Heart Surgery Forum 2024; 27(12): E1422–E1432
doi: 10.59958/hsf.7725

Article

Evidence of the Advantages of Preoperative Intra-aortic Balloon Pump in Surgical Revascularization of Acute Myocardial Infarction

Ümit Arslan[1,*], Eyüpserhat Çalık[1]

[1]Department of Cardiovascular Surgery, Faculty of Medicine, Ataturk University, 25040 Erzurum, Turkey
*Correspondence: kvcumit@gmail.com (Ümit Arslan)
Submitted: 29 May 2024 Revised: 31 October 2024 Accepted: 5 November 2024 Published: 23 December 2024

Abstract

Background: Early coronary artery bypass grafting (CABG) in patients with acute myocardial infarction (AMI) is associated with considerable risk. The optimal timing of surgery and the preoperative use of an intra-aortic balloon pump (IABP) in these patients remain unclear. **Methods**: To asses the effect of preoperative IABP on troponin levels, surgical timing, and postoperative outcomes, 230 AMI patients scheduled for CABG were divided into two groups: Group A received support with IABP, whereas Group B served as the control group without IABP. The analysis evaluated the preoperative reduction in high-sensitivity cardiac troponin I (hsCTI) levels, timing of surgery, durations of intensive care unit (ICU) and hospital stays (HS), and mortality rates. **Results**: After propensity score matching, Group A comprised 64 patients with a mean age of 63.1 ± 8.9 years, and Group B comprised 92 patients with a mean age of 65.2 ± 8.1 years. In the IABP group, participants exhibited relief from angina symptoms, faster reduction in hsCTI levels, improved transit-time flow measurement (TTFM) of grafts, and shorter ICU and HS durations. The overall mortality rate was 7.1%. However, preoperative IABP support reduced the mortality rate by a factor of 0.6 compared to intraoperative IABP (β = –0.86; Z = –2.41; OR = 0.42, 95% CI: 0.2–0.85; p = 0.016). **Conclusions**: The IABP provides myocardial preconditioning in patients with AMI, thus preparing the myocardium for CABG. Its use should be considered, particularly for high-risk patients. This study has obtained a clinical registration number (NCT number: NCT06468982).

Keywords

acute myocardial infarction; coronary artery bypass surgery; intra-aortic balloon pump; high-sensitivity cardiac troponin I; postoperative complications

Introduction

Acute myocardial infarction (AMI) is caused by coronary artery disease or an imbalance between the heart's oxygen supply and demand and is characterized by the deterioration of cardiac markers and ischemia [1]. Percutaneous coronary intervention (PCI) is the first-line treatment for myocardial ischemia; however, in cases of left main coronary artery disease, multivessel disease, or complex coronary architecture where PCI is not feasible, approximately 10% of patients may require coronary artery bypass grafting (CABG) [2–4]. Although there are studies in the literature addressing optimal surgical planning for AMI patients, CABG clearly poses a significant risk to this patient group [5]. In the 1980s, while surgical reperfusion showed potential for restoring myocardial function, concerns were raised regarding potential damage to myocytes [6]. Avoiding surgical reperfusion in AMI patients is justifiable given the associated 50% mortality rate [7]. The intra-aortic balloon pump (IABP) can benefit patients with ongoing ischemia and elevated cardiac enzymes by altering myocardial oxygen consumption through increased coronary blood flow and reduced afterload [8]. However, current evidence on the preventive effectiveness of IABP remains inconclusive [9]. The IABP-SHOCK II trial (Intra-aortic Balloon Pump in Cardiogenic Shock) [10] found no association between IABP use and 30-day mortality, while Zangrillo *et al*. [11] reported a lower mortality rate. This study aimed to evaluate the effects of preoperative IABP on troponin levels, surgical timing, and intraoperative and postoperative outcomes.

Materials and Methods

The prospective observational cohort study included 268 patients who were hospitalized for AMI and decided for CABG at the cardiology and cardiovascular surgery council. Excluding 38 patients with cardiogenic shock, emergency surgery, and mechanical problems, the study focused on the remaining 230 patients by using propensity scoring. As a result, 156 patients were classified into two groups: Group A, consisting of 64 patients (41%) who received IABP support (Datascope® Medical Co., Ltd., Cambridgeshire, United Kingdom), and the control group (Group B), consisting of 92 patients (59%) who did not receive IABP support.

The patients' medical records, including anamnesis, medical history, physical examination findings, laboratory results, and EuroScore-II scores, were documented. Chest pain severity was evaluated using a scoring system based on the Wong-Baker FACES® pain scale (0–10; Wong-Baker FACES Foundation; from https://wongbakerfaces.org) before IABP insertion and at the 12th and 24th hour after implantation. Laboratory findings included hemoglobin (g/dL), hematocrit (%), platelet count, troponin (ng/mL), creatine kinase isoenzyme MB (CK-MB, U/L), low density lipoprotein (LDL, mg/dL), C-reactive protein (CRP, mg/L), glycated hemoglobin (HbA1c, %), and creatinine (mg/dL). In our hospital laboratory, high-sensitivity cardiac troponin I (hsCTI) was analyzed, with reference values of 0–0.04 ng/mL for both genders (Abbott Core Laboratory Systems®, Lake Forest, USA). Patients with coronary artery disease confirmed by coronary angiography and hsCTI levels exceeding the 99th percentile (0.04 ng/mL) were diagnosed with AMI, irrespective of electrocardiographic (ECG) changes. hsCTI levels were measured at admission and subsequently monitored every morning for both groups until the day of surgery. Patients in Group A were regularly monitored for complications associated with IABP use, such as hematoma and acute arterial ischemia. Echocardiography (ECHO) was performed on the first day to assess ventricular function, ejection fraction (EF%), valve pathologies, ventricular aneurysm, and ventricular septal rupture. Additionally, ECHO was repeated postoperatively to evaluate EF% and to detect pericardial effusion.

Surgical intervention was performed on patients who showed a decline in hsCTI levels or experienced recurrent episodes of chest pain. All procedures were conducted by the same surgical team using a median sternotomy approach under cardiopulmonary bypass (CPB), with an aortic cross-clamp (ACC) applied to achieve complete revascularization based on the vascular anatomy identified during angiography. Following the removal of the ACC, transit-time flow measurement (TTFM; MediStim VQ-1101, Oslo, Norway) was employed to assess graft flow rates [12].

In the postoperative period, the duration of mechanical ventilation (MV; hours), the amount of bleeding (mL; during the initial 24-hour period), the length of intensive care unit (ICU) stay (from the postoperative phase to transfer to the general ward; days), and total hospitalization stay. (HS; from admission to discharge; days) were recorded. Low cardiac output syndrome (LCOS) was defined by the requirement for high doses of positive inotropic agents (such as adrenaline, dobutamine, or noradrenaline) administered by continuous infusion, accompanied by lactic acidosis (>4 mmol/L), sustained hypotension, and reduced or absent urine output. In-hospital mortality was defined as any death occurring within 30 days postoperatively.

