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Research Article

A Single-Center Experience in Low Ejection Fraction Coronary Artery Bypass Surgery

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Background. Coronary artery bypass graft (CABG) in patients with an ejection fraction (EF) ≤ 35% predisposes them to higher complications and mortality risks. Given the usually compromised status of other end organs in low EF patients, ONCAB, involving cardiopulmonary bypass (CPB) and aortic cross-clamping, might intuitively pose more complications than OPCAB. *Objective*. To explore short- and long-term outcomes between ONCAB and OPCAB procedures in patients with EF ≤ 35%. *Methods*. A retrospective and observational analysis was conducted in 196 patients with EF ≤ 35% who underwent ONCAB ($n = 58$) or OPCAB ($n = 138$) procedures at a single center between January 2015 and May 2023. Baseline characteristics were well matched using the stabilized inverse probability treatment weighted matching technique. *Results*. After matching, ONCAB and OPCAB had comparable 30-day mortality and 30-day cardiac mortality. OPCAB exhibited significantly shorter length of hospital and ICU stays, with a trend towards more discharges to home. Rates of composite complication and its individual components such as acute kidney injury, reoperation bleeding, stroke, pneumonia, GI disease, and atrial fibrillation were similar between the two groups. Rates of sepsis, liver dysfunction, and blood transfusion were significantly lower in the OPCAB group. As assessed by EF and LVDD, neither procedure showed superiority in improving cardiac function. Median follow-up time was 4.9 (interquartile range: 2.1–7.2) years. After matching, long-term overall survival (1, 3, 7 years) and cardiac mortality rates were comparable between OPCAB and ONCAB. Cumulative rates of cardiac arrest, heart failure, myocardial infarction (MI), atrial fibrillation (Afib), renal disease, and readmission (overall and cardiac) at 7 years were similar. *Conclusion*. This study demonstrates comparable short-term and long-term outcomes between ONCAB and OPCAB in patients with reduced EF, with OPCAB favoring faster recovery. OPCAB appears as a safer and equally effective option for low EF CABG patients. Larger samples and longer follow-ups are needed for conclusive clinical evidence.

1. Introduction

Coronary artery disease (CAD) is the most common cause of heart failure leading to the highest number of deaths in the USA and worldwide [1, 2]. Coronary artery bypass grafting (CABG) is a well-established surgical procedure for the management of CAD and its associated complications [3, 4]. Over the years, there has been a growing interest in comparing the outcomes of on-pump (ONCAB) and off-pump (OPCAB) CABG surgeries [5–11], particularly in patients with reduced EF [12, 13]. Reduced EF, defined as an EF of 35% or less, is a strong predictor of adverse cardiac events and is associated with increased morbidity and mortality following cardiac surgeries [14, 15]. Therefore, determining the optimal surgical approach for patients with reduced EF is of paramount importance. However, few trials have compared outcomes from OPCAB and ONCAB procedures in CAD patients with severely reduced EF [6, 12, 16]. Current evidence on the superiority of one procedure over the other remains inconclusive.

We studied short-term (30-day) and long-term (7-year follow-up) outcomes between the two procedures in our CABG patients with severely reduced EF (≤35%). Given the usually compromised status of other end organs in low EF patients and systemic inflammatory response syndrome (SIRS) caused by the use of cardiopulmonary bypass (CPB) in ONCAB, one would intuitively expect higher complication rates postoperatively. In addition, coronary collateral circulation may be disrupted due to transient changes in ventricular anatomical geometry during the use of CPB [17], which may provide further challenges on the functionality of global ischemia that was already compromised due to CAD [18].

2. Methods

2.1. Design and Study Population. We conducted a retrospective, single-center observational study including patients who underwent CABG surgery between January 2015 and May 2023. The study focused on patients who underwent either on-pump coronary artery bypass grafting or off-pump coronary artery bypass grafting procedures and had an EF ≤ 35%. Patients who underwent concomitant valve procedures with CABG or minimally invasive coronary artery bypass surgery were excluded from the study. The research ethics board at BSWH approved this study and waived the requirement for individual patient consent, as the data collected were not identifiable.

2.2. Data Collection. We used the STS registry data for collecting baseline demographics, historical risk factors, perioperative, and postoperative short-term attributes. For the short-term cohort, the primary outcome was 30-day mortality of any cause, and the secondary outcomes were postoperative complications, hospital stay, ICU, and ventilation times. All variables were defined according to the STS standards. For the 7-year follow-up cohort, we used our institutional database. The primary outcome was 7-year mortality of any cause, and the secondary outcomes were stroke, infection of any causes, cardiac arrest, myocardial infarction, renal failure, readmit for any reasons, cardiac readmission, atrial fibrillation, and heart failure. The identification of these variables was retrieved from the operative notes written by the surgeon or physician assistant.

2.3. Statistical Analysis. The statistical analyses were conducted using SAS EG 9.4. Quantitative parametric variables were summarized as the mean ± standard deviation, while nonparametric variables were summarized as the median (interquartile range: IQR). Group comparisons were performed using standard t-tests, Mann–Whitney U tests, or quantile regression tests as appropriate. Categorical variables were presented as numbers (%) and analyzed using the chi-square test or Fisher exact test. The design for the presurgery and postsurgery continuous variables involved repeated measures ANCOVA.

For the 7-year follow-up data, time-to-event analysis (Cox regression) was utilized. Kaplan–Meier survival curves were used to present the primary outcome (mortality), and the log-rank test was used for subgroup comparisons with the use of stabilized inverse probability treatment weighted sample. Failure plots, hazard ratios, and 95% confidence intervals were used to present the secondary outcomes, and comparisons between groups were performed using the log-rank test of inequality with the stabilized IPTW rounded sample.

