



Off-pump versus On-pump Coronary Artery Bypass Grafting in Patients with Severe Left Ventricular Dysfunction

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Abstract: Background: The comparative effectiveness of off-pump (OPCAB) and on-pump coronary artery bypass grafting (ONCAB) in severe left ventricular dysfunction remains uncertain. Methods: We conducted a retrospective institutional cohort study of isolated CABG procedures performed from 1996 to 2023. Registry-coded severe dysfunction comprised left ventricular ejection fraction below 30% or the legacy category of 21-30%. The primary outcomes were 30-day mortality and long-term all-cause mortality. Propensity-score overlap weighting included calendar year and baseline clinical characteristics. Restricted mean survival and time-stratified models were used because proportional hazards were not satisfied. Results: Of 557 eligible operations with known pump status, 541 had usable survival time (301 ONCAB; 240 OPCAB); 140 deaths occurred. After weighting, all assessed covariates were balanced (maximum absolute standardized mean difference, 0.001). Weighted 30-day mortality was 8.7% after ONCAB and 3.8% after OPCAB (odds ratio 0.42, 95% confidence interval 0.13-1.34; $p=0.144$). Long-term mortality did not differ (hazard ratio 0.96, 95% confidence interval 0.67-1.37; $p=0.819$). Fifteen-year restricted mean survival differed by 0.33 years in favor of OPCAB. The proportional-hazards assumption was violated; neither the 0-5-year nor post-5-year estimate was significant. Conclusions: In this long-running, expertise-based cohort, OPCAB was associated with a numerically lower early mortality rate but no statistically reliable early or long-term advantage after calendar-era and baseline adjustment. The findings support equipoise and careful strategy selection rather than preferential use of either technique.

Keywords: coronary artery bypass grafting, left ventricular dysfunction, off-pump surgery, overlap weighting, survival

INTRODUCTION

Patients with severe left ventricular systolic dysfunction undergoing coronary artery bypass grafting (CABG) have limited myocardial reserve and an increased risk of perioperative death and organ injury [1-4]. Surgical revascularization may nevertheless provide durable symptom relief and survival benefit in appropriately selected patients, making the operative platform clinically important. Off-pump CABG (OPCAB) avoids cardiopulmonary bypass and global cardioplegic arrest, potentially reducing inflammatory activation, haemodilution, bleeding and ischaemia-reperfusion injury [5,6]. Conversely, on-pump CABG (ONCAB) offers a motionless, bloodless field and may facilitate technically complete revascularization. Comparative studies in ventricular dysfunction have reported inconsistent early and late outcomes, and treatment effects are strongly influenced by operator experience, case

selection and surgical era [2,5-8]. The comparative effectiveness of OPCAB and ONCAB in patients with severe left ventricular dysfunction therefore remains uncertain. This study evaluated early morbidity, 30-day mortality and long-term survival using propensity-score overlap weighting that incorporated surgical era and prespecified baseline clinical characteristics. Complementary time-stratified and restricted-mean-survival analyses were planned to provide interpretable estimates if proportional hazards were not satisfied. We hypothesized that outcomes would not materially differ between operative strategies after adjustment for calendar era and baseline case mix.

METHODS

Data Source and Governance

This retrospective cohort study used the prospectively maintained Patient Analysis and Tracking System registry (Dendrite Clinical Systems Ltd, Oxford, United Kingdom). The registry captures demographic, clinical, operative and in-hospital outcome data and contributes to the National Adult Cardiac Surgery Audit. Vital status was cross-checked against institutional records and the NHS Spine. The evaluation was approved through the institutional clinical governance pathway (CIRIS ID 7537; 9 May 2025); individual consent was waived. Reporting follows the STROBE principles [9].

Cohort and Exposure

All isolated CABG operations between January 1996 and September 2023 with registry-coded severe left ventricular dysfunction and known cardiopulmonary-bypass status were eligible. Severe dysfunction included contemporary LVEF categories below 30% and the legacy registry category “21-30%”. ONCAB was defined by recorded use of cardiopulmonary bypass; OPCAB was defined by its absence, including minimally invasive direct coronary artery bypass procedures. Of 558 potentially eligible records, one lacked pump status. Sixteen further records lacked a usable time-to-event interval and were excluded from outcome analyses, leaving 541 patients (Table 1).

