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Original Article

Comparative outcomes of coronary artery bypass grafting with different perfusion methods: Conventional CPB vs miniaturized CPB vs off-pump techniques

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Abstract

Aim: Conventional cardiopulmonary bypass (CCPB) remains the standard technique for coronary artery bypass grafting (CABG) but is associated with a systemic inflammatory response resulting from blood contact with artificial surfaces and the blood–air interface. Miniaturized cardiopulmonary bypass (MCPB) was developed to mitigate these adverse effects, whereas off-pump coronary artery bypass (OPCAB) avoids extracorporeal circulation altogether. However, direct comparisons of these three perfusion strategies remain limited. The primary objective of this study was to compare perioperative and early postoperative outcomes among patients undergoing elective isolated CABG using CCPB, MCPB, or OPCAB. Secondary objectives included the comparison of baseline demographic characteristics, coronary anatomy, and preoperative clinical variables to assess the comparability of the study groups.
Material and Methods: We retrospectively analyzed 213 consecutive patients who underwent isolated elective coronary artery bypass grafting at a single institution between May 2013 and May 2018. According to the perfusion strategy used, patients were allocated to the conventional cardiopulmonary bypass (CCPB; n = 118), miniaturized cardiopulmonary bypass (MCPB; n = 62), or off-pump coronary artery bypass (OPCAB; n = 33) groups. Baseline demographic and preoperative characteristics were compared to ensure group comparability, while perioperative characteristics and early postoperative outcomes were evaluated to assess the clinical impact of each perfusion strategy.
Results: Baseline demographic and preoperative characteristics were comparable between groups. Patients undergoing OPCAB received fewer distal anastomoses and fewer venous grafts than patients undergoing CCPB or MCPB (both $p < 0.001$) and demonstrated a significantly lower postoperative lactate index ($p = 0.010$). Operative duration was longer in the MCPB group than in the CCPB and OPCAB groups ($p = 0.009$). Perioperative blood transfusion was more frequently required in the CCPB group than in the MCPB and OPCAB groups ($p < 0.001$). Compared with MCPB, CCPB was associated with higher postoperative creatinine index ($p = 0.020$), greater inotropic requirements 6 hours after ICU admission ($p = 0.009$), and increased mediastinal drainage ($p = 0.001$). Rates of major postoperative complications did not differ significantly among the three techniques.
Conclusion: CCPB, MCPB, and OPCAB all provided satisfactory early clinical outcomes following isolated CABG. MCPB combined several advantages of conventional and off-pump surgery by reducing transfusion requirements, postoperative renal dysfunction, inotropic support, and postoperative bleeding while maintaining the benefits of an arrested-heart procedure. The optimal perfusion strategy should be individualized according to patient characteristics, coronary anatomy, and surgical expertise. Larger prospective studies are warranted to confirm these findings.

Keywords: Coronary artery bypass grafting, conventional cardiopulmonary bypass, miniaturized cardiopulmonary

INTRODUCTION

Coronary artery bypass grafting (CABG) remains one of the most frequently performed cardiac surgical procedures worldwide and continues to represent the standard treatment for patients with complex multivessel coronary artery disease. Since its introduction into clinical practice in the 1960s, continuous advances in surgical techniques, myocardial protection, perioperative care, and extracorporeal circulation have substantially improved both early and long-term outcomes (1).

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One of the major challenges during CABG is minimizing myocardial ischemic injury while providing optimal conditions for complete coronary revascularization. Early CABG procedures were performed on the beating heart before the widespread adoption of cardiopulmonary bypass (CPB) (2). Conventional cardiopulmonary bypass (CCPB) subsequently became the standard technique because it provides a bloodless and motionless operative field, thereby facilitating precise construction of coronary anastomoses (3).

Despite these advantages, CCPB is associated with activation of a systemic inflammatory response resulting from blood contact with artificial surfaces and the blood–air interface of the extracorporeal circuit. This inflammatory response has been associated with coagulation disturbances, increased transfusion requirements, postoperative organ dysfunction, and prolonged recovery (4).

To reduce these adverse effects, miniaturized cardiopulmonary bypass (MCPB) systems were introduced in the early 2000s. Compared with conventional circuits, MCPB systems eliminate the open venous reservoir, shorten the tubing length, reduce the priming volume, and use biocompatible heparin-coated surfaces, thereby limiting blood–air interaction and activation of inflammatory pathways (5,6). Previous studies have demonstrated that MCPB may reduce the inflammatory response, perioperative blood transfusion, postoperative organ injury, and vasopressor requirements while maintaining the advantages of arrested-heart surgery (7,8).