Exclusion Criteria

To ensure a homogeneous distribution of risk factors between the groups and to evaluate the impact of IABP on troponin levels, we excluded patients requiring urgent surgery due to iatrogenic cardiac or coronary injuries resulting from angiography, as well as patients with mechanical complications of acute myocardial infarction, such as chordal or ventricular septal rupture. Patients who underwent surgery with the off-pump or on-pump beating heart method were not included in the study. Additionally, patients with peripheral arterial disease, renal failure, a history of cerebrovascular events, or presenting with acute cardiogenic shock or cardiac arrest were excluded from the study.

Indications for Preoperative IABP

The primary indication for utilizing IABP was due to the presence of elevated troponin levels and recurrent or persistent chest pain at rest among the patients included. It was also employed in instances involving hemodynamic instability, multivessel disease, left main coronary artery disease, and narrow and/or tortuous coronary artery anatomy where percutaneous coronary intervention (PCI) was unsuccessful or not feasible. (Fig. 1A–C) The IABP catheter was inserted into the femoral artery by IABP cardiovascular surgeons under local anesthetic. The catheter's placement was verified either in the hybrid room or using portable scopy.

Statistical Analysis

The research was conducted utilizing IBM SPSS 24 (IBM, Armonk, NY, USA) software and R-project version 4.2.3 for statistical analysis. The statistics were provided in terms of mean, standard deviation, median, minimum, maximum, percentage, and count. After testing for normality, baseline characteristics of the two groups were compared using Student's t-test or the Mann–Whitney U-test for continuous variables and chi-square or Fisher's exact tests for categorical variables. Differences between the IABP group and the control group regarding repeatedly measured were analyzed using mixed ANOVA. The prognostic value of risk factors for in-hospital mortality were evaluated by multivariate logistic regression analysis. The propensity score was computed using a logistic regression model. The model incorporated the following covariates: age, gender, creatinine, CK-MB, hs-CTI levels, preoperative left ventricular ejection fraction (LVEF), and EuroScore II. The statistical significance level was accepted as $p < 0.05$.

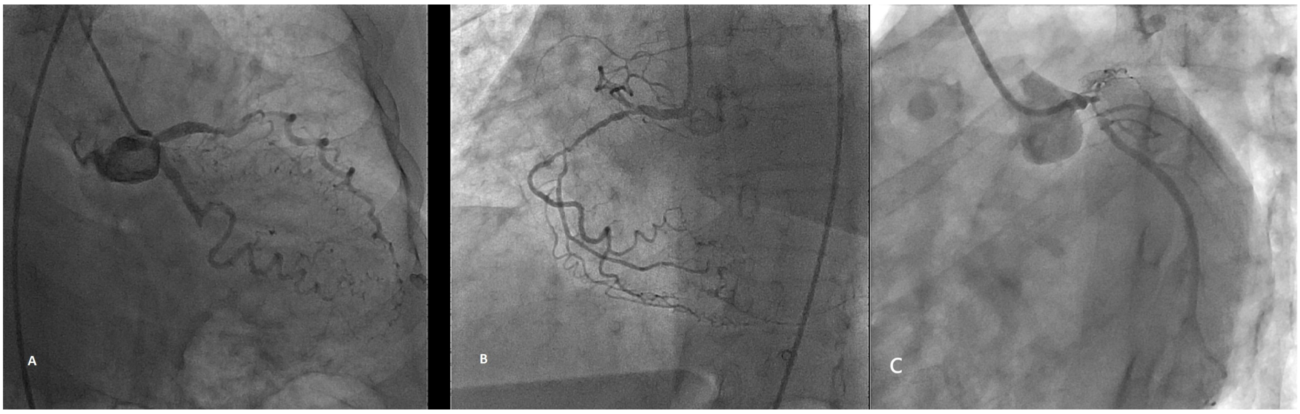

Fig. 1. Preoperative coronary angiography images of two different patients with intra-aortic balloon pump support. (A) A 58-year-old female patient with diabetes had tortuous vascular structure, left main artery stenosis, and circumflex artery occlusion. (B) The same patient had a thin and long lesion in the right coronary artery. (C) A 25-year-old male patient presented with left anterior descending and circumflex artery stenosis extending up to the left main coronary artery, along with stent occlusion in the proximal left anterior descending artery.

Table 1. Preoperative data of patients.

Variable	Unmatched study population			Matched study population		
	IABP (n = 88; 38%)	Control (n = 142; 62%)	*p* value	IABP (n = 64; 41%)	Control (n = 92; 59%)	*p* value
Sex, M/F	62/26	101/41	0.91	47/17	67/25	0.93
Age, (years)	63.4 ± 8.7	64.3 ± 8.0	0.45	63.1 ± 8.9	65.2 ± 8.1	0.12
Hypertension	49	67	0.21	32	46	1
Smoker	45	65	0.42	35	53	0.71
Diabetes	38	60	0.89	27	38	0.91
LVEF%	43.2 ± 7.3	47.3 ± 7.2	<0.01	44.9 ± 7.7	47.9 ± 7.0	0.013
Angina pain score*	7.8 ± 1.7	2.8 ± 1.5	<0.01	7.6 ± 1.8	2.3 ± 1.4	<0.01
EuroScore II	2.6 ± 1.5	2.1 ± 1.3	0.04	2.2 ± 1.4	2.0 ± 1.2	0.37
Hemoglobin (g/dL)	15.1 ± 1.1	15 ± 1.5	0.57	14.9 ± 1.1	14.8 ± 1.7	0.82
Hematocrit (%)	44.1 ± 4.1	44.2 ± 4.8	0.84	44.2 ± 4.3	44.4 ± 4.8	0.79
Platelet count	256 ± 61	245 ± 52	0.23	253 ± 59	247 ± 53	0.49
Creatinine (mg/dL)^a	0.9 ± 0.2	0.9 ± 0.2	0.82	0.94 ± 0.3	0.96 ± 0.2	0.77
CRP (mg/L)	25.8 ± 18.8	24 ± 17.9	0.49	23.4 ± 19.8	21.7 ± 16.4	0.57
LDL (mg/dL)^a	141 ± 29	125 ± 25	<0.01	133 ± 28	126 ± 23	0.24
HbA1c%^{a}	7.8 ± 2.1	6.6 ± 1.7	0.02	7.4 ± 2.3	6.7 ± 1.9	0.06
CK-MB (U/L)	67.8 ± 24.7	55.5 ± 20.8	<0.01	64.5 ± 22.8	56.1 ± 21.6	0.021
hsCTI (ng/mL; day zero)	30.4 ± 21	20.2 ± 19	<0.01	29.2 ± 20.5	17.3 ± 16.6	<0.01
PCI before CABG	47	60	0.41	33	47	0.97
LMCA	56	32	<0.01	52	23	<0.01
Two vessels	16	53	<0.01	16	36	0.08
Three vessels	72	87	0.75	48	76	0.31

M, male; F, female; CABG, coronary artery bypass grafting; CRP, C-reactive protein; CK-MB, creatine kinase MB isoenzyme; hsCTI, high sensitivity cardiac troponin I; IABP, intra-aortic balloon pump; LMCA, left main coronary artery; LVEF, left ventricular ejection fraction; LDL, low density lipoprotein; PCI, percutaneous coronary intervention; HbA1c, glycated hemoglobin.
* Wong-Baker FACES® pain scale (0–10); ^{a} Mann-Whitney U-test.