To address baseline imbalances and confounding factors between the OPCAB and ONCAB groups (as shown in Table 1), we employed the stabilized inverse probability treatment weighting (IPW) matching technique. This approach assigns weights to individuals based on their propensity score to receive a specific treatment, resulting in improved balance and reduced bias [19]. Covariates such as age, BMI, gender, diabetes, chronic lung disease, liver dysfunction, kidney dialysis, stroke, peripheral vascular disease, myocardial infarction, hypertension, arrhythmia, number of deceased vessels, sleep apnea, hemoglobin, creatinine, and EF were incorporated in the matching process. The balance achieved through weighted matching was confirmed through examination of the distribution of logit propensity scores plots (Figure 1) and statistical differences in each covariate between the treatment groups (Table 1). All statistical significance was defined as a two-sided p value of less than 0.05.

3. Results

2,150 patients had cardiac surgery at our cardiovascular clinic during seven years, from January 1, 2015, to May 31, 2023. 1,022 of them had undergone isolated coronary artery bypass grafting (CABG) operations. To create the study cohort, we further chose 196 patients (13.8% of the CABG patients) from this group who had an EF ≤ 35%. We finally split these patients into two groups to examine the outcomes: on-pump CABG (58 patients, or 29.6%) and off-pump CABG (138 patients, or 70.4%). Following a rigorous process of stabilized IPTW matching, we successfully obtained a weighted cohort of 54 patients from the ONCAB surgery and 137 patients from the OPCAB group. The postoperative and 7-year follow-up outcomes of these patients are meticulously presented in the following analysis.

3.1. Baseline Characteristics. Details of baseline characteristics along with patients' demographics are tabulated in Table 1. The mean ± SD age of our study cohort was 63 ± 11.3 years with 120 (81%) men and 24 (17%) Hispanic patients. Over 79% of the total patients had a previous myocardial infarction (MI). After stabilized-weighted matching, there was no significant difference between the OPCAB and ONCAB groups in age (62.7 ± 11.4 vs. 62.4 ± 10.7, $p = 0.873$), sex (82.5% vs. 83.8%, $p = 0.835$), dialysis (9.3% vs. 10.8%, $p = 0.753$), previous history of stroke (16.4% vs. 23.7, $p = 0.238$), chronic lung disease (36.3% vs. 36.2%, $p = 0.994$), peripheral vascular disease-PVD (20.5% vs. 25.7%, $p = 0.443$), and MI (79.4% vs 81.5%, $p = 0.739$) (Table 1). No significant differences were observed in the history of heart failure for systolic (35.6% vs. 34.3%, $p = 0.968$), diastolic (4% vs. 1.4%, $p = 0.176$), or both (57.5% vs. 58.1%, $p = 0.610$) between the two study groups (Table 1). The mean EF (27.2 ± 6.1 vs. 27.6 ± 5.3, $p = 0.645$) and the rates of hypertension (87.4% vs. 91.4%, $p = 0.458$) were similar between the two study groups after matching.

Table 1: Baseline characteristics, demographics, and risk factors.

Characteristics		Unmatched			Stabilized IPTW-matched		
		ONCAB ($n = 58$)	OPCAB ($n = 138$)	p value	ONCAB (Nw = 54)	OPCAB (Nw = 137)	p value
Age (mean ± SD) (years)		63.3 ± 10.7	62.8 ± 11.8	0.393	62.4 ± 10.7	62.7 ± 11.4	0.873
BMI		29.6 ± 5.3	28.7 ± 6.2	0.369	29.5 ± 5.1	29.7 ± 7.6	0.789
Male sex		44 (75.9)	115 (83.3)	0.222	45 (83.8)	113 (82.5)	0.835
Hispanic		11 (19)	21 (15.2)	0.517	12 (21.4)	20 (14.8)	0.268
Previous MI (at any time prior surgery)		51 (87.9)	104 (75.4)	0.048	44 (81.5)	109 (79.4)	0.739
Angina		21 (36.2)	54 (39.1)	0.704	17 (31.5)	50 (36.5)	0.395
STEMI		6 (10.3)	19 (13.8)	0.509	5 (9.3)	21 (15.6)	0.147
NON-STEMI		21 (36.2)	47 (34.1)	0.771	18 (32.8)	49 (35.8)	0.522
Arrhythmia		6 (10.3)	26 (18.8)	0.142	7 (13.2)	22 (16.2)	0.604
Hypertension		55 (94.8)	115 (83.3)	0.030	49 (91.2)	120 (87.4)	0.458
Dialysis		5 (8.6)	13 (9.4)	0.860	6 (10.8)	13 (9.3)	0.753
CVA (previous history of stroke)		9 (15.5)	23 (16.7)	0.943	13 (23.7)	22 (16.4)	0.238
Chronic lung disease		25 (43.1)	43 (31.2)	0.109	20 (36.2)	50 (36.3)	0.994
PVD (history of PAD)		15 (25.9)	29 (21)	0.458	14 (25.7)	28 (20.5)	0.433
Sleep apnea		10 (17.2)	28 (20.3)	0.622	10 (18.7)	30 (21.9)	0.623
History of heart failure	Systolic	17 (29.3)	43 (31.2)	0.794	16 (34.3)	41 (35.6)	0.968
	Diastolic	1 (1.7)	4 (2.9)	1	1 (1.4)	5 (4)	0.176
	Both	25 (43.1)	69 (50)	0.378	27 (58.1)	67 (57.5)	0.610
	Unknown	4 (6.9)	4 (2.9)	0.197	3 (6.1)	3 (2.95)	0.150
Liver disease		2 (3.4)	10 (7.2)	0.515	4 (7.2)	9 (6.3)	0.821
Diabetes		35 (60.3)	91 (65.9)	0.455	37 (69.1)	90 (65.9)	0.673
Hemoglobin (mean ± SD)		12.5 ± 2.1	12.8 ± 2.1	0.377	12.8 ± 2.1	12.6 ± 2	0.688
EF (mean ± SD)		28.7 ± 5.1	26.4 ± 6.1	0.015	27.6 ± 5.3	27.2 ± 6.1	0.645
Creatine (mean ± SD)		1.4 ± 1.04	1.5 ± 1.1	0.609	1.5 ± 1.3	1.44 ± 1.1	0.737
Single vessel Dis		1 (1.7)	6 (4.3)	0.676	1 (1.4)	3 (2.5)	0.573
Double vessel Dis		6 (10.3)	25 (18.1)	0.174	7 (12.4)	21 (15.5)	0.429
Triple vessel Dis		50 (86.2)	106 (76.8)	0.136	46 (85)	111 (81.2)	0.276
Cardiogenic shock		5 (8.62)	11 (10.23)	0.881	5 (9.3)	11 (8.1)	0.849

