

ON-PUMP VERSUS OFF-PUMP CORONARY ARTERY BYPASS GRAFTING: A COMPARISON OF EARLY NEUROLOGICAL OUTCOMES AND PERIOPERATIVE MYOCARDIAL INJURY IN A SINGLE TERTIARY CENTRE

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Abstract

Background: Cardiopulmonary bypass (CPB) is implicated in the systemic inflammatory response, cerebral microembolisation and myocardial reperfusion injury associated with coronary artery bypass grafting (CABG). Off-pump CABG (OPCAB) was developed to attenuate these insults, but whether it confers measurable early neurological or myocardial protection remains debated. We compared early neurological outcomes and perioperative myocardial injury between on-pump (ONCAB) and off-pump CABG at a single tertiary centre. **Materials and Methods:** Seventy-six consecutive patients undergoing isolated CABG were analysed (ONCAB n=40; OPCAB n=36). Co-primary outcomes were early neurological events (stroke, transient ischaemic attack, postoperative delirium assessed by CAM-ICU, early postoperative cognitive dysfunction [POCD] defined as a Mini-Mental State Examination [MMSE] fall of ≥ 2 points at discharge, and seizure) and perioperative myocardial injury (peak cardiac troponin I and CK-MB within 48 hours, and perioperative myocardial infarction [MI]). Continuous variables were compared with the Student t or Mann-Whitney U test and categorical variables with the chi-square or Fisher exact test; $p < 0.05$ was significant. **Results:** The groups were comparable in age, sex, comorbidity burden, left ventricular function and EuroSCORE II (all $p > 0.05$). Perioperative myocardial injury was significantly greater after ONCAB: peak troponin I 5.02 ± 2.91 versus 3.21 ± 1.44 ng/mL ($p < 0.001$) and peak CK-MB 35.3 ± 10.5 versus 25.9 ± 10.2 ng/mL ($p < 0.001$); perioperative MI occurred in 20.0% versus 5.6% ($p = 0.091$). Early neurological events were numerically more frequent after ONCAB (composite 55.0% versus 38.9%, $p = 0.160$), but no individual neurological endpoint reached statistical significance, including stroke (2.5% versus 0%), delirium (20.0% versus 19.4%) and POCD (32.5% versus 19.4%). ONCAB was associated with longer ventilation time and greater transfusion requirement (both $p < 0.05$). Thirty-day mortality did not differ (5.0% versus 2.8%). **Conclusions:** In this single-centre cohort, off-pump CABG was associated with significantly less biochemical myocardial injury and a lower transfusion and ventilation burden, while early neurological events were numerically but not significantly less frequent. The study was underpowered for low-incidence hard endpoints such as stroke, and the neurological signal should be interpreted as hypothesis-generating.

INTRODUCTION

Coronary artery bypass grafting (CABG) remains the standard of care for patients with extensive multivessel and left main coronary artery disease. The conventional technique employs cardiopulmonary bypass (CPB) with a cross-clamped, cardioplegically arrested heart, which

provides a still and bloodless operative field but exposes the patient to the systemic inflammatory response of extracorporeal circulation, aortic manipulation and myocardial ischaemia-reperfusion. Off-pump coronary artery bypass (OPCAB), performed on the beating heart without CPB, was popularised to avoid these insults, and after three

decades of investigation the relative merits of the two strategies continue to be debated.^[1]

Neurological injury is among the most feared complications of cardiac surgery and ranges from overt stroke to the more frequent but subtler entities of postoperative delirium and early postoperative cognitive dysfunction (POCD).^[2,3] CPB-related cerebral microembolisation, aortic atheroembolism during cannulation and cross-clamping, hypoperfusion and a systemic inflammatory milieu have all been implicated, providing a mechanistic rationale for the hypothesis that avoidance of CPB might reduce early neurological morbidity.^[3]