Results

Both groups were matched in terms of age (p = 0.12) and gender distribution (p = 0.93). Group A (IABP support) consisted of 64 patients (male/female; 47/17) with a mean age of 63.1 ± 8.9 years (range 39–82). Group B (control group; without IABP support) consisted of 92 patients (male/female; 67/25) with a mean age of 65.2 ± 8.1 years (range 35–84). The patients' demographic and clinical features, Euroscore-II scores, and laboratory data are displayed in Table 1. Patients in the IABP group experienced more se-

Table 2. Daily measurements of troponin levels in the groups.

	n (patient)		hsCTI level (ng/mL)		
Days	Group A*	Group B**	Group A	Group B	*p* value
0.	64	92	29.2 ± 20.5	17.3 ± 16.6	<0.001
1.	64	92	23.2 ± 17.7	16.7 ± 16.3	0.023
2.	64	92	15.8 ± 13.2	14.9 ± 14.8	0.68
3.	64	92	9.9 ± 9.3	12.3 ± 12.6	0.15
4.	56	92	5.9 ± 6.2	9.5 ± 12.8	0.022
5.	36	88	4.4 ± 4.5	6.9 ± 10	0.06
6.	23	73	2.3 ± 2.2	5.3 ± 7.5	0.003
7.	9	50	1.5 ± 1.7	4.2 ± 5.6	0.008
8.	4	35	0.7 ± 0.6	2.8 ± 3.5	0.24
9.		20		2.1 ± 2.2	
10.		11		1.4 ± 1.4	
11.		4		0.9 ± 0.6	

hsCTI, high sensitivity cardiac troponin I (normal range 0–0,04 ng/mL).
*IABP group, **without IABP group.

vere angina, had more tortuous vascular structures, and had a greater number of affected coronary arteries. Based on HbA1c values, individuals with diabetes in Group A had worse glucose control (7.4 ± 2.3 and 6.7 ± 1.9; $p = 0.06$; respectively). Additionally, among the 27 diabetic patients in Group A, nine were using insulin, while another nine with HbA1c values above 10% were not on any antidiabetic medication.

Patients in Group B had a pain score of 2.3 ± 1.4, whereas patients in Group A experienced a higher severity of chest pain, with a pre-IABP score of 7.6 ± 1.8. This score decreased to 3.5 ± 2.1 at the 12th hour and further declined to 2.0 ± 2.0 at the 24th hour ($p < 0.01$).

On day zero, patients in Group A exhibited elevated hsCTI levels (29.2 ± 20.5 vs. 17.3 ± 16.6 ng/mL; $p < 0.01$) and reduced EF% values (44.9 ± 7.7% vs. 47.9 ± 7%; $p = 0.013$). Daily hsCTI values are presented in Table 2, and as shown in Table 3, hsCTI levels in both groups decreased over time (Tables 2,3). This decline in hsCTI levels was an expected outcome, likely due to the redistribution of blood flow in the myocardium over time and nutrient supply through collateral development. However, IABP support appears particularly beneficial in reducing hsCTI levels during the first four days. By the 5th day, the nearly 50% reduction in the number of patients in Group A may have impacted the validity of hsCTI measurements.

Surgery was performed on patients with decreasing hsCTI values or those exhibiting a tendency for increasing hsCTI levels accompanied by recurrent chest discomfort. The timing of surgery was shorter in Group A, with an average of 5.0 ± 1.2 days (range: 4th to 8th day), compared to Group B, which had an average of 7.04 ± 1.7 days (range: 5th to 11th day) ($p < 0.001$). Intraoperative data are presented in Table 4. No significant differences were observed in CPB times ($p = 0.95$), ACC times ($p = 0.49$), or the number of anastomoses ($p = 0.96$). However, patients with elevated HbA1c exhibited approximately 15% longer CPB durations ($p = 0.032$), highlighting the adverse impact of diabetes on the cardiovascular system.

TTFM assessments indicated that the IABP group had higher pulse index (PI), flow, and diastolic flow fraction (DF%) values, with particularly notable increases in flow and DF% for the left anterior descending artery (LAD) and right coronary artery (RCA) anastomoses. Fig. 2 presents TTF measurements of the left internal mammary artery (LIMA) graft before and after IABP activation, following CPB termination (Fig. 2A,B). Given that LIMA functions as an arterial graft supplying blood during systole, and IABP enhances diastolic flow, elevated flow and DF% readings were anticipated. The higher average flow in the RCA may reflect the right ventricle's blood supply characteristics, as it receives blood during both systole and diastole (Table 4). Considering factors like graft length, resistance, coronary anatomy, and probe position can impact TTF measurements. A standardized study is needed to confirm the effect of IABP on TTFM. In two patients from Group A and five from Group B, the LIMA-LAD anastomosis was revised due to inadequate flow. Papaverine hydrochloride was administered to optimize flow in the LIMA graft, which showed good PI and DF% values but low average flow. Additionally, saphenous grafts were evaluated and repositioned as needed.

Postoperative findings are detailed in Table 5. The overall mortality rate was 7.1% (11/156), with four patients (6.3%) in Group A and seven patients (7.6%) in Group B who died from various causes ($p = 0.74$). Although mortality rates between the two groups were not statistically different, a multivariable survival analysis conducted post-surgery indicated a favorable effect of IABP on survival (HR 0.55, 95% CI 0.38–0.78; $p = 0.001$). The surgical timing for patients who died was, on average, 3.2 ± 0.5 days in Group A, whereas it was 6.7 ± 0.95 days in Group B. Early

Table 3. Reduction in troponin levels over consecutive days.

	Group A			Group B			
Between days	Difference	Rate %	p value^a	Difference	Rate %	p value^a	p value^b
1.-0.	–6.0 ± 8.6	21	<0.01	–5.5 ± 6.7	7	0.18	<0.01
2.-1.	–7.3 ± 7.5	30	<0.01	–1.8 ± 4.2	10	<0.01	<0.01
3.-2.	–5.9 ± 5.6	42	<0.01	–2.5 ± 4.7	16	<0.01	<0.01
4.-3.	–4.9 ± 5.0	50	<0.01	–2.8 ± 4.9	32	<0.01	0.013
5.-4.	–3.3 ± 2.7	48	<0.01	–3.0 ± 3.9	42	<0.01	0.76
6.-5.	–3.3 ± 3.2	57	<0.01	–2.8 ± 3.4	48	<0.01	0.55
7.-6.	–2.2 ± 1.3	65	0.008	–3.2 ± 3.6	55	<0.01	0.38

$^a p$ = value within the group; $^b p$ = value between groups.