Outcomes

The primary outcomes were all-cause mortality within 30 days and long-term all-cause mortality. Survival time was determined from the registry event indicator, updated death date, in-hospital death date and administrative follow-up date, using a prespecified hierarchy. Secondary in-hospital outcomes were reoperation for bleeding or tamponade, stroke, new renal replacement therapy and deep sternal wound infection. Cohort derivation, outcome coding and missing-data handling are summarized in Table 1.

Statistical Analysis

Continuous variables are summarized as mean $\pm$ standard deviation or median (interquartile range), and categorical variables as number (percentage). Unadjusted operative characteristics were compared using Welch’s t test for continuous variables and Fisher’s exact test for categorical variables. A propensity score for OPCAB was estimated from age,

sex, body mass index, smoking, New York Heart Association class, heart-failure status, previous myocardial infarction, previous cardiac surgery, diabetes, hypercholesterolaemia, hypertension, severe chronic kidney disease, dialysis, pulmonary disease, cerebrovascular disease, peripheral vascular disease, arrhythmia, coronary-disease extent, left-main disease, operative urgency and calendar year. Continuous missing values were median-imputed with missingness indicators; categorical missingness was retained explicitly.

Overlap weights were 1-propensity score for OPCAB and the propensity score for ONCAB, targeting patients with clinical equipoise and limiting the influence of extreme scores [10,11]. Balance was assessed with absolute standardized mean differences (SMDs), with <0.10 considered acceptable. Operative features were treated as descriptive post-exposure characteristics and were not included in the propensity model. Weighted generalized linear models with robust variance estimated binary-outcome odds ratios. Weighted Kaplan-Meier curves and a robust weighted Cox model evaluated long-term mortality. The proportional-hazards assumption was tested with scaled Schoenfeld residuals [12]. Because it was violated, prespecified supportive summaries included 0-5-year and post-5-year Cox models and 15-year restricted mean survival time [13]. Analyses used Python 3.12.13 (Python Software Foundation, Wilmington, Delaware, USA), pandas 2.3.3, scikit-learn 1.9.0, stats models 0.15.0 and lifelines 0.30.3. Two-sided $p < 0.05$ denoted statistical significance.

RESULTS

Cohort and Balance

A total of 557 eligible operations had known operative strategy (313 ONCAB and 244 OPCAB). Survival time was usable for 541 (301 ONCAB and 240 OPCAB), among whom 140 deaths occurred (Table 1). OPCAB was performed later on average (2009.4 vs 2007.6) and the largest unweighted absolute SMD was 0.246. Overlap weighting produced near-identical covariate distributions; the maximum assessed absolute SMD was 0.001 (Table 2 and Figure 1).

Table 1: Cohort derivation, outcome hierarchy and missing-data handling

Item	Result or rule
Potentially eligible severe-LV-dysfunction CABG records	558
Excluded: cardiopulmonary-bypass status missing	1
Eligible after exposure ascertainment	557 (313 ONCAB; 244 OPCAB)
Excluded from outcome analysis: unusable time-to-event interval	16
Primary analytic cohort	541 (301 ONCAB; 240 OPCAB)
Deaths during follow-up	140 (78 ONCAB; 62 OPCAB)
Mortality ascertainment hierarchy	Registry event flag; updated death date; in-hospital death date; administrative follow-up date
Continuous missing covariates	Median imputation plus missingness indicator
Categorical missing covariates	Explicit missing category

CABG, coronary artery bypass grafting; LV, left ventricular; ONCAB, on-pump CABG; OPCAB, off-pump CABG.

