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A multivariate and retrospective analysis of the impact of intra-aortic balloon counterpulsation in Open-Heart surgery

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Background The use of intraaortic balloon pump (IABP) effectively reduces left ventricular afterload and significantly increases coronary perfusion pressure by raising aortic diastolic pressure. This study examined the short and medium-term outcomes of 22,540 adult cardiac surgical patients requiring an IABP. Methods From 2009 to 2018, 1114 patients (4.94%) undergoing open-heart surgery at a single tertiary cardiac hospital received IABP support and were included in this retrospective study. They were categorized into pre-operative (Group A, n = 577), intra-operative (Group B, n = 475), and post-operative (Group C, n = 62) IABP insertion groups. Results Cardiogenic shock occurred in 11.2% of cases, mainly in Group A. Hemodynamic instability (38.8%) drove IABP use in Groups A and C, while difficulty weaning from CPB was the primary reason in Group C. The overall operative mortality rate was 10.9%, highest at 25.8% postoperatively. Multivariate analysis identified significant predictors of mortality: age (OR: 1.067, 95% CI: 1.041–1.094, $p < 0.001$), higher BMI (OR: 1.071, 95% CI: 1.017–1.128, $p = 0.009$), pulmonary hypertension (OR: 2.085, 95% CI: 1.302–3.341, $p = 0.002$), renal disease (OR: 2.780, 95% CI: 1.556–4.967, $p < 0.001$), and cardiogenic shock (OR: 3.684, 95% CI: 2.066–6.569, $p < 0.001$). Complications were more common in Group C, especially with renal disease. Average preoperative and postoperative stays were 4.0 ± 4.8 days and 15.2 ± 20.4 days, respectively, with no significant differences between groups. Conclusion IABP might offer safety for open-heart surgery, with longer hospital stays potentially associated with high-risk patients. Pre-operative IABP prophylaxis could be crucial in high-risk open-heart cases to reduce mortality.

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Keywords Intra-aortic balloon pump, Open heart surgery, Mortality, Hospital-stay, Clinical outcomes, Complications

Abbreviations

AKI	Acute kidney injury
ANOVA	Analysis of variance
ASA	American Society of Anesthesiologists
BMI	Body mass index
CABG	Coronary artery bypass graft
CAD	Coronary artery disease
CI	Confidence interval
CPB	Cardiopulmonary bypass
CPSS	Computerized Patient Support System
DSRB	Domain Specific Review Board
EF	Ejection fraction
ECMO	Extracorporeal membrane oxygenation

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IABP	Intra-aortic balloon pump
IQR	Interquartile range
MI	Myocardial infarction
MCS	Mechanical circulatory support
NYHA	New York Heart Association
OR	Odds ratio
PASP	Pulmonary artery systolic pressure
PCI	Percutaneous coronary intervention
SD	Standard deviation
SBP	Systolic blood pressure
SPSS	Statistical Package for the Social Sciences
TVD	Triple vessel disease

Annually, over 70,000 patients in the United States alone benefit from IABP support. Its effectiveness stems from its ability to simultaneously reduce left ventricular afterload while significantly increasing coronary perfusion pressure by elevating aortic diastolic pressure[1]. In peri-operative period of open heart surgery, the intra-aortic balloon pump (IABP) stands out as the primary tool for providing temporary mechanical circulatory support to cardiac surgical patients experiencing low cardiac output[2–4].

The IABP is a percutaneously implanted device positioned in the descending thoracic aorta, with its tip typically placed 2–3 cm distal to the origin of the left subclavian artery[5]. Its inflation and deflation are timed to the electrocardiogram, occurring in diastole and early systole respectively. By increasing myocardial oxygen supply while reducing myocardial oxygen demand, it enhances ventricular performance. This is accomplished by decreasing both preload and afterload, which in turn increases cardiac output and coronary blood flow[6,7]. Indications for IABP use in cardiac surgical patients primarily involve perioperative management of refractory low cardiac output, often due to cardiogenic shock. High-risk patients include those presenting with severe left ventricular dysfunction, advanced age, significant comorbidities (such as diabetes, chronic kidney disease, or peripheral vascular disease), and those with a history of myocardial infarction. Additionally, IABP is utilized in patients experiencing mechanical complications following myocardial infarction, such as ventricular septal rupture or acute mitral valve insufficiency, as well as in those suffering from refractory angina who may require surgical intervention[7,8]. However, despite its benefits, mortality rates within hospitals and within 30 days for patients requiring IABP support remain high, ranging from 26 to 50%, primarily due to the underlying cardiac issues that necessitated its use[9,10].

In coronary artery bypass surgery (CABG), IABP is used both pre- and intra-operatively. Preoperatively, it stabilizes acute myocardial infarction cases and is elective in high-risk patients. Intra-operatively, it aids in weaning patients from cardiopulmonary bypass (CPB), especially in those with hypotension and low cardiac index despite inotropic support[11,12]. This study aims to analyze our clinical experience with IABP in a high-risk cohort of operated patients, especially patient undergoing CABG. These included a multivariate analysis predicting mortality, hospital stay, and early clinical outcomes.