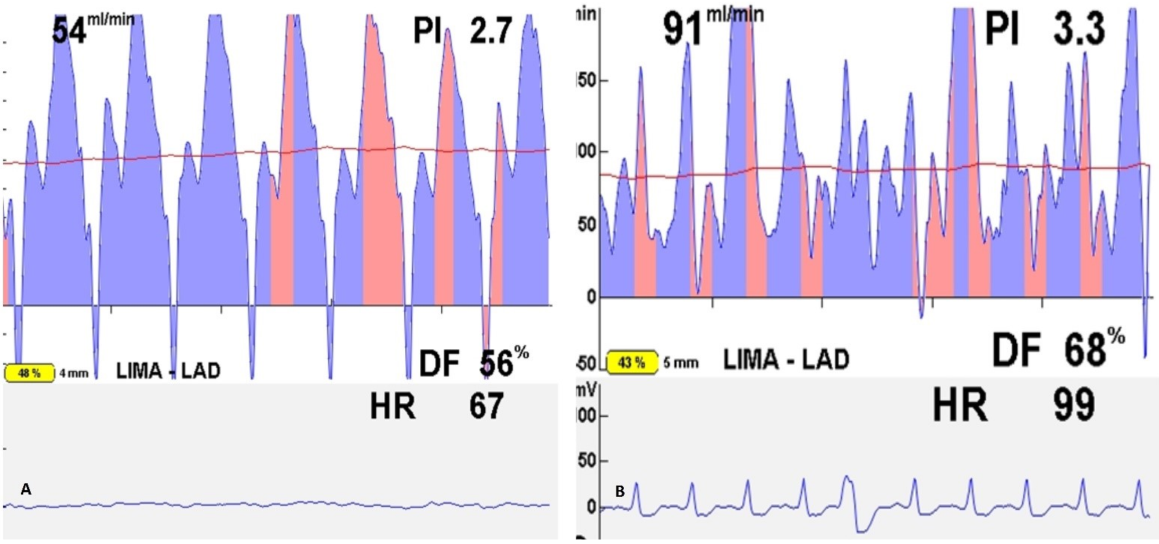

Fig. 2. Effect of intra-aortic balloon pump (IABP) on flow in left internal mammary artery-left anterior descending artery (LIMA-LAD) anastomosis. (A) Transit-time flow measurement of the LIMA graft before activated IABP. (B) Transit-time flow measurement of the LIMA graft after activated IABP.

surgery was associated with a 1.06-fold increase in mortality, although this was not statistically significant (OR 1.06; 95% CI 0.76–1.5; p = 0.72). Notably, an average of 6.4 ± 1.4 days of IABP support reduced mortality by 0.6 times compared to intraoperative IABP (β = –0.86; Z = –2.41; OR 0.42, 95% CI 0.2–0.85; p = 0.016), potentially reflecting the positive effect of preoperative IABP support.

In Group A, two patients died due to low cardiac output syndrome (LCOS), and one patient experienced a cerebrovascular event within the first week after their surgery. Another patient was diagnosed with COVID-19 and was subsequently admitted to the critical care unit on the 9th day of follow-up due to respiratory failure. Regrettably, the patient passed away. Three patients in Group B died from LCOS requiring extracorporeal membrane oxygenation (ECMO), while four patients died from stroke. LCOS was identified in a total of seven patients: two in Group A and five in Group B (p = 0.39). Two patients in the IABP group who died from LCOS exhibited elevated troponin levels at baseline, indicating a 2200-fold increase compared to those in Group B. Two patients in Group B completed the surgery with intraoperative IABP support. Although three patients had intraoperative IABP insertion, they ultimately required ECMO support to complete the procedure due to inadequate hemodynamics.

The comparison between the two groups revealed no significant differences in the duration of mechanical ventilation (p = 0.15), incidence of atrial fibrillation (p = 0.82), or cerebrovascular events (p = 0.31). However, Group A experienced a significantly greater increase in creatinine levels compared to Group B after surgery (p = 0.049). Group A exhibited a substantial increase of 0.21 ± 0.4 mg/dL (p < 0.01), while Group B showed an increase of 0.07 ± 0.3 mg/dL (p = 0.06).

The IABP group experienced more bleeding in the first 24 hours, with an average of 527 ± 256 mL compared to 460 ± 188 mL in the control group (p = 0.17). However, a greater number of patients in Group A required a revision due to bleeding (n = 9 vs. n = 4; p = 0.031).

IABP support was discontinued as quickly as feasible during the postoperative phase, considering the hemodynamic features. The average time from IABP insertion

Table 4. Intraoperative data between groups.

Variable	Group A (with IABP)	Group B (without IABP)	*p* value
CPB time(min)	100.1 ± 25.8	99.9 ± 26.6	0.95
ACC time(min)	48.3 ± 15.3	50.1 ± 16.3	0.49
Distal anastomosis	3.1 ± 0.9	3.1 ± 0.8	0.96
Transit-time flow measurement			
LAD (n = 156)			
PI	3.3 ± 0.9	3.0 ± 1.4	0.06
Flow*	64.8 ± 23.4	56.8 ± 21.8	0.03
DF%	75.3 ± 7.5	66.9 ± 10.7	<0.001
Cx (n = 113)			
PI	3.5 ± 1.1	3.3 ± 1.3	0.32
Flow	51.9 ± 18.9	47.4 ± 15.3	0.13
DF%	65.2 ± 9.4	64.1 ± 7.7	0.44
RCA (n = 118)			
PI	3.4 ± 1.0	3.0 ± 1.3	0.07
Flow	57.7 ± 19.5	49.5 ± 21.4	0.03
DF%	66.3 ± 7.5	63.3 ± 8.2	0.04
D1 (n = 57)			
PI	3.0 ± 1.2	2.9 ± 1.3	0.71
Flow	54.3 ± 22.7	45.9 ± 13	0.12
DF%	66.9 ± 10.3	64.9 ± 7.6	0.42
RIM (n = 23)			
PI	3.1 ± 1.0	2.8 ± 1.1	0.61
Flow	56 ± 19.4	44.2 ± 18.3	0.15
DF%	67.7 ± 4.8	64.3 ± 5.2	0.12

CPB, cardiopulmonary bypass; ACC, aortic cross-clamp; IABP, intra-aortic balloon pump LAD, left anterior descending artery; Cx, circumflex artery; RCA, right coronary artery; D1, diagonal artery; RIM, ramus intermedius artery; PI, pulsatility index; DF%, diastolic filling percentage.
*Flow, mean flow (mL/min).

to removal was 6.4 ± 1.4 days, while the duration from IABP removal after surgery was approximately 1.4 ± 1.1 days. Additionally, two patients required early removal of the IABP shortly after surgery due to lower limb pain. The patients' pulses were detectable, and no further intervention was necessary as there was no evidence of ischemia.

The duration of stay in ICU ($p = 0{,}01$) and the HS ($p < 0.01$) were shorter in Group A. The rapid reduction in troponin levels and the earlier operation in patients receiving IABP support can both account for the short length of stay in the ICU and HS.

EF% was measured in the first month of outpatient follow-up. Group A (n = 60) showed a 4.8 ± 9.4 rise in EF values (+14% compared to preoperative value; $p < 0.01$), while group B (n = 85) showed a 2.1 ± 8.4 increase (+7% compared to preoperative value; $p = 0.023$). However, EF improvement was not significantly different between groups ($p = 0.76$).