An alternative strategy consists of completely avoiding extracorporeal circulation through off-pump coronary artery bypass (OPCAB). By maintaining native cardiac perfusion throughout the procedure, OPCAB may further attenuate the inflammatory response and reduce postoperative organ dysfunction. However, concerns remain regarding the completeness of myocardial revascularization, particularly in patients with complex multivessel disease (9–12).

Although numerous studies have compared conventional and off-pump CABG or evaluated MCPB against CCPB, direct comparisons of all three perfusion strategies within a single institutional experience remain limited. Such comparisons are particularly valuable because they reduce variability related to perioperative management and institutional practice.

The primary objective of the present study was to compare perioperative and early postoperative outcomes following isolated coronary artery bypass grafting performed using CCPB, MCPB, or OPCAB. Secondary objectives included the comparison of baseline demographic characteristics, coronary anatomy, and preoperative clinical variables to evaluate the comparability of the study groups.

MATERIAL AND METHODS

Study design and population

This retrospective single-center observational study was approved by the Geneva Cantonal Ethics Committee for research involving human participants (BASEC-ID 2018-01084; approval date: 6 November 2018). The requirement for written informed consent was waived because of the retrospective nature of the study.

Between 1 May 2013 and 31 May 2018, a total of 307 consecutive patients underwent CABG at the Division of Cardiovascular Surgery of Geneva University Hospitals. After application of the predefined inclusion and exclusion criteria, 213 patients were included in the final analysis.

Patients undergoing isolated elective CABG were eligible for inclusion. Exclusion criteria comprised previous cardiac surgery, combined procedures (e.g., CABG associated with valve surgery or patent foramen ovale closure), aortic surgery combined with CABG, emergency operations (defined as surgery performed within two days of hospital admission or classified as an emergency in the operative report), and documented refusal to participate in research (Figure 1).

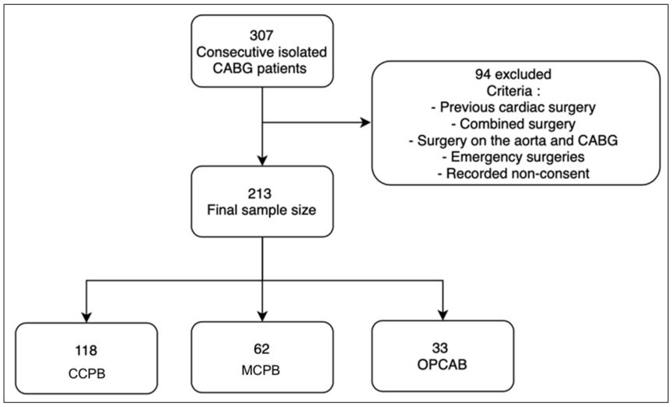

Figure 1. Population flowchart

MCPB was introduced into routine clinical practice at our institution in September 2016. Consequently, patients undergoing MCPB were operated during the latter part of the study period, whereas CCPB and OPCAB procedures were performed throughout the entire study period.

Data Collection

Clinical data were extracted retrospectively from the institutional electronic medical record system called Dossier Patient Informatisé (DPI).

Baseline variables included age, sex, body mass index, cardiovascular risk factors, left ventricular ejection fraction, coronary anatomy, left main coronary artery disease, and the European System for Cardiac Operative Risk Evaluation II (EuroSCORE II) (13).

Perioperative variables included the number of distal anastomoses, arterial and venous grafts, operative duration, cardiopulmonary bypass time, aortic cross-clamp time, and perioperative blood transfusion.

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Postoperative variables included fluid retention, serum lactate, serum creatinine, cardiac troponin concentrations, inotropic support, postoperative blood transfusion, duration of mechanical ventilation, intensive care unit (ICU) and hospital length of stay, mediastinal drainage, and postoperative complications.

Fluid retention was calculated as the difference between the preoperative body weight and the first recorded body weight obtained between postoperative days 2 and 7.

The inotropic score was calculated according to the formula described by Yamazaki et al. (14) (Equation 1).

