



In-hospital Outcomes and Long-term Survival after Off-Pump and On-Pump Redo Coronary Artery Bypass Grafting: A Propensity Matched Analysis

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Abstract: Background: Redo coronary artery bypass grafting (redo-CABG) carries substantial perioperative risk, and comparative evidence between on-pump and off-pump approaches remains limited. This study evaluates short-term outcomes and long-term survival in patients undergoing redo-CABG with (on-pump) or without cardiopulmonary bypass (off-pump). Methods: We retrospectively analyzed 191 patients undergoing redo-CABG (off-pump: n=143; on-pump: n=48) from 2006-2019. Primary endpoints included 30-day mortality, re-exploration, re-intubation/tracheostomy, and hemofiltration; secondary endpoint was long-term survival. Propensity score matching (1:1, caliper 0.20) yielded 40 well-balanced pairs. Kaplan-Meier analysis and Cox regression assessed survival and predictors of mortality. Results: In the unmatched cohort, 30-day mortality was similar (8.4% off-pump vs 6.3% on-pump, p=0.76). Off-pump patients required fewer transfusions (22.4% vs 43.8%, p=0.01), received fewer grafts (median 2 vs 3, p<0.001), and had lower index of completeness of revascularization scores (0.87±0.39 vs 1.03±0.25, p=0.001). In matched cohorts, 30-day and in-hospital mortality did not differ (12.5% vs 2.5%, p=0.20), but all on-pump patients required transfusion versus none off-pump (p<0.001). Long-term survival was comparable (10-year: 63.5% vs 73.7% unmatched; 68.7% vs 74.3% matched; log-rank p=0.20 and p=0.52, respectively). Independent predictors of long-term mortality included peripheral vascular disease (HR 2.44, p=0.006), operative urgency (HR 2.20, p=0.005), and age (HR 1.04, p=0.021). Conclusions: Off-pump redo-CABG offers similar short- and long-term outcomes to on-pump surgery, with reduced transfusion needs. Both techniques remain viable, with selection guided by patient factors, anatomy, and surgical expertise.

Keywords: Coronary artery bypass grafting, coronary revascularization, off-pump, on-pump, redo-CABG.

INTRODUCTION

Redo coronary artery bypass grafting (redo-CABG) is warranted when patients with prior CABG develop progression of native coronary artery disease or atherosclerosis of grafts with stenosis or occlusion. Redo-CABG represents one of the most technically demanding procedures in cardiac surgery [1]. The complexity arises from multiple factors including dense adhesions from prior surgery, patent but potentially diseased grafts, altered cardiac anatomy, and a patient population typically older and with more comorbidities than those undergoing primary procedure [1]. Approximately 10-20% of patients require repeat

revascularization within 10 years following initial CABG, with prior percutaneous coronary intervention, dyslipidemia, diabetes, and hypertension serving as key risk factors predicting redo procedures [2]. While improvements in operative strategies have resulted in comparable perioperative outcomes and long-term survival compared to first-time CABG after risk adjustment, the frequency of redo procedures remains a clinically important problem with significant resource requirements [3].

Off-pump CABG has gained recognition as a viable alternative to on-pump CABG, with potential advantages in selected patient populations. It has shown potential for reduced morbidity by avoiding cardiopulmonary bypass-related complications [4]. Evidence evaluating long-term survival after on-pump versus off-pump redo-CABG is relatively sparse, with the majority of studies limited to five-year endpoints [5,6]. Persistent uncertainty surrounding the efficacy of off-pump CABG prompted us to review our institutional experience over a 13-year period, with the aim of comparing short-term outcomes and long-term survival between off-pump and on-pump techniques at a center with substantial off-pump procedural volume.

To ensure methodological robustness and mitigate selection bias, we employed rigorous statistical techniques, including propensity score matching, to balance baseline characteristics and isolate the effect of surgical approach. In addition to comparing short- and long-term outcomes, we aimed to identify independent predictors of late mortality, thereby contributing to the evolving evidence base that informs conduit selection, operative planning, and risk stratification in redo-CABG.

METHODS

Study Design and Population

This study retrospectively analyzed cardiac surgical cases recorded in a prospectively curated institutional database, maintained using the Patient Analysis & Tracking System (PATS) software (Dendrite Clinical Systems, Oxford, UK). The dataset undergoes routine validation and contributes annually to the National Adult Cardiac Surgery Audit, coordinated by the National Institute for Cardiovascular Outcomes Research. Ethical approval for this analysis was granted by the local audit committee, with waiver of individual consent due to the retrospective nature of the study and anonymized data handling, in accordance with the principles outlined in the Declaration of Helsinki (QS/SR-RC: 04-2020). The cohort comprised 191 consecutive patients who underwent repeat coronary artery bypass grafting (redo-CABG) between January 2006 and December 2019. Eligibility was restricted to those undergoing redo-CABG as their second cardiac operation. Patients undergoing concomitant procedures or with incomplete records were excluded. Based on operative technique, patients were categorized into two groups: those receiving off-pump redo-CABG (n=143) and those undergoing on-pump redo-CABG (n=48).