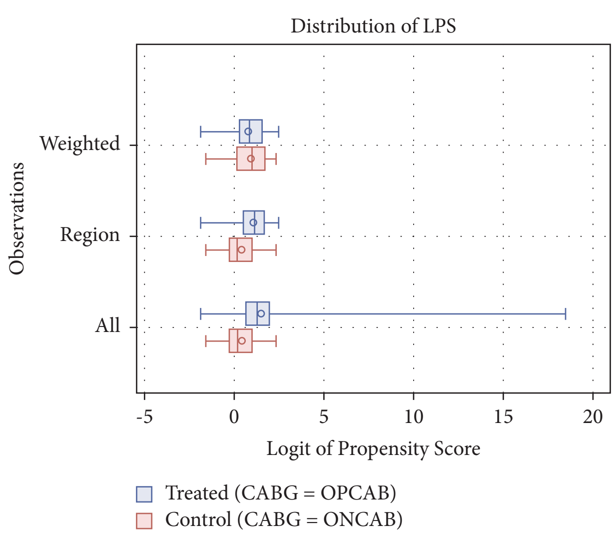

Figure 1: Balancing of the proportion of CABG patients between OPCAB and ONCAB was achieved through stabilized inverse probability treatment weighted matching. The incorporated covariates for the matching included age, BMI, gender, diabetes, chronic lung disease, liver dysfunction, kidney dialysis, stroke, peripheral vascular disease, myocardial infarction, hypertension, arrhythmia, number of diseased vessels, sleep apnea, hemoglobin, creatinine, and EF. The weighted matching samples resulted in improved balance between the two CABG procedures.

Most of these patients (81.5%) had multivessel disease, and there was no significant difference between the OPCAB and ONCAB cohorts (81.2% vs. 85%, $p = 0.276$).

3.2. Operative Characteristics. The utilization of grafts was significantly lower in number for the OPCAB group (2.95 ± 1.04 vs. 3.4 ± 1.06; $p = 0.009$). Although similar left IMA were performed between the OPCAB and ONCAB groups (97.73% vs. 98.28%, $p = 0.687$), a significantly greater bilateral IMA (44.7% vs. 1.6%, $p < 0.0001$) was deployed in the OPCAB group. While pedicled IMA harvesting was greater in the ONCAB group (70.4% vs. 98%, $p = 0.007$), the skeletonized IMA harvesting was utilized only in the OPCAB cases (45.4% vs. 0%, $p < 0.0001$). The rates of total arterial graft usage were similar between the two study groups (OPCAB vs. ONCAB: 58% vs. 43%; $p = 0.057$), and the rates were 38.1% with bilateral IMA grafts. The conversion rate from OPCAB to ONCAB was <2.2% (3 out of 138 cases). The rates of cardiogenic shock cases were similar between the OPCAB and ONCAB groups (8.1% vs. 9.3%, $p = 0.849$). The median (IQR) crossclamp and CPB times were 87 (65-115.5 mins) and 117 (85–160 mins), respectively. Blood (del Nido) type cardioplegia was used in 54 (96.5%) ONCAB cases crystalloid in 2 (3.5%) cases, with no need for cardioplegia in 2 patients. The cardioplegia

Table 2: Postoperative in-hospital outcomes.

Variables	Unmatched			Stabilized IPTW-matched		
	ONCAB ($n = 58$)	OPCAB ($n = 138$)	p	ONCAB (Nw = 54)	OPCAB (Nw = 137)	p
30-day mortality (overall)	7 (12.07)	5 (3.6)	0.024	5 (9.5)	9 (6.6)	0.490
30-day mortality (cardiac)	4 (6.9)	5 (3.2)	0.204	4 (7.4)	9 (6.6)	0.897
Postop blood transfused	30 (51.7)	50 (36.2)	0.044	30 (55.6)	50 (36.8)	0.017
Composite complications	34 (58.6)	68 (49.3)	0.232	32 (59.1)	66 (48.1)	0.171
Liver disease	1 (1.7)	0	0.296	3 (5)	0	0.024
Sepsis	6 (17.6)	5 (7.4)	0.114	6 (11.1)	4 (2.9)	0.032
Reoperation bleeding	0	4 (5.8)	0.298	0	5 (3.6)	0.324
Stroke (permanent)	1 (1.7)	4 (2.9)	0.167	1 (1.8)	6 (4.4)	0.675
Pneumonia	6 (17.6)	10 (14.7)	0.700	7 (13)	9 (6.6)	0.135
Acute kidney injury (AKI)	5 (8.6)	4 (3.6)	0.156	4 (7.4)	4 (2.9)	0.124
GI complications	9 (26.5)	10 (14.7)	0.150	7 (13)	9 (6.6)	0.174
Atrial fibrillation	18 (31)	38 (27.5)	0.778	18 (33.3)	37 (27)	0.716
LOHS (days)	10.5 (7–16)	8 (6–12)	0.135	11 (8–15)	8 (5–12)	0.022
ICU (days)	5.02 (3.2–9.3)	3.9 (2.05–6.04)	0.128	5.9 (3.8–9.03)	3.5 (2.05–6.03)	0.014
Ventilation time (hours)	17.8 (5.4–58.9)	6.2 (3.8–20.1)	0.075	17.8 (5–65.6)	6.8 (3.8–22.4)	0.222
Impella/IABP/ECMO	17 (29.3)	53 (38.4)	0.225	16 (30.3)	50 (36.1)	0.443
Postoperative Impella	2 (3.4)	8 (7.2)	0.496	3 (5.5)	10 (7.3)	0.768
Readmission	9 (15.5)	22 (15.9)	0.938	8 (14.8)	22 (16)	0.763
Cardiac readmission	7 (12)	15 (10.8)	0.810	7 (12)	15 (10.8)	0.897
Discharge-to-home	38 (65.5)	104 (75.5)	0.158	35 (64.8)	103 (75.4)	0.149

