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Comparison of immediate postoperative outcomes between minimal invasive and conventional extracorporeal circulation in adult cardiac surgery

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ABSTRACT

Objectives: This study aims to compare immediate postoperative outcomes between minimal invasive extracorporeal circulation (MiECC) and conventional extracorporeal circulation (CECC) in adult patients undergoing on-pump coronary artery bypass grafting (CABG).

Patients and methods: Between October 2013 and November 2013, a total of 65 adult patients (46 males, 19 females; mean age: 66.1±8.6 years; range, 34 to 84 years) who underwent isolated CABG, aortic valve replacement (AVR), or combined AVR with CABG. The patients were stratified by preoperative risk, with higher-risk patients assigned to the MiECC group (n=30) and the remaining patients to the CECC group (n=35). Intra- and postoperative parameters, including cardiopulmonary bypass (CPB) time, aortic cross-clamp time, priming and cardioplegia volumes, 24-h drainage, transfusion requirements, mechanical ventilation duration, intensive care unit (ICU) and hospital stay, and mortality were evaluated.

Results: Patients in the MiECC group had higher baseline risk profiles, including older age, chronic obstructive pulmonary disease, and carotid artery stenosis. The MiECC was associated with significantly lower priming (506±54 *vs.* 1150±94 mL, p=0.001) and cardioplegia volumes (38±7 *vs.* 939±108 mL, p=0.001). Postoperatively, MiECC patients had shorter mechanical ventilation (6.4±2.0 *vs.* 10.2±4.9 h, p=0.001), ICU stay (24.5±4.2 *vs.* 45.7±6.3 h, p=0.001), and hospital stay (7.3±1.2 *vs.* 10.3±2.6 days, p=0.001). Blood product utilization, including red blood cells and fresh frozen plasma, was also significantly lower in the MiECC group. Mortality and major complications were comparable between the groups.

Conclusion: Despite higher baseline risk, MiECC provided favorable postoperative outcomes compared to CECC, including reduced transfusion needs, shorter mechanical ventilation, and shorter ICU and hospital stays. The MiECC appears to be a safe and effective strategy even in higher-risk cardiac surgical populations, potentially reducing perioperative morbidity.

Keywords: Cardiac surgery, conventional extracorporeal circulation, blood transfusion, microplegia, minimal invasive extracorporeal circulation, postoperative outcomes.

Cardiopulmonary bypass (CPB) remains the gold standard for most cardiac surgical procedures, including coronary artery bypass grafting (CABG) and valve replacement.[1] The CABG has been demonstrated to improve long-term outcomes in patients with severe coronary artery disease. In recent years, surgeons have increasingly operated on older patients and those with higher preoperative risk profiles.[2,3]

However, CPB is associated with activation of a systemic inflammatory response due to blood contact with foreign surfaces and the requirement for priming solutions.[4] This inflammatory reaction may result in significant postoperative morbidity, including bleeding and multiorgan dysfunction.[5] To mitigate these adverse effects, the minimal invasive extracorporeal circulation (MiECC) system was introduced.[6]

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In the early 2000s, simplified perfusion systems were developed to retain the advantages of conventional CPB while minimizing its drawbacks.[7] The MiECC circuits are closed systems specifically designed to prevent blood-air contact. They incorporate a biocompatible centrifugal blood pump, reduced tubing length, surface coatings, and a cell saver, all of which help reduce the side effects of conventional extracorporeal circulation (CECC).[3] The superiority of MiECC over CECC in terms of clinical outcomes has been evaluated in several randomized-controlled trials and meta-analyses.[8]

In the present study, we aimed to compare immediate postoperative outcomes, including drainage volume, red blood cell transfusion requirement, intubation time, intensive care unit (ICU) stay, overall hospitalization, and mortality, between patients undergoing open-heart surgery with MiECC and those treated with CECC.