Methods

Between 2009 and 2018, a total of 22,540 patients underwent open-heart surgery at this tertiary institute and were enrolled in compliance with the ethical standards set forth in the Declaration of Helsinki. This retrospective study, approved by the Domian Specific Review Board (DSRB) Ref No# 2016/01070 and 2019/00397 at the National Healthcare Group, Singapore was conducted at the National University Heart Centre on 26 June 2019. Comprehensive patient data, encompassing pre-operative, intra-operative, and post-operative variables, was recorded and stored in the Department of Cardiac, Thoracic, and Vascular Surgery Registry.

Enrolment criteria

The criteria for commencing IABP treatment in this patient cohort were as follows: (a) pre-operative persistent low cardiac output (cardiac index < 2.2 L/min/m²) despite maximal medical therapy; (b) unable to be weaned off CPB despite forced inotropic support - often arises in cases of severe myocardial dysfunction; (c) Patients developing low cardiac output syndrome (LCOS) during the perioperative period, characterized by hypotension, low stroke volume, and poor tissue perfusion; (d) arrhythmias (premature ventricular contractions or ventricular tachycardia) unresponsive to anti-arrhythmic continuous infusion; (e) hemodynamic instability defined as a Mean Arterial Pressure (MAP) < 65 mmHg, A drop in systolic BP by more than 40 mmHg, or a cardiac index < 2.2 L/min/m²; and (f) post-cardiotomy cardiogenic shock characterized by severe left ventricular dysfunction, low blood pressure (SBP < 90 mmHg), elevated filling pressures, and signs of end-organ hypoperfusion. Prophylactic IABP treatment was recommended per institutional protocols, particularly for high-risk patients identified via EuroSCORE II. Preoperative insertion was timed based on urgency—either the day before, hours before anesthesia, or immediately before surgery in emergencies. In our series, IABP was used for patients with severe left ventricular dysfunction, hemodynamic instability from left main coronary artery disease, acute MI, cardiogenic shock, and unstable angina. Additionally, IABP helped reduce myocardial oxygen demand, mitigate postoperative complications, or serve as a bridge to further clinical decisions.

Groupings and study outcomes

The analysis cohort of 1114, patients were sub-divided into three groups based on the timing of the insertion of IABP. Group A consists of pre-operative insertion of IABP; Group B consists of intra-operative insertion of IABP, and Group C consists of post-operative insertion of IABP patients. The primary outcome of this study is the operative mortality rate among patients undergoing cardiac surgery with IABP support. Operative mortality was defined as occurring during index hospitalization and withing 30 days postoperatively. The secondary outcomes focus on the incidence of postoperative complications, specifically: hospital stay (including pre-operative stay in days, post-operative stay in days, and prolonged post-operative length of stay > 14 days), prolonged ventilation (> 48 h), postoperative acute kidney injury (defined as an increase in serum creatinine by ≥ 0.3 mg/dL from baseline or a ≥ 50% increase from baseline values within 48 h), postoperative hepatic dysfunction identified by elevated liver enzymes, reoperation for bleeding/tamponade, postoperative unplanned reoperation/intervention (such as angiography, catheterization, or ablation), and status at 30 days (including survival status).

Device specification and use

Maquet Datascope™ CS-300 and Cadiosave Hybrid intra-aortic balloon pumps (Getinge, Gothenburg, Sweden), sized at 34 cc balloons for patients below 162 cm in height and 50 cc balloons for those 162 cm and above, were utilized. Following insertion, X-rays were taken to confirm proper positioning of the balloon tip just distal to the aortic arch. Upon achieving minimal mediastinal drainage (< 50 ml/Hr), patients underwent anticoagulation via Heparin infusion, ensuring that the activated clotting time (ACT) remained above 180–200 s. Throughout the duration of IABP support, a standard protocol of administering intra-venous antibiotics was consistently followed.

Statistical analysis

The Computerized Patient Support System (CPSS), established by the National University Hospital in 1998, serves as a comprehensive medical registry. Data extraction for analysis was performed on all patients who underwent open-heart surgery between 2009 and 2018. Data analysis utilized IBM's Statistical Package for the Social Sciences version 27.0 (SPSS v27). Descriptive analysis summarized patient demographics, initial baseline clinical characteristics, and surgical outcomes and complications. Numerical variables were reported as mean with standard deviation (SD) or median with interquartile range (IQR), whichever was more appropriate. Categorical variables were presented as counts (N) with percentages. Univariate analysis identified potential risk factors for primary and secondary outcomes. Numerical covariates were compared using two-sample t-tests, ANOVA, or Kruskal-Wallis tests or Mann-Whitney U test, while categorical variables were assessed with Chi-square tests or Fisher's Exact tests. Bonferroni Correction was applied to o the p-values to avoid risk of Type I errors, where appropriate. Logistic regression with backward model selection determined significant risk factors for operative mortality and secondary outcomes, with a significance level set at $p < 0.05$.

Results

Over a span of 10 years, a collective sum of 22,540 patients underwent open-heart surgery, with 1,114 patients (4.94%) receiving IABP support. The average age of the patients was 61.4 ± 10.2, with a predominant representation of Chinese (65.2%) and Malay (21.2%) ethnicities among the mixed multiracial Asian population. Of the total, 929 (83.4%) were male, with an average body mass index (BMI) of 24.8 ± 4.4, and 23.2% of the population classified as morbidly obese (BMI ≥ 27.5). At the time of admission, 24.1% of patients were deemed unstable, and 63.1% were emergency admissions. Approximately 35.5% of patients were admitted to the intensive care or high-dependency unit prior to their surgery.