delivered was antegrade in 31 (53.4%), retrograde in 1 (1.7%), and a combination of both in 24 (41.4%) patients. Throughout ONCAB procedures, the median (IQR) body temperature was maintained at 35 (33.8–35.7) °F. Body temperature was measured through jugular-venous in 27 (46.5%), bladder in 12 (20.6%), nasopharyngeal in 14 (24%), CPB venous return in 1 (1.7%), esophageal in 2 (3.4%), and other sources in 2 (3.4%) patients.

3.3. Postoperative 30-Day Mortality. 30-day deaths occurred in 12 (6.1%) patients in our study cohort. After stabilized weighted matching, the rates of 30-day mortality were similar between the two study cohorts (OPCAB vs. ONCAB: 6.6% vs. 9.5%, $p = 0.490$). The 30-day cardiac mortality was similar between the OPCAB and ONCAB groups (6.6% vs. 7.4%, $p = 0.897$) (Table 2).

3.4. Postoperative In-Hospital Secondary Outcomes. After matching, the quantile regression test found significantly shorter median length of hospital stay (LOHS) in the OPCAB group than the ONCAB group (8 vs. 11 days, $p = 0.022$). Median ventilation time was 6.8 hours in the OPCAB group and 17.8 hours in the ONCAB group ($p = 0.222$). Median ICU stay was about 3.5 days in the OPCAB group and 5.9 days in the ONCAB group ($p = 0.014$) (Table 2).

Acute kidney injury (AKI: renal failure or dialysis) occurred in 9 patients during their in-hospital stay after surgery. Rates of AKI were similar between the OPCAB and ONCAB groups (2.9% vs. 7.4%, $p = 0.174$). Between the OPCAB and ONCAB groups, rates of composite complication and its individual components such as reoperation for bleeding (3.6% vs. 0%, $p = 0.277$), stroke (4.4% vs. 1.8%, $p = 1$), pneumonia (6.6% vs. 13%, $p = 0.135$), GI complications (6.6% vs. 13%, $p = 0.174$), and atrial fibrillation (27% vs. 33%, $p = 0.716$) were similar (Table 2). There were no significant differences in readmission (OPCAB vs. ONCAB: 16% vs. 14.8%, $p = 0.763$) or cardiac readmission (OPCAB vs. ONCAB: 10.8% vs. 12%, $p = 0.897$) rates between the two groups. Rates of discharge-to-home were similar (ONCAB vs. OPCAB: 64.8% vs. 75.4%, $p = 0.149$). However, rates of sepsis were significantly lower in the OPCAB group than the ONCAB counterpart (2.9% vs. 11.1%, $p = 0.032$). There was a significantly lower blood transfusion rate in the OPCAB group (36.8% vs. 55.6%, $p = 0.017$). Rates of postoperative liver dysfunction were significantly lower in the OPCAB group (0% vs. 5%, $p = 0.024$) (Table 2). Note that among the matched samples, OPCAB with total arterial grafts was significantly associated with lower rates of 30-day permanent stroke (0% vs. 5.4%; $p = 0.041$), whereas this association was not significant in ONCAB (0% vs. 2.2%; $p = 0.453$).

A total of 70 perioperative mechanical assist devices were used (8 Impellas, 2 ECMOs, and 66 IABPs): 53 (38.4%) in the OPCAB group and 17 (29.3%) in the ONCAB group. Notably, all 8 Impella devices were utilized postoperatively, 1 in ONCAB and 7 in OPCAB, with 6 of the latter having preoperative device support (5 IABPs and 1 ECMO).

Among the matched patients, there was no significant difference in the overall utilization of these devices between OPCAB and ONCAB surgeries [50 (36.1%) vs. 16 (30.3%); $p = 0.443$]. The utilization of these devices was not significantly different between OPCAB and ONCAB procedures either pre/intraoperatively [49 (35%) vs. 14 (26%); $p = 0.194$] or postoperatively [10 (7.3%) vs. 3 (5.5%); $p = 0.768$]. Moreover, the presence of these devices did not impact the 30-day mortality rates in either procedure [hazard ratio 0.52 (95% CI: 0.14–1.9); $p = 0.326$].

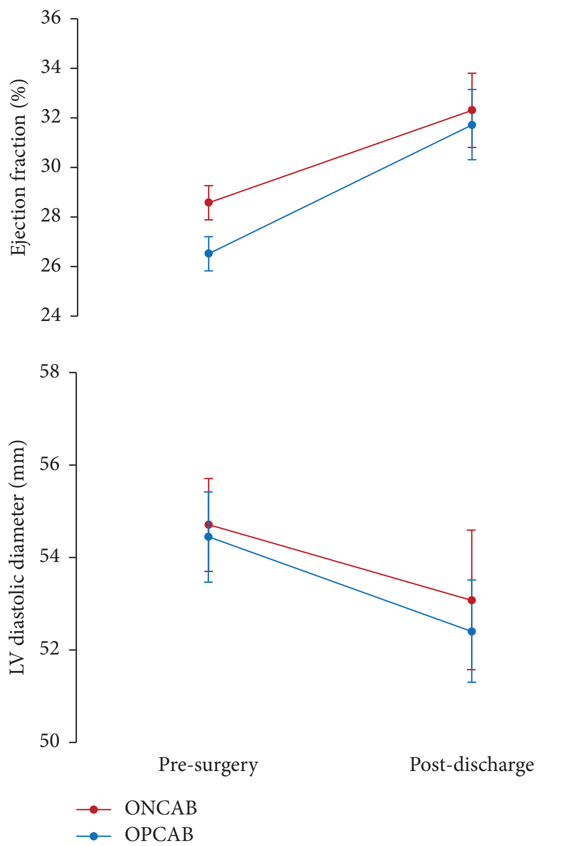

Figure 2: Repeated-measures ANCOVA tests of left ventricular (LV) diastolic diameter and ejection fraction between presurgery and postsurgery periods for the OPCAB and ONCAB groups. Here, the error bars are the standard errors of means.