Inotropic score (IS) = (dopamine * 1) + (dobutamine * 1) + (adrenaline * 100) + (noradrenaline * 100) + (phenylephrine * 100)
Doses of each vasopressor calculated in μg/kg/min

Equation 1. Modified inotropic score (IS)

To account for changes in laboratory practice during the study period, conventional cardiac troponin I assays (2013–2015) and high-sensitivity cardiac troponin T assays (2015–2018) were harmonized using validated conversion equations (Equation 2), allowing comparison of troponin concentrations across the entire study population. During the study period, the institutional clinical chemistry laboratory replaced the conventional cardiac troponin I assay with a high-sensitivity troponin T assay. Consequently, two different analytical methods were used during the study period. To enable comparison of postoperative myocardial injury across the entire cohort, troponin values were harmonized using an institutional conversion formula developed specifically for this study based on the analytical characteristics of the two assays (Equation 2). This conversion was applied solely to standardize measurements across the study period and does not represent an externally validated conversion model.

2013 - 2015: 0.09 μg/L was the upper limit for normal conventional troponin I
All values of troponin obtained between 2013-2015 were divided by 0.09 to obtain a proportion.

2015 - 2018: 14 ng/L was the upper limit for normal high-sensitivity troponin T
All values of troponin obtained between 2015-2018 were divided by 14 to obtain a proportion.

$$\text{Final troponin index} = \frac{\text{Troponin between 12 and 24 hours after ICU admission}}{\text{Troponin at ICU admission}}$$

Equation 2. Homogenisation of troponin values

The postoperative lactate index was calculated as the ratio between serum lactate measured 24 hours after ICU admission and the value measured at ICU admission.

Similarly, the creatinine index was defined as the ratio of serum creatinine measured 24 hours after ICU admission to the preoperative creatinine value. Postoperative acute kidney injury was defined as a postoperative creatinine increase of at least 1.5 times the baseline value.

Postoperative complications included reoperation for bleeding or cardiac tamponade, repeat coronary revascularization, myocardial infarction, atrial fibrillation or atrial flutter, stroke, respiratory complications, acute kidney injury requiring dialysis, cardiac arrest, and in-hospital mortality.

Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics for Windows, version 25.0 (IBM Corp., Armonk, NY, USA). A two-sided p value ≤0.05 was considered statistically significant.

Continuous variables are presented as mean ± standard deviation (SD), whereas categorical variables are expressed as frequencies and percentages.

The distribution of continuous variables was assessed using the Shapiro–Wilk test, and homogeneity of variances was evaluated using Levene's test. Normally distributed variables with homogeneous variances were compared among the three study groups using one-way analysis of variance (ANOVA), followed by Bonferroni-adjusted post hoc pairwise comparisons, when appropriate.

For variables that did not meet the assumption of normality, logarithmic transformation was performed. If normality was achieved after transformation, ANOVA with Bonferroni-adjusted post hoc testing was applied to the transformed data. Variables that remained non-normally distributed after transformation, or exhibited unequal variances, were analyzed using the Kruskal–Wallis test, followed by Dunn–Bonferroni-adjusted post hoc pairwise comparisons.

Categorical variables were compared using the Pearson chi-square test or Fisher's exact test, as appropriate. When an overall statistically significant difference was identified, post hoc pairwise comparisons between the CCPB, MCPB, and OPCAB groups were performed using Bonferroni correction for multiple testing.

RESULTS

Demographics

A total of 307 consecutive patients underwent coronary artery bypass grafting during the study period. After application of the inclusion and exclusion criteria, 213 patients were included in the final analysis (Figure 1). Of these, 118 patients (55.4%) underwent CCPB, 62 (29.1%) underwent miniaturized cardiopulmonary bypass (MCPB), and 33 (15.5%) underwent off-pump coronary artery bypass (OPCAB). The study population was predominantly male (87.8%), with a mean age of 63.9 ± 9.3 years.

Although no statistically significant differences were observed, CCPB was more frequently performed in patients with double-vessel (52.8%) and triple-vessel (56.3%) coronary artery disease. In contrast, MCPB was more commonly used than OPCAB in patients with triple-vessel disease (33.5% vs. 10.2%), whereas OPCAB was performed more frequently in patients with single-vessel disease (50.0%) (Table 1).