Data pertaining to the pre-operative baseline clinical characteristics and associated variables (Table 1), which encompassed age, gender, race, family history of coronary artery disease (CAD), diabetes mellitus, hyperlipidemia, highest serum cholesterol level, renal disease at the time of surgery, creatinine levels, chronic lung disease, pulmonary hypertension, pulmonary artery systolic hypertension (PASP), peripheral vascular disease, extracardiac arteriopathy, poor mobility, neurological dysfunction, cerebrovascular disease, and carotid disease.

Preoperative risk analysis

Analysis of angina status reveals a distribution where 41.0% of patients experienced no chest pain, while 31.6% reported stable angina, and 26.4% had unstable angina (Table 2). 80.1% in Group A had surgery within 30 days of MI, significantly higher than Group B (57.7%) and Group C (45.2%) ($p < 0.001$). Regarding dyspnea status, patients exhibited varying degrees of dyspnoea severity, with more than 51.0% distributed across NYHA ≥ 2. A notable proportion of patients had a history of percutaneous coronary intervention (PCI), with 20.7% of the cohort having undergone this procedure. Subsequent analyses detail the timing of PCI relative to surgery and other cardiovascular interventions, providing insights into the temporal relationship between these procedures and surgical intervention. Other risk factors included 11.2% of patients presenting with cardiogenic shock, 27.6% of patients having poor EF (< 30%), and 39.9% of patients having diastolic dysfunction. Higher prevalence of triple vessel disease (TVD) across all groups ($p = 0.003$), whereas 42.0% of patients having left mainstem disease, with Significantly higher in Group A (55.5%) compared to other groups ($p < 0.001$).

Indication of IABP

There were 577 patients had pre-operative insertion of IABP (group A), while 475 patients underwent intra-operative insertion of IABP (group B), and only 62 patients had post-operative insertion of IABP (group C). Firstly, the difficulties to wean from CPB accounts for 11.4% of all cases, suggesting it is crucial for stabilizing hemodynamic in patients transitioning from CPB to normal circulation, with instances recorded highest in Group B. Secondly, "Hemodynamic Instability" is the most common indication, comprising 33.8% of all cases. This category denotes the use of IABP due to hemodynamic instability, which may occur at various points throughout the surgical procedure. Likewise, most patients required IABP due to hemodynamic instability intra-operatively.

Demographic	Group A (Pre-Op) (*n* = 577)	Group B (Intra-Op) (*n* = 475)	Group C (Post-Op) (*n* = 62)	Total (*n* = 1114)	*p*-value
Age at operation, mean ± SD*	62.1 ± 9.7	61.0 ± 9.1	57.3 ± 11.8	61.4 ± 10.2	< .001[S]
Gender – Male (%)	467(80.9)	415(87.4)	47(75.8)	929 (83.4)	0.005
Body mass index (BMI)*	24.8 ± 3.9	24.7 ± 4.3	26.0 ± 5.3	24.8 ± 4.4	0.054
Morbid obesity (BMI ≥ 27.5)	127 (22.0)	111 (23.4)	20 (32.3)	258 (23.2)	0.190
Race					
Chinese (%)	376 (65.2)	315 (66.3)	35 (56.5)	726 (65.2)	
Malay (%)	128 (21.2)	96 (20.2)	14 (22.6)	238 (21.4)	0.231
Indian (%)	56 (9.7)	39 (8.2)	9 (14.5)	104 (9.3)	
Others (%)	17 (2.9)	25 (5.3)	4 (6.5)	46 (4.1)	
Admission					
Elective (%)	57 (9.9)	250 (52.6)	37 (59.7)	344 (30.9)	< .001[S]
Emergency (%)	473 (82.0)	207 (43.6)	23 (37.1)	703 (63.1)	
Urgent (%)	47 (8.1)	18 (3.8)	2 (3.2)	67 (6.0)	
Admission status					
Stable (%)	366 (63.4)	427 (89.9)	52 (83.9)	845 (75.9)	< .001[S]
Unstable (%)	211 (36.6)	48 (10.1)	10 (16.1)	269 (24.1)	
Smoking – Current (%)	167 (28.9)	137 (28.8)	14 (22.6)	318 (28.5)	0.564
Family history of coronary artery disease – Yes (%)	37 (6.4)	35 (7.4)	2 (3.2)	74 (6.6)	0.445
Diabetes mellitus – Yes (%)	278 (48.2)	238 (50.1)	31 (50.0)	547 (49.1)	0.816
Hyperlipidemia – Yes (%)	456 (79.0)	399 (84.0)	54 (87.1)	909 (81.6)	0.061
Highest serum cholesterol (mmol/L), median (IQR)[#]	5.3 (1.8)	5.3 (2.0)	5.3 (2.3)	5.3 (2.1)	0.941
Renal disease at time of surgery – Yes (%)	58 (10.1)	39 (8.2)	11 (17.7)	108 (9.7)	0.053
Last creatinine level mmol/L, median (IQR)[#]	89 (49)	88 (37)	87.5 (73)	88.1 (53)	0.835
Highest creatinine level, mmol/L, median (IQR)[#]	102 (64)	101.5 (53)	99 (89)	100.8 (69)	0.985
Hypertension (SBP > 160mmHg) – Yes (%)	170 (70.4)	106 (77.5)	13 (79.0)	289 (73.9)	0.021[S]
Chronic lung disease – Severe (%)	2 (0.3)	5 (1.1)	1 (1.6)	8 (0.7)	0.473
Pulmonary hypertension (PASP ≥ 38 mmHG) (%)	142 (24.6)	139 (29.3)	26 (41.9)	307 (27.6)	0.008[S]
PASP (mmHg), mean ± SD*	37.3 ± 15.2	38.9 ± 15.0	42.15 ± 16.3	38.3 ± 15.2	0.081
Peripheral vascular disease (PVD) – Yes (%)	41 (7.1)	35 (7.4)	9 (14.5)	85 (7.6)	0.108
Extracardiac arteriopathy – Yes (%)	67 (11.6)	57 (12.0)	10 (16.1)	134 (12.0)	0.583
Poor mobility – Yes (%)	28 (4.9)	19 (4.0)	2 (3.2)	49 (4.4)	0.717
Neurological dysfunction – Yes (%)	7 (1.2)	3 (0.6)	1 (1.6)	11 (1.0)	0.559
Cerebrovascular disease (CVD) – Yes (%)	64 (11.1)	46 (9.7)	4 (6.5)	114 (10.2)	0.453
Carotid disease – Yes (%)	45 (7.8)	41 (8.6)	3 (4.8)	89 (8.0)	0.568

