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# Emergency and Salvage Coronary Artery Bypass Grafting: Surgical Techniques, Outcomes, and Predictors of In-Hospital Mortality

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## Abstract

**Background**: Emergency and salvage coronary artery bypass grafting (CABG) is a high-risk procedure often performed on critically ill patients where percutaneous coronary intervention is unsuitable or has been unsuccessful. Despite advancements in surgical techniques, the optimal approach between on-pump CABG (ONCAB) and off-pump CABG (OPCAB) in these settings remains debated, particularly concerning their impact on in-hospital mortality and long-term outcomes. This study aimed to compare the effects of ONCAB and OPCAB on in-hospital outcomes and long-term survival of patients undergoing emergency and salvage CABG and determine the predictors of in-hospital mortality for this high-risk cohort of patients. **Method**: A retrospective analysis was conducted on data from 459 patients who underwent emergency or salvage CABG between January 1996 and September 2023. Of these, 246 underwent ONCAB, and 213 underwent OPCAB. Propensity score matching (PSM) was applied to create a balanced cohort of 181 patients in each group, adjusting for preoperative characteristics. Univariate and multivariate logistic regression analyses were performed to identify predictors of in-hospital mortality, and Kaplan–Meier survival curves were generated to assess long-term survival. **Results**: In the matched cohort, in-hospital mortality was 11.6% for ONCAB and 6.6% for OPCAB ($p = 0.100$). Independent predictors of in-hospital mortality included advanced age ($p = 0.042$), high New York Heart Association classification ($p = 0.002$), diabetes ($p = 0.042$), and salvage procedures ($p < 0.001$). OPCAB was not independently associated with in-hospital mortality ($p = 0.189$). Long-term survival at 20 years was similar between ONCAB and OPCAB ($p = 0.6263$). **Conclusions**: Despite a relatively high in-hospital mortality, emergency and salvage CABG patients have acceptable short-term outcomes and long-term survival. The choice of surgical strategy does not impact outcomes. Emergency and salvage CABG remains viable and should be offered to suitable candidates.

## Keywords

coronary artery bypass grafting; emergency; in-hospital mortality; off-pump coronary artery bypass grafting; salvage; survival

## Introduction

Patients with acute coronary syndrome (ACS) having threatening anatomy, ongoing ischemia, or hemodynamic compromise are best served by revascularization [1]. Historically, these critically ill patients were revascularized by coronary artery bypass grafting (CABG). However, advances in percutaneous coronary intervention (PCI) in recent years have made PCI as the preferred revascularization strategy for ACS patients resulting in a significant decline in emergency and salvage CABG procedures [2]. In the current era, emergency and salvage CABG are indicated for patients with a history of failed PCI or an anatomy unsuitable for PCI, ongoing ischemia despite maximal nonsurgical therapy, procedural mishap during PCI, or cardiogenic shock with unsuitability for PCI [2,3].

Owing to a low occurrence of emergency and salvage CABG, the published literature on the subject is limited and predominantly focuses on immediate postoperative outcomes [2–9]. Similarly, there is a paucity of publications on the choice of surgical strategy, on-pump CABG (ONCAB) or off-pump CABG (OPCAB), for revascularization in these high-risk settings [10–12]. Lastly, not much is reported on long-term survival following emergency and salvage CABG [3].

This study aimed to compare the impact of ONCAB and OPCAB on in-hospital outcomes and long-term survival of patients undergoing emergency and salvage CABG as well as determine the predictors of in-hospital mortality for this high-risk cohort of patients.

## Methods

### *Study Design and Patients*

We retrospectively analyzed data of all patients who had emergency and salvage CABG at our institution from January 1996 to September 2023. The definitions of emergency and salvage CABG were in line with the EuroSCORE-II criteria [13]. Patients were further stratified into ONCAB and OPCAB groups and propensity score matching (PSM) was used to reduce treatment selection bias and potential confounding factors. Predictors of in-hospital mortality were determined and survival curves were generated to assess long-term survival. The study was conducted in accordance with the principles of the Declaration of Helsinki. The local audit committee approved the study, and the requirement for individual patient consent was waived due to the retrospective nature of the study.

### *Interventions*

Over the study period, ONCAB and OPCAB procedures were performed by surgeons with exclusive on-pump and off-pump practice, respectively. We had previously described our operative technique in detail [14]. All interventions were performed via a midline sternotomy. The choice of conduits was based on the surgeon's preference as well as dictated by patient characteristics.

### *Data Collection and Variables*

The data was prospectively collected in a cardiac surgery database (PATS; Dendrite Clinical Systems, Ltd., Oxford, UK). The PATS database captures detailed information on a wide range of preoperative, intraoperative and hospital postoperative variables (including complications and mortality) for all patients undergoing cardiac surgery at our institution. Reproducible cleaning algorithms were applied to the database, which are regularly updated as required. Briefly, duplicate records were removed, transcriptional discrepancies were harmonized, and clinical conflicts and extreme values were corrected or removed. The data are validated and also submitted to the National Institute for Cardiovascular Outcomes Research (National Adult Cardiac Surgery Audit registry) annually.