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Table 1. Distribution of coronary artery disease within the three perfusion sub-groups

Pathology	Perfusion method, n (%)		
	CCPB	MCPB	OPCAB
Common trunk disease (N = 6)	4 (66.7)	0 (0.0)	2 (33.3)
Single coronary artery disease (N = 4)	1 (25.0)	1 (25.0)	2 (50.0)
Double coronary artery disease (N = 36)	19 (52.8)	5 (13.9)	12 (33.3)
Triple coronary artery disease (N = 167)	94 (56.3)	56 (33.5)	17 (10.2)

Primary Outcomes

Perioperative Outcomes

Perioperative outcomes are summarized in Table 2. Patients undergoing OPCAB received significantly fewer distal anastomoses than those undergoing CCPB or MCPB ($p < 0.001$). Similarly, the number of venous grafts was significantly lower in the OPCAB group ($p < 0.001$), whereas the number of arterial grafts was comparable among the three groups.

Operative duration differed significantly among the groups ($p = 0.009$), with MCPB procedures requiring the longest operative time. As expected, cardiopulmonary bypass time and aortic cross-clamp time were only applicable to the two on-pump techniques.

Perioperative blood transfusion was required significantly more frequently in the CCPB group than in the MCPB and OPCAB groups ($p < 0.001$). No other perioperative variables differed significantly between the three perfusion strategies.

Table 2. Peri-operative variables compared between the three perfusion groups

	Total (N = 213)	CCPB (N = 118)	MCPB (N = 62)	OPCAB (N = 33)	P-value	Post-hoc analysis (Bonferroni test)
Number of bypasses	2.77 ± 0.81	2.86 ± 0.75	2.94 ± 0.83	2.15 ± 0.67	< 0.001	CCPB*MCPB (p = 1.000) MCPB*OPCAB (p < 0.001) CCPB*OPCAB (p < 0.001)
Number of arterial bypasses	1.47 ± 0.54	1.55 ± 0.56	1.35 ± 0.48	1.42 ± 0.50	0.077	
Number of venous bypasses	1.00 ± 0.81	1.08 ± 0.81	1.16 ± 0.82	0.39 ± 0.50	< 0.001	CCPB*MCPB (p = 1.000) MCPB*OPCAB (p < 0.001) CCPB*OPCAB (p < 0.001)
Length of surgery (h), [a] (N = 212)	04h24 ± 00h59	04h19 ± 00h57	04h42 ± 00h56	04h06 ± 01h07	0.009	CCPB*MCPB (p = 0.043) MCPB*OPCAB (p = 0.014) CCPB*OPCAB (p = 0.756)
Length of aortic clamping (min), [bc] (N = 175)	58min03 ± 20min08	57min20 ± 18min89	59min57 ± 22min23	Not applicable	0.458	
Length of cardiopulmonary bypass (min), [b] (N = 177)	87min13 ± 31min31	85min99 ± 30min38	89min23 ± 33min12	Not applicable	0.514	
Peri-operative transfusion	82 (38.5)	61 (51.7)	15 (24.2)	6 (18.2)	< 0.001	CCPB*MCPB (p < 0.001) MCPB*OPCAB (p = 0.608) CCPB*OPCAB (p = 0.001)

[a] Missing value in CCPB, [b] Reduced sample size as OPCAB not taken into consideration, [c] Missing data in the CCPB and MCPB groups, h = hour: minute; m = minute: second

Early Postoperative Outcomes

Early postoperative outcomes are presented in Table 3. Patients undergoing OPCAB demonstrated a significantly lower postoperative lactate index than those treated with CCPB or MCPB ($p = 0.010$).

Compared with MCPB, patients undergoing CCPB had significantly higher postoperative creatinine index ($p = 0.020$), greater inotropic requirements six hours after intensive care unit admission ($p = 0.009$), and increased mediastinal drainage volume ($p = 0.001$).

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Table 3. Post-operative variables compared between the three perfusion groups