Table 1. Pre-operative baseline clinical characteristics. PASP = Pulmonary artery systolic pressure; SD = Standard deviation; S = significant; *=AOVA;[#]= Kruskal-Wallis Test.

Prophylactic use of IABP, representing 29.8% of all cases. These instances involve the preventive use of IABP, possibly in patients with known risk factors for post-operative complications. The majority of prophylactic cases occur pre-operatively (Group A), reflecting proactive measures to mitigate potential hemodynamic challenges. Further details of the indication of IABP have been summarized in Fig. 1A.

Peri-operative clinical characteristics

Majority of the patients (97.0%) was in at least category 3 of the American Society of Anesthesiologists (ASA) Physical Status Classification. ASA 3 classification stands out as the most prevalent pre-operatively, constituting 21.9% of cases, followed by ASA 4 at 26.3%. Redo surgery was low prevalence overall, slightly higher during intra-operative compared to pre- and post-operative stages (Table 3). Figure 1B shows, emergency and urgent surgeries are most prevalent pre-operatively. CABG is the most common procedure, and prevalence of combined procedures is relatively low (Fig. 1C). CABG categories demonstrate that on-pump procedures are the most prevalent (76.5%), followed by non-isolated CABG (17.8%), while off-pump and on-pump beating procedures are less common (Fig. 1D). CPB types indicate a predominant use of full CPB (96.2%), with converted and combined types being relatively rare (Fig. 1E). The evaluation of distal coronary anastomoses illustrates that most cases involve 3 anastomoses (44.9%), with numbers decreasing with higher anastomosis counts (Fig. 1F).

Primary outcomes (operative mortality)

The overall operative mortality rate stands at 10.9%, with the highest percentage observed in the post-operative group (25.8%), followed by a decline pre-operatively (11.4%) and least at the intra-operative group (8.2%). Post-

Variables	Group A (Pre-Op) ($n = 577$)	Group B (Intra-Op) ($n = 475$)	Group C (Post-Op) ($n = 62$)	Total ($n = 1114$)	*p*-value
Angina status – Unstable (%)	239 (21.45)	49 (4.39)	6 (0.54)	294 (26.4)	< .001^{S}
Angina class – Canadian cardiovascular society (CCS)					< .001^{S}
CCS 0 (%)	294 (51.0)	298 (62.7)	35 (56.5)	627 (56.3)	
CCS 1 (%)	83 (14.4)	72 (15.2)	12 (19.4)	167 (15.0)	
CCS 2 (%)	92 (15.9)	67 (14.1)	10 (16.1)	169 (15.2)	
CCS 3 (%)	62 (10.7)	24 (5.1)	4 (6.5)	90 (8.1)	
CCS 4 (%)	46 (8.0)	14 (2.9)	1 (1.6)	61 (5.5)	
Dyspnoea status – New York Heart Association (NYHA)					0.353
NYHA 0 (%)	207 (35.9)	192 (40.4)	22 (35.5)	421 (37.8)	
NYHA 1 (%)	63 (10.9)	54 (11.4)	8 (12.9)	125 (11.2)	
NYHA 2 (%)	181 (31.4)	145 (30.5)	23 (37.1)	349 (31.3)	
NYHA 3 (%)	96 (16.6)	72 (15.2)	8 (12.9)	176 (15.8)	
NYHA 4 (%)	30 (5.2)	12 (2.5)	1 (1.6)	43 (3.9)	
Interval Last MI to Surgery – 30 days (%)	462 (80.1)	274 (57.7)	28 (45.2)	764 (68.6)	< .001^{S}
Previous PCI – Yes (%)	136 (23.6)	80 (16.8)	15 (24.2)	231 (20.7)	0.022^{S}
Interval PCI to surgery > 6 h – Yes (%)	91 (15.8)	77 (16.2)	13 (21.0)	180 (16.2)	0.574
Previous cardiovascular intervention – Yes (%)	6 (1.0)	16 (3.4)	2 (3.2)	24 (2.2)	0.029^{S}
Previous open-heart surgery – Yes (%)	5 (0.9)	15 (3.2)	2 (3.2)	22 (2.0)	0.022^{S}
Any previous surgery/intervention – Yes (%)	571 (99.0)	460 (96.8)	60 (96.8)	1091 (97.9)	0.045^{S}
Cardiogenic shock – Yes (%)	107 (18.5)	14 (2.9)	4 (6.5)	125 (11.2)	< .001^{S}
IV nitrates/Heparin – Yes (%)	420 (72.8)	62 (13.1)	10 (16.1)	492 (44.2)	< .001^{S}
Extent of coronary artery disease					0.003^{S}
No coronary artery disease (%)	22 (3.8)	39 (8.2)	8 (12.9)	69 (6.2)	
Single vessel disease – SVD (%)	25 (4.3)	16 (3.4)	5 (8.1)	46 (4.1)	
Double vessel disease – DVD (%)	116 (20.1)	76 (16.0)	8 (12.9)	200 (18.0)	
Tripple vessel disease – TVD (%)	414 (71.8)	344 (72.4)	41 (66.1)	799 (71.7)	
Left mainstem disease – Yes (%)	320 (55.5)	135 (28.4)	13 (21.0)	468 (42.0)	< .001^{S}
Ejection fraction (EF), mean ± SD*	41.4 ± 15.5	38.9 ± 16.1	45.7 ± 16.2	40.5 ± 15.7	0.001^{S}
Ejection fraction categories					< .001^{S}
Fair [30–49%] (%)	230 (39.9)	156 (32.8)	17 (27.4)	403 (36.2)	
Good [> 49%] (%)	209 (36.2)	162 (34.1)	32 (51.6)	403 (36.2)	
Poor [< 30%] (%)	138 (23.9)	157 (33.1)	13 (21.0)	308 (27.6)	
Diastolic dysfunction (%)	212 (36.7)	208 (43.8)	25 (40.3)	445 (39.9)	0.067
Logistic EUROScore, mean ± SD#	4.9 ± 7.3	3.6 ± 4.8	4.0 ± 5.8	4.3 ± 6.3	0.208