The large randomised trials, however, have not consistently confirmed this expectation. The ROOBY, CORONARY and GOPCABE trials each found no significant difference in the 30-day composite of death, stroke, myocardial infarction or renal failure between the techniques, and the 5-year CORONARY results showed equivalent late composite outcomes.^[4,5,6,7] A contemporary meta-analysis of randomised trials reported that off-pump surgery modestly reduces the incidence of early stroke (1.27% versus 1.78%) but is associated with more mid-term repeat revascularisation and a small excess of long-term mortality, while in octogenarians off-pump grafting appears to lower early stroke more clearly.^[8,9,10] Pooled neurocognitive data have likewise failed to demonstrate a durable advantage for either technique.^[11]

In contrast, the biochemical evidence of myocardial protection with off-pump surgery is more consistent. Studies measuring serial cardiac troponin and creatine kinase-MB (CK-MB) release have generally reported lower peak concentrations after off-pump grafting, reflecting the avoidance of global ischaemia-reperfusion during aortic cross-clamping.^[12,13] The clinical translation of this attenuated biochemical injury, and its relationship to early neurological outcomes, has been incompletely characterised in single-centre series from the Indian subcontinent.

We therefore conducted this comparative study at a single tertiary centre to evaluate, between on-pump and off-pump CABG, the co-primary domains of early neurological outcomes and perioperative myocardial injury, together with relevant secondary perioperative outcomes.

MATERIALS AND METHODS

Study design and population. This was a comparative analysis of 76 consecutive patients undergoing isolated, first-time CABG at the Institute of Medical Sciences, Banaras Hindu University (IMS-BHU), Varanasi. Patients undergoing concomitant valve or aortic procedures, emergency or redo surgery, or preoperative mechanical circulatory support were excluded. The choice between on-pump and off-pump technique was made by the operating surgeon on the basis of coronary anatomy, target-vessel quality, aortic atheroma burden and haemodynamic

status. Forty patients underwent on-pump CABG (ONCAB) and 36 underwent off-pump CABG (OPCAB).

Operative technique. All operations were performed through a median sternotomy using internal thoracic and saphenous vein conduits. On-pump procedures used moderate systemic hypothermia, ascending aortic and two-stage venous cannulation, and intermittent antegrade cold blood cardioplegia with aortic cross-clamping. Off-pump procedures were performed on the beating heart with epicardial stabilisation and intracoronary shunts, with proximal anastomoses constructed using a partial-occlusion clamp or a clampless facilitating device where the aorta was suitable.

Neurological assessment. Stroke was defined as a new focal neurological deficit persisting beyond 24 hours with confirmatory imaging, and transient ischaemic attack as a deficit resolving within 24 hours. Postoperative delirium was screened twice daily in the intensive care unit using the Confusion Assessment Method for the ICU (CAM-ICU). Cognitive function was assessed with the Mini-Mental State Examination (MMSE) preoperatively and at discharge; early POCD was defined as a fall of ≥ 2 points from the preoperative score. Seizures were recorded clinically.

Myocardial injury assessment. Cardiac troponin I and CK-MB were measured preoperatively and serially at 6, 12, 24 and 48 hours postoperatively, and the peak value within 48 hours was used for analysis. Perioperative myocardial infarction was defined in accordance with contemporary consensus criteria by a substantial rise in cardiac biomarkers accompanied by new pathological Q waves, new left bundle-branch block, or imaging evidence of new loss of viable myocardium. Low cardiac output syndrome was defined as the need for inotropic support or mechanical assistance to maintain adequate perfusion beyond 24 hours.

Statistical analysis. Continuous variables are presented as mean \pm standard deviation and were compared using the Student t test when normally distributed (Shapiro-Wilk $p > 0.05$) or the Mann-Whitney U test otherwise. Categorical variables are presented as number (percentage) and were compared using the Pearson chi-square test, or the Fisher exact test when any expected cell count was below five. A two-sided p value below 0.05 was considered statistically significant. Analyses were performed in Python 3 (NumPy, SciPy and pandas).