Discussion

This study demonstrated that preoperative IABP support provides benefits to patients with AMI undergoing CABG.

Ensuring coronary perfusion through PCI or CABG facilitates repair at the myocyte level by reducing or preventing ischemic episodes, thereby supporting myocardial survival. CABG remains a crucial treatment option despite its high risks, particularly for patients who are unable to undergo PCI [4,13,14]. Although there are no randomized controlled trials directly comparing percutaneous and surgical revascularization in patients with AMI, CABG is highly beneficial because, unlike stents, it can supply blood to the myocardium through anastomosis and enhance collateral flow [15–17].

The European Society of Cardiology outlined the criteria for emergency CABG in patients with AMI in the "2023 ESC Guidelines for the Management of Acute Coronary Syndromes" [3]. According to this guideline, emergency surgery is recommended for patients with anatomy unsuitable for PCI, those experiencing shock or mechanical complications, or when a large myocardial area is at risk. Thirty-eight patients were excluded from the study due to undergoing emergency surgery prompted by critical conditions. Our view is that cardiologists should notify cardiac surgeons at the initial intervention stage for patients whose clinical status indicates potential complications, allowing for timely preparation and minimizing delays.

However, the optimal timing for surgical revascularization in patients with AMI remains a challenging consideration for cardiac surgeons. It is unsurprising that the literature offers differing views on the optimal timing of surgery, as individual risk factors are greatly influenced by the extent of myocardial damage and the severity of coronary artery disease. A metanalysis by Chen and Liu [7], indicates that performing CABG more than two days after the onset of AMI, particularly after one week, is linked to lower mortality rates compared to surgeries conducted within the first two days. Lee *et al.* [18] discovered that mortality rates significantly declined after the first day compared to the initial twelve hours, and they suggested that aggressive support devices should be available if early CABG is planned. The California discharge data analysis [19] revealed that AMI patients who underwent CABG within the first 48 hours experienced higher mortality rates due to inadequate collateral circulation. Kim *et al.* [20] reported that if surgical revascularization is not performed on the first day, it should be delayed until after the third day. A metanalysis by Lang *et al.* [21], included 19 studies, and suggests that surgery, particularly in STEMI patients, should be performed after 24 hours, and Patlolla *et al.* [22] further indicate that revascularization performed between days 1 and 7 appears to offer greater benefits in long-term follow-up.

Table 5. Postoperative parameters between groups.

Variable	Group A	Group B	p value
Mortality (within 30 d)	4	7	0.74
LCOS[a]	2	5	0.39
Intraoperative IABP insertion	-	2	-
ECMO	0	3	0.14
Creatinine increase (mg/dL)	0.2 ± 0.4	0.07 ± 0.3	0.049
Neurological complications	1	4	0.31
Atrial fibrillation[b]	12	16	0.82
Drainage (mL)[c]	527 ± 256	460 ± 188	0.17
Surgical revision for bleeding[b]	9	4	0.03
Mechanical ventilation (h)	6 ± 1.6	6.5 ± 1.8	0.15
ICU stay (days)	2.7 ± 0.9	3.3 ± 1.5	0.01
Hospital stay (days)	14 ± 1.7	17.2 ± 2	<0.01
LVEF increase % (first month)	14%	7%	0.76

IABP, intra-aortic balloon pump; ICU, intensive care unit; LCOS, low cardiac output syndrome; LVEF, left ventricular ejection fraction; ECMO, extracorporeal membrane oxygenation.

[a] Fisher's Exact Test; [b] Pearson Chi-Square; [c] Mann-Whitney U-test.

The retrospective study by Bernard *et al*. [23] supports our perspective, highlighting that the risk associated with surgery is particularly elevated within the first four days. Nevertheless, they emphasize that the patient's overall health status and the severity of the disease are more crucial considerations than the timing of the procedure. At our clinic, we monitor patients who have experienced AMI in the intensive care unit, except for those requiring urgent surgical intervention (for example, patients with coronary dissection, escalating ischemic symptoms, or persistent hemodynamic instability). During this period, we wait for troponin levels to decrease and allow time for the myocardium to recover from acute stress. According to the data from our study, we also believe that CABG should not be performed early and that the waiting period should be at least four days.

A significant benefit for patients who do not undergo early CABG is the opportunity to assess and address modifiable risk factors. Solodky *et al*. [24] highlighted diabetes and hyperlipidemia as significant among patients with acute coronary syndrome. In our study, the ratio of male to female patients was almost 3:1, and LDL levels were greater than 150 mg/dL in 36 participants in group A (Table 1). Diabetic patients with HbA1c levels above 10% who remain untreated may suffer heightened negative impacts of diabetes on the heart. Although not statistically significant, we observed a positive correlation between HbA1c levels and troponin levels (estimate = 1.12; 95% CI 0.36–2.6; p = 0.13). Mehri *et al*. [25] demonstrated that the positive association between HbA1c and troponin levels (r = 0.244; p = 0.001) influenced the rate pressure product (RPP; heart rate multiplied by systolic blood pressure), a strong predictor of AMI. Although HbA1c levels were significantly higher in Group A, our control group included patients with AMI rather than healthy individuals, similar to the study by Mehri *et al*. [25].

IABP support may be indicated for patients with elevated troponin levels and persistent chest pain, left main coronary artery stenosis, proximal triple-vessel disease, or thin vascular structures, thereby allowing the myocardium adequate time to recover from ischemic burden and reducing the need for emergency CABG. We noted a reduction in chest pain score within the initial 24 hours in individuals with IABP. IABP reduces the incidence and severity of angina pectoris, according to Gold *et al*. [26], and patients whose symptoms returned after discontinuing IABP treatment had a significantly increased risk of angina recurrence. Relief of angina may indicate that coronary perfusion has started to improve and that myocardial stress has decreased, thereby ensuring endocardial viability. The decline in scores for chest pain related to ischemia may lack specificity due to factors such as the high prevalence of vitamin D deficiency in our high-altitude region, musculoskeletal pain associated with aging, the patient's anxiety levels, and challenges in pinpointing the origin of the disease.

Elevated troponin levels are correlated with myocardial injury and have an adverse impact on prognosis [1]. The plasma half-life of hsCTI in healthy individuals is approximately 120 minutes, while it is prolonged in cases of myocardial ischemia. A decrease in hsCTI levels indicates a faster recovery of the myocardium. The reduction in EF% in Group A, along with elevated hsCTI levels, is indicative of this process (44.9 ± 7.7% versus 47.9 ± 7.0%, p = 0.013). In light of the favorable impacts of IABP, we investigated its influence on hSCTI levels. While the levels of hsCTI fell in both groups over time, the decrease was more rapid in the IABP group, particularly during the first four days. (Tables 2,3) Grieshaber *et al*. [27] discovered that troponin levels in 150 patients with AMI who received IABP support fell from high levels before IABP to the lowest level4 days after surgery. This decrease may be significant because CABG increases collateral circulation. Our research did not focus on hsCTI during the postoperative period because we assumed that the effect of surgery would naturally lead to an elevation in troponin levels.