Table 2. Pre-operative clinical risk factors analysis. PCI = Percutaneous coronary intervention; CV=; CABG = Coronary artery bypass surgery; NYHA = New York Heart Association; MI = Myocardial infraction; CABG = Coronary artery bypass grafting; CAD = Coronary artery disease; SD = Standard deviation; S = Significant; *=ANOVA;#= Kruskal-Wallis Test.

op group had higher operative mortality (Table 3). Univariate analysis of the risk factors associated with mortality were Age at operation, Female gender, BMI, Emergency operation, Unstable preoperative state, Pulmonary hypertension, Renal disease at time of surgery, Cardiogenic shock, Interval between surgery and last MI (≤ 30 days), Extra cardiac arteriopathy, Unstable angina, Intravenous nitrates or any Heparin, Extent of coronary artery disease (TVD), Left main stem disease, EF (Poor ≤ 30%), and Diastolic dysfunction. Multivariate logistic regression analysis showed significant associations between the timing of intra-aortic balloon pump (IABP) usage and operative mortality. The adjusted odds ratios (OR) reveal that intraoperative and postoperative IABP usage significantly reduces the odds of operative mortality compared to preoperative usage, with ORs of 0.251 (95% CI: 0.107–0.592, $p = 0.002$) and 0.260 (95% CI: 0.120–0.565, $p < 0.001$), respectively.

Age at operation was significantly associated with higher mortality, with a mean age of 65.2 years in those who died compared to 60.9 years in survivors (OR: 1.067, 95% CI: 1.041–1.094, $p < 0.001$). Female gender was associated with lower mortality (OR: 0.544, 95% CI: 0.326–0.907, $p = 0.020$). Higher body mass index (BMI) was also linked to increased mortality (OR: 1.071, 95% CI: 1.017–1.128, $p = 0.009$). Certain clinical conditions were significant predictors of higher operative mortality. Pulmonary hypertension (PASP ≥ 38 mmHg) (OR: 2.085, 95% CI: 1.302–3.341, $p = 0.002$), renal disease at the time of surgery (OR: 2.780, 95% CI: 1.556–4.967, $p < 0.001$), and cardiogenic shock (OR: 3.684, 95% CI: 2.066–6.569, $p < 0.001$) were all strongly associated with increased mortality. Conversely, the use of intravenous nitrates or heparin was associated with lower mortality (OR: 0.582, 95% CI: 0.339–0.997, $p = 0.049$) **(Supplementary Table 1).**