	Total sample (N = 213)	CCPB (N = 118)	MCPB (N = 62)	OPCAB (N = 33)	P-value	Post-hoc analysis (Dunn-Bonferroni test)
Fluid retention (kg), [abs] (N = 139)	4.45 ± 3.37	3.95 ± 3.16	5.17 ± 3.53	3.98 ± 3.30	0.113	
Troponin index (log), [ab]	-0.047 ± 0.323	-0.058 ± 0.354	-0.009 ± 0.211	-0.081 ± 0.376	0.836	
Lactate index (log)	0.043 ± 0.203	0.059 ± 0.196	0.064 ± 0.182	-0.055 ± 0.242	0.01*	CCPB*MCPB (p = 1.000) MCPB*OPCAB (p = 0.019) CCPB*OPCAB (p = 0.012)
Creatinine index (log)	-0.041 ± 0.106	-0.024 ± 0.096	-0.074 ± 0.074	-0.036 ± 0.164	0.002*	CCPB*MCPB (p = 0.003) MCPB*OPCAB (p = 1.000) CCPB*OPCAB (p = 0.129)
Post-operative AKI,	5 (2.3)	3 (2.5)	0 (0.0)	2 (6.1)	> 0.05[d]	
Inotropic score						
1 hour [abc] (N = 23)	296.03 ± 217.16	514.58 ± 380.43	281.44 ± 183.72	160.21 ± 53.71	0.171	
6 hours [abc] (N = 42)	360.15 ± 347.16	604.32 ± 383.04	241.92 ± 294.68	409.60 ± 309.97	0.009*	CCPB*MCPB (p = 0.010) MCPB*OPCAB (p = 0.309) CCPB*OPCAB (p = 1.000)
12 hours [abc] (N = 39)	392.76 ± 326.62	432.84 ± 352.14	359.80 ± 263.90	403.63 ± 478.41	0.608	
Post-operative transfusion, [c] (N = 212)	57 (26.9)	29 (24.6)	21 (33.9)	7 (21.9)	0.322	
LOS ICU (days)	3.18 ± 3.03	3.10 ± 2.72	2.89 ± 2.17	4.00 ± 4.88	0.240	
Length of ventilation ICU (days)	1.40 ± 2.09	1.44 ± 1.89	1.15 ± 0.85	1.76 ± 3.78	0.357	
LOS hospital (log)	1.113 ± 0.208	1.127 ± 0.205	1.095 ± 0.222	1.099 ± 0.193	0.572	
Total drainage ICU (log), [ac]	2.969 ± 0.342	3.045 ± 0.311	2.865 ± 0.336	2.894 ± 0.398	0.001*	CCPB*MCPB (p = 0.002) MCPB*OPCAB (p = 1.000) CCPB*OPCAB (p = 0.074)
Complications	103 (48.4)	57 (48.3)	32 (51.6)	14 (42.4)	0.695	
Reoperation for bleeding or tamponade	6 (2.8)	4 (3.4)	2 (3.3)	0 (0.0)	> 0.05[d]	
Re-intervention on coronary arteries	17 (8.0)	12 (10.2)	3 (4.8)	2 (6.1)	> 0.05[d]	
Myocardial infarction	3 (1.4)	3 (2.5)	0 (0.0)	0 (0.0)	> 0.05[d]	
Atrial fibrillation, flutter	47 (22.1)	27 (22.9)	13 (21.0)	7 (21.2)	0.950	
Stroke	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	N/A	
Respiratory	65 (30.5)	38 (32.2)	20 (32.3)	7 (21.2)	0.451	
AKI required dialysis	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	N/A	
Cardiac arrest	3 (1.4)	1 (0.8)	1 (1.6)	1 (3.0)	> 0.05[d]	
Death	3 (1.4)	2 (1.7)	0 (0.0)	1 (3.0)	> 0.05[d]	

[a] Missing data in the CCPB group, [b] Missing data in the MCPB group, [c] Missing data in the OPCAB group, [d] Not valid in Chi-squared test and insignificant result in Fisher's Exact test between the subcategories of perfusion, *Significant variables,; AKI: Acute Kidney Injury, LOS. Length of Stay, ICU: Intensive Care Unit

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No statistically significant differences were observed among the three groups regarding postoperative troponin levels, duration of mechanical ventilation, intensive care unit stay, hospital length of stay, postoperative blood transfusion, postoperative weight gain, or postoperative complications (all $p > 0.05$).

Secondary Outcomes

Baseline demographic and preoperative characteristics are presented in Tables 4 and 5. No statistically significant differences were observed among the three groups with respect to demographic characteristics, cardiovascular risk factors, or preoperative clinical variables.

Although not statistically significant, patients undergoing OPCAB had a slightly higher mean EuroSCORE II than patients treated with CCPB or MCPB. Similarly, CCPB was more frequently performed in patients with double- and triple-vessel coronary artery disease, whereas OPCAB was more commonly selected for patients with single-vessel disease. However, these differences did not reach statistical significance.

Overall, the three study groups were well balanced with regard to baseline characteristics, allowing meaningful comparison of perioperative and postoperative outcomes.