During bridging, IABP support maintains the balance between oxygen delivery and consumption, which is crucial for attenuating ischemic injury by increasing systolic unloading, enhancing diastolic coronary flow, and facilitating self-regulatory mechanisms. Potential complications, including bleeding, limb ischemia, stroke, infection, IABP malfunction, hematoma, and other vascular issues, should be considered during the waiting period. There is currently no consensus regarding the optimal timing and specific indications for preoperative IABP support [8]. Baskett *et al*. [28] observed a significant rise in the use of preoperative IABP over the past six years, with variations across different centers. In our study, the timing of IABP administration was distinct from previous research [8]; it was neither administered within 0–24 hours prior to surgery nor immediately following anesthesia induction. We are of the opinion that the beneficial effects of IABP on cardiac function provide substantial therapeutic support, rather than merely serving a prophylactic purpose.

Cardiovascular surgeons utilize IABP to enable high-risk patients to undergo procedures with minimal complications, due to its ease of application and lower cost compared to alternative mechanical support devices. Although the criteria for identifying high-risk patients vary between clinics, the outcomes following preoperative IABP administration also differ. Christenson *et al*. [29] recommend preoperative IABP because of its positive effects on cardiac index and mortality rates, as well as its ability to reduce the duration of CPB and length of ICU stay. Additionally, they reported favorable outcomes in patients undergoing redo-CABG [30]. Studies suggest that preoperative IABP use is associated with higher survival rates compared to intraoperative IABP [29,30]. Patients who received intraoperative IABP had a 16-fold increased risk of death within 30 days [31,32]. The addition of mechanical support to high-dose inotropic therapy in patients unable to wean from CPB indicates poor prognosis, thereby anticipating high mortality rates. Nevertheless, the impact of additional variables on mortality should not be overlooked [33].

Conflicting research exists regarding the beneficial impact of preoperative IABP support. According to Ranucci *et al*. [34], IABP should not be administered immediately prior to surgical incision in patients with an EF below 35%. Findings by Ranucci *et al*. [34] may be justified by the suboptimal effect of administering IABP immediately before incision on the myocardium undergoing stress during CABG. In our practice, we administer IABP to patients with low EF% scheduled for CABG several days prior to surgery rather than immediately before incision. This approach allows the myocardium to recover and provides preconditioning. Yu *et al*. [35] conducted a retrospective analysis of 877 patients and found that the IABP group exhibited higher in-hospital morbidity and mortality rates, extended ICU stays, and increased transfusion requirements. Given the complication rates, a prolonged ICU stay is expected, leading to longer overall hospital stays. Surprisingly, the mortality rate for IABP patients was 2.5%, despite a complication incidence of 24.1%. Similarly, Samanidis *et al*. [36] found no difference in 30-day mortality or length of HS between preoperative and intraoperative insertion of IABP. In the study by Samanidis *et al*. [36], all types of cardiac surgeries were included except off-pump CABG, and the rate of preoperative IABP support was reported as only 8.7%. We believe that a more focused study is essential to fully understand the impact of IABP.

The design of our investigation closely resembled the study conducted by Grieshaber *et al*. [27]. Grieshaber *et al*. [27] developed a specific model by excluding patients presenting with shock or LCOS, as well as those undergoing concomitant surgery, and by including patients who had suffered from MI at least five days prior. After creating the matched study population, there was a substantial reduction in cardiac markers among patients receiving IABP support, particularly troponin (p = 0.035). Additionally, preoperative IABP was found to be protective against in-hospital mortality (HR 0.56; 95% CI 0.23–0.74; p = 0.021). However, the incidence of acute kidney injury (AKI) was higher, and the duration of ICU and HS was longer in the IABP group. In contrast, the study conducted by Yang *et al*. [37] supports our findings by demonstrating that high-risk patients who received IABP prior to surgery were discharged earlier. However, higher postoperative creatinine levels ($p < 0.01$) and moderately increased postoperative hemorrhage observed in Group A patients (p = 0.17) may be regarded as potential adverse effects of IABP. The administration of dual antiplatelet therapy (clopidogrel and acetylsalicylic acid) in conjunction with low molecular weight heparin in IABP patients may contribute to the increased bleeding observed (Table 5).

The overall mortality rate was 7.1%. (6.3% in Group A and 7.6% in Group B; p = 0.74). The favorable effect of IABP is supported by the fact that it reduces the mortality rate by 0.6 times when started in the preoperative phase and continued until the early postoperative period (p = 0,016). We agree with Grieshaber *et al*.'s [27] assertion that IABP has a protective effect on mortality (HR 0.55, 95% CI 0.38–0.78; p = 0.001). Our results, such as LCOS and mortality rates, ICU stay, and hospital stay duration, are similar to the findings of the study conducted by Miceli *et al*. [38]. Two patients in Group A who developed LCOS died. Both of these patients exhibited significantly elevated troponin levels and required prompt surgical intervention as a result of their persistent angina. This suggests that it is a more suitable strategy to delay the procedure without subjecting the heart muscle to an additional strain in patients with AMI who are scheduled to undergo CABG.

Limitations

The following are our study's constraints: (1) Using multiple troponin test kits would provide a more comprehensive evaluation of the impact of IABP on troponin levels, but in our hospital, we just use one kit. (2) Our institution does not provide every patient a Swan-Ganz catheter or cardiac index device. In our IABP impact study, this led to insufficient results. (3) The severity of angina pectoris at hospital admission prevented precise scoring. (4) Studies on the effect of IABP on heart function and long-term survival may yield more meaningful results.

Conclusions

Although indications for IABP use may vary among clinics, its application in AMI patients undergoing CABG is beneficial for relieving angina, decreasing hsCTI levels by enhancing myocardial perfusion, and preconditioning the myocardium for surgery. Additionally, it promotes faster postoperative recovery of the myocardium by improving the flow through coronary bypass grafts [39,40]. IABP also reduces hospital costs by shortening the duration of ICU and overall hospital stay. Given its ease of application, lower cost compared to other mechanical support devices, and the numerous positive outcomes reported in meta-analyses, it should be considered for patients with AMI who are at risk, particularly in the context of surgical revascularization [8,41,42]. Randomized controlled trials utilizing invasive hemodynamic monitors that measure cardiac output are likely to offer a clearer understanding of the effects of IABP.

Availability of Data and Materials

The original data of this article can be requested from the corresponding author on reasonable grounds.

Author Contributions

ÜA designed this study and obtained the data. ÜA and ESÇ interpreted and analyzed the data. ESÇ prepared the draft of the work. ÜA revised it critically for important intellectual content. All authors read and approved the final manuscript. All authors read and approved the final manuscript. All authors agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Ethics Approval and Consent to Participate

The study was carried out according to the Declaration of Helsinki and approved by the Erzurum City Hospital Ethics Committee, (2021-07-137) and the informed consent for surgical or interventional procedures was obtained from the patients and their families (NCT number: NCT06468982).

Acknowledgment

Not applicable.

Funding

This research received no external funding.

Conflict of Interest

The authors declare no conflict of interest.