Preoperative variables of interest included age, gender, New York Heart Association class, congestive heart failure (never, past, now), number of previous myocardial infarction (MI), timing of last MI, diabetes, hypercholesterolemia, hypertension, smoking history (never, ex-smoker, current), renal impairment, dialysis, chronic obstructive pulmonary disease/asthma, cerebrovascular disease, peripheral vascular disease, atrial fibrillation, extent of coronary artery disease (CAD), left main stem (LMS) disease, left ventricular ejection fraction (good >50%; fair 30–50%; poor <30%), urgency (emergency, salvage), cardiogenic shock, and logistic EuroSCORE.

Intraoperative variables of interest included left internal mammary artery (LIMA) use, grafts per patient, cardiopulmonary bypass (CPB) time, single arterial grafting, multiple arterial grafting, total arterial grafting, aortic cross-clamp time, conversion to CPB, and index of completeness of revascularization (ICOR). The ICOR was defined as the total number of distal grafts constructed divided by the number of the affected coronary vessels reported on the preoperative coronary angiogram [15]. Complete revascularization was assumed when the ICOR was 1 or greater.

Postoperative variables of interest included reoperation for bleeding, tracheostomy, neurological complications (stroke or transient ischaemic attack), deep sternal wound infection, postoperative renal replacement therapy, and in-hospital mortality.

The long-term outcome of interest was all-cause mortality beyond 30 days. Information about death was obtained from the institutional database and NHS Spine for all patients. Data regarding postoperative complications and survival were available for all patients in the study.

### *Statistical Analysis*

Continuous variables are expressed as mean ± standard deviation if normally distributed and as median and interquartile range for the numerical variables not normally distributed. Categorical variables are shown as count and percentages. The Lilliefors (Kolmogorov–Smirnov) test was used for normality assessment. Comparison between continuous variables has been conducted using unpaired Student's $t$-test if normally distributed and Mann–Whitney U-test if not normally distributed. Categorical variables have been compared using Pearson Chi-square test or Fisher's exact test as appropriate.

A multiple logistic regression model has been used to identify predictors of in-hospital mortality. After conducting univariable analysis, the final multivariable models were obtained using a stepwise approach, with $p$-values serving as the criteria for variable inclusion. The statistical model focused on selecting relevant predictors based on their significance in explaining in-hospital mortality. While propensity score matching helped control for known confounders, the logistic regression model allowed us to assess the influence of multiple variables simultaneously, thereby providing insight into the independent contribution of each factor to in-hospital mortality.

The survival analysis was conducted comparing the survival functions of the 2 groups using the log-rank test and Kaplan–Meier curves. Survival curves were plotted with 95% confidence interval (CI) and survival probability (%) at 5, 10, 15 and 20 years was reported.

Propensity score matching (PSM) was used to minimize baseline differences between patients undergoing OP-

CAB and ONCAB. A logistic regression model was developed using preoperative characteristics to estimate propensity scores for each patient. All pre-treatment variables were included in the model. The goal of PSM was to account for these differences, thus ensuring more valid comparisons between the two groups. Propensity score (mean 0.470 ± 0.124) was generated for each patient and each patient in the ONCAB group was paired with one patient in the OPCAB group using greedy 1:1 matching, with a calibre width of 0.20 standard deviation of the logit of the propensity score. We used a caliper width of 0.20 standard deviations of the logit of the propensity score, which is a commonly accepted threshold in the literature for achieving a good balance between reducing bias and retaining an adequate sample size. The 0.20 threshold has been shown to minimize the risk of residual bias while maintaining enough matched pairs for meaningful statistical analysis. A stricter caliper width could have led to the exclusion of more patients, reducing the statistical power of the study, while a wider caliper would have allowed for greater imbalance between groups.

Clinical data were recorded and subsequently tabulated with Microsoft Excel (Microsoft Corp, Redmond, Washington). Data analysis was performed in SPSS (SPSS Statistics 29.0.2.0, IBM Corp, Armonk, NY, USA).

## Results

### *Preoperative Demographics*

A total of 459 patients had emergency and salvage CABG over the study period (Fig. 1).