Table 4. Demographic data compared between the three perfusion methods

	Total sample (N = 213)	CCPB (N = 118)	MCPB (N = 62)	OPCAB (N = 33)	P-value
Sex, n (%)					
Male	187 (87.8)	103 (87.3)	57 (91.9)	27 (81.8)	0.346
Female	26 (12.2)	15 (12.7)	5 (8.1)	6 (18.2)	
Age	63.87 ± 9.28	64.15 ± 9.19	62.71 ± 8.68	65.03 ± 10.65	0.453
Body mass index, [a]	27.63 ± 4.41	27.57 ± 4.22	27.35 ± 4.81	28.42 ± 4.34	0.522
Risk factors, n (%)					
Obesity, [a] **(N = 212)**	58 (27.4)	32 (27.1)	16 (25.8)	10 (31.3)	0.851
Hypertension	153 (71.8)	87 (73.7)	42 (67.7)	24 (72.7)	0.692
Dyslipidemia	154 (72.3)	82 (69.5)	45 (72.6)	27 (81.8)	0.375
Diabetes	75 (35.2)	46 (39.0)	20 (32.3)	9 (27.3)	0.390
Smoker	122 (57.3)	61 (51.7)	41 (66.1)	20 (60.6)	0.162
Personal history, n (%)					
Myocardial infarction	48 (22.5)	29 (24.6)	12 (19.4)	7 (21.2)	0.714
Stent, [b] **(N = 212)**	45 (21.2)	26 (22.2)	12 (19.4)	7 (21.2)	0.905
Stroke	14 (6.6)	7 (5.9)	5 (8.1)	2 (6.1)	> 0.05[c]
Cardiac arrest	7 (3.3)	4 (3.4)	3 (4.8)	0 (0.0)	> 0.05[c]

[a] Missing data in the OPCAB group, [b] Missing data in the CCPB group, [c] Not valid in Chi-squared test and insignificant result in Fisher's Exact test between the subcategories of perfusion

Table 5. Pre-operative data compared between the three perfusion techniques

	Total sample (N = 213)	CCPB (N = 118)	MCPB (N = 62)	OPCAB (N = 33)	P-value
LVEF (%)	52.37 ± 12.13	53.01 ± 11.51	50.56 ± 13.09	53.48 ± 12.41	0.453
EuroSCORE II	1.95 ± 2.46	1.61 ± 1.37	2.12 ± 2.30	2.76 ± 4.69	0.718
Left coronary arterial commun trunk disease, n (%)	73 (34.3)	37 (31.4)	20 (32.3)	16 (48.5)	0.172

LVEF: Left Ventricular Ejection Fraction

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DISCUSSION

Principal Findings

The present study provides a direct comparison of the three contemporary perfusion strategies used for isolated coronary artery bypass grafting in a single-center cohort. Four principal observations emerged from our analysis.

First, patients undergoing OPCAB received fewer distal anastomoses and fewer venous grafts than those treated with either CCPB or MCPB.

Second, MCPB was associated with lower perioperative blood transfusion requirements, reduced postoperative mediastinal drainage, lower postoperative creatinine index, and reduced inotropic requirements compared with CCPB.

Third, patients undergoing OPCAB demonstrated significantly lower postoperative lactate levels.

Finally, despite these differences in perioperative variables, no significant differences were observed in major early postoperative complications or hospital outcomes among the three perfusion strategies.

Completeness of Revascularization

Patients undergoing OPCAB received significantly fewer distal anastomoses than those treated with either CCPB or MCPB. This finding is consistent with previous reports demonstrating that complete myocardial revascularization may be more challenging during beating-heart surgery, particularly in patients with diffuse coronary artery disease or technically demanding posterior targets. Nevertheless, advances in surgical expertise and patient selection have substantially improved OPCAB outcomes over the past two decades, allowing excellent results in experienced centers (9-12).

Similarly, the lower number of venous grafts observed in the OPCAB group probably reflects both the lower number of distal anastomoses and a greater reliance on arterial conduits whenever feasible. Increasing use of arterial grafting has been associated with improved long-term graft patency and survival after CABG (15).

Blood Transfusion

One of the most important findings of the present study was the significantly lower perioperative blood transfusion requirement in patients undergoing MCPB compared with CCPB. Miniaturized extracorporeal circulation was specifically developed to reduce the adverse effects associated with conventional cardiopulmonary bypass, including hemodilution, activation of inflammatory pathways, platelet dysfunction, and coagulation disturbances. Several randomized studies and meta-analyses have consistently demonstrated reduced transfusion requirements with MCPB while maintaining comparable clinical outcomes. Our findings are therefore in agreement with the existing literature (16–19).