References

[1] Thygesen K, Alpert JS, Jaffe AS, Chaitman BR, Bax JJ, Morrow DA, *et al*. Fourth Universal Definition of Myocardial Infarction (2018). Circulation. 2018; 138: e618–e651. https://doi.org/10.1161/CIR.0000000000000617.

[2] Hwang B, Williams ML, Tian DH, Yan TD, Misfeld M. Coronary artery bypass surgery for acute coronary syndrome: A network meta-analysis of on-pump cardioplegic arrest, off-pump, and on-pump beating heart strategies. Journal of Cardiac Surgery. 2022; 37: 5290–5299. https://doi.org/10.1111/jocs.17149.

[3] Byrne RA, Rossello X, Coughlan JJ, Barbato E, Berry C, Chieffo A, *et al*. 2023 ESC Guidelines for the management of acute coronary syndromes. European Heart Journal. 2023; 44: 3720–3826. https://doi.org/10.1093/eurheartj/ehad191.

[4] Caceres M, Weiman DS. Optimal timing of coronary artery bypass grafting in acute myocardial infarction. The Annals of Thoracic Surgery. 2013; 95: 365–372. https://doi.org/10.1016/j.athoracsur.2012.07.018.

[5] Neumann FJ, Sousa-Uva M, Ahlsson A, Alfonso F, Banning AP, Benedetto U, *et al*. 2018 ESC/EACTS Guidelines on myocardial revascularization. European Heart Journal. 2019; 40: 87–165. https://doi.org/10.1093/eurheartj/ehy394.

[6] Roberts CS, Schoen FJ, Kloner RA. Effect of coronary reperfusion on myocardial hemorrhage and infarct healing. The American Journal of Cardiology. 1983; 52: 610–614. https://doi.org/10.1016/0002-9149(83)90036-x.

[7] Chen HL, Liu K. Timing of coronary artery bypass graft surgery for acute myocardial infarction patients: a meta-analysis. International Journal of Cardiology. 2014; 177: 53–56. https://doi.org/10.1016/j.ijcard.2014.09.127.

[8] Pilarczyk K, Boening A, Jakob H, Langebartels G, Markewitz A, Haake N, *et al*. Preoperative intra-aortic counterpulsation in high-risk patients undergoing cardiac surgery: a meta-analysis of randomized controlled trials†. European Journal of Cardio-

thoracic Surgery: Official Journal of the European Association for Cardio-thoracic Surgery. 2016; 49: 5–17. https://doi.org/10.1093/ejcts/ezv258.

[9] Poirier Y, Voisine P, Plourde G, Rimac G, Barria Perez A, Costerousse O, *et al*. Efficacy and safety of preoperative intra-aortic balloon pump use in patients undergoing cardiac surgery: a systematic review and meta-analysis. International Journal of Cardiology. 2016; 207: 67–79. https://doi.org/10.1016/j.ijcard.2016.01.045.

[10] Thiele H, Zeymer U, Neumann FJ, Ferenc M, Olbrich HG, Hausleiter J, *et al*. Intraaortic balloon support for myocardial infarction with cardiogenic shock. The New England Journal of Medicine. 2012; 367: 1287–1296. https://doi.org/10.1056/NEJMoa1208410.

[11] Zangrillo A, Pappalardo F, Dossi R, Di Prima AL, Sassone ME, Greco T, *et al*. Preoperative intra-aortic balloon pump to reduce mortality in coronary artery bypass graft: a meta-analysis of randomized controlled trials. Critical Care (London, England). 2015; 19: 10. https://doi.org/10.1186/s13054-014-0728-1.

[12] Kaya U, Çolak A, Becit N, Ceviz M, Koçak H. Intraoperative transit-time flow measurement in on-pump coronary artery bypass graft surgery: Single center experience. Turk Gogus Kalp Damar Cerrahisi Dergisi. 2018; 26: 167–176. https://doi.org/10.5606/tgkdc.dergisi.2018.15004.

[13] Landon BE, Hatfield LA, Bakx P, Banerjee A, Chen YC, Fu C, *et al*. Differences in Treatment Patterns and Outcomes of Acute Myocardial Infarction for Low- and High-Income Patients in 6 Countries. JAMA. 2023; 329: 1088–1097. https://doi.org/10.1001/jama.2023.1699.

[14] Wu X, Reboll MR, Korf-Klingebiel M, Wollert KC. Angiogenesis after acute myocardial infarction. Cardiovascular Research. 2021; 117: 1257–1273. https://doi.org/10.1093/cvr/cvaa287.

[15] Head SJ, Milojevic M, Daemen J, Ahn JM, Boersma E, Christiansen EH, *et al*. Mortality after coronary artery bypass grafting versus percutaneous coronary intervention with stenting for coronary artery disease: a pooled analysis of individual patient data. Lancet (London, England). 2018; 391: 939–948. https://doi.org/10.1016/S0140-6736(18)30423-9.

[16] Lawton JS, Tamis-Holland JE, Bangalore S, Bates ER, Beckie TM, Bischoff JM, *et al*. 2021 ACC/AHA/SCAI Guideline for Coronary Artery Revascularization: Executive Summary: A Report of the American College of Cardiology/American Heart Association Joint Committee on Clinical Practice Guidelines. Circulation. 2022; 145: e4–e17. https://doi.org/10.1161/CIR.0000000000001039.

[17] Doenst T, Haverich A, Serruys P, Bonow RO, Kappetein P, Falk V, *et al*. PCI and CABG for Treating Stable Coronary Artery Disease: JACC Review Topic of the Week. Journal of the American College of Cardiology. 2019; 73: 964–976. https://doi.org/10.1016/j.jacc.2018.11.053.

[18] Lee DC, Oz MC, Weinberg AD, Lin SX, Ting W. Optimal timing of revascularization: transmural versus nontransmural acute myocardial infarction. The Annals of Thoracic Surgery. 2001; 71: 1197–1202; discussion 1202–1204. https://doi.org/10.1016/s0003-4975(01)02425-0.

[19] Weiss ES, Chang DD, Joyce DL, Nwakanma LU, Yuh DD. Optimal timing of coronary artery bypass after acute myocardial infarction: a review of California discharge data. The Journal of Thoracic and Cardiovascular Surgery. 2008; 135: 503–511, 511.e1–511.e3. https://doi.org/10.1016/j.jtcvs.2007.10.042.

[20] Kim HH, Lee M, Yoo KJ. Optimal Revascularization Timing of Coronary Artery Bypass Grafting in Acute Myocardial Infarction. Clinical Cardiology. 2024; 47: e24325. https://doi.org/10.1002/clc.24325.

[21] Lang Q, Qin C, Meng W. Appropriate Timing of Coronary Artery Bypass Graft Surgery for Acute Myocardial Infarction Patients: A Meta-Analysis. Frontiers in Cardiovascular Medicine. 2022; 9: 794925. https://doi.org/10.3389/fcvm.2022.794925.

[22] Patlolla SH, Crestanello JA, Schaff HV, Pochettino A, Stulak JM, Daly RC, *et al*. Timing of coronary artery bypass grafting after myocardial infarction influences late survival. JTCVS Open. 2024; 20: 40–48. https://doi.org/10.1016/j.xjon.2024.05.008.