Table 2: Baseline characteristics before and after overlap weighting

Variable	ONCAB raw	OPCAB raw	SMD	ONCAB weighted	OPCAB weighted	SMD
Age, years	64.9	66.0	0.106	65.4	65.4	0.001
Body mass index, kg/m ²	27.4	27.2	0.048	27.2	27.2	0.000
Year of surgery	2007.6	2009.4	0.246	2009.3	2009.3	0.000
Female sex	12.6%	10.4%	0.069	10.9%	10.9%	0.000
Previous cardiac surgery	5.6%	4.2%	0.069	4.8%	4.8%	0.001
Diabetes	41.9%	39.6%	0.046	42.1%	42.1%	0.000
Hypercholesterolaemia	72.1%	74.2%	0.047	73.3%	73.3%	0.000
Hypertension	71.1%	75.4%	0.098	73.8%	73.8%	0.000
Severe CKD	7.6%	7.5%	0.005	8.2%	8.2%	0.001
Dialysis	0.3%	0.4%	0.014	0.5%	0.5%	0.000
Pulmonary disease	14.0%	12.9%	0.030	13.7%	13.8%	0.000
Cerebrovascular disease	5.0%	6.2%	0.055	6.7%	6.7%	0.001
Peripheral vascular disease	14.3%	16.2%	0.055	16.7%	16.7%	0.000
Preoperative arrhythmia	10.6%	14.6%	0.119	12.0%	12.0%	0.000
Left-main disease	28.6%	26.2%	0.052	27.3%	27.3%	0.000

Binary variables are shown as percentages; continuous variables as means. CKD, chronic kidney disease; ONCAB, on-pump CABG; OPCAB, off-pump CABG; SMD, standardized mean difference.

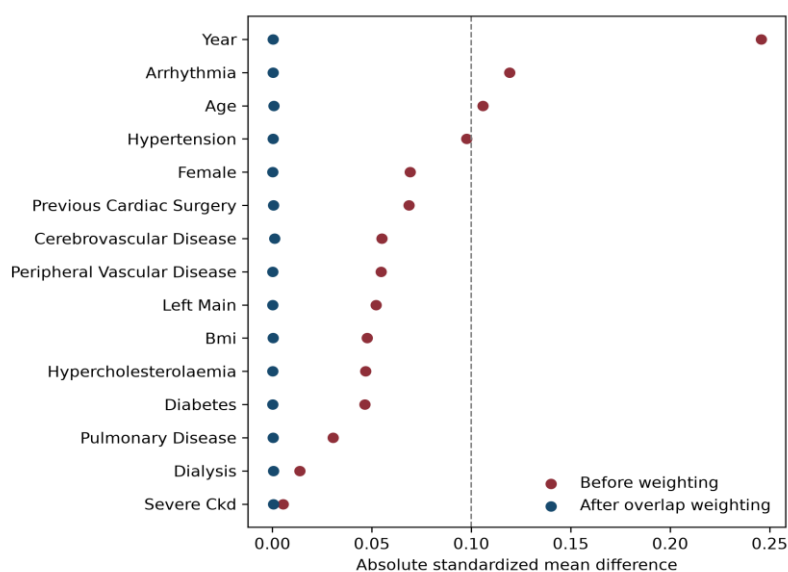


Figure 1: Covariate balance before and after propensity-score overlap weighting. The dashed line denotes an absolute standardized mean difference of 0.10.

Operative Characteristics

ONCAB patients received more distal anastomoses than OPCAB patients (3.0 ± 0.7 vs 2.6 ± 0.8 ; $p < 0.001$). Multiple arterial grafting occurred in 15.0% and 17.5%, respectively ($p = 0.480$), whereas total arterial grafting was more frequent with OPCAB (16.7% vs 6.0%; $p < 0.001$) (Table 3). These variables describe how each strategy was delivered and were not used as baseline confounders.

Table 3: Operative characteristics

Characteristic	ONCAB (n=301)	OPCAB (n=240)	p value
Distal anastomoses	3.0±0.7	2.6±0.8	<0.001
Multiple arterial grafting	45 (15.0%)	42 (17.5%)	0.480
Total arterial grafting	18 (6.0%)	40 (16.7%)	<0.001

P values were calculated using Welch's t test for distal anastomoses and Fisher's exact test for categorical variables. Operative variables are descriptive and were not included in the propensity model because they occur after treatment assignment. ONCAB, on-pump CABG; OPCAB, off-pump CABG.