Data Collection

Cardiac surgical data were captured using the institutional PATS system (Dendrite Clinical Systems, Oxford, UK), which maintains detailed records across the preoperative, intraoperative, and postoperative phases, including adverse events and mortality. Data

integrity was upheld through structured validation processes, which were routinely applied and updated as necessary. These included the removal of duplicate records, correction of transcription errors, and resolution of clinical inconsistencies or statistical outliers. The dataset encompassed a wide range of perioperative variables, such as patient characteristics, comorbid conditions, procedural information, and outcome metrics. Preoperative risk stratification was conducted using the logistic EuroSCORE model.

Data Variables

Baseline clinical variables included demographic details (age, sex), symptom burden (Canadian Cardiovascular Society angina classification, New York Heart Association functional status), lifestyle factors (smoking history), and comorbid conditions such as chronic pulmonary disease, diabetes, renal dysfunction, hypertension, peripheral and cerebrovascular disease. Cardiac-specific metrics encompassed left ventricular ejection fraction (LVEF categorized as >50% [preserved], 30-50% [moderate], and <30% [poor]), urgency of surgery (defined as within 24 hours of referral), prior myocardial infarction, history of percutaneous coronary intervention, atrial fibrillation on admission, left main coronary artery involvement, and extent of coronary artery disease. Temporal stratification was applied based on surgical era (2007-2010 vs. 2011-2019).

Operative variables included graft type (arterial or venous), total graft count per patient, cardiopulmonary bypass duration, aortic cross-clamp time, and any intraoperative conversion from off-pump to on-pump technique. Completeness of revascularization was quantified using the Index of Completeness of Revascularization (ICOR), calculated as the ratio of distal grafts to target vessels identified on angiography; values ≥ 1 indicated full revascularization.

Postoperative endpoints comprised reoperation for bleeding, respiratory complications, wound infections (sternal or graft site), elective renal replacement therapy, airway interventions (re-intubation or tracheostomy), gastrointestinal events, and 30-day mortality during hospitalization.

Long-term survival was tracked beyond 30 days, with mortality status verified through institutional records and the UK General Register Office.

Operative Technique

We have previously described our operative technique in detail [7]. All interventions were performed via a midline sternotomy. The choice of surgical strategy was based on the surgeon's preference as well as dictated by patient characteristics.

Postoperative Management

Postoperative intensive care unit management was standardized for all patients and has been described previously [7,8]. The practice of prescription of dual anti-platelet therapy was variable and influenced by surgeon's preference [7].

Statistical Analysis

Analyses were conducted using data extracted from PATS database. Data integrity was maintained through routine validation procedures, which included removal of duplicate records, correction of transcription errors, and resolution of clinical anomalies or statistical outliers.

Categorical variables were summarized as counts and percentages. Continuous data were expressed as mean \pm standard deviation when normally distributed, or as median with interquartile range for skewed distributions. Distribution normality was assessed using appropriate statistical tests to guide selection of parametric or non-parametric methods.

Group comparisons at baseline were performed using independent t-tests for parametric continuous variables and Mann-Whitney U-tests for non-parametric data. Categorical comparisons employed Pearson's chi-squared test or Fisher's exact test, depending on expected cell counts. To mitigate confounding and selection bias between off-pump and on-pump redo-CABG groups, propensity score matching (PSM) was applied. Logistic regression was used to generate propensity scores based on preoperative variables, followed by 1:1 nearest-neighbor matching with a caliper of 0.20 standard deviations of the logit score. This approach yielded balanced cohorts for comparative outcome analysis.

Long-term survival was the secondary endpoint, defined as death from any cause during follow-up. Survival duration was calculated from the date of surgery to either the date of death or last known follow-up. Vital status was confirmed via institutional records and the UK General Register Office.

Survival curves were generated using the Kaplan-Meier method, with differences assessed by log-rank testing. Multivariable Cox proportional hazards modelling was used to identify independent predictors of late mortality. Variables with significance in univariable analysis were entered into the final model, and results were reported as adjusted hazard ratios with 95% confidence intervals.

Statistical analyses were conducted using R (version 2025.09.2) with the following core packages: MatchIt for propensity score matching using logistic regression and 1:1 nearest-neighbor matching with caliper specification; survival and survminer for generation of Kaplan-Meier survival curves, log-rank testing, and multivariable Cox proportional hazards regression modeling with assessment of the proportional hazards assumption using Schoenfeld residuals; and tidyverse, including dplyr for data wrangling and ggplot2 for visualization. Additional R packages utilized included cobalt for covariate balance assessment and diagnostics.

RESULTS

Patient Demographics and Baseline Characteristics

The study included 191 patients undergoing redo-CABG. Of the 191 patients, 143 (74.9%) underwent off-pump technique and 48 (25.1%) underwent on-pump technique (Figure 1). The baseline characteristics are summarized in Table 1. Following PSM, 40 patients from each group successfully matched for most variables, creating well-balanced cohorts with standardized mean differences <0.30 for all variables.

