection type and red-blood-cell transfusion were independently associated with elevation. Liu et al. [9] reported MINS in 10.4% of 1314 patients undergoing pulmonary resection for lung cancer, with creatinine, thoracotomy and lobectomy among the variables independently associated with the outcome. Our frequency of 33.7% represents a different, study-specific outcome: any hs-cTnT value at or above 14 ng/L on postoperative day 1, 3 or 5, among patients whose preoperative value was below that limit. Unlike this threshold-based outcome, MINS additionally requires attribution to a presumed ischaemic mechanism [4]. Differences in eligibility, assays, sampling schedules and endpoint definitions preclude attributing the between-study differences in frequency to any particular factor. The findings concerning renal function and procedure type are broadly compatible with these reports but do not constitute replication: creatinine analysed as a continuous variable is not interchangeable with a diagnosis of chronic renal failure, and the procedure contrasts and adjustment sets differ. The present cohort adds estimates obtained under explicit baseline-troponin and sampling criteria, including associations with preoperative potassium and pre-existing atrial fibrillation, as well as procedure-specific contrasts that include oesophageal surgery.

Several of the identified factors were measured before or during surgery. Older age may reflect accumulated vascular and physiological vulnerability. Compared with the heterogeneous reference category of other thoracic procedures, wedge resection, segmentectomy/lobectomy and oesophageal surgery were associated with higher adjusted odds of hs-cTnT elevation. These estimates represent separate contrasts with the reference category rather than direct comparisons among the three procedure categories. No ordinal trend was tested, and the numerical ordering of the point estimates should not be interpreted as a validated gradient of operative invasiveness. The oesophageal-surgery estimate was particularly imprecise, with sparse outcome cells in both that category and the reference group. All of these estimates are conditional on operation duration and on the other covariates included in the model. Longer operation duration may integrate prolonged anaesthesia, haemodynamic fluctuation, fluid shifts, blood loss, and reduced oxygenation, and has been associated with adverse perioperative outcomes in previous non-cardiac surgical cohorts [2,3,10].

Postoperative day-1 Hb showed an inverse association with hs-cTnT elevation in the main model, but the confidence interval included the null and the association did not reach statistical significance ($p = 0.069$); day-3 Hb was also non-significant. In the sensitivity analysis excluding day-3 Hb, the day-1 Hb association was statistically significant (OR 0.957, 95% CI 0.932–0.982; $p = 0.001$), but this sensitivity result does not replace the main-model interpretation. Because Hb and hs-cTnT were measured within overlapping postoperative windows, day-1 Hb is best regarded as an early concurrent marker rather than a predictor; the direction is consistent with previous evidence linking postoperative anaemia with myocardial injury after non-cardiac surgery [10]. Higher creatinine and higher potassium were independently associated with the outcome and may reflect renal and metabolic vulnerability [4,12]. Unlike postoperative Hb, both were measured preoperatively and therefore preceded outcome ascertainment. Their adjusted estimates are nevertheless conditional on the postoperative Hb terms retained in the model, and temporal precedence alone establishes neither causality nor validated predictive value. Atrial fibrillation was more frequent among patients with hs-cTnT elevation (unadjusted OR 6.31) and remained independently associated after adjustment (OR 5.56), which may indicate a vulnerable cardiovascular substrate; because postoperative new-onset atrial fibrillation was not included in the definition, this association reflects pre-existing rhythm status [4,5]. EF showed a non-significant inverse association ($p = 0.216$), although the direction was consistent with the recognised importance of ventricular reserve in perioperative cardiac risk [4,5,12].

Interestingly, preoperative NT-proBNP levels were higher in patients with postoperative hs-cTnT elevation, whereas postoperative day-1 levels showed an opposite pattern. The underlying reasons for this reversal remain unclear. Differences in perioperative haemodynamic conditions, fluid balance, and volume status may have contributed; however, these factors were not adequately documented in the present dataset, and no specific mechanism can be established.