Early Outcomes

In the overlap-weighted population, estimated 30-day mortality was 8.7% after ONCAB and 3.8% after OPCAB. The corresponding odds ratio favored OPCAB but was imprecise and not statistically significant (OR 0.42, 95% CI 0.13-1.34; p=0.144). Reoperation for bleeding was also numerically less frequent after OPCAB (2.2% vs 4.8%; OR 0.45, 95% CI 0.10-2.07; p=0.307). Renal replacement therapy and deep sternal wound infection did not differ materially (Table 4). Sparse events precluded stable adjusted estimation for stroke.

Table 4: Overlap-weighted early outcomes

Outcome	ONCAB	OPCAB	Odds ratio (95% CI)	p value
30-day mortality	8.7%	3.8%	0.42 (0.13-1.34)	0.144
Reoperation for bleeding	4.8%	2.2%	0.45 (0.10-2.07)	0.307
New renal replacement therapy	10.9%	9.9%	0.90 (0.38-2.11)	0.802
Deep sternal wound infection	1.0%	0.6%	0.66 (0.03-13.25)	0.783

Odds ratios compare OPCAB with ONCAB. CI, confidence interval.

Long-term Survival

Weighted survival probabilities were similar between groups: at 5, 10, 15 and 20 years they were 80.2%, 74.1%, 72.4% and 69.5% after ONCAB and 83.3%, 75.2%, 71.5% and 70.9% after OPCAB (Table 5 and Figure 2).

Table 5: Overlap-weighted survival estimates.

Time after CABG	ONCAB survival	OPCAB survival
5	80.2%	83.3%
10	74.1%	75.2%
15	72.4%	71.5%
20	69.5%	70.9%

CABG, coronary artery bypass grafting. ONCAB, on-pump coronary artery bypass; OPCAB, off-pump coronary artery bypass

The overall weighted Cox estimate was HR 0.96 (95% CI 0.67-1.37; p=0.819). A conventional multivariable model including calendar year produced a consistent estimate

(HR 0.89, 95% CI 0.65-1.23; $p=0.479$). The proportional-hazards assumption was rejected ($p<0.001$). Time-stratified estimates did not demonstrate a significant difference during 0-5 years (HR 0.79, 95% CI 0.51-1.23; $p=0.305$) or after 5 years (HR 1.43, 95% CI 0.76-2.71; $p=0.268$). Fifteen-year restricted mean survival was 11.74 years after ONCAB and 12.07 years after OPCAB, an adjusted difference of 0.33 years (Table 6).

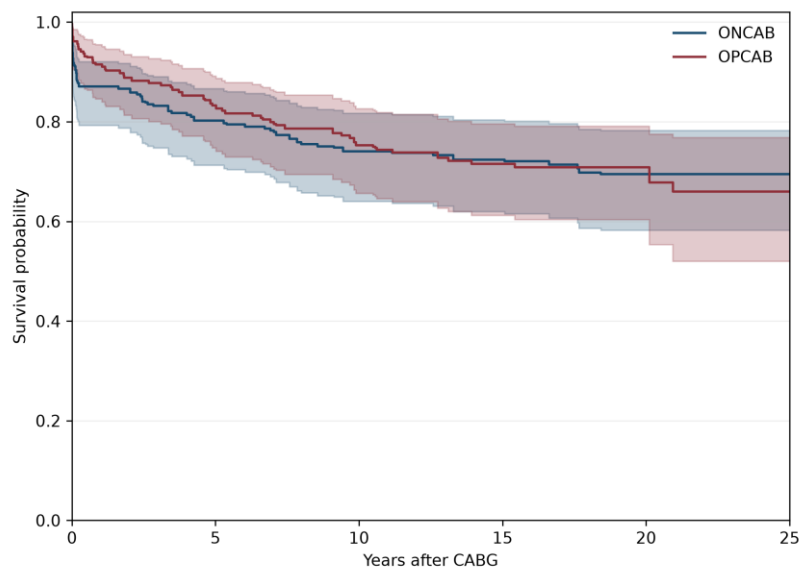


Figure 2: Overlap-weighted Kaplan-Meier survival curves comparing on-pump and off-pump coronary artery bypass grafting.