We also investigated whether OPCAB or ONCAB procedures had any influence on the improvement of left ventricular diastolic diameter and/or the EF. A repeated-measures ANCOVA analysis indicated significant improvement in postdischarge EF for both OPCAB ($p < 0.0001$) and ONCAB ($p = 0.006$) surgeries individually. However, there was no significant difference between the two procedures in terms of improvement ($p = 0.634$) (Figure 2, top). Similarly, a repeated-measures ANCOVA test did not find any significant impact on postdischarged LVEDD between the two CABG surgeries ($p = 0.631$) (Figure 2, bottom).

3.5. 7-Year Follow-Up Mortality Outcomes. The median follow-up period was approximately 2 years in the OPCAB group and 5 years in the ONCAB group. Throughout the 7-year follow-up, a total of 50 patients (25.5% of the entire cohort) passed away, with 29 of them (58%) succumbing to cardiac disease.

Among the matched patients, the survival rates at 1 year, 3 years, and 7 years were as follows: in the OPCAB group, the rates were 86% (95% CI: 80-91.5), 73% (95% CI: 64–83), and 46% (95% CI: 28–76); in the ONCAB group, the rates were 86% (95% CI: 79–94), 73.3% (95% CI: 63–85), and 46.4% (95% CI: 30–72). The hazard ratio between the OPCAB and ONCAB groups for overall survival was 1 (95% CI: 0.6–1.8; $p = 0.976$) (Figure 3).

Regarding mortality due to cardiac causes, the rates at 1 year, 3 years, and 7 years were as follows: in the OPCAB group, the rates were 9.7% (95% CI: 5–14.4), 18.3% (95% CI: 9–26.6), and 38.7% (95% CI: 17–54.7); in the ONCAB group, the rates were 8.8% (95% CI: 2.6–14.6), 16.6% (95% CI: 6.8–25.4), and 35.6% (95% CI: 18–44). The hazard ratio for cardiac mortality between the OPCAB and ONCAB groups was 1.1 (95% CI: 0.5–2.3; $p = 0.778$) (Figure 3).

3.6. 7-Year Follow-Up Secondary Outcomes. Among the matched patients, the 7-year cumulative rates of cardiac arrest were 10.1% (95% CI: 0.3–19) in the OPCAB group and 10% (95% CI: 1.5–17.7) in the ONCAB group. The hazard ratio (OPCAB/ONCAB) for cardiac arrest was 1 (95% CI: 0.3–3.9; $p = 0.983$). The rates of permanent stroke were 11.6% (95% CI: 5.8–17.5) in the OPCAB and 1.8% (95% CI: 2.4–6.12) in the ONCAB group. The hazard ratio for the CVA was 6.4 (1.3–112.5; $p = 0.037$). The long-term MI rates were 32.7% (95% CI: 21.5–42.3) in the OPCAB and 39.8% (95% CI: 24.7–51.8) in the ONCAB group. The hazard ratio for the MI was 0.8 (95% CI: 0.45–1.4; $p = 0.759$). The atrial fibrillation (Afib) rates were 61.2% (95% CI: 35–77) in the OPCAB group and 62.2% (95% CI: 37–77.5) in the ONCAB group. The hazard ratio for the Afib was 0.97 (95% CI: 0.6–1.6; $p = 0.907$) (Figure 4).

The long-term cumulative rates of heart failure (systolic, diastolic, or both) were 77.5% (95% CI: 59–87.7) in the OPCAB group and 63% (95% CI: 44–75.4) in the ONCAB group. The hazard ratio for heart failure was 1.5 (95% CI: 0.45–1.4; $p = 0.078$). The readmission rates for any reasons were 70.7% (95% CI: 50.6–82.6) in the OPCAB group and 67% (95% CI: 46.5–80) in the ONCAB group with an overall hazard ratio of 1.1(0.7–1.7; $p = 0.674$). The readmission rates for cardiac reasons were 50.4% (95% CI: 35.8–61.7) in the OPCAB group and 52% (95% CI: 35–64.3) in the ONCAB group with an overall hazard ratio of 0.96 (0.6–1.6; $p = 0.874$) (Figure 4).

Regarding renal disease (failure or dialysis), the cumulative rates were 45.6% (95% CI: 21.8–62.2) in the OPCAB group and 36.8% (95% CI: 16.6–52.2) in the ONCAB group with an overall hazard ratio of 1.3 (95% CI: 0.7–2.5; $p = 0.795$) (Figure 4).