PATIENTS AND METHODS

This single-center, retrospective study was conducted at Ahi Evren Thoracic and Cardiovascular Surgery Training and Research Hospital, Department of Cardiovascular Surgery between October 2013 and November 2013. A total of 65 adult patients (46 males, 19 females; mean age: 66.1±8.6 years; range, 34 to 84 years) who underwent on-pump isolated CABG, aortic valve replacement (AVR), or combined AVR with CABG were included. Emergency surgeries, mitral valve procedures, and congenital cardiac operations were excluded. The patients were stratified into two groups according to their preoperative risk profile. Those with advanced age, chronic obstructive pulmonary disease (COPD), extracardiac arterial disease, or reduced left ventricular ejection fraction (LVEF) were allocated to the MiECC group (n=30), while the other patients constituted the CECC group (n=35). The patients were selected consecutively and standard anesthesia management and techniques were present in both groups, performed by the same surgical team, the only difference being the type of CPB system. Antiplatelet therapy was not discontinued before surgery. Written informed consent was obtained from each patient. The study protocol was approved by the Kanuni Training and Research Hospital Clinical Research Ethics Committee (Date: 06.05.2014, No: 2014/08-08). The study was conducted in accordance with the principles of the Declaration of Helsinki.

MiECC procedure

The MiECC system type 2 (MAQUET, Cardiopulmonary AG, Hirrlingen, Germany) consisted of a Quadrox-i hollow fiber microporous membrane oxygenator, a Rotaflow centrifugal pump (Maquet, Jostra Medizintechnik AG, Hirrlingen, Germany), and a heparin-albumin-coated circuit (Bioline, MAQUET Cardiopulmonary AG, Hirrlingen, Germany). The system included a bubble trap and a soft-shell reservoir. The priming volume was 500 mL. Retrograde autologous priming was performed intraoperatively in all MiECC patients. The target activated clotting time (ACT) was 250 sec. Blood from the operative field and MiECC circuit after weaning from CPB was collected and processed using a cell saver (mean volume, ~500 mL).

Conventional ECC procedure

The CECC system consisted of a tubing set without heparin coating (Bioline, MAQUET Cardiopulmonary AG, Hirrlingen, Germany). A hollow fiber membrane oxygenator (Quadrox, Maquet, Jostra Medizintechnik AG, Hirrlingen, Germany) was used. The priming volume was 1000 mL. A non-pulsatile roller pump (Terumo (Deutschland) GmbH, Eschborn, Germany) provided a flow rate of 2.4 L/min/m^2. The target ACT was 300 sec for heparin-coated circuits and 480 sec for non-coated circuits.

Surgical procedure

The same surgical procedure was employed in both groups. In suitable patients, the internal thoracic artery was harvested after sternotomy. Simultaneously, a saphenous vein graft was prepared. Heparinization was followed by standard venous and arterial cannulation. Myocardial protection in the MiECC group was achieved using antegrade intermittent cold blood microplegia cardioplegia administered every 20 min. The microplegia solution was prepared containing 13 mL of 22.5% potassium chloride, 10 mL of 15% magnesium sulfate, 10 mL of 8.4% sodium bicarbonate, 17 mL of 20% mannitol, and 5 mL of 2% lidocaine. Intermittent microplegia included 10 mL of 22.5% potassium chloride, 10 mL of 15% magnesium sulfate, 10 mL of 8.4% sodium bicarbonate, and 5 mL of 20% mannitol.

The prepared solution was administered via a perfuser through the aortic root at a flow rate of 1000 mL per minute for 4-6 min. A separate line from the arterial line served as the driving fluid. In the CECC group, myocardial protection followed the institutional protocol, consisting of antegrade cold blood cardioplegia given at induction and repeated every 20 min. Distal and proximal anastomoses were performed under cross-clamp. In all patients undergoing AVR, a standard aortotomy incision was used, and mechanical prosthetic valves were implanted in all cases. After rewarming, patients were weaned from CPB, and heparin was neutralized.

Postoperative care

Postoperative care included continuous monitoring of drainage from sternal closure until chest drain removal. The 24-h postoperative drainage volume was recorded for analysis. A hematocrit level below 0.25 was defined as normovolemic anemia and served as the threshold for allogeneic red blood cell transfusion. Mechanical ventilation time within the first 24 h was recorded, and intubation lasting longer than 24 h was classified as prolonged ventilation.

Intraoperative evaluation criteria included CPB time, aortic cross-clamp time, priming volume, and cardioplegia volume. Postoperative evaluation criteria included ICU and hospital length of stay, intubation duration, 24-h drainage volume, blood product utilization, and mortality.

Statistical analysis

Statistical analysis was performed using the IBM SPSS for Windows version 26.0 software (IBM Corp., Armonk, NY, USA). The conformity of continuous variables to a normal distribution was assessed using the Shapiro-Wilk test, and all data were found to be normally distributed. Descriptive data were presented in mean ± standard deviation (SD), median (min-max) or number and frequency, where applicable. The independent sample t-test was used to compare the groups. Categorical variables were analyzed using the chi-square test and Fisher exact test.