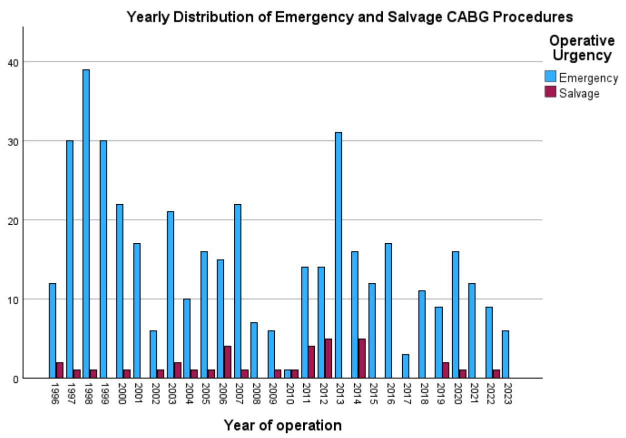


**Fig. 1. Yearly Distribution of Emergency and Salvage Coronary Artery Bypass Grafting (CABG) Procedures (1996–2023).**

Salvage CABG was performed in 35 cases. ONCAB was performed in 246 cases while 213 patients received OPCAB. The 2 groups were reasonably well-matched for most pre-treatment variables with the exception of OPCAB patients being older (66.9 ± 10.7 vs. 62.9 ± 11.2; $p < 0.001$) and having more diabetes (33.3% vs. 23.6%; $p = 0.020$), single vessel and double vessel CAD (36.6 vs. 24.8; $p = 0.006$) compared with ONCAB patients. On the other hand, ONCAB patients had more three vessel CAD (75.2 vs. 63.4; $p = 0.006$) and salvage procedures (10.6% vs. 4.2%; $p = 0.011$) compared to OPCAB patients. Overall, the OPCAB patients had a similar risk profile as the ONCAB patients (logistic EuroSCORE: 6.1 ± 8.1 vs. 5.6 ± 9.0; $p = 0.503$). PSM created a total of 181 pairs perfectly matched for all pre-treatment variables (Fig. 2). Distribution of pre-treatment variables in the off-pump and on-pump groups is summarized in Table 1.

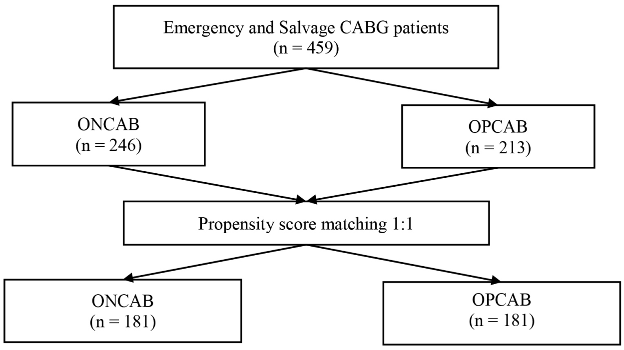


**Fig. 2. Flowchart of propensity score matching for on-pump CABG (ONCAB) and off-pump CABG (OPCAB) Groups.**

### *Intraoperative Data*

There were fewer grafts performed after OPCAB compared with ONCAB for unmatched (2.58 ± 0.8 vs. 2.77 ± 0.8; $p = 0.016$) and matched (2.56 ± 0.8 vs. 2.77 ± 0.8; $p = 0.015$) cohorts (**Supplementary Table 1**). However, ICOR was similar for unmatched (1.06 ± 0.4 vs. 1.07 ± 0.4; $p = 0.824$) cohort but significantly lower for OPCAB patients in the matched cohort (1.00 ± 0.3 vs. 1.09 ± 0.4; $p = 0.014$). The use of the left internal mammary artery (LIMA) was observed in 89.3% of patients overall, with a statistically significant difference between the ONCAB and OPCAB groups in the unmatched cohort (86.6% vs. 92.5%, $p = 0.041$). This trend persisted in the matched cohort, where LIMA usage remained higher in the OPCAB group compared to the ONCAB group (91.7% vs. 85.1%, $p = 0.049$). CPB time averaged 83.1 ± 40.5 minutes, with an aortic cross-clamp (ACC) time of 35.0 ± 27.0 minutes. Over the study period, 5 OPCAB were converted to ONCAB.