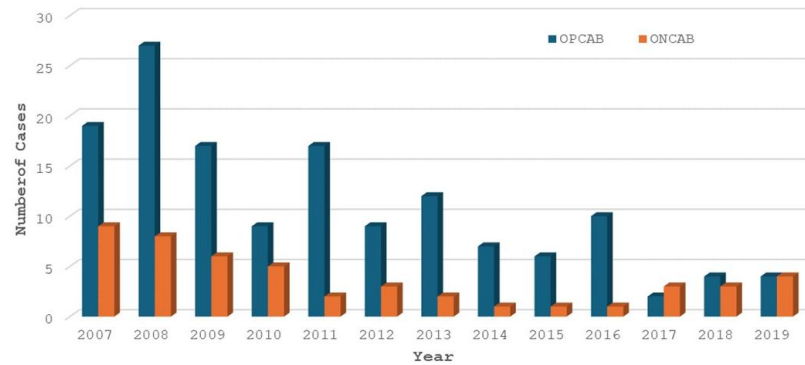


Figure 1: Yearly proportion of off-pump and on-pump redo coronary artery bypass grafting

Table 1: Baseline characteristics

Variable	Unmatched off-pump (n=143)	Unmatched on-pump (n=48)	p value	SMD	Matched off-pump (n=40)	Matched on-pump (n=40)	p value	SMD
Age (years)	68.69±8.64	66.02±7.98	.05	.324	66.85±8.16	65.75±7.87	.54	.137
Male Gender	121 (84.6%)	42 (87.5%)	.80	.084	37 (92.5%)	35 (87.5%)	.71	.167
BMI	28.43±4.52	28.41±4.56	.98	.003	28.01±3.79	28.48±4.53	.62	.113
CCS Class ≥ 3	27 (18.9%)	15 (31.2%)	.11	.288	16 (40%)	11 (27.5%)	.34	.267
NYHA Class >2	6 (4.2%)	4 (8.3%)	.27	.171	2 (5%)	3 (7.5%)	1.00	.103
Previous MI	88 (61.5%)	37 (77.1%)	.07	.342	29 (72.5%)	29 (72.5%)	1.00	.000
Previous PCI	61 (42.7%)	20 (41.7%)	1.00	.020	18 (45%)	19 (47.5%)	1.00	.050
Diabetes	57 (39.9%)	21 (43.8)	.76	.079	21 (52.5%)	16 (40%)	.37	.253
Hypertension	82 (57.3%)	27 (56.3)	1.00	.020	21 (52.5%)	23 (57.5%)	.82	.101
Smoker								
Current smoker	4 (2.8%)	3 (6.3%)	.37	.169	2 (5%)	2 (5%)	1.00	.000
Ex-Smoker	100 (69.9%)	27 (56.3%)	.21	.285	28 (70%)	25 (62.5%)	.64	.159
Non-Smoker	39 (27.3%)	18 (37.5%)	.06	.219	10 (25%)	13 (32.5%)	.62	.166
Pre-op renal disease	41 (28.7%)	14 (29.2%)	1.00	.011	10 (25%)	11 (27.5%)	1.00	.057
Pre-op respiratory disease	15 (10.5%)	2 (4.2%)	.25	.244	3 (7.5%)	2 (5%)	1.00	.103
Previous CVA	7 (4.9%)	3 (6.2%)	.71	.059	3 (7.5%)	3 (7.5%)	1.00	.000
PVD	21 (14.7%)	6 (12.5%)	.89	.064	7 (17.5%)	5 (12.5%)	.75	.140
Extent of CAD								
1 vessel	40 (28.0%)	2 (4.2%)	.00	.651	1 (2.5%)	2 (5%)	1.00	.132
2 vessels	28 (19.6%)	9 (18.8%)	.90	.020	7 (17.5%)	9 (22.5%)	.78	.125
3 vessels	75 (52.4%)	37 (77.1%)	.00	.535	32 (80%)	29 (72.5%)	.60	.177
LMS disease	33 (23.1%)	13 (27.1%)	.27	.092	9 (22.5%)	10 (25%)	1.00	.059
LVEF								
Good (>50%)	102 (71.3%)	26 (54.2%)	.03	.359	19 (47.5%)	25 (62.5%)	.26	.295
Fair (30-50%)	38 (26.6%)	19 (39.6%)	.09	.279	19 (47.5%)	14 (35%)	.36	.256
Poor (<30%)	3 (2.1%)	3 (6.2%)	.17	.207	2 (5%)	1 (2.5%)	1.00	.132
Preop IABP	1 (0.7%)	1 (2.1%)	.44	.119	1 (2.5%)	0 (0%)	1.00	.226
Operative Urgency	103 (72%)	35 (72.9%)	.91	.020	26 (65%)	30(75%)	.47	.220
Logistic EuroSCORE	7 [5.5-8.0]	6 [4.0-9.0]	.50	.065	6.7 [5.2-8.1]	6.0 [4.0-8.2]	.17	.236
Era of surgery								
2006-2010	72 (50.3%)	28 (58.3%)	.43	.161	25 (62.5%)	24 (60%)	1.00	.051
2011-2019	71 (49.65%)	20 (41.6%)	.43	.161	15 (37.5%)	16 (40%)	1.00	.051