RESULTS

Baseline characteristics. The two groups were well matched (Table 1). There were no statistically significant differences in age (58.7 ± 7.3 versus 61.5 ± 7.6 years, $p = 0.105$), sex distribution, body mass index, prevalence of diabetes, hypertension, smoking, chronic obstructive pulmonary disease, previous myocardial infarction, carotid disease, prior

cerebrovascular events, left ventricular ejection fraction, extent of coronary disease, EuroSCORE II or baseline creatinine (all $p > 0.05$), indicating comparable baseline operative risk.

Operative data. The mean number of distal anastomoses was similar between groups (3.1 ± 0.6 versus 2.9 ± 0.7 , $p = 0.148$), as was total operative time ($p = 0.779$). In the on-pump group the mean cardiopulmonary bypass time was 102.1 ± 20.2 minutes and the mean aortic cross-clamp time was 61.4 ± 9.5 minutes (Table 2).

Perioperative myocardial injury. The on-pump group sustained significantly greater myocardial injury (Table 3). Peak cardiac troponin I was almost 60% higher after on-pump surgery (5.02 ± 2.91 versus 3.21 ± 1.44 ng/mL, $p < 0.001$), and peak CK-MB was correspondingly elevated (35.3 ± 10.5 versus 25.9 ± 10.2 ng/mL, $p < 0.001$). Perioperative myocardial infarction was diagnosed in 8 on-pump patients (20.0%) compared with 2 off-pump patients (5.6%), a difference that approached but did not reach significance ($p = 0.091$). Low cardiac output syndrome followed a similar non-significant trend (12.5% versus 5.6%, $p = 0.435$).

Early neurological outcomes. Early neurological events were numerically more frequent after on-pump surgery but none reached statistical significance (Table 4). Stroke occurred in 1 on-pump patient (2.5%) and no off-pump patient ($p = 1.000$), and transient ischaemic attack in 7.5% versus 5.6% ($p = 1.000$). Postoperative delirium was almost identical between groups (20.0% versus 19.4%, $p = 0.952$), whereas early POCD was more common after on-pump surgery (32.5% versus 19.4%, $p = 0.197$). Seizures occurred only in the on-pump group (10.0% versus 0%, $p = 0.117$). The composite of any early neurological event occurred in 55.0% of on-pump versus 38.9% of off-pump patients ($p = 0.160$), and the mean MMSE score at discharge did not differ significantly (26.6 ± 1.6 versus 26.9 ± 2.0 , $p = 0.391$).

Secondary outcomes. On-pump surgery was associated with significantly longer mechanical ventilation ($p = 0.031$) and greater red-cell transfusion requirements ($p = 0.017$) (Table 5). New-onset atrial fibrillation (25.0% versus 11.1%, $p = 0.119$), acute kidney injury, re-exploration for bleeding, intensive care and total hospital stay, and 30-day mortality (5.0% versus 2.8%, $p = 1.000$) did not differ significantly between groups.

Table 1: Baseline and preoperative characteristics

Variable	On-pump (n=40)	Off-pump (n=36)	Test	p value
Age (years)	58.7 ± 7.3	61.5 ± 7.6	Student t	0.105
Male sex	34 (85.0)	28 (77.8)	Chi-square	0.417
BMI (kg/m ²)	25.8 ± 3.2	25.6 ± 3.4	Student t	0.805
Diabetes mellitus	20 (50.0)	19 (52.8)	Chi-square	0.809
Hypertension	27 (67.5)	17 (47.2)	Chi-square	0.074
Dyslipidaemia	17 (42.5)	23 (63.9)	Chi-square	0.062
Current/recent smoker	19 (47.5)	11 (30.6)	Chi-square	0.131
COPD	8 (20.0)	4 (11.1)	Chi-square	0.289
Previous myocardial infarction	13 (32.5)	11 (30.6)	Chi-square	0.856
Carotid disease (>50%)	6 (15.0)	8 (22.2)	Chi-square	0.417
Prior stroke/TIA	5 (12.5)	2 (5.6)	Fisher	0.435
LVEF (%)	50.1 ± 9.7	52.9 ± 8.3	Student t	0.190
Triple-vessel disease	31 (77.5)	29 (80.6)	Chi-square	0.744
EuroSCORE II (%)	2.01 ± 1.13	2.35 ± 1.46	Mann-Whitney	0.399
Baseline creatinine (mg/dL)	1.03 ± 0.23	0.97 ± 0.22	Student t	0.231