**Table 1. Preoperative characteristics.**

| Variable | Total CABG (n = 459) | Unmatched | | | Matched | | |
|---|---|---|---|---|---|---|---|
| | | ONCAB (n = 246) | OPCAB (n = 213) | *p* value | ONCAB (n = 181) | OPCAB (n = 181) | *p* value |
| Demographics | | | | | | | |
| Age | 64.8 ± 11.1 | 62.9 ± 11.2 | 66.9 ± 10.7 | <0.001 | 65.3 ± 10.5 | 65.7 ± 10.9 | 0.713 |
| Female gender | 106 (23.1) | 57 (23.2) | 49 (23.0) | 0.966 | 44 (24.3) | 41 (22.7) | 0.710 |
| Cardiac Status | | | | | | | |
| NYHA | | | | | | | |
| I | 127 (27.7) | 81 (32.9) | 46 (21.6) | | 62 (34.3) | 42 (23.2) | |
| II | 147 (32.0) | 74 (30.1) | 73 (34.3) | 0.055 | 52 (28.7) | 63 (34.8) | 0.114 |
| III | 121 (26.4) | 54 (22) | 67 (31.5) | | 45 (24.9) | 56 (30.9) | |
| IV | 64 (13.9) | 37 (15) | 27 (12.7) | | 22 (12.2) | 20 (11.0) | |
| Congestive HF | | | | | | | |
| Never | 387 (84.3) | 206 (83.7) | 181 (85) | 0.744 | 150 (82.9) | 155 (85.6) | 0.488 |
| Past | 11 (2.4) | 7 (2.8) | 4 (1.9) | | 6 (3.3) | 4 (2.2) | |
| Now | 61 (13.3) | 33 (13.4) | 28 (13.1) | | 25 (13.8) | 22 (12.2) | |
| Number of previous MI | | | | | | | |
| 0 | 173 (37.7) | 91 (37) | 82 (38.5) | | 70 (38.7) | 68 (37.6) | |
| 1 | 237 (51.6) | 131 (53.3) | 106 (49.8) | 0.977 | 91 (50.3) | 90 (49.7) | 0.670 |
| 2 | 19 (4.1) | 12 (4.9) | 7 (3.3) | | 11 (6.1) | 7 (3.9) | |
| 3 or more | 30 (6.5) | 12 (4.9) | 18 (8.5) | | 9 (5.0) | 16 (8.8) | |
| Last MI | | | | | | | |
| Less than 24 hrs | 74 (16.1) | 92 (37.4) | 82 (38.5) | | 71 (39.2) | 68 (37.6) | |
| 1–30 days | 134 (29.2) | 42 (17.1) | 32 (15) | 0.699 | 25 (13.8) | 27 (14.9) | 0.855 |
| 31–90 days | 53 (11.5) | 39 (15.9) | 14 (6.6) | | 47 (26.0) | 60 (33.1) | |
| More than 90 days | 24 (5.2) | 9 (3.7) | 15 (7) | | 7 (3.9) | 13 (7.2) | |
| Comorbidities | | | | | | | |
| Diabetes | 129 (28.1) | 58 (23.6) | 71 (33.3) | 0.020 | 51 (28.2) | 50 (27.6) | 0.907 |
| Hypercholesterolemia | 318 (69.3) | 165 (67.1) | 153 (71.8) | 0.270 | 123 (68.0) | 129 (71.3) | 0.493 |
| Hypertension | 286 (62.3) | 156 (63.4) | 130 (61.0) | 0.600 | 114 (63.0) | 106 (58.6) | 0.389 |
| Smoking | | | | | | | |
| Never | 165 (35.9) | 87 (35.4) | 78 (36.6) | 0.488 | 72 (39.8) | 68 (37.6) | 0.921 |
| Ex-smoker | 229 (49.9) | 120 (48.8) | 109 (51.2) | | 82 (45.3) | 90 (49.7) | |
| Current | 65 (14.2) | 39 (15.9) | 26 (12.2) | | 27 (14.9) | 23 (12.7) | |
| Renal impairment | 33 (7.2) | 18 (7.3) | 15 (7.0) | 0.909 | 14 (7.7) | 11 (6.1) | 0.534 |
| Dialysis | 6 (1.3) | 2 (0.8) | 3 (1.4) | 0.463 | 2 (1.1) | 0 (0.0) | 0.156 |
| COPD/Asthma | 30 (6.5) | 13 (5.3) | 17 (8.0) | 0.244 | 8 (4.4) | 16 (8.8) | 0.091 |
| Cerebrovascular disease | 27 (5.9) | 17 (6.9) | 17 (6.9) | 0.314 | 14 (7.7) | 10 (5.5) | 0.398 |
| Peripheral vascular disease | 44 (9.6) | 26 (10.6) | 18 (8.5) | 0.442 | 20 (11.0) | 17 (9.4) | 0.603 |
| AF | 10 (2.2) | 4 (1.6) | 6 (2.8) | 0.383 | 4 (2.2) | 6 (3.3) | 0.521 |