Table 6: Long-term survival sensitivity analyses

Analysis	Estimate	95% CI / contrast	p value
Overlap-weighted Cox model	0.96	0.67-1.37	0.819
Conventional multivariable Cox model	0.89	0.65-1.23	0.479
0-5-year weighted Cox model	0.79	0.51-1.23	0.305
After-5-year weighted Cox model	1.43	0.76-2.71	0.268
Schoenfeld proportional-hazards test	—	—	<0.001
15-year restricted mean survival difference	0.33 years	OPCAB minus ONCAB	—

Hazard ratios compare OPCAB with ONCAB. The conventional model adjusted for age, sex, calendar year, diabetes, hypertension, severe chronic kidney disease, previous cardiac surgery, pulmonary disease, cerebrovascular disease, peripheral vascular disease and left-main disease. CI, confidence interval; ONCAB, on-pump CABG; OPCAB, off-pump CABG.

DISCUSSION

The principal finding is that OPCAB was associated with a clinically notable but statistically uncertain reduction in 30-day mortality, while adjusted long-term survival was closely similar between operative strategies. The restricted-mean difference of approximately four

months over 15 years was modest, and confidence intervals around the strategy effects remained wide. These results do not demonstrate a statistically reliable early or durable survival advantage for either approach.

These findings are consistent with the heterogeneous published literature. Marin-Cuartas and colleagues reported that OPCAB could be performed safely in severe ventricular dysfunction, but comparative long-term advantages have varied across cohorts [5]. Wang and colleagues similarly found broadly comparable longer-term outcomes in severe dysfunction despite differences in early morbidity [2]. Meta-analytic evidence suggests that OPCAB may reduce selected short-term complications in left ventricular dysfunction, although certainty is limited by observational designs, inconsistent definitions and operator dependence [7]. The early numerical advantage remains biologically plausible. Avoidance of cardiopulmonary bypass may attenuate systemic inflammation, haemodilution and myocardial ischaemia-reperfusion injury [6]. It may also reduce bleeding in patients with marginal organ reserve. Nevertheless, the present confidence intervals include both important benefit and limited or no benefit. These results therefore do not justify a claim that OPCAB is the preferred platform for all patients with LVEF below 30%.

Calendar era was a particularly important confounder. OPCAB patients underwent surgery approximately two years later on average, across a 27-year interval during which perioperative care, secondary prevention, revascularization practice and survival ascertainment evolved. Adjustment for year was therefore necessary to distinguish operative-strategy associations from secular improvements in care. Bypass and cross-clamp times exist only within ONCAB and occur after treatment assignment, so they were not included in models comparing operative strategies. Conduit choice and graft number were similarly reported descriptively rather than treated as baseline confounders.

The non-proportional hazards finding also matters. A single Cox hazard ratio assumes a constant relative hazard over follow-up and can obscure changing associations. Here, the direction of the point estimate differed before and after five years, although neither interval-specific estimate was significant. Agreement between adjusted survival probabilities, restricted mean survival and the calendar-adjusted sensitivity model strengthens the conclusion that no durable strategy advantage was demonstrated.

Strengths and Limitations

Strengths include long follow-up, explicit calendar-era adjustment, excellent overlap-weighted balance and complementary estimands when proportional hazards failed. The analysis also separates baseline confounding control from operative characteristics that may lie on the causal pathway. Important limitations remain. This was a retrospective single-centre study, operative strategy was strongly linked to surgeon expertise, and surgeon identity was unavailable in the dataset; treatment and operator effects therefore cannot be separated. LVEF coding changed over time and a legacy 21-30% category does not map perfectly to a strict <30% threshold. Sixteen records lacked usable survival time. Registry definitions and missingness varied by era, postoperative ventricular recovery, graft patency, cause-specific mortality and quality of life were unavailable, and sparse early events limited precision. Residual and unmeasured confounding remain possible despite balance in measured variables.