Postoperative Bleeding

Patients treated with MCPB also exhibited significantly lower postoperative mediastinal drainage than those undergoing CCPB. Previous studies have reported similar findings, suggesting that the reduced priming volume, closed extracorporeal circuit, and diminished blood–air interface associated with MCPB contribute to improved preservation of coagulation and platelet function, thereby reducing postoperative bleeding (20). These mechanisms likely explain the lower chest tube drainage observed in our cohort.

Renal Function

Another important finding was the significantly lower postoperative creatinine index observed in the MCPB group compared with CCPB. Acute kidney injury remains one of the most serious complications after cardiac surgery and is associated with increased postoperative morbidity and mortality. Previous investigations have suggested that minimizing hemodilution, inflammatory activation, and microembolic load during extracorporeal circulation may improve renal perfusion and reduce postoperative renal dysfunction. Although the incidence of clinically overt renal failure was low in our cohort, our findings support the potential renoprotective effect of miniaturized cardiopulmonary bypass (21–24).

Lactate Levels

Patients undergoing OPCAB demonstrated significantly lower postoperative lactate levels than those treated with either CCPB or MCPB. Hyperlactatemia after cardiac surgery is generally considered a marker of impaired tissue perfusion and has been associated with increased postoperative morbidity and mortality. Avoidance of extracorporeal circulation during OPCAB may contribute to improved microcirculatory perfusion and reduced metabolic stress, thereby explaining the lower lactate levels observed in our study (25,26).

Major Clinical Outcomes

Despite significant differences in several perioperative variables, no statistically significant differences were observed in mortality, stroke, myocardial infarction, atrial fibrillation, prolonged ventilation, intensive care unit stay, or overall hospital stay. These findings are consistent with large randomized trials demonstrating that although different CABG techniques may influence perioperative physiology, they generally produce comparable short-term clinical outcomes when performed by experienced surgical teams. Consequently, selection of the perfusion strategy should be individualized according to coronary anatomy, patient characteristics, and surgeon experience (27,28).

Strengths and Limitations

The present study has several strengths. It directly compares the three principal CABG perfusion strategies within a single

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tertiary referral center using standardized perioperative management and surgical protocols, thereby minimizing institutional variability. Moreover, all procedures were performed by an experienced cardiac surgery team, allowing a consistent comparison of perioperative and early postoperative outcomes.

Several limitations should be acknowledged. First, this was a retrospective single-center study with a relatively limited sample size, particularly in the OPCAB group. Second, MCPB was introduced into routine clinical practice during the latter part of the study period. Consequently, a learning-curve effect associated with the implementation of this technique may have influenced operative duration and certain perioperative outcomes, despite all procedures being performed by experienced cardiac surgeons. Third, several variables contained missing data, including family history, postoperative vasoactive-inotropic score, and variables required for retrospective EuroSCORE II calculation. Finally, because the institutional clinical chemistry laboratory changed the cardiac troponin assay during the study period, an institutional conversion formula was developed to harmonize measurements between the conventional and high-sensitivity assays. Although this approach allowed standardized analysis across the study period, the conversion has not been externally validated.

CONCLUSION

Overall, our findings suggest that all three perfusion strategies provide comparable early clinical outcomes when applied to appropriately selected patients undergoing isolated CABG. However, each technique demonstrated distinct perioperative characteristics. MCPB was associated with reduced perioperative blood transfusion, postoperative mediastinal drainage, renal dysfunction, and inotropic support compared with CCPB, whereas OPCAB was associated with lower postoperative lactate levels but fewer distal anastomoses. These observations highlight that the choice of perfusion strategy should be individualized according to patient characteristics, coronary anatomy, and surgical expertise, rather than based on a single standardized approach. Larger prospective multicenter studies are warranted to determine whether these perioperative advantages translate into improved long-term clinical outcomes.

Conflict of Interest: The authors declare that there is no conflict of interest.

Financial Disclosure: The authors declare that they received no financial support.

Ethics Committee Approval: This retrospective mono-centric study was approved by the Geneva Ethical Committee for research using personal data involving human beings (BASEC-ID 2018-01084; dated 06.11.2018).

Informed Consent: The need for written informed consent was waived by the committee.

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