Values are mean \pm SD or n (%). BMI, body mass index; COPD, chronic obstructive pulmonary disease; LVEF, left ventricular ejection fraction; TIA, transient ischaemic attack.

Table 2: Operative variables

Variable	On-pump (n=40)	Off-pump (n=36)	Test	p value
Number of distal grafts	3.1 ± 0.6	2.9 ± 0.7	Mann-Whitney	0.148
Total operative time (min)	261.5 ± 29.9	263.9 ± 42.8	Student t	0.779

Values are mean \pm SD. Cardiopulmonary bypass time (102.1 ± 20.2 min) and aortic cross-clamp time (61.4 ± 9.5 min) apply to the on-pump group only and were not applicable to off-pump patients.

Table 3: Perioperative myocardial injury (co-primary outcome)

Variable	On-pump (n=40)	Off-pump (n=36)	Test	p value
Peak troponin I (ng/mL)	5.02 ± 2.91	3.21 ± 1.44	Mann-Whitney	<0.001
Peak CK-MB (ng/mL)	35.3 ± 10.5	25.9 ± 10.2	Student t	<0.001
Perioperative MI	8 (20.0)	2 (5.6)	Fisher	0.091
Low cardiac output syndrome	5 (12.5)	2 (5.6)	Fisher	0.435

Values are mean \pm SD or n (%). CK-MB, creatine kinase-MB; MI, myocardial infarction. Peak biomarker values are the highest concentration recorded within 48 hours of surgery.

Table 4: Early neurological outcomes (co-primary outcome)

Variable	On-pump (n=40)	Off-pump (n=36)	Test	p value
Stroke	1 (2.5)	0 (0.0)	Fisher	1.000
Transient ischaemic attack	3 (7.5)	2 (5.6)	Fisher	1.000
Postoperative delirium	8 (20.0)	7 (19.4)	Chi-square	0.952
Early POCD (MMSE drop >=2)	13 (32.5)	7 (19.4)	Chi-square	0.197
Seizure	4 (10.0)	0 (0.0)	Fisher	0.117
MMSE at discharge	26.6 ± 1.6	26.9 ± 2.0	Mann-Whitney	0.391
Composite neurological event	22 (55.0)	14 (38.9)	Chi-square	0.160

Values are mean ± SD or n (%). POCD, postoperative cognitive dysfunction; MMSE, Mini-Mental State Examination. The composite endpoint includes stroke, transient ischaemic attack, delirium, POCD or seizure.

Table 5: Secondary perioperative outcomes

Variable	On-pump (n=40)	Off-pump (n=36)	Test	p value
Ventilation time (h)	9.8 ± 5.9	7.3 ± 3.7	Mann-Whitney	0.031
New-onset atrial fibrillation	10 (25.0)	4 (11.1)	Chi-square	0.119
Acute kidney injury	7 (17.5)	6 (16.7)	Chi-square	0.923
Re-exploration for bleeding	1 (2.5)	2 (5.6)	Fisher	0.601
RBC transfusion (units)	1.9 ± 1.3	1.2 ± 1.1	Mann-Whitney	0.017
ICU stay (days)	3.0 ± 1.2	2.9 ± 0.8	Mann-Whitney	0.803
Hospital stay (days)	9.9 ± 3.0	8.7 ± 2.0	Mann-Whitney	0.101
30-day mortality	2 (5.0)	1 (2.8)	Fisher	1.000

DISCUSSION

In this single-centre comparison of 76 patients undergoing isolated CABG, off-pump surgery was associated with a clear and statistically significant reduction in biochemical myocardial injury, evidenced by substantially lower peak troponin I and CK-MB concentrations, together with a strong trend towards fewer perioperative myocardial infarctions. Early neurological events were numerically less frequent after off-pump surgery, but no individual neurological endpoint reached statistical significance. These findings are internally coherent and are consistent with the prevailing balance of evidence in the literature.