Data n (%), mean±standard deviation, median [inter-quartile range], BMI = body mass index, CAD = coronary artery disease, CCS = Canadian Cardiovascular Society, CVA = cerebrovascular accident,

IABP = intra-aortic balloon pump, LMS = left main stem, LVEF = left ventricular ejection fraction, MI = myocardial infarction, NYHA = New York Heart Association, PCI = percutaneous coronary intervention, PVD = peripheral vascular disease

In the unmatched cohort, off-pump patients were significantly older (68.69 ± 8.61 vs 66.02 ± 7.98 years, $p=0.05$) and demonstrated different patterns of coronary artery disease extent, with higher rates of single-vessel disease (26.5% vs 4.2%, $p<0.001$) and lower rates of three-vessel disease (52.4% vs 77.1%, $p<0.001$) compared to on-pump patients. Off-pump patients also had better preserved left ventricular function, with 71.3% having good LVEF ($>50\%$) compared to 54.2% in the on-pump group ($p=0.03$). After propensity score matching, baseline characteristics were well-balanced between groups.

Intraoperative Variables

Significant differences were observed in operative characteristics between groups. Off-pump patients received fewer grafts compared to on-pump patients in both unmatched (2.0 [1.0-2.0] vs 3.0 [2.75-3], $p<0.001$) and matched cohorts (2.0 [1.0-3.0] vs 3.0 [2.0-3.0], $p=0.001$). This translated to lower ICOR scores in off-pump patients (0.87 ± 0.39 vs 1.03 ± 0.25 , $p=0.001$ unmatched; 0.82 ± 0.48 vs 1.01 ± 0.26 , $p=0.03$ matched). All the variables have been summarized in Table 2.

Table 2: Intra-operative data

Variable	Unmatched off-pump (n = 143)	Unmatched on-pump (n = 48)	p value	Matched off-pump (n = 40)	Matched on-pump (n = 40)	p value
Endoscopic vein harvest	49 (34.3%)	20 (41.7%)	.03	15 (39.5)	16 (42.1)	1.00
All arterial grafts	41 (28.7%)	2 (4.2%)	<.001	6 (15.0%)	2 (5.0%)	.26
Conversion	23 (16.1%)	-	.00	9 (22.5%)	-	.00
Blood used	32 (22.4%)	21 (43.8%)	.01	0 (0.0%)	40 (100.0%)	<.001
RBC use	25 (17.5%)	18 (37.5%)	.01	5 (12.5%)	14 (35.0%)	.04
FFP use	18 (12.6%)	13 (27.1%)	.03	6 (15.0%)	10 (25.0%)	.40
Platelets use	19 (13.3%)	15 (31.2%)	.01	5 (12.5%)	12 (30.0%)	.10
Distal anastomosis						
1	63 (44.0%)	2 (2.1%)	<.0001	11 (27.5%)	2 (2.5%)	.003
2	48 (33.6%)	10 (20.8%)	.11	17 (42.5%)	10 (25%)	.16
3	26 (18.2%)	29 (60.4%)	<.0001	7 (17.5%)	24 (60%)	.0001
4	5 (3.5%)	7 (14.6%)	.01	4 (10%)	4 (10%)	1.00
5	1 (0.7%)	0 (0%)	.72	1 (2.5%)	0 (0%)	.64
Cross clamp time	-	64.60±23.29	.00	-	61.45±21.45	.00
CPB time	-	131.19±47.15	.00	-	127.83±44.69	.00
No. of grafts	2.0 [1.0-2.0]	3.0 [2.75-3.0]	.001	2.0 [1.0-3.0]	3.0 [2.0-3.0]	.001
ICOR	0.87±0.39	1.03±0.25	.001	0.82±0.48	1.01±0.26	.03

Data n (%), mean±standard deviation, median [inter-quartile range], CPB = cardiopulmonary bypass, FFP = fresh frozen plasma, ICOR = index of completeness of revascularization, RBC = red blood cells

Conversion from off-pump to on-pump technique occurred in 23 patients (16.1%) in the unmatched cohort and 9 patients (22.5%) in the matched cohort (included in the off-

pump group). All-arterial grafting was significantly more common in off-pump patients (28.7% vs 4.2%, $p < 0.001$ unmatched; 15.0% vs 5.0%, $p = 0.26$ matched).

Blood product utilization was significantly different between groups. In the matched cohort, 100% of on-pump patients required blood products compared to 0% of off-pump patients ($p < 0.001$). Red blood cell usage was significantly higher in on-pump patients (35.0% vs 12.5%, $p = 0.04$), as was fresh frozen plasma (25.0% vs 15.0%, $p = 0.40$) and platelet usage (30.0% vs 12.5%, $p = 0.10$). On-pump patients had mean cross-clamp time of 61.45 ± 21.45 minutes and cardiopulmonary bypass time of 127.83 ± 44.69 minutes in the matched cohort.