4. Discussion

The present study aimed to compare the outcomes of ONCAB and OPCAB surgeries in patients with reduced EF (≤35%). The analysis included a well-matched cohort of 54 ONCAB and 137 OPCAB patients with similar baseline characteristics that include patients' age, BMI, sex, comorbidities, previous myocardial infarction, or history of heart failure. Most of our patients in both groups had multivessel disease. Operative features showed that the OPCAB group used fewer number of grafts. In the context of grafting, our surgical team prioritizes the use of high-quality arterial grafts over their quantity. Low EF patients typically experience significant collateral damage, and our philosophy

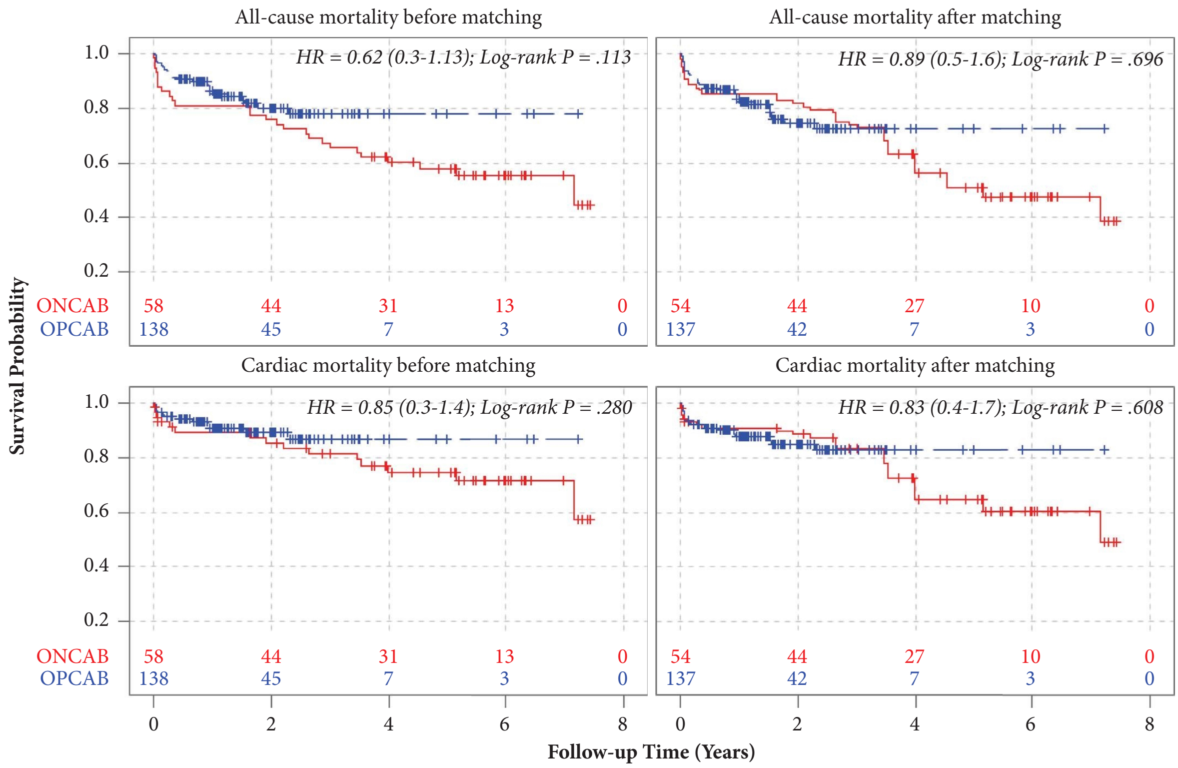

FIGURE 3: Kaplan–Meier survival curves were plotted to compare the mortality outcomes between OPCAB and ONCAB, incorporating hazard ratio (HR) and log-rank statistics for both procedures prior to and following the application of stabilized weighted matching. The figures also include the count of patients at risk for each procedure at various time points.

holds that, in this context, one IMA is better than two veins. This is evident in the comparable long-term outcomes observed between the two cohorts, despite the lower graft count in the OPCAB group. Further, the OPCAB group demonstrated a higher utilization of bilateral and skeletonized IMAs. It is noteworthy, at the beginning of this discussion, that these discrepancies may be reflective of the surgical team's philosophy rather than a generalized approach. The rates of cardiogenic shock cases were comparable between the two groups.

Regarding short-term postoperative outcomes, the 30-day mortality rate was significantly lower in the OPCAB group compared to the ONCAB group. However, after matching, the rates of 30-day mortality and 30-day cardiac mortality were similar between the two groups. A recent research work found no significant difference in short-term mortality between the two surgical approaches in patients with reduced EF, which aligns with our matched analysis [16]. This suggests that the initial disparity in 30-day mortality may be attributed to differences in baseline characteristics that were subsequently mitigated through matching.

Few other studies further support our findings, demonstrating no significant difference in 30-day mortality between OPCAB and ONCAB groups [6, 11, 20]. This indicates that the surgical approach itself may not significantly impact short-term mortality rates. Instead, other factors such as patient characteristics, surgical expertise, and perioperative care may play a more substantial role.

Furthermore, we found that the rates of 30-day cardiac mortality were similar between the OPCAB and ONCAB groups, with rates of 6.6% and 7.4%, respectively. These results align with other studies [21, 22] that showed no significant difference in 30-day cardiac mortality rates between the two approaches. This consistency in findings across different studies suggests that both OPCAB and ONCAB procedures have comparable efficacy in terms of reducing cardiac mortality within the early postoperative period.

The convergence of 30-day mortality rates between the OPCAB and ONCAB groups after matching aligns with other studies, demonstrating comparable outcomes in case of short-term mortality. The absence of significant differences in 30-day cardiac mortality further supports the notion that both approaches are equally effective in reducing cardiac-related mortality within the early postoperative period. These findings emphasize the safety of performing low EF CABGs by experienced OPCAB teams.