The myocardial findings reinforce a relatively consistent body of work. Avoidance of aortic cross-clamping and global cardioplegic arrest spares the myocardium the ischaemia-reperfusion cycle that drives troponin and CK-MB release, and several studies have reported lower biomarker peaks after off-pump grafting.^[12,13] In our cohort the magnitude of the troponin difference was considerable, which is biologically plausible given that the on-pump group experienced a mean cross-clamp time of approximately one hour. Whether this attenuated biochemical injury translates into improved long-term ventricular function or survival remains uncertain, and the large randomised trials have not demonstrated a corresponding survival advantage.^[5,7] Our neurological results mirror the central tension in this field. Mechanistically, off-pump surgery should reduce cerebral microembolic load, and registry and meta-analytic data suggest a modest reduction in early stroke, particularly in elderly and high-risk patients.^[8,9] In patients with established cerebrovascular disease, off-pump surgery has been associated with fewer postoperative neurological events.^[14] However, the absolute incidence of stroke after elective CABG is low, and a study of our size has very limited power to detect a difference in such

an infrequent event; the single stroke observed in the on-pump group is concordant with this expectation rather than informative about it. The softer endpoints of delirium and POCD are more common and therefore more tractable, yet pooled randomised data have not shown a durable cognitive advantage for off-pump surgery, implying that cardiopulmonary bypass is not the sole driver of postoperative neurocognitive change.^[11] The numerically higher rate of POCD and the composite neurological endpoint in our on-pump group is in keeping with, but does not confirm, a CPB-related contribution.

Delirium and early cognitive decline after cardiac surgery are multifactorial, with consistently identified contributors including older age, preoperative cognitive impairment, depression, diabetes, hypertension, prolonged intubation, postoperative arrhythmia and longer intensive care stay, several of which are modifiable.^[3] Systemic inflammation has been increasingly implicated as a shared mechanistic pathway for both delirium and POCD.^[15] The longer ventilation time observed in our on-pump patients is itself a recognised correlate of delirium and may partly mediate any neurological difference between techniques, underscoring that operative strategy is only one of several determinants of early brain injury.

The secondary outcomes are consistent with the established profile of off-pump surgery, which reduces transfusion requirements and can shorten ventilation without compromising early survival.⁵ Importantly, the equivalence of 30-day mortality and the comparable rates of renal injury and re-exploration in our series are reassuring and align with the randomised evidence that, in experienced hands, off-pump surgery is a safe alternative to conventional CABG.^[4,6] These benefits must be weighed against the recognised concerns of off-pump surgery in the wider literature, namely the potential for less complete revascularisation and a higher rate of repeat revascularisation over time.^[8,10]

Limitations

Several limitations merit emphasis. First, and most importantly, the patient-level data analysed here are synthetic and were generated to illustrate the analytical approach; the numerical results should not be interpreted as empirical findings from real patients, and the manuscript is intended as a template to be populated with a genuine institutional cohort. Second, the sample size of 76 confers limited statistical power, particularly for low-incidence hard endpoints such as stroke, so the absence of significant neurological differences should be read as inconclusive rather than as evidence of no effect. Third, allocation to technique was non-randomised and at the surgeon's discretion, introducing the potential for selection bias despite the comparable measured baseline characteristics. Fourth, the assessment of cognitive outcomes by MMSE at discharge is relatively insensitive and cannot capture domain-specific or delayed neurocognitive decline. Finally, the analysis is confined to early in-hospital outcomes from a single centre, limiting generalisability and precluding inferences about graft patency or late events.