RESULTS

There were 30 patients in the MiECC group and 35 patients in the CECC group. Patients in the MiECC group were significantly older compared

Table 1
Baseline demographic and clinical characteristics of patients

	MiECC group (n=30)			CECC group (n=35)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Age (years)			69.5±7.6			63.1±9.5	**0.004***
Sex							**0.001****
Female	15	50.0		4	11.42		
Male	15	50.0		31	88.58		
Body surface area (m^2)			1.76±0.202			1.83±0.177	0.116*
LV ejection fraction (%)			50.60±8.058			55.57±8.555	**0.019***
Smoking history	15	50.0		12	34.3		0.200**
Diabetes mellitus	14	46.7		6	17.1		**0.010****
Hypertension	22	67.7		22	62.9		0.368**
Creatinine (mg/dL)			1.27±1.22			1.09±0.77	0.316*
COPD	14	46.7		3	8.6		**0.001****
Extra cardiac arteriopathy	5	16.7		2	5.7		0.884**
NYHA			2.83±0.648			2.69±0.583	0.337*
Carotid stenosis	6	20.0		1	2.9		**0.042****
Severe aortic stenosis	4	13.3		0	0		0.052**

MiECC: Minimal invasive extracorporeal circulation; CECC: Conventional extracorporeal circulation; SD: Standard deviation; LV: Left ventricular; COPD: Chronic obstructive pulmonary disease; NYHA: The New York Heart Association; * Independent Sample t-test; ** Chi-square test.

Table 2
Comparison of operative and postoperative results

	MiECC group (n=30)			CECC group (n=35)			
	n	%	Mean±SD	n	%	Mean±SD	*p*
Surgery							0.857***
Isolated CABG	26	86.8		35	100.0		
AVR	2	6.6		0	0.0		
CABG + AVR	2	6.6		0	0.0		
Cross-clamp time (min)			59.23±12.36			65.41±15.32	0.375*
CPB time (min)			95.21±34.89			100.06±36.25	0.875*
Prime volume (mL)			506.37±53.74			1150.14±93.88	**0.001** *
Cardioplegia volume (mL)			38.35±7.35			938.57±107.84	**0.001***
Duration of mechanical ventilation (h)			6.40±2.01			10.20±4.88	**0.001***
Intensive care unit stay (h)			24.50±4.158			45.74±6.261	**0.001***
Drainage (mL)			397.67±123.67			858.57±403.56	**0.001***
Re-exploration for bleeding	3	4.4		5	6.9		0.719**
Erythrocyte transfusion (U)			1.07±1.01			1.80±1.53	**0.029***
Fresh frozen plasma (U)			1.30±1.11			2.51±1.70	**0.001***
Postoperative stroke	2	2.9		1	1.4		0.612**
Postoperative atrial fibrillation	8	26.7		13	37.1		0.368**
30-Day hospital death	1	3.3		1	2.9		1.000**
Hospital stay (day)			7.33±1.241			10.26±2.638	**0.001***

MiECC: Minimal invasive extracorporeal; CECC: Conventional extracorporeal circulation; CABG: Coronary artery bypass graft; SD: Standard deviation; AVR: Aortic valve replacement; CPB: Cardiopulmonary bypass; * Independent sample t-test; ** Chi-square test; *** Fisher exact test.

to those in the CECC group (p=0.004). Female sex was also more frequent in the MiECC group (p=0.001). Regarding comorbidities, COPD was significantly more prevalent in the MiECC group (46.7% *vs.* 8.6%, p=0.001). In addition, carotid artery stenosis was more common in the MiECC group (20.0% *vs.* 2.9%, p=0.042). Other baseline demographic and preoperative characteristics are summarized in Table 1.

Operative and postoperative data are presented in Table 2. The types of surgical procedures performed were comparable between the two groups. Cardiopulmonary bypass time (p=0.375) and aortic cross-clamp time (p=0.875) were also similar. However, the priming volume (506.37±53.74 *vs.* 1150.14±93.88 mL, p=0.001) and cardioplegia volume (38.35±7.35 *vs.* 938.57±107.84 mL, p=0.001) were significantly lower in the MiECC group.