Short-term Outcomes

Post-operative intra-aortic balloon pump usage was numerically higher in on-pump patients in the unmatched cohort (10.4% vs 2.8%, $p = 0.05$), though this difference was not significant after matching (5% vs 7.5%, $p = 1.00$). Reoperation for bleeding rates were similar between groups (5% vs 5%, $p = 1.00$ matched). Pulmonary complications occurred in 17.5% of off-pump patients versus 15% of on-pump patients ($p = 1.00$) in the matched cohort. Superficial sternal wound complications were more frequent in the on-pump group (10% vs 0%, $p = 0.12$), while deep sternal wound complications were rare in both groups. Hospital length of stay showed a trend toward shorter duration in the off-pump group (9.0 [6.0-12.2] vs 10.0 [8.0-15.5] days, $p = 0.13$ matched), though this did not reach statistical significance. Short-term outcomes are summarized in Table 3.

Table 3: Post-operative outcomes and mortality data

Variable	Unmatched			Matched		
	Off-pump (n = 143)	On-pump (n = 48)	p value	Off-pump (n = 40)	On-pump (n = 40)	p value
Postoperative inotropes	41 (28.7%)	14 (29.2%)	1.00	13 (32.5%)	12 (30%)	1.00
Post-operative IABP	4 (2.8%)	5 (10.4%)	0.05	3 (7.5%)	2 (5%)	1.00
Reoperation for bleeding	4 (2.8%)	2 (4.2%)	0.64	2 (5%)	2 (5%)	1.00
Pulmonary complications	30 (21%)	8 (16.7%)	0.66	7 (17.5%)	6 (15%)	1.00
Superficial sternal wound infection.	5 (3.5%)	4 (8.3%)	0.23	0 (0%)	4 (10%)	0.12
Deep sternal wound infection	1 (0.7%)	0 (0%)	1.00	0 (0%)	0 (0%)	0.00
Leg wound infection	1 (0.7%)	2 (4.2%)	0.16	0 (0%)	2 (5%)	0.47
Hemofiltration or dialysis	15 (10.5%)	4 (8.3%)	0.79	7 (17.5%)	3 (7.5%)	0.31
Gastrointestinal complications	5 (3.5%)	2 (4.2%)	1.00	1 (2.5%)	2 (5%)	1.00
Post-operative multi organ failure	9 (6.3%)	1 (2.1%)	0.46	5 (12.5%)	1 (2.5%)	0.20
Atrial fibrillation	31 (21.7%)	8 (17%)	0.63	7 (17.5%)	8 (20%)	1.00
Hospital length of stay	9.0 [7.0-13.0]	10.0 [8.0-17.0]	0.09	9.0 [6.0-12.2]	10.0 [8.0-15.5]	0.13
In-hospital mortality	8 (5.6%)	3 (6.3%)	1.00	5 (12.5%)	1 (2.5%)	0.20
30-day mortality	12 (8.4%)	3 (6.3%)	0.76	5 (12.5%)	1 (2.5%)	0.20
Status February 2020 mortality	48 (33.6%)	12 (25%)	0.35	14 (35%)	10 (25%)	0.46

Data n (%), median [interquartile range], IABP = intra-aortic balloon pump

Mortality Outcomes

Postoperative outcomes showed no significant differences in 30-day mortality between off-pump and on-pump groups in both unmatched (8.4% vs 6.3%, $p=1.00$) and matched cohorts (12.5% vs 2.5%, $p=0.20$). Similarly, in-hospital mortality rates were comparable (5.6% vs 6.3%, $p=1.00$ unmatched; 12.5% vs 2.5%, $p=0.2007$ matched).

Long-term Survival

Kaplan-Meier analysis demonstrated no significant difference in long-term survival between patients undergoing off-pump versus on-pump CABG. Mean follow-up extended to February 2020, with overall mortality rates in of 35% in the off-pump group and 25% in the on-pump group ($p=0.46$ matched). In the unmatched cohort, survival probability at 1, 2, 3, 5, and 10 years was 88.8, 88, 85.8, 81 and 63.5 for off-pump patients versus 93.7, 91.5, 91.5, 85.9 and 73.7 for on-pump patients (log-rank $p=0.20$; Figure 2).