**Table 1. Continued.**

| Variable | Total CABG (n = 459) | Unmatched ONCAB (n = 246) | Unmatched OPCAB (n = 213) | Unmatched *p* value | Matched ONCAB (n = 181) | Matched OPCAB (n = 181) | Matched *p* value |
|---|---|---|---|---|---|---|---|
| Extent of CAD | | | | | | | |
| 1 | 35 (7.6) | 15 (6.1) | 20 (9.4) | 0.006 | 12 (6.6) | 11 (6.1) | 0.420 |
| 2 | 104 (22.7) | 46 (18.7) | 58 (27.2) | | 40 (22.1) | 49 (27.1) | |
| 3 | 320 (69.7) | 185 (75.2) | 135 (63.4) | | 129 (71.3) | 121 (66.9) | |
| LMS disease | 179 (39.0) | 87 (35.4) | 92 (43.2) | 0.086 | 64 (35.4) | 75 (41.4) | 0.235 |
| LVEF | | | | | | | |
| Good (>50%) | 292 (63.6) | 156 (63.4) | 136 (63.8) | 0.695 | 116 (64.1) | 114 (63.0) | 0.969 |
| Fair (30–50%) | 123 (26.8) | 62 (25.2) | 61 (28.6) | | 47 (26.0) | 53 (29.3) | |
| Poor (<30%) | 44 (9.6) | 28 (11.4) | 16 (7.5) | | 18 (9.9) | 14 (7.7) | |
| Logistic EuroSCORE | 5.8 ± 8.6 | 5.6 ± 9.0 | 6.1 ± 8.1 | 0.503 | 5.4 ± 9.0 | 6.2 ± 8.6 | 0.374 |
| Operative and Procedural Variables | | | | | | | |
| Operative Urgency | | | | | | | |
| Emergency | 424 (92.4) | 220 (89.4) | 204 (95.8) | 0.011 | 168 (92.8) | 172 (95.0) | 0.380 |
| Salvage | 35 (7.6) | 26 (10.6) | 9 (4.2) | | 13 (7.2) | 9 (5.0) | |
| Cardiogenic Shock | 48 (10.5) | 29 (11.8) | 19 (8.9) | 0.317 | 19 (10.5) | 18 (9.9) | 0.862 |
| IABP | 99 (21.6) | 50 (20.6) | 49 (23.0) | 0.729 | 37 (20.4) | 39 (21.5) | 0.810 |

AF, atrial fibrillation; CABG, coronary artery bypass grafting; COPD, chronic obstructive pulmonary disease; IABP, intra-aortic balloon pump; LMS, left main stem; LVEF, left ventricular ejection fraction; MI, myocardial infarction; NYHA, New York Heart Association; ONCAB, on-pump coronary artery bypass; OPCAB, off-pump coronary artery bypass; PCI, percutaneous coronary intervention; CAD, coronary artery disease.

**Table 2. In hospital outcomes and long-term mortality.**

| Variable | Total CABG (n = 459) | Unmatched ONCAB (n = 246) | Unmatched OPCAB (n = 213) | Unmatched *p* value | Matched ONCAB (n = 181) | Matched OPCAB (n = 181) | Matched *p* value |
|---|---|---|---|---|---|---|---|
| Reoperation for bleeding | 31 (6.8) | 21 (8.5) | 10 (4.7) | 0.102 | 14 (7.7) | 8 (4.4) | 0.187 |
| Tracheostomy | 16 (3.5) | 13 (5.3) | 3 (1.4) | 0.024 | 8 (4.4) | 2 (1.1) | 0.054 |
| TIA/CVA | 6 (1.3) | 3 (1.2) | 3 (1.4) | 0.859 | 3 (1.7) | 3 (1.7) | 1.000 |
| DSWI | 13 (2.8) | 7 (2.8) | 6 (2.8) | 0.985 | 5 (2.8) | 4 (2.2) | 0.736 |
| Postoperative RRT | 32 (7.0) | 19 (7.7) | 13 (6.1) | 0.497 | 14 (7.7) | 8 (4.4) | 0.187 |
| Postoperative IABP | 74 (16.1) | 39 (15.9) | 35 (16.4) | 0.897 | 29 (16.0) | 28 (15.4) | 0.892 |
| In-hospital mortality | 41 (8.9) | 26 (10.6) | 15 (7.0) | 0.186 | 21 (11.6) | 12 (6.6) | 0.100 |
| Mortality at 20 years | 220 (48) | 122 (49.5) | 97 (45.4) | 0.001 | 103 (56.9) | 79 (43.8) | <0.001 |

CABG, coronary artery bypass grafting; CVA, cerebrovascular accident; DSWI, deep sternal wound infection; IABP, intra-aortic balloon pump; ONCAB, on-pump coronary artery bypass; OPCAB, off-pump coronary artery bypass; RRT, renal replacement therapy; TIA, transient ischemic accident.

### *In-Hospital Outcomes*

In-hospital outcomes are summarized in Table 2. There was no difference in major complication rates during hospitalization for unmatched as well as matched OPCAB and ONCAB cohorts except for higher tracheostomy rates in unmatched ONCAB patients (5.3% vs. 1.4%; $p = 0.024$) compared to OPCAB patients.

### *In-Hospital Mortality & Predictors of In-Hospital Mortality*

Overall 30-day mortality was 8.9% (41 patients) with no difference between the unmatched and matched groups (Table 2). There were 2 deaths (40%) in the cohort of 5 OPCAB patients who required conversion to ONCAB. On univariate analysis (**Supplementary Table 2**), significant predictors for in-hospital mortality were advancing age, NYHA class, diabetes, pulmonary disease, preoperative AF, LMS disease, and salvage procedures. Among them, after consideration of collinearity, multivariate analysis revealed that the independent predictors for in-hospital death were advancing age, NYHA class, diabetes, and salvage procedures (**Supplementary Table 2**). OPCAB was not independently associated with in-hospital mortality (OR: 0.641, 95% CI: 0.330–1.245, $p = 0.189$).