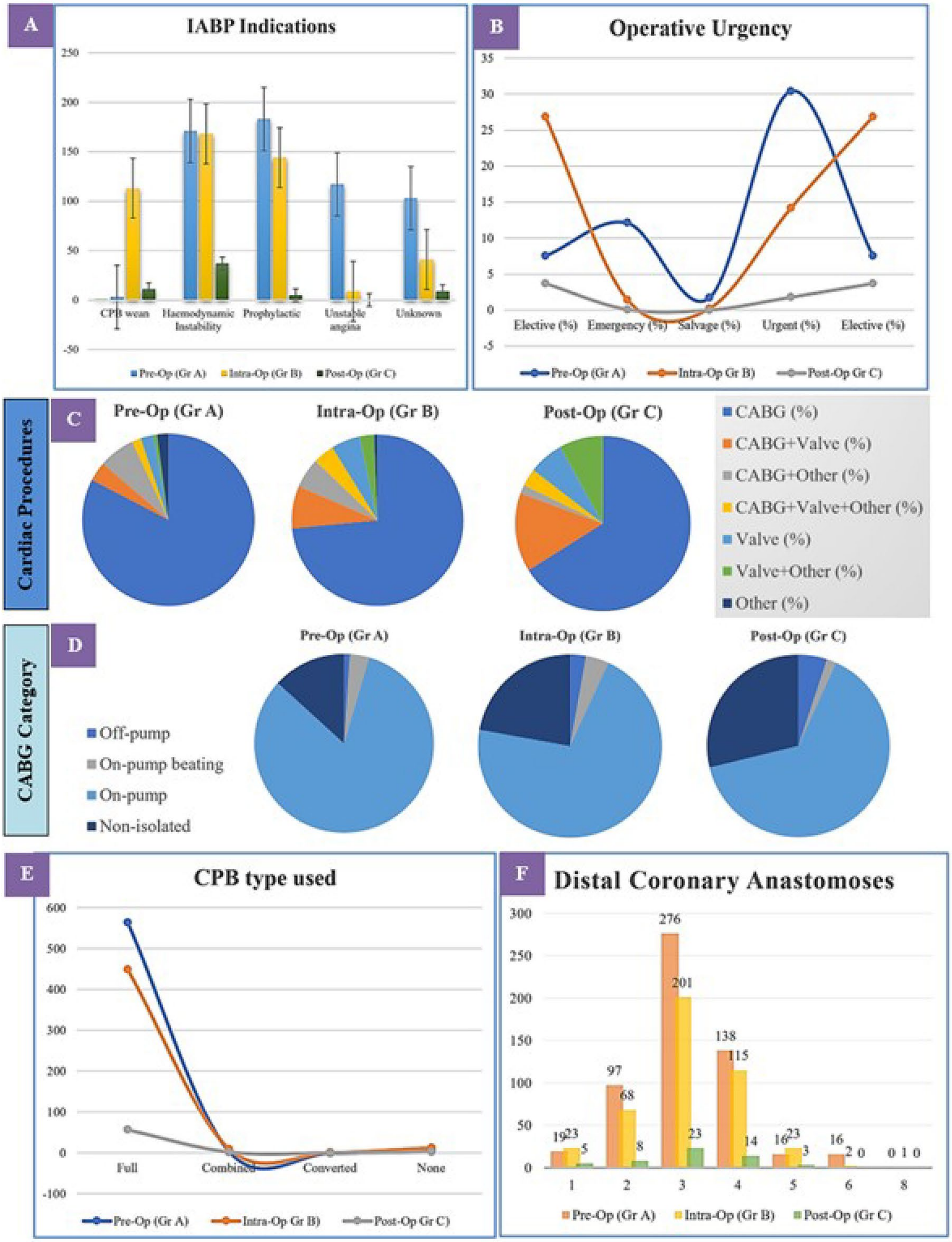

Fig. 1. Peri-operative clinical characteristics showing (**A**) Indication of IABP insertion: hemodynamic instability and prophylactic insertion were the most common indications for IABP insertion; (**B**) Operative urgency: urgent cases was highest in the preoperative group (**C**) Cardiac surgical procedure: coronary artery bypass graft (CABG) surgery was the most frequent cardiac surgical procedure in the preoperative group, while combined procedures were most common in the postoperative group (**D**) Categories of CABG: On-pump CABG procedures were significantly high across all groups, with non-isolated CABG being most prevalent in the postoperative group; (**E**) Full cardiopulmonary bypass (CPB) was used in most cases, with the number of conversions being minimal across all groups (**F**) Distal coronary anastomoses with three grafts were most common in all groups.

Variables	Group A (Pre-Op) (n = 577)	Group B (Intra-Op) (n = 475)	Group C (Post-Op) (n = 62)	Total (n = 1114)	p-value
ASA class ≥ 3 (%)	559 (98.1)	462 (98.5)	60 (98.4)	1081 (98.3)	0.864
Redo operation (%)	4 (0.7)	15 (3.2)	2 (3.2)	21 (1.9)	0.010^{S}
Length of procedure (min), mean ± SD$^{\#}$	298.5 ± 98.6	326.5 ± 112.5	320.0 ± 115.8	311.6 ± 106.5	0.007^{S}
Cumulative bypass time (min), mean ± SD$^{\#}$	152.8 ± 66.5	166.6 ± 90.1	172.9 ± 88.4	159.7 ± 78.8	0.099
Cumulative cross clamp time (min), mean ± SD$^{\#}$	87.0 ± 39.7	87.0 ± 52.1	99.2 ± 54.6	87.7 ± 46.2	0.109
Operative complications – Yes (%)	76 (13.2)	63 (13.3)	23 (37.1)	162 (14.5)	< .001^{S}
Transit time flowmetry – Yes (%)	141 (12.66)	111 (9.96)	1 (0.09)	253 (22.71)	0.015^{S}
Hospital stay$^{\#}$					
Pre-op stay in days, mean ± SD	4.1 ± 4.6	3.9 ± 5.1	3.1 ± 4.1	4.0 ± 4.8	0.086
Post-op stay in days, mean ± SD	15.0 ± 17.2	15.0 ± 23.7	19.8 ± 20.0	15.2 ± 20.4	
Total stay in days, mean ± SD	19.0 ± 18.2	18.8 ± 25.1	22.8 ± 21.9	19.1 ± 21.6	
Prolonged postop length of stay – Yes (%)	386 (67.2)	318 (67.2)	44 (71)	748 (67.4)	0.831
Prolonged ventilation (%)	139 (24.1)	98 (20.6)	28 (45.2)	265 (23.8)	< 0.001
Postop acute kidney injury – Yes (%)	13 (2.3)	12 (2.5)	3 (4.8)	28 (2.5)	0.466
Postop hepatic dysfunction – Yes (%)	3 (0.5)	3 (0.6)	0 (0.00)	6 (0.5)	0.812
Reoperation for bleeding/tamponade (%)	36 (6.2)	31 (6.5)	17 (27.4)	84 (7.5)	< .001^{S}
Postoperative unplanned reoperation/intervention (%)	76 (13.2)	63 (13.3)	23 (37.1)	162 (14.5)	< .001^{S}
Status at 30 days – Dead (%)	66 (11.4)	39 (8.2)	16 (25.8)	121 (10.9)	< .001^{S}
Operative mortality – Yes (%)	66 (11.4)	39 (8.2)	16 (25.8)	121 (10.9)	< .001^{S}
Cardiac (%)	36 (6.2)	12 (2.5)	5 (8.1)	53 (4.8)	
Non-cardiac (%)	20 (3.4)	22 (4.6)	9 (14.5)	51 (4.6)	
Other (%)	10 (1.7)	5 (1.1)	2 (3.2)	17 (1.5)	