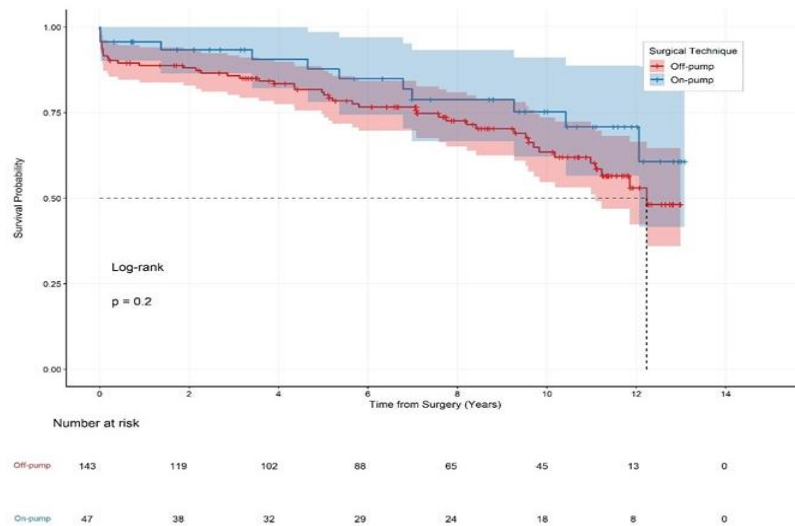


Figure 2: Kaplan-Meier survival curves of unmatched cohorts

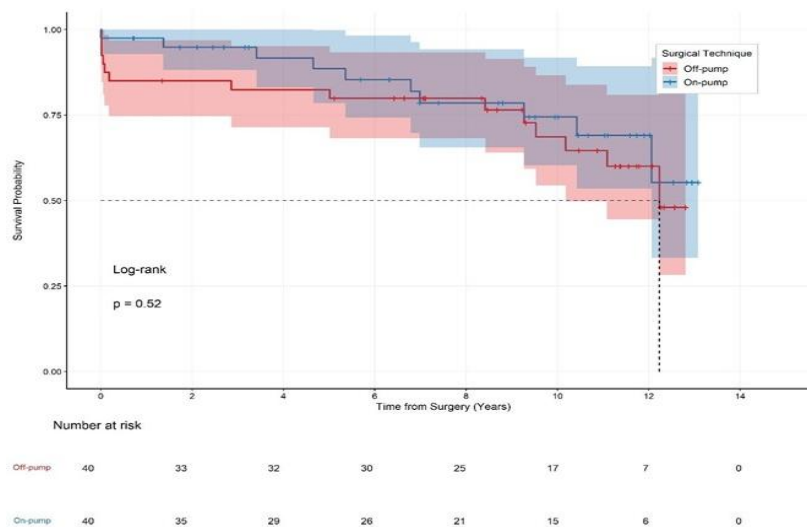


Figure 3: Kaplan-Meier survival curves of matched cohorts

After PSM, survival curves showed different patterns. Off-pump patients demonstrated survival rates of 85%, 85%, 82.4%, 82.4%, and 68.7% at 1, 2, 3, 5, and 10 years, respectively, compared to on-pump patients with survival rates of 97.5%, 94.9%, 94.9%, 88.5%, and 74.3% at the same time intervals (log-rank $p=0.52$; Figure 3). The data is summarized in Table 4. Over ten years, off-pump and on-pump survival converged further (63.5% vs. 73.7%).

Table 4: Survival probability for unmatched and matched cohorts

Unmatched				Matched			
Time (Years)	Survival	95% CI	p value	Time (Years)	Survival	95% CI	p value
ONCAB			.295	ONCAB			.524
1	93.7	87.1 - 100		1	97.5	92.8 - 100	
2	91.5	83.8 - 99.8		2	94.9	88.2 - 100	
3	91.5	83.8 - 99.8		3	94.9	88.2 - 100	
5	85.9	76 - 97.2		5	88.5	78.5 - 99.9	
10	73.7	60.6 - 89.6		10	74.3	60.1 - 91.8	
OPCAB				OPCAB			
1	88.8	83.8 - 94.1		1	85	74.6 - 96.8	
2	88	82.9 - 93.5		2	85	74.6 - 96.8	
3	85.8	80.2 - 91.8		3	82.4	71.4 - 95.1	
5	81	74.6 - 87.9	5	82.4	71.4 - 95.1		
10	63.5	54.7 - 73.6	10	68.7	54.4 - 86.6		

CI = confidence interval, ONCAB = on-pump coronary artery bypass, OPCAB = off-pump coronary artery bypass

Predictors of Long-term Mortality

Among the 191 patients in the analysis, 60 patients (31.4%) experienced long-term mortality during a median follow-up of 9.5 years (interquartile range: 6.4-11.4 years), with the remaining 131 patients (68.6%) censored at last contact in February 2020. In multivariable Cox proportional-hazards regression, three independent pre-operative factors significantly predicted long-term mortality: age (hazard ratio [HR], 1.04; 95% confidence interval [CI], 1.01-1.08; $p=0.021$), operative urgency (HR, 2.20; 95% CI, 1.27-3.82; $p=0.005$), and peripheral vascular disease (HR, 2.44; 95% CI, 1.29-4.60; $p=0.006$) (Table 5).