### *Long-Term Survival*

Long-term survival analysis showed a mean follow-up of 11.6 ± 8.1 years (range: 0–20 years). During this period, there were a total of 220 deaths (48%) across the entire cohort. In the unmatched cohort, ONCAB patients had higher mortality rate at 20 years compared to OPCAB patients (49.5% vs. 45.4%, $p = 0.001$). In the matched cohort, this difference was even more pronounced, with ONCAB patients showing a mortality rate of 56.9% compared to 43.8% in the OPCAB group ($p < 0.001$). The mean follow-up was significantly longer for ONCAB patients compared to OPCAB patients in both the unmatched cohort (12.4 ± 8.8 years vs. 10.7 ± 7.2 years, $p = 0.027$) and the matched cohort (12.2 ± 8.7 years vs. 10.8 ± 7.3 years, $p < 0.001$).

Fig. 3 shows that survival for the entire cohort was 88.3%, 84.9%, 78.1%, 68.4%, and 52.0% at 1, 5, 10, 15, and 20 years respectively (**Supplementary Table 3**). Survival at 1, 5, 10, 15, and 20 years was 88.8%, 85.8%, 77.6%, 66.4% and 50.5% versus 87.7%, 84.0%, 78.6%, 71.1%, and 54.6% in the unmatched ONCAB and OPCAB groups, respectively (Fig. 4, **Supplementary Table 4**). Long-term survival was similar for propensity matched groups as well (Fig. 5, **Supplementary Table 5**).

Cox regression analysis identified several variables as significant predictors of long-term mortality in the univariate analysis. Advanced age (HR: 1.050, 95% CI: 1.035–1.067, $p < 0.001$), NYHA class (HR: 1.238, 95% CI: 1.069–1.434, $p = 0.004$), peripheral vascular disease (HR: 0.759, 95% CI: 0.612–0.942, $p = 0.012$), LMS disease (HR: 0.826, 95% CI: 0.708–0.964, $p = 0.015$), and lack of arterial graft use (HR: 1.473, 95% CI: 1.003–2.162, $p = 0.048$) were all associated with increased mortality. In multivariate analysis, advanced age remained a significant predictor (HR: 1.046, 95% CI: 1.030–1.063, $p = 0.001$), and the absence of arterial grafts had a stronger association with mortality (HR: 1.733, 95% CI: 1.168–2.569, $p = 0.006$). Other variables, including NYHA class, peripheral vascular disease, and LMS disease, did not retain significance in the multivariate model, indicating that advanced age and arterial graft usage are the most influential factors in predicting long-term survival (**Supplementary Table 6**).