CONCLUSION

In this single-centre comparative analysis, off-pump CABG was associated with significantly less perioperative myocardial injury and a lower transfusion and ventilation burden than on-pump CABG, while early neurological events were numerically but not statistically less frequent. The biochemical cardioprotection of off-pump surgery is concordant with existing evidence, whereas the neurological comparison remains underpowered and hypothesis-generating. Adequately powered, randomised studies with sensitive neurocognitive testing are required before a definitive neurological advantage can be attributed to either technique.

Conflicts of interest: The authors declare no conflicts of interest.

REFERENCES

1. Gaudino M, Angelini GD, Antoniadis C, et al. Off-pump coronary artery bypass grafting: 30 years of debate. *J Am Heart Assoc.* 2018;7:e009934.
2. Newman MF, Kirchner JL, Phillips-Bute B, et al. Longitudinal assessment of neurocognitive function after coronary-artery bypass surgery. *N Engl J Med.* 2001;344(6):395-402.
3. Greaves D, Psaltis PJ, Davis DHJ, et al. Risk factors for delirium and cognitive decline following coronary artery bypass grafting surgery: a systematic review and meta-analysis. *J Am Heart Assoc.* 2020;9(22):e017275.
4. Shroyer AL, Grover FL, Hattler B, et al. On-pump versus off-pump coronary-artery bypass surgery. *N Engl J Med.* 2009;361(19):1827-1837.
5. Lamy A, Devereaux PJ, Prabhakaran D, et al. Off-pump or on-pump coronary-artery bypass grafting at 30 days. *N Engl J Med.* 2012;366(16):1489-1497.
6. Diegeler A, Börgermann J, Kappert U, et al. Off-pump versus on-pump coronary-artery bypass grafting in elderly patients. *N Engl J Med.* 2013;368(13):1189-1198.
7. Lamy A, Devereaux PJ, Prabhakaran D, et al. Five-year outcomes after off-pump or on-pump coronary-artery bypass grafting. *N Engl J Med.* 2016;375(24):2359-2368.
8. He L, Tiemuerniyazi X, Chen L, et al. Clinical outcomes of on-pump versus off-pump coronary-artery bypass surgery: a meta-analysis. *Int J Surg.* 2024;110(8). doi:10.1097/JS9.0000000000001481.
9. Altarabsheh SE, Deo SV, Rababa'h AM, et al. Off-pump coronary artery bypass reduces early stroke in octogenarians: a meta-analysis of 18,000 patients. *Ann Thorac Surg.* 2015;99(5):1568-1575.
10. Takagi H, Umemoto T. Worse long-term survival after off-pump than on-pump coronary artery bypass grafting. *J Thorac Cardiovasc Surg.* 2014;148(5):1820-1829.
11. Marasco SF, Sharwood LN, Abramson MJ. No improvement in neurocognitive outcomes after off-pump versus on-pump coronary revascularisation: a meta-analysis. *Eur J Cardiothorac Surg.* 2008;33(6):961-970.
12. Malik V, Kale SC, Chowdhury UK, Ramakrishnan L, Chauhan S, Kiran U. Myocardial injury in coronary artery bypass grafting: on-pump versus off-pump comparison by measuring heart-type fatty-acid-binding protein release. *Tex Heart Inst J.* 2006;33(3):321-327.
13. Peivandi AA, Dahm M, Opfermann UT, et al. Comparison of cardiac troponin I versus T and creatine kinase MB after coronary artery bypass grafting in patients with and without perioperative myocardial infarction. *Herz.* 2004;29(7):658-664.
14. Dominici C, Salsano A, Nenna A, et al. Neurological outcomes after on-pump vs off-pump CABG in patients with cerebrovascular disease. *J Card Surg.* 2019;34:941-947.
15. Devinney MJ, Mathew JP, Berger M. Postoperative Delirium and Postoperative Cognitive Dysfunction: Two Sides of the Same Coin? *Anesthesiology.* 2018 Sep;129(3):389-391.