Table 5: Univariable & Multivariable Cox regression for long term mortality

Variable	Univariable Cox Regression		Multivariable Cox Regression	
	HR (95% CI)	p value	HR (95% CI)	p value
Age	1.04 (1.01-1.07)	.02	1.04 (1.01-1.08)	.021
Gender	0.99 (0.50-1.95)	.97		
BMI	1.00 (0.94-1.06)	.96		
Diabetes mellitus	1.46 (0.88-2.43)	.15		
Hypertension	1.00 (0.60-1.69)	.99		
Extent of CAD >2 vessels	1.14 (0.67-1.93)	.63		
Left Main Stem disease	1.21 (0.67-2.18)	.53		
LV impairment	0.60 (0.36-1.01)	.06		
Operative urgency	1.80 (1.06-3.08)	.03	2.2 (1.27-3.82)	.005
Preoperative neurological disease	1.56 (0.56-4.29)	.39		

Preoperative pulmonary pathology	1.19 (0.48-2.97)	.71		
Preoperative renal impairment	1.67 (0.90-3.12)	.11		
Previous MI	0.93 (0.55-1.58)	.80		
Previous PCI	0.81 (0.48-1.37)	.44		
Peripheral vascular disease	2.22 (1.20-4.11)	.01	2.44 (1.29-4.6)	.006
Former smoking	1.45 (0.82-2.58)	.20		
Never smoking	0.85 (0.48-1.50)	.57		

BMI = body mass index, CAD = coronary artery disease, CI = confidence interval, HR = hazard ratio, MI = myocardial infarction, LV = left ventricle, PCI = percutaneous coronary intervention

DISCUSSION

The present study conducted on the data from single center demonstrates that off-pump redo-CABG yields comparable outcomes to on-pump surgery, with a notable advantage in blood product conservation. Among the cohorts, matched and unmatched, there was no significant statistical difference in short-term and long-term outcomes. One of the most striking findings of this study is the dramatic difference in blood product utilization between groups. This represents a fundamental biologic advantage of avoiding cardiopulmonary bypass and its associated complications. The physiologic rationale for these benefits lies in the reduced inflammatory burden of off-pump surgery, which avoids cardiopulmonary bypass-induced cytokine release and preserves native hemostasis [9]. This translates to fewer transfusions and potentially fewer complications.

Single distal anastomosis was significantly more common in off-pump patients (27.5% vs 2.5%, $p=0.003$ matched), indicating more selective, clinically-indicated revascularization. Conversely, triple graft procedures were predominant in on-pump patients (60% vs 17.5%, $p<0.001$ matched). All-arterial grafting was more frequent in off-pump patients (15.0% vs 5.0%), which may contribute to improved graft patency and longevity despite fewer total grafts. This data supports the concept that off-pump techniques facilitate meticulous, lesion-specific revascularization rather than routine complete anatomical revascularization, potentially resulting in more physiologically appropriate and durable outcomes [10].

In this cohort, conversion from off-pump to on-pump coronary artery bypass grafting occurred in 16.1% of unmatched cases and 22.5% of matched off-pump cases, with no conversions reported in the on-pump group. This reflects the inherent complexity of redo-CABG procedures, where dense adhesions, altered cardiac anatomy, and limited target vessel accessibility often challenge the feasibility of completing revascularization without cardiopulmonary bypass. Several plausible factors may have contributed to these conversions. Prior sternotomy and pericardial scarring can restrict heart mobilization and obscure coronary targets, making stable off-pump anastomosis technically difficult. Additionally, intraoperative hemodynamic instability during cardiac manipulation may necessitate urgent initiation of bypass to maintain patient safety [11]. The lower number of distal anastomoses and reduced ICOR observed in the off-pump group suggest that conversion may have been employed to achieve more comprehensive graft coverage when off-pump access was inadequate. Ultimately, these decisions reflect intraoperative judgment, balancing technical success, myocardial protection, and long-term graft patency. In high-volume off-pump centers, conversion remains a pragmatic and patient-centered strategy to optimize outcomes in anatomically or hemodynamically challenging redo-CABG cases.

In this comparative study of off-pump and on-pump redo-CABG, the similarity in short-term postoperative complications across both unmatched and matched cohorts likely reflects a combination of surgical expertise, balanced patient selection, and consistent institutional protocols. Despite the physiological differences between techniques—particularly the avoidance of cardiopulmonary bypass in off-pump surgery—both approaches were performed in a high-volume center with extensive experience in redo procedures, which may have mitigated expected disparities in outcomes such as bleeding, arrhythmia, and infection. The matched design ensured comparable baseline risk profiles, reducing confounding influences. These findings underscore that, when executed in experienced hands, both off-pump and on-pump redo-CABG can achieve safe and effective early outcomes, with surgical judgment and intraoperative adaptability playing a more decisive role than the choice of pump strategy alone.

Kaplan-Meier analysis demonstrated no significant difference in long-term survival between off-pump and on-pump groups in either unmatched or matched cohorts. The convergence of survival curves over time suggests that while surgical technique may influence perioperative events, long-term survival is predominantly determined by other factors including disease burden, comorbidities, and medical management. The median follow-up of 9.5 years provides strong evidence regarding durability of the surgical techniques employed.