Table 3. Peri-operative clinical characteristics, operative outcomes, and postoperative complications. ASA = American Society of Anesthesiologists physical status classification; CABG = Coronary artery bypass graft; SD = Standard deviation; S = Significant; * = ANOVA; $^{\#}$ = Kruskal-Wallis Test.

Secondary outcomes

Overall, postoperative acute kidney injury (AKI) is observed in 2.5% of cases, and hepatic failure/dysfunction exhibits in 0.5% patients (Table 3). However, the operative complications demonstrate a noticeable higher occurrence in the post-operative group (Group C).

Univariate analysis of the operative complications and prolonged post operative length of stay showed association with Age at operation, Female gender, BMI, Emergency admission/operation, Unstable preoperative state, Pulmonary hypertension (PASP ≥ 38 mmHg), Hyperlipidemia, Renal disease at time of surgery, Hypertension (SBP > 160mmHg), Previous PCI, Previous cardiovascular intervention, Cardiogenic shock, Interval Last MI to Surgery – 30 days, Unstable angina, Intravenous nitrates or any Heparin, Extent of coronary artery disease (TVD), Left mainstem disease, EF (Poor ≤ 30%), and Diastolic dysfunction. Multivariate logistic regression analysis revealed that renal disease at the time of surgery was strongly associated with increased complications (OR: 2.688, 95% CI: 1.632–4.429, $p < 0.001$) (**Supplementary Table 2**).

Preop-Hospital stay was 4.0 ± 4.8 days on average, while 4.1 ± 4.6, 3.9 ± 5.1, 3.1 ± 4.1 days in Groups A, B, and C respectively. Postop-Hospital stay was 15.2 ± 20.4 days on average, while 15.0 ± 17.2, 14.9 ± 23.7, 19.8 ± 20.0 days in Groups A, B, and C respectively (Kruskal-Wallis $p = 0.086$). Prolonged post operative length of stay was not significantly different among the three study groups. Multivariate logistic regression analysis showed no significant difference in OR between the groups for the risk factors influencing prolonged postoperative hospital stay (**Supplementary Table 3**).

Discussion

The demand for increased utilization of IABP during cardiac surgeries has garnered significant attention from multiple research groups[5,13] in recent years. This heightened requirement is primarily attributed to shifting patient demographics, notably the inclusion of older individuals with multi-vessel disease and compromised ventricular function. Conversely, technological advancements and a notable decrease in complication rates have contributed to a more favourable perception of IABP usage, resulting in a lowered threshold for its application. In our series, approximately 4.9% received IABP support, emphasizing the relevance of advanced circulatory support strategies in contemporary cardiac surgery.

Pre-operative risk analysis illuminated the diverse array of risk factors present among patients, including angina status, dyspnea severity, and previous interventions like PCI. Notably, prophylactic use of IABP was prevalent in nearly 30% of cases, suggesting a proactive approach to managing potential hemodynamic challenges during surgery. According to previous studies[14,15], a significant proportion of IABP were inserted before and during surgery, totaling 82.4% of cases. Notably, IABP utilization for prophylactic purposes was limited, as the literature lacks clear guidelines regarding which patients would derive the most benefit from pre-op IABP support[16–19]. We report prophylactic use of IABP has significantly reduced mortality, as adopted by our institutional practice of an early and frequent use of the device, especially in the patients with cardiogenic shock requiring urgent surgery.