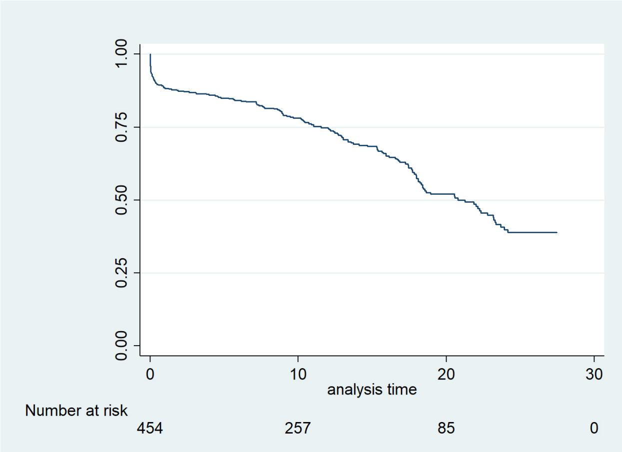


**Fig. 3. Kaplan-Meier survival estimates for the entire cohort.**

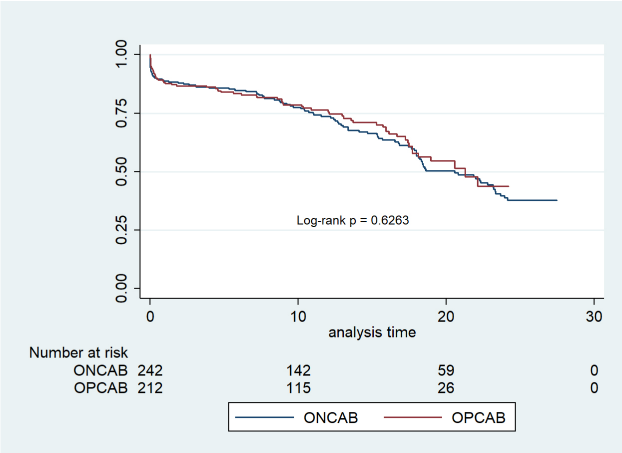


**Fig. 4. Kaplan-Meier survival estimates for the unmatched ONCAB and OPCAB cohorts.**

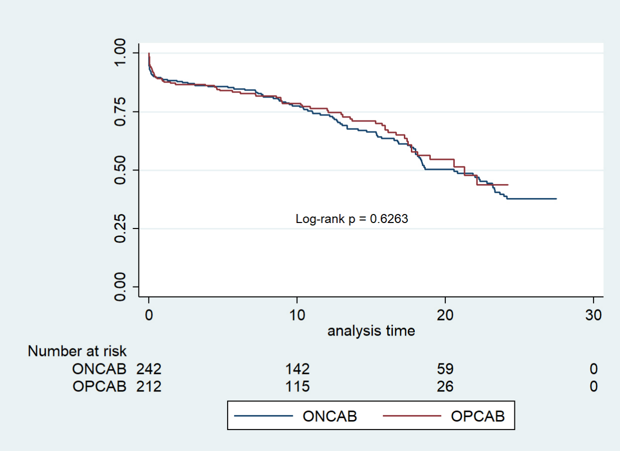


**Fig. 5. Kaplan-Meier survival estimates for matched ONCAB and OPCAB cohorts.**

## Discussion

This single-centre series with the largest emergency and salvage CABG cohort and longest follow-up validates the feasibility and efficacy of emergency and salvage CABG. Furthermore, the study shows that there is no difference in postoperative outcomes and long-term survival between on- or off-pump revascularization strategies.

Similar to our experience, another large volume study of 614 patients (580 emergency and 34 salvage CABG), from four North-European university hospitals, reported substantial in-hospital mortality and acceptable long-term survival justifying life-saving emergency and salvage CABG [3]. Overall, in-hospital mortality in our study of 8.9% is comparable to that reported by previously published studies ranging from 4.6% to 24% for this cohort of patients [3,5–10].

This study reports advancing age, NYHA class, diabetes, and salvage surgery as independent preoperative predictors of in-hospital mortality. Advancing age has also been reported as a predictor of in-hospital death in this cohort by Axelsson *et al*. [3]. Advancing age due to increased comorbidities, reduced physiological reserves, fragility, and poor tissue quality results in more complications and this translates into higher in-hospital mortality [16]. NYHA class is a surrogate for the severity of heart failure symptoms and overall functional status of the patient. Higher NYHA classes (III and IV) imply more severe heart failure which reflects worse cardiac function and increased risk [17]. Higher NYHA classes also correlate with reduced functional capacity, presence of other comorbid conditions such as renal dysfunction and pulmonary disease, as well as hemodynamic instability all of which can increase the risk of perioperative mortality after CABG [17,18]. Diabetes due to its association with systemic complications, diffuse and extensive coronary artery disease, as well as increased risk of recurrent cardiovascular events contributes to enhanced in-hospital mortality in this cohort of patients [19]. Salvage status is well recognized as a risk factor for increased mortality after coronary artery bypass grafting in this cohort [3]. Patients needing salvage surgery are usually faced with life threatening situations such as cardiogenic shock, failed PCI with ongoing ischemia or a serious PCI complication, such as rupture of a coronary vessel with or without cardiac tamponade. Additionally, patients needing salvage surgery have limited or no time for optimization which coupled with increased surgical complexity lead to poorer outcomes including higher mortality [3].

The lack of a significant difference in in-hospital mortality between OPCAB and ONCAB underscores that OPCAB is not inferior to ONCAB in emergency CABG settings. This finding aligns with recent literature, which has shown comparable outcomes between the two techniques, suggesting that OPBAC may be a viable and potentially advantageous alternative to traditional on-pump methods, even in high-risk emergency cases [20]. A recent meta-analysis further supports this view, finding no significant difference in mortality outcomes between OPCAB and ONCAB in emergency settings, which reinforces the viability of off-pump surgery as a safe alternative to on-pump techniques [21].

OPCAB offers the advantage of avoiding CPB, potentially reducing complications associated with CPB, such as systemic inflammation and reperfusion injury. However, hemodynamic instability during heart manipulation in OPCAB, particularly when grafting lateral vessels, can pose challenges and risks that may offset these benefits. The comparable outcomes between OPCAB and ONCAB in our study imply that when performed by experienced surgeons, OPCAB can achieve similar in-hospital results to ONCAB, supporting its use as a non-inferior alternative in suitable emergency cases.