[23] Bernard C, Morgant MC, Jazayeri A, Perrin T, Malapert G, Jazayeri S, *et al*. Optimal Timing of Coronary Artery Bypass Grafting in Haemodynamically Stable Patients after Myocardial Infarction. Biomedicines. 2023; 11: 979. https://doi.org/10.3390/biomedicines11030979.

[24] Solodky A, Behar S, Boyko V, Battler A, Hasdai D. The outcome of coronary artery bypass grafting surgery among patients hospitalized with acute coronary syndrome: the Euro Heart Survey of acute coronary syndrome experience. Cardiology. 2005; 103: 44–47. https://doi.org/10.1159/000081851.

[25] Mehri S, Chaaba R, Finsterer J, Khamlaoui W, Hammami S, Hammami M. Relevance of oxidative stress biomarkers, hemoglobin A1c, troponin-I, and angiotensin-converting enzyme metabolism to blood pressure in acute myocardial infarction: a case-control study. Redox Report: Communications in Free Radical Research. 2023; 28: 2209360. https://doi.org/10.1080/13510002.2023.2209360.

[26] Gold HK, Leinbach RC, Buckley MJ, Mundth ED, Daggett WM, Austen WG. Refractory angina pectoris: follow-up after intraaortic balloon pumping and surgery. Circulation. 1976; 54: III41–6.

[27] Grieshaber P, Schneider T, Oster L, Orhan C, Roth P, Niemann B, *et al*. Prophylactic intra-aortic balloon counterpulsation before surgical myocardial revascularization in patients with acute myocardial infarction. Perfusion. 2018; 33: 390–400. https://doi.org/10.1177/0267659118760384.

[28] Baskett RJF, O'Connor GT, Hirsch GM, Ghali WA, Sabadosa K, Morton JR, *et al*. A multicenter comparison of intraaortic balloon pump utilization in isolated coronary artery bypass graft surgery. The Annals of Thoracic Surgery. 2003; 76: 1988–1992; discussion 1992. https://doi.org/10.1016/s0003-4975(03)01197-4.

[29] Christenson JT, Simonet F, Badel P, Schmuziger M. The effect of preoperative intra-aortic balloon pump support in patients with coronary artery disease, poor left-ventricular function (LVEF $<$ 40%), and hypertensive LV hypertrophy. The Thoracic and Cardiovascular Surgeon. 1997; 45: 60–64. https://doi.org/10.1055/s-2007-1013688.

[30] Christenson JT, Badel P, Simonet F, Schmuziger M. Preoperative intraaortic balloon pump enhances cardiac performance and improves the outcome of redo CABG. The Annals of Thoracic Surgery. 1997; 64: 1237–1244. https://doi.org/10.1016/S0003-4975(97)00898-9.

[31] Marra C, De Santo LS, Amarelli C, Della Corte A, Onorati F, Torella M, *et al*. Coronary artery bypass grafting in patients with severe left ventricular dysfunction: a prospective randomized study on the timing of perioperative intraaortic balloon pump support. The International Journal of Artificial Organs. 2002; 25: 141–146. https://doi.org/10.1177/039139880202500209.

[32] Böning A, Buschbeck S, Roth P, Scheibelhut C, Bödeker RH, Brück M, *et al*. IABP before cardiac surgery: clinical benefit compared to intraoperative implantation. Perfusion. 2013; 28: 103–108. https://doi.org/10.1177/0267659112471577.

[33] Samanidis G, Kanakis M, Balanika M, Khoury M. Analysis of risk factors for in-hospital mortality in 177 patients who underwent isolated coronary bypass grafting and received intra aortic balloon pump. Journal of Cardiac Surgery. 2021; 36: 1460–1465. https://doi.org/10.1111/jocs.15437.

[34] Ranucci M, Castelvecchio S, Biondi A, de Vincentiis C, Bal-

lotta A, Varrica A, *et al*. A randomized controlled trial of preoperative intra-aortic balloon pump in coronary patients with poor left ventricular function undergoing coronary artery bypass surgery*. Critical Care Medicine. 2013; 41: 2476–2483. https://doi.org/10.1097/CCM.0b013e3182978dfc.

[35] Yu PJ, Cassiere HA, Dellis SL, Kohn N, Manetta F, Hartman AR. Propensity-matched analysis of the effect of preoperative intraaortic balloon pump in coronary artery bypass grafting after recent acute myocardial infarction on postoperative outcomes. Critical Care (London, England). 2014; 18: 531. https://doi.org/10.1186/s13054-014-0531-z.

[36] Samanidis G, Georgiopoulos G, Bousounis S, Zoumpourlis P, Perreas K. Outcomes after intra-aortic balloon pump insertion in cardiac surgery patients. Revista Brasileira De Terapia Intensiva. 2020; 32: 542–550. https://doi.org/10.5935/0103-507X.20200091.

[37] Yang F, Wang L, Hou D, Wang J, Wang X, Cui Y, *et al*. Preoperative intra-aortic balloon pump inserted in acute myocardial infarction patients without cardiogenic shock undergoing surgical coronary revascularization. Perfusion. 2020; 35: 145–153. https://doi.org/10.1177/0267659119865834.

[38] Miceli A, Fiorani B, Danesi TH, Melina G, Sinatra R. Prophylactic intra-aortic balloon pump in high-risk patients undergoing coronary artery bypass grafting: a propensity score analysis. Interactive Cardiovascular and Thoracic Surgery. 2009; 9: 291–294. https://doi.org/10.1510/icvts.2008.196105.

[39] Iida A, Sezai A, Orime Y, Nakata KI, Takamori T, Taniguchi Y, *et al*. An Experimental Study of the Effects of IABP on Coronary Artery Bypass Graft Flow Waveform. Annals of Thoracic and Cardiovascular Surgery: Official Journal of the Association of Thoracic and Cardiovascular Surgeons of Asia. 2021; 27: 176–184. https://doi.org/10.5761/atcs.oa.20-00150.

[40] Onorati F, Santini F, Rubino AS, Amoncelli E, Gianbruno V, Renzulli A, *et al*. Effects of intra-aortic balloon pump on coronary artery bypass grafts blood flow: differences by graft type and coronary target. Artificial Organs. 2011; 35: 849–856. https://doi.org/10.1111/j.1525-1594.2011.01285.x.

[41] Dyub AM, Whitlock RP, Abouzahr LL, Cinà CS. Preoperative intra-aortic balloon pump in patients undergoing coronary bypass surgery: a systematic review and meta-analysis. Journal of Cardiac Surgery. 2008; 23: 79–86. https://doi.org/10.1111/j.1540-8191.2007.00499.x.

[42] Sá MPBO, Ferraz PE, Escobar RR, Martins WN, Nunes EO, Vasconcelos FP, *et al*. Prophylactic intra-aortic balloon pump in high-risk patients undergoing coronary artery bypass surgery: a meta-analysis of randomized controlled trials. Coronary Artery Disease. 2012; 23: 480–486. https://doi.org/10.1097/MCA.0b013e328358784d.