Across various literature sources, mortality rates exhibit a broad spectrum, ranging from 7 to 86%[9,20]. This variability likely stems from the heterogeneous nature of patient cohorts considered. Within this diverse range of indications, certain series encompass low-risk patients where prophylactic insertion of the device yielded favorable outcomes. In contrast, our series observed an overall low mortality rate of approximately 10.9%, indicative of a population characterized by risk profiles. Several studies[11,21]have investigated the relationship between the timing of IABP insertion and operative mortality, yielding outcomes consistent with our findings. Consistent with previous research[21], the lowest mortality rates were observed in elective CABG patients who underwent preoperative IABP insertion. This observation suggests that the improved survival associated with preoperative IABP insertion may be anticipated due to the predominance of this subgroup suffering from intractable unstable angina, as opposed to those requiring IABP support following perioperative or postoperative cardiogenic shock. However, it can be argued that optimal pre-operative support with IABP minimizes perioperative ischemia and inotropic use, thereby reducing the incidence of postoperative hemodynamic instability or consequences. However, this report did yield a robust data of a large multiracial Asian population, it indicated a positive outcome when the IABP was inserted preoperatively.

Peri-operative clinical characteristics further highlighted the dominance of CABG procedures, predominantly performed on-pump, and underscored the critical role of full CPB in ensuring successful surgical outcomes. Recent literature indicates a downward trend in complication rates, reflecting advancements in surgical techniques and peri-operative management[22–25]. In contrast, older studies reported higher complication rates, underscoring the progress made in this field[4,9,11,15,19]. Our study similarly identified that IABP support was linked to significantly increased morbidity, manifested through prolonged hospital stays, and higher rates of post-operative complications. Notably, variations in hospital stay durations were observed across different patient groups, indicating potential differences in post-operative management strategies and patient recovery trajectories. These findings highlight the importance of tailoring clinical approaches based on specific patient risk profiles. A multidisciplinary care model is critical in managing this high-risk subgroup, as it can facilitate comprehensive patient evaluation and optimize outcomes.To build on these findings, future research could explore long-term outcomes for patients receiving IABP support compared to those utilizing other forms of mechanical circulatory support (MCS), such as ventricular assist devices (VADs) or extracorporeal membrane oxygenation (ECMO). Understanding the long-term implications of different support strategies could guide clinical decision-making and enhance patient management protocols. Additionally, the development of specific guidelines based on risk profiles would be invaluable.

Limitations
This study presents insights from current clinical practices. It's important to note that the subgroups of patients receiving IABP, such as those undergoing valve and combined procedures, are relatively small. Hence, prudence is advised when interpreting the obtained outcomes. Additionally, the study's weaknesses stem from its retrospective and observational nature, which inherently limits the ability to establish causality. Moreover, the single-center design of the study may restrict the generalizability of our findings to other institutions with different patient populations and treatment protocols. We also recognize that the indications for IABP use have evolved in recent years, which may impact the current relevance of our findings. Additionally, the absence of data on mechanical circulatory support MCS/ECMO patients is significant, as they represent an important comparison group, particularly with the global decline in IABP use and the growing preference for alternative forms of circulatory support. However, our study ended in 2018 was primarily dictated by the availability of complete and verifiable data at that time, ensuring the integrity and reliability of our findings. Lastly, there may be a selection bias towards patients receiving IABP support, whether preoperatively or postoperatively, influenced by individual clinical practice patterns. We advocate for future research that incorporates more recent data. Such studies would be instrumental in evaluating the impact of these changes on patient outcomes and refining clinical protocols to enhance the effectiveness of IABP use in contemporary practice.

Conclusion
In conclusion, peri-operative mortality rates among patients requiring IABP were notably reduced, with specific risk profiles well categorized within our patient population. Pre-operative IABP prophylaxis could be essential for reducing mortality in high-risk open-heart surgery cases. Although IABP improves safety in open-heart surgery, extended hospital stays for high-risk patients remain a factor to consider. Despite current findings, it remains uncertain whether outcomes would be better or worse with MCS or ECMO. However, the favorable short-term results may support its use. The trend toward earlier deployment of the device during the peri-operative period might lead to improved outcomes, likely due to enhanced myocardial protection.

Data availability
All data analyzed during this study are included and reflected in the findings presented. Any requests for additional data can be directed to the corresponding author and will be considered based on the availability of the data.

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Author contributions

Study conceptualization, S.S., J.H., V.S., L.H., S.L, H.L., G.C., D.W., Z.O., T.K., G.K., and F.S.; Methodology, F.S., and J.H., Software, S.S., J.H., V.S., L.H., S.L, and FS; Validation, H.L., G.C., D.W., Z.O., and F.S.; Formal analysis, S.L., J.H., and F.S.; Data curation, S.S., J.H., V.S., L.H., and F.S.; Writing—original draft preparation, S.S., J.H., V.S., L.H., S.L, H.L., G.C., D.W., Z.O., T.K., G.K., and F.S.; Writing—review and editing, S.S., J.H., V.S., L.H., S.L, H.L., G.C., D.W., Z.O., T.K., G.K., and F.S.; Resources, S.L., T.K., G.K., and F.S.; Supervision, F.S., and G.K.; Project administration, F.S.; Funding acquisition, G.K., and T.K. All authors have read and agreed to the final version of the manuscript.

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Declarations

Competing interests
The authors declare no competing interests.

Ethics statement
The study received approval from the Domain Specific Review Board (DSRB), National Healthcare Group, Singapore, under reference numbers NHG DSRB#2016/01070 and 2019/00397, on 26 June 2019. It was conducted at the National University Heart Centre, National University Hospital, Singapore. Given the retrospective nature of the study, the requirement for informed consent was waived by Domain Specific Review Board (DSRB) Ethics committee.

Additional information
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