Conventional on-pump technique is considered the preferred strategy for performing emergency and salvage CABG due to the benefits of operating on a flaccid heart in a bloodless field. However, in recent years advances in technology and anaesthetic techniques have resulted in emergence of OPCAB as a suitable alternative for ONCAB [22]. OPCAB by avoiding the well-established deleterious effects of CPB and cardioplegic arrest ensures myocardial revascularization without global myocardial ischemia and avoidance of reperfusion injury, advantages which translate into fewer complications [23]. On the other hand, manipulation of the heart during OPCAB especially for grafting vessels on the lateral surface can cause significant hemodynamic compromise which can result in emergency conversion that carries considerable morbidity and mortality rendering OPCAB inappropriate for emergency and salvage CABG surgery [24]. This study reports similar outcomes for the ONCAB and OPCAB matched and unmatched cohorts except for higher need for tracheostomy in unmatched

ONCAB group. The most plausible explanations for similar outcomes for the two cohorts can be identical ICOR and the fact that surgeons with exclusive ONCAB and OPCAB practices performed all the procedures. Exaggerated systemic inflammatory response and fluid shifts in ONCAB patients resulting in prolonged ventilation could be the likely explanation for more need for tracheostomy in this cohort. Locker and colleagues have found that the use of off-pump is especially favourable in patients with cardiogenic shock [10]. Although we did not notice a significant difference in outcomes however, our experience similar to that of other authors [10–12] challenges the general perception that patients who are haemodynamically unstable are not suitable for off-pump surgery, given the patient may not tolerate further haemodynamic alterations with manipulation of the heart.

The 1-year and 5-year survival of this cohort is similar to that reported by other authors [3,10]. This study is unique as it also reports 10-, 15-, and 20-year survival all of which are reassuring substantiating the long-term effectiveness of emergency and salvage CABG. Similar late survival at various time points for ONCAB and OPCAB cohorts can be attributed to completeness of revascularization in the two cohorts unlike the experience of Locker *et al.* [10].

This is a retrospective observational analysis of our institutional database and has all the limitations of a retrospective study. While this study provides valuable insights into the outcomes of emergency and salvage CABG, its retrospective design introduces inherent limitations that affect the generalizability of the findings. Although PSM was used to mitigate confounding variables and create balanced groups, this method cannot account for unmeasured confounders that may have influenced both treatment choice (ONCAB vs. OPCAB) and outcomes. This limitation reduces the ability to apply these findings universally across different populations or clinical settings. Additionally, the inclusion of earlier OPCAB cases, which may not have benefited from recent technological and procedural advancements, could have influenced the outcomes observed in the OPCAB group. Off-pump CABG techniques have evolved over time, with improvements in stabilizers, anesthetic protocols, and surgeon experience likely leading to better outcomes in more recent years. The inclusion of older OPCAB cases in this study could, therefore, understate the potential benefits of contemporary off-pump approaches. Earlier surgeries, particularly OPCAB procedures, may not have benefited from recent technological improvements, thus potentially skewing outcomes. This temporal variability further limits the generalizability of the results to modern clinical practice.

It is important to emphasize that the study does not have the issue of patient selection bias as patients were referred to surgeons in our institution notwithstanding their preferred revascularization strategy. However, the fact that different surgeons performed off-pump and on-pump surgery can be a significant source of bias and remains a substantial limitation of this study. Similarly, one can argue that inclusion of cases from the early phase of off-pump experience in this study can affect the results and their exclusion will minimize bias. On the contrary, we strongly believe that exclusion of cases does not provide a true reflection of real-world experience and acknowledge this aspect as a limitation of the study. There were minor differences in the 2 groups that would not profoundly affect the key results as the variables with significant differences have minimal effect on the hard end points. However, to have a more robust comparison these minor differences were addressed with propensity matching. The propensity score adjustment is no substitute for a properly designed randomized controlled trial (RCT). The retrospective nature of the study cannot account for the unknown variables affecting the outcome that are not correlated strongly with measured variables. However, retrospective comparisons with propensity score adjustment are more versatile and offer a useful way of interpreting large amounts of audit data and of seeking answers to questions that may present insurmountable difficulties in the design of RCTs. Lastly, the lack of information beyond 30 days for short-term outcomes other than mortality is clearly a limitation due to the fact that any significant event immediately after this period might have been related to the surgery and was not captured.

## Conclusions

Emergency and salvage CABG, with initial high in-hospital mortality and reassuring long-term survival, remains a reasonable option for a very high-risk cohort of patients who without surgical intervention will have a bleak outcome. The choice of surgical revascularization strategy should be dictated by the institutional experience and individual surgeon's expertise as both off-pump and on-pump CABG have comparable outcomes.

## Availability of Data and Materials

The datasets generated and/or analyzed during the current study are not publicly available due to General Data Protection Regulation (GDPR) but are available from the corresponding author on reasonable request.

## Author Contributions

MC contributed to the design of the work, analyzed the data, interpreted the data, and drafted the work. KU acquired the data. AA acquired the data. NM and SKB revised critically for important intellectual content. SGR contributed to the conception of the work, drafted the work, and revised critically for important intellectual content. All authors made substantial contributions to the conception or design of the work; the acquisition, analysis, or interpretation of data for the work; drafting the work or revising it critically for important intellectual content. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

## Ethics Approval and Consent to Participate

The study was conducted in accordance with the principles of the Declaration of Helsinki. The local audit committee approved the study (Q&S 25/05/2024), and the requirement for individual patient consent was waived due to the retrospective nature of the study.

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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/10.59958/hsf.8097.

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