The OPCAB group showed shorter lengths of hospital stay, shorter ICU stay, and a trend towards lower rates of complications such as AKI, stroke, pneumonia, GI complications, and atrial fibrillation. In addition, the OPCAB group showed higher rates of discharge-to-home meaning 10.6% lower rates of discharge to acute care facilities compared to the ONCAB group (Table 2). Notably, sepsis and blood transfusion rates were significantly lower in the OPCAB group. Furthermore, the OPCAB group had a lower

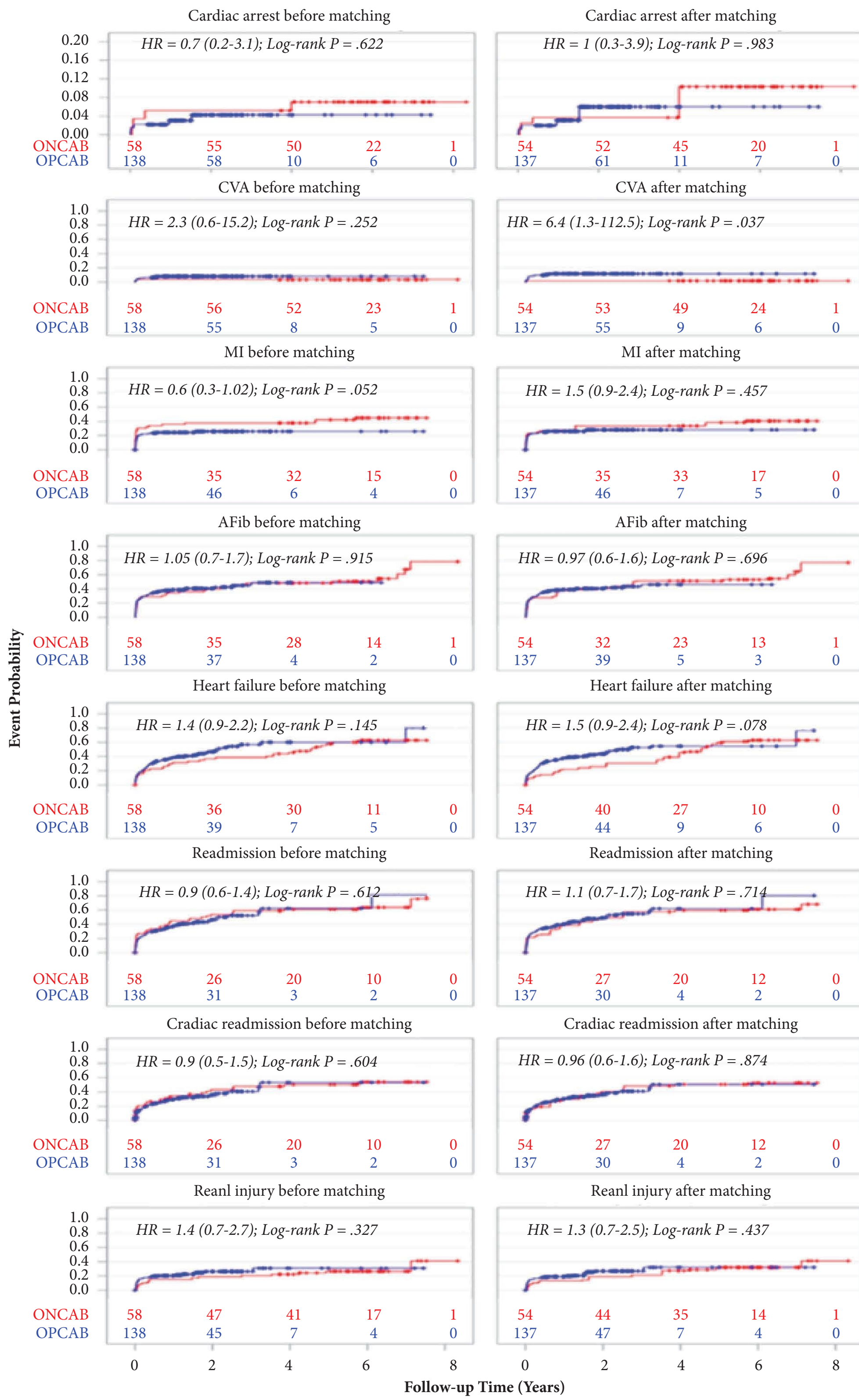

Figure 4: Kaplan–Meier survival curves were plotted to compare the secondary outcomes between OPCAB and ONCAB, incorporating hazard ratio (HR) and log-rank statistics for both procedures prior to and following the application of stabilized weighted matching. For each outcome, the figures also include the count of patients at risk for each procedure at various time points.

incidence of postoperative liver dysfunction. These findings align with the results of a multicenter trial, which reported similar advantages of OPCAB over ONCAB in terms of shorter hospital stays and reduced rates of postoperative complications [23]. Another study reported similar results, highlighting a shorter hospital stay in OPCAB patients compared to ONCAB patients [21]. Although our study showed no statistically significant difference in the median ventilation time between the OPCAB and ONCAB groups, the OPCAB group exhibited about 3 times shorter (~12 hours) stay on the ventilation support (Table 2). However, we observed a significantly shorter median ICU stay in the OPCAB group compared to the ONCAB group. This aligns with the results of other research studies that reported a shorter ICU stay in OPCAB patients [24, 25]. The shorter hospital stays, reduced ICU stay, or a trend of reduced ventilation hours in the OPCAB group may reflect the lower incidence of postoperative complications and faster recovery, leading to a shorter duration of critical care management.

Furthermore, our study found that the rates of acute kidney injury (AKI) were similar between the OPCAB and ONCAB groups. This is consistent with a recent research reported by Phothikun et al. 2023 and by a meta-analysis conducted by Parissis et al., who showed comparable rates of AKI in both groups [26, 27]. However, we observed significantly lower rates of sepsis and postoperative liver dysfunction in the OPCAB group compared to the ONCAB group. These findings are in line with another study that also reported lower rates of sepsis and liver dysfunction in OPCAB patients [28]. The lower incidence of sepsis and liver dysfunction in the OPCAB group may be attributed to the reduced need for blood transfusion and less systemic inflammatory response associated with off-pump surgery.