These findings should be interpreted as hypothesis-generating associations. Age, rhythm status, procedure-related factors, renal–metabolic markers, and the direction of the day-1 Hb estimate may inform the design of prospective monitoring studies, but the present analysis does not establish causality, a validated risk score, or a clinical resource-allocation rule. Prospective multicentre studies should test these associations using clearly defined measurement landmarks and clinically confirmed procedure categories.

Limitations

This study has several limitations. Its retrospective, single-centre design and the requirement for complete perioperative records may affect generalisability and introduce selection bias. The hs-cTnT outcome was defined using the stated postoperative thresholds, but the underlying mechanism was not formally adjudicated. Screening excluded only those records with documented sepsis, pulmonary embolism, or acute decompensated heart failure present at the time of surgery; conditions arising after operation were not identified or excluded on a case-by-case basis. Postoperative conditions that can contribute to troponin elevation, including sepsis, pulmonary embolism, acute heart failure,

tachyarrhythmia and deterioration of renal function, were not systematically evaluated to distinguish ischaemic from non-ischaemic mechanisms, so the endpoint does not establish myocardial injury after non-cardiac surgery or perioperative myocardial infarction. Because postoperative laboratory measurements overlapped the outcome ascertainment window, postoperative Hb and NT-proBNP associations should be interpreted as concurrent rather than predictive. NT-proBNP was measured at two time points only, and perioperative fluid balance and volume status were not recorded, so the direction of the observed change cannot be attributed to a specific mechanism. Multiple comparisons were addressed with BH adjustment, but some nominal associations could still reflect chance. Serial Hb measurements were strongly correlated, and although VIF values were below 10 and the sensitivity analysis excluding day-3 Hb left the remaining estimates essentially unchanged, residual collinearity cannot be excluded. The multivariable model was not externally validated, and sparse outcome cells limited the precision of the procedure-specific estimates: only four patients in the oesophageal-surgery group did not have hs-cTnT elevation, and only seven patients in the reference category did. Residual confounding remains possible, because smoking, surgical approach, intraoperative haemodynamic instability, blood loss, transfusion and medication use were not available in the dataset and could not be included. Generalisability is limited to patients meeting the preoperative troponin, cardiac-history and record-completeness criteria, and the requirement for complete postoperative measurements may itself select patients according to their care and testing pathway. Finally, the endpoint is defined by a laboratory threshold; it was not tested against adjudicated cardiovascular events, and the study did not evaluate whether monitoring guided by these associations would change patient outcomes. Larger multicentre prospective studies with independent validation are warranted.

Conclusions

Older age, procedure type, longer operation duration, higher preoperative creatinine, higher preoperative potassium, and pre-existing atrial fibrillation were associated with postoperative hs-cTnT elevation after multivariable adjustment. Postoperative day-1 haemoglobin showed a non-significant inverse association in the main model. These findings are hypothesis-generating and require prospective validation before use for prediction, surveillance policy, or resource allocation.

Availability of Data and Materials

De-identified data supporting the findings of this study are available from the corresponding author upon reasonable request, subject to approval by the Institutional Ethics Committee of The Central Hospital of Xiaogan and applicable privacy restrictions. The data are not publicly available because they contain potentially identifiable clinical information.

Author Contributions

ZW contributed to conceptualization, methodology, data curation, formal analysis, funding acquisition, and writing of the original draft. WZ contributed to data curation, formal analysis, and validation. WH contributed to investigation and data curation. QH and LP contributed to investigation and resources. ZL contributed to conceptualization, supervision, and project administration. All authors have been involved in revising the manuscript 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

This retrospective study was approved by the Ethics Committee of The Central Hospital of Xiaogan (approval number: KY-2022122923). Written informed consent was obtained from each participant. The study was conducted in accordance with the Declaration of Helsinki.

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Conflict of Interest

The 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.4916.

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