Three major meta-analyses collectively demonstrate that off-pump redo-CABG is associated with early perioperative benefits, including reduced mortality and complication rates, yet these advantages do not consistently extend into long-term survival when compared with conventional on-pump surgery. Zhang et al. (2020, n=4,889) reported significantly lower 30-day mortality (OR 0.43; 95% CI 0.26-0.72) and in-hospital mortality (OR 0.55; 95% CI 0.39-0.76) with off-pump techniques, alongside reductions in atrial fibrillation, myocardial infarction, acute kidney injury, and transfusion requirements [12]. Tzoumas et al. (2021, n=5,330) similarly found reduced 30-day mortality (OR 0.46; 95% CI 0.34-0.61) and myocardial infarction (OR 0.48; 95% CI 0.31-0.72), though 5-year mortality remained comparable (OR 0.73; 95% CI 0.34-1.53) [13]. Another 2022 meta-analysis (n=5,197) confirmed higher early mortality with on-pump surgery (OR 2.11; 95% CI 1.54-2.89), but no significant differences in 1-, 3-, or 5-year mortality (OR 1.12; 95% CI 0.41-3.02), reinforcing the transient nature of early off-pump benefits [5].

Contemporary single-center data support these findings. Aranda-Michel et al. (n=350) found no significant differences in 30-day, 1-year, or 5-year mortality between techniques. Their multivariable Cox analysis showed surgical approach was not an independent predictor of 5-year mortality (HR 0.45; 95% CI 0.19-1.07; p=0.072), echoing our matched cohort results. Off-pump patients had lower transfusion rates (31.7% vs. 58.9%, p=0.001) and atrial fibrillation (17.1% vs. 35.6%, p=0.018), consistent with our findings [14].

Our multivariable analysis identified peripheral vascular disease [HR 2.44], operative urgency [HR 2.20], and age [HR 1.04/year] as independent predictors of long-term mortality. These findings reflect the systemic burden of atherosclerosis and the compounded surgical risk in patients with advanced vascular pathology. Peripheral vascular disease, in particular, is a well-established marker of diffuse arterial involvement and is strongly associated with adverse cardiovascular outcomes, impaired wound healing, and increased perioperative morbidity [15]. Operative urgency further amplifies risk by limiting

preoperative optimization and increasing susceptibility to hemodynamic instability and ischemic injury. Age, as a continuous variable, contributes incrementally to mortality risk, likely reflecting cumulative comorbidity, frailty, and diminished physiological reserve [16]. These findings underscore the need for individualized surgical planning, with technique selection guided by anatomy, comorbidities, urgency, and surgeon expertise.

This study employed PSM to create well-balanced cohorts, substantially reducing confounding from observed baseline characteristics. The long follow-up duration (median 9.5 years) provides good evidence regarding durability of surgical techniques. Data were derived from a prospectively maintained cardiac surgery database that undergoes annual validation and submission to national registries, ensuring data quality and accuracy. The comprehensive documentation of pre-operative, intraoperative, and postoperative variables permitted detailed outcome assessment. However, several limitations warrant acknowledgment. The retrospective cohort design, despite propensity matching, remains susceptible to residual confounding from unobserved covariates. Surgeon preference regarding technique selection and factors influencing that preference was not captured in our analysis. The extended study timeframe (2006-2019) spans distinct periods of cardiac surgical advancement, including evolving cardiopulmonary bypass protocols, anesthetic techniques, and postoperative management strategies, potentially affecting case selection and outcomes. The modest frequency of serious adverse events limited statistical power to detect clinically important differences in complication rates. Single-center design may limit generalizability to institutions with different case volumes, surgeon experience, and patient demographics. The conversion rate from off-pump to on-pump in 22.5% of intended off-pump cases suggests potential selection of simpler anatomies for off-pump approaches, potentially underestimating the technical difficulty of off-pump redo-CABG. Missing data for some variables, particularly EuroSCORE (42 missing values), required imputation to maximize statistical power, which may have introduced bias.

Future research should prioritize prospective randomized controlled trials comparing off-pump and on-pump redo-CABG, which would reduce selection bias inherent to observational studies. Multicenter studies would enhance generalizability and statistical power for detecting important differences in rare complications. Subgroup analyses examining optimal patient-selection criteria for technique choice, such as predictive models incorporating peripheral vascular disease status, complexity of coronary anatomy, prior graft status, and operative urgency, would refine surgical decision-making algorithms. Investigation of graft patency and long-term angiographic outcomes between techniques remains important. Evaluation of quality-of-life measures, functional capacity, and need for repeat revascularization would provide comprehensive outcome assessment beyond mortality. Registry studies with standardized data collection across multiple centers would complement clinical trial evidence.

This retrospective analysis demonstrates that both on-pump and off-pump techniques represent viable approaches for redo-CABG with acceptable short-term and long-term outcomes. Off-pump redo-CABG offers distinct advantages including complete elimination of blood transfusion requirements and reduced perioperative complications, while maintaining equivalent long-term survival compared to on-pump surgery. Long-term outcomes are principally determined by patient-specific factors including age, peripheral vascular disease status, and operative urgency rather than surgical technique. Surgical decision-making should be individualized based on patient anatomy, risk profile,

comorbidities, and institutional expertise, with both techniques retained as essential components of the cardiac surgery armamentarium for redo-CABG patients.

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