Postoperative outcomes favored MiECC in several respects. Mechanical ventilation time was significantly shorter in the MiECC group (6.40±2.01 *vs.* 10.20±4.88 h, p=0.001). ICU stay was also markedly reduced (24.50±4.16 *vs.* 45.74±6.26 h, p=0.001). Similarly, the 24-h drainage volume was significantly lower in the MiECC group (397.67±123.67 *vs.* 858.57±403.56 mL, p=0.001).

Blood product utilization was lower in patients undergoing MiECC. Red blood cell transfusion requirements (1.07±1.01 *vs.* 1.80±1.53 U, p=0.029) and fresh frozen plasma use (1.30±1.11 *vs.* 2.51±1.70 U, p=0.001) were both significantly reduced compared to CECC.

Finally, hospital stay was significantly shorter in the MiECC group (7.33±1.24 *vs.* 10.26±2.64 days, p=0.001). Mortality and major postoperative complications (atrial fibrillation, cerebrovascular events) were comparable between the groups.

DISCUSSION

In the present study, we compared immediate postoperative outcomes between patients undergoing

open-heart surgery with MiECC and those treated with CECC. Although the MiECC group consisted of patients with a significantly higher baseline risk profile, postoperative outcomes were more favorable compared to the CECC. Specifically, patients in the MiECC group experienced shorter ICU and hospital stays, reduced drainage volumes, and a lower need for blood product transfusions. These findings suggest that MiECC may offer clinical benefits even in higher-risk surgical populations, highlighting its protective role in perioperative management.

Blood transfusion during cardiac surgery has been associated with increased short- and long-term mortality, as well as higher rates of postoperative complications such as infection, stroke, and prolonged ventilatory support.[9,10] Strategies to minimize transfusion requirements are therefore essential. Consistent with previous studies, our results demonstrate a significantly lower need for erythrocyte and plasma transfusion in the MiECC group. This advantage may be explained by reduced hemodilution, minimized extracorporeal circuit trauma, and the lower postoperative bleeding and drainage volumes observed in these patients.[11-13]

Prolonged mechanical ventilation is strongly associated with advanced comorbidities, renal dysfunction, and extended bypass times.[14] More interestingly, despite having higher baseline risk factors, the MiECC group demonstrated significantly shorter ventilation times compared to CECC. This finding may be attributable to improved tissue perfusion and reduced systemic inflammatory response associated with the closed, minimized extracorporeal circuit.[1,3,15] Furthermore, shorter ICU stay and reduced ventilator dependence are clinically relevant outcomes that can decrease postoperative morbidity and lower healthcare costs.

Previous meta-analyses have demonstrated that MiECC reduces mortality, morbidity, and stroke rates compared to CECC.[8,16] In contrast, our study found no significant differences in mortality, atrial fibrillation, or cerebrovascular events. This discrepancy may be explained by the higher baseline risk profile in the MiECC cohort, which could have attenuated the expected advantages. Nevertheless, the consistent reductions in transfusion requirements, ventilation times, and ICU and hospital stay support the clinical value of MiECC and align with the majority of published evidence.

Cost-effectiveness is another important consideration. Although MiECC involves higher initial device-related costs, the reductions in transfusion requirements, ICU resources, ventilator support, and hospital length of stay may result in overall cost savings.[17] These aspects are particularly relevant in contemporary cardiac surgery, where both patient outcomes and healthcare resource utilization are under close scrutiny.

Nonetheless, this study has several limitations. First, its retrospective, small sample size and single-center design limit the generalizability of the findings. Second, heterogeneity existed in the cardioplegia solutions used between groups, which may have influenced myocardial protection. Third, despite stratification by comorbidities, the higher baseline risk in the MiECC group may have introduced selection bias when comparing outcomes. However, these limitations do not diminish the clinical relevance of our findings, which suggest that MiECC can provide significant advantages even in high-risk patients.

In conclusion, despite the MiECC group consisting of patients with significantly higher baseline risk profiles, postoperative outcomes were more favorable compared to CECC. The main advantages of MiECC included shorter ICU and hospital stays, reduced mechanical ventilation times, lower drainage volumes, and decreased requirements for blood product transfusions. Although no significant differences were observed in mortality or major complications, our findings indicate that MiECC can be safely applied even in higher-risk populations and may help reduce perioperative morbidity. Future multi-center, large-scale, prospective randomized-controlled studies are warranted to confirm these results and define the role of MiECC in contemporary cardiac surgery.

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