Regarding mechanical assist devices, a vast majority (94.3% of all devices and 33.8% of all cases) consisted of preoperative IABPs with 9% higher in the OPCAB group. This is worth mentioning here that the OPCAB group had significantly lower preoperative EF. In addition, the higher rate of IABP utilization in the OPCAB procedure is a common phenomenon aimed at preventing hypotension during surgery and avoiding conversion to ONCAB and does not result in extended ICU stay (our conversion rate was <2.2%). Notably, these IABPs were promptly removed in the early postoperative phase. Furthermore, all 8 Impella devices were used postoperatively, 1 in ONCAB and 7 in OPCAB, with 6 of the latter group having IABPs preoperatively.

The study also assessed the impact of the two procedures on the improvement of left ventricular diastolic diameter (LVEDD) and EF. The results showed that both OPCAB and ONCAB surgeries led to significant improvements in postdischarge EF, while the changes in postdischarge LVEDD were not significant. Few studies have examined the impact of OPCAB and ONCAB on left ventricular function, particularly EF. For example, a study conducted by Letsou et al. found a similar improvement but no significant differences in postoperative EF between OPCAB and ONCAB patients [29]. Similarly, Youn et al. reported comparable results in terms of overall left ventricle function after OPCAB and ONCAB procedures [30]. It is important to note that our study and previous literature have shown a significant improvement in postdischarge EF from the presurgical stage in both OPCAB and ONCAB groups. This indicates that regardless of the surgical approach, coronary artery bypass grafting leads to an overall improvement in left ventricular function. The improvement in EF may be attributed to the restoration of blood flow to the ischemic myocardium and reactivation of hibernating myocardium.

In terms of long-term outcomes, the 7-year follow-up revealed that the survival rates and cardiac mortality rates were similar between the OPCAB and ONCAB groups. This finding is consistent with a recent study by Neumann et al., which analyzed long-term outcomes in patients with reduced EF (≤35%) undergoing CABG [16]. They did not find any significant difference in survival rates between ONCAB and OPCAB groups over a 3-year follow-up period. These findings are consistent with several previous studies that have also reported comparable long-term survival rates between OPCAB and ONCAB patients. For instance, a study by Jiang et al. conducted a meta-analysis of randomized controlled trials and found no significant differences in long-term survival between the two groups [11]. Another study by Matkovic et al. reported similar results, supporting the notion that both OPCAB and ONCAB procedures provide comparable long-term (6 years) survival in patients with poor left ventricle function [31]. These findings were in line with another meta-analysis conducted by Zhang et al., which reported similar long-term mortality between the two procedures in patients with redo CABG settings [32]. Furthermore, our analysis of mortality due to cardiac causes also revealed similar rates between the OPCAB and ONCAB groups at 1 year, 3 years, and 7 years. This indicates that the choice of surgical approach does not significantly impact the risk of mortality specifically attributed to cardiac disease. These findings align with previous studies that have consistently shown comparable cardiac mortality rates between OPCAB and ONCAB patients. For example, a study by Youn et al. found no significant difference in cardiac mortality between the two procedures during a long-term follow-up in patients with reduced EF (≤35%) [30]. Similarly, a recent study by Bassano et al. reported similar results, highlighting the equivalent 14-year cardiac mortality outcomes between OPCAB and ONCAB surgeries [33]. Other studies have reported similar findings between the two groups [30, 34–37].

The overall hazard of CVA events was notably higher in OPCAB. Nevertheless, the wide confidence interval of 111.2 indicates that this significance is accompanied by a low precision of the estimate, possibly due to an insufficient sample size and hence a lack of the occurrence of CVA events in the proportional hazard analysis. Importantly, no significant difference in the occurrence of CVA events was observed over a 7-year period between the ONCAB and OPCAB groups in cases involving bilateral IMA with total arterial grafts (log-rank $p = 0.752$). The distinction between single and bilateral IMA, as well as the choice between arterial and venous grafts, may play a crucial role in influencing the occurrence of long-term CVA events. Therefore, this study calls for further assessment of long-term CVA differences between the two procedures particularly focusing on the distinctions between single and bilateral IMA and the choice between venous and arterial grafts. However, there were no significant differences in the rates of cardiac arrest, heart failure, myocardial infarction, atrial fibrillation, renal disease, and overall or cardiac readmission.

From a physiological perspective, the underlying mechanism behind the comparable long-term outcomes can be attributed to the shared goal of revascularization achieved by both on-pump and off-pump CABG procedures. Both techniques aim to restore blood flow to the ischemic myocardium, thereby improving cardiac function and reducing the risk of adverse cardiac events [38, 39].

Overall, the findings of this study suggest that both ONCAB and OPCAB surgeries can be performed safely in patients with reduced EF. Although the short- and long-term mortality was comparable between the two procedures accomplishing the primary objective of successful revascularization of the myocardium and the improvement of overall cardiac function, the OPCAB group showed favorable short-term outcomes with shorter hospital stays, shorter ICU stays, and lower rates of complications such as sepsis, blood transfusion, and postoperative liver dysfunction. These findings are well supported by previous studies that compare the outcomes between the OPCAB and ONCAB procedures in low EF patients [12, 16, 40].

Although our results are comparable with several previous studies and hence may add value to the scientific community in the field, the study has certain limitations. First, it has a retrospective design and has the potential for unmeasured confounders. We believe that stabilized inverse probability treatment weighted matching could mitigate this bias [19]. A randomized controlled trial may be warranted to address the potential confounders and selection bias. Second, further prospective studies with larger sample sizes and longer follow-up periods are warranted to validate these findings and provide more comprehensive insights into the long-term outcomes of CABG surgeries in this high-risk patient population.

In conclusion, our results are consistent with previous studies, indicating similar short- and long-term mortality rates between the two procedures. Furthermore, our study highlights the advantages of OPCAB in terms of shorter hospital stays, reduced postoperative complications, and comparable long-term outcomes. Therefore, the OPCAB is a safer and equally effective option for the low EF CABG patients.

Data Availability

The data that generate the results of this research work are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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