Clinical Implications

For centres with established expertise, OPCAB remains a reasonable option for selected patients with severe left ventricular dysfunction, particularly when avoidance of cardiopulmonary bypass is judged advantageous. A severely reduced ejection fraction alone should not be regarded as a contraindication; suitability depends more importantly on ventricular geometry, residual myocardial reserve, coronary distribution, right-heart function and haemodynamic stability.

Within this population, features suggesting poor tolerance of OPCAB include a markedly dilated or spherical left ventricle, extensive akinetic or dyskinetic myocardium, a large ventricular aneurysm, restrictive filling physiology, low forward stroke volume, severe functional mitral regurgitation, significant right ventricular dysfunction and pulmonary hypertension. These abnormalities reduce the capacity to maintain cardiac output when the heart is elevated or rotated for grafting of the lateral and inferior walls. The combination of severe biventricular dysfunction, high filling pressures and low baseline cardiac output is particularly concerning because relatively modest reductions in venous return during cardiac displacement may precipitate profound hypotension.

Coronary anatomy should be considered in relation to the amount and location of viable myocardium at risk. Critical left-main or proximal multivessel disease supplying a large area of viable but jeopardised myocardium, limited collateral circulation, or dependence on a dominant circumflex or right coronary system may increase susceptibility to ischaemia during temporary target-vessel occlusion. Similarly, a revascularisation plan requiring multiple grafts to the circumflex and posterior descending territories may necessitate repeated or prolonged cardiac displacement that is poorly tolerated by a severely remodelled ventricle. Extensive scar with little demonstrable viability may also alter the expected benefit of complex revascularisation, although this concerns the indication for CABG itself rather than selection of the pump strategy. ONCAB may therefore be preferable when preoperative echocardiography demonstrates severe biventricular failure, advanced adverse remodelling, restrictive physiology, severe secondary mitral regurgitation or pulmonary hypertension, particularly when these findings coexist with low cardiac output or extensive jeopardised myocardium. Intraoperative inability to maintain arterial pressure, cardiac output or acceptable filling pressures during positioning should prompt early institution of cardiopulmonary bypass rather than persistence with OPCAB at the expense of patient safety or completeness of revascularisation. Strategy should be individualized according to ventricular geometry, myocardial viability, coronary territory, right-heart function, haemodynamic reserve, conduit plan, and operator expertise. Prospective multicentre studies should characterize these anatomical and echocardiographic phenotypes, assess completeness and quality of revascularisation, account for surgeon experience, and report restricted-mean as well as hazard-based survival summaries.

CONCLUSION

After adjustment for calendar era and baseline case mix, OPCAB was associated with numerically lower 30-day mortality but no statistically reliable early or long-term advantage over ONCAB in patients with severe left ventricular dysfunction. These data support clinical equipoise and individualized selection rather than routine preference for either strategy.

DECLARATIONS

Acknowledgements: The authors acknowledge the contributions of the Cardiac Outcomes Research Group and Initiative (CORGI).

Funding: No funding was received for this study.

Conflicts of interest: The authors declare no financial or non-financial competing interests.

Data availability: The patient-level registry data contain confidential clinical information and are not publicly available. De-identified analytic code and aggregate results may be made available on reasonable request, subject to institutional governance approval.

Author contributions: Man King Newman Lau: data curation, formal analysis, investigation, visualization, writing—original draft. Maria Comanici: investigation, resources, project administration, writing—review and editing. Sunil K. Bhudia: supervision, writing—review and editing. Nandor Marczin: supervision, writing—review and editing. Shahzad G. Raja: conceptualization, methodology, project administration, supervision, writing—review and editing. All authors approved the final manuscript.

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