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Long-term Outcomes of Coronary Artery Bypass Grafting and Staged Hybrid Myocardial Revascularization in Patients With Ischemic Heart Disease

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Abstract:

Introduction: Ischemic Heart Disease (IHD) remains a critical health concern both in Russia and globally. Surgical interventions, such as Coronary Artery Bypass Grafting (CABG) and coronary stenting, are commonly used to address IHD. However, in certain cases, single-stage complete revascularization may not be feasible. Hybrid Coronary Revascularization (HCR), a technique combining CABG with subsequent endovascular interventions, offers a potential solution to this challenge.

Purpose: This study aims to compare the efficacy and safety of surgical myocardial revascularization using CABG *vs*. staged HCR.

Materials and Methods: This retrospective, single-center, cohort, non-randomized study included 95 patients with IHD who underwent myocardial revascularization at the Pirogov National Medical and Surgical Center between 2017 and 2021. Group I (n=45) consisted of patients who received complete myocardial revascularization through CABG. Group II (n=50) comprised patients who underwent Hybrid Myocardial Revascularization (HMR), with CABG followed by Percutaneous Coronary Intervention (PCI). The median interval between CABG and PCI in Group II was 32.1±15.7 days.

Results: Intraoperatively, the total procedure duration significantly differed between the groups, with Group I (CABG) having a mean duration of 242.8±45.9 min compared with 310±55.8 min in Group II (HMR) P<0.001). During the perioperative period, the need for inotropic support differed significantly between the groups (24.4% in group I, 8.0% in group II P=0.028). No significant differences were observed between the groups regarding the length of stay in the intensive care unit, the number of blood transfusions required, or the incidence of Myocardial Infarctions (MI), postoperative bleeding, or strokes. With a mean follow-up period of 755±286 days, the frequency of Major Adverse Cardiovascular Events (MACEs) did not differ significantly between the two groups. The rate of Venous Graft Failure (VGF) was also comparable, with 18 cases (22.8%) in Group I and 6 cases (18.8%) in Group II (P=NS). Meanwhile, group II demonstrated a higher incidence of restenosis with 2 cases [10.5%] *vs*. 10 cases [16.1%], P=0.023) over the 24-month follow-up. Early and long-term postoperative mortality rates were similar between the groups, with no statistically significant differences.

Conclusion: The efficacy and safety of standard CABG with extensive myocardial revascularization possible and the staged hybrid approach are comparable in the surgical treatment of patients with diffuse Coronary Artery Disease (CAD).

Keywords: Coronary artery disease, Coronary artery bypass grafting, Percutaneous coronary intervention, Myocardial revascularization, Heart disease, Cardiovascular surgery.

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1. INTRODUCTION

IHD remains the leading cause of death and disability worldwide, claiming 9.4 million lives annually. According to the ICD, various forms of IHD, both acute and chronic, account for 21.8% of the total incidence of Cardiovascular Diseases (CVDs), which equates to 6,687 cases per 100,000 people. In the general population, the prevalence of CAD among men aged 25–64 years is 12.4%, while in women, it is 10.0%. Epidemiological data show that the painless form of CAD is more commonly detected in men, whereas angina pectoris is more frequently diagnosed in women [1-3].

IHD remains the leading cause of cardiovascular-related mortality, accounting for 52.1% of deaths due to CVD. Notably, overall mortality is predominantly linked to chronic forms of IHD rather than acute events. Specifically, the average contribution of acute IHD, including MI, to the standardized mortality rate from CVD is 10.3% among men over 50 years of age and 7% among women. In contrast, these rates are higher in the United States, where acute IHD and MI account for 19.1% of mortality in men and 16.3% in women [4-6].

The two primary surgical interventions for achieving adequate myocardial perfusion in patients with IHD are CABG and PCI [7, 8]. Complete myocardial revascularization has been shown to be more effective than drug therapy alone in reducing the severity of angina, decreasing the need for antianginal medications, and improving exercise tolerance and quality of life, both in the short and long-term postoperative periods [9, 10].

However, the potential for complete myocardial revascularization is limited by certain factors. Diffuse atherosclerotic lesions, an intramyocardial course, and the small diameter of the target Coronary Artery (CA) can limit the extent of CABG. Additionally, if a cardiac surgical center lacks sufficient expertise in performing sequential CABG or composite grafting, significant stenoses in large Diagonal Arteries (DAs) or Left Marginal Arteries (LMAs) may further restrict the scope of revascularization. In certain cases, incomplete myocardial revascularization may occur due to the unavailability of tissue, particularly in patients with significant varicose veins in the lower extremities [11–14]. Moreover, atypical coronary anatomy can present additional challenges during surgical myocardial revascularization. These anatomical variations include early trifurcation of the Right Coronary Artery (RCA) with a large right ventricular branch, anomalous origin of the RCA from the pulmonary artery or the Anterior Descending Artery (ADA), and a common trunk of the RCA and Left Coronary Artery (LCA) [15–17].

Although IHD outcomes have significantly improved over the past decade, graft patency remains a critical concern in surgical treatment. While the 10-year patency rate of Left Internal Thoracic Artery (LITA) grafts exceeds 90%, VGF occurs in 40–50% of patients. The progression of atherosclerotic disease and VGF is driven by complex pathophysiological processes that can result in complete graft occlusion, significantly impacting long-term clinical outcomes [18, 19].

Enhancing the extent of revascularization following a previous CABG can be achieved through PCI or repeat CABG (reCABG). However, it is important to note that reCABG is a technically demanding procedure [20, 21]. In Europe, reCABG constitutes between 2.6% and 14.0% of the total surgical procedures performed in major cardiovascular centers. In Russia, several medical centers conduct reCABG procedures, with a perioperative MI incidence of 17% and an in-hospital mortality rate of 14% [22]. Given these risks, reCABG cannot be recommended for routine, widespread use.

HMR is a potential solution to the issue of incomplete surgical revascularization. HMR involves creating a LITA anastomosis to the ADA and performing the minimum necessary bypass surgery using venous conduits, followed by either single- or multiple-stage PCI [23, 24].

While HMR may offer certain advantages, there are currently no established guidelines for myocardial revascularization in patients who may be candidates for both CABG and PCI (Class IIB, Level of Evidence B) [25]. This study aimed to compare the efficacy and safety of CABG extensive revascularization to staged HMR.

2. MATERIALS AND METHODS

This retrospective, single-center, cohort, non-randomized study included 95 IHD patients with a history of prior surgical or endovascular myocardial revascularization procedures performed at the St. George Clinic of Thoracic and Cardiovascular Surgery (the Pirogov National Medical and Surgical Center) between 2017 and 2021. Group I (n=45) had complete myocardial revascularization with CABG. Group II (n=50) included patients who had CABG combined with PCI, *i.e.*, HMR. To rule out

immobilizing interstitial cardiac fibrosis, all the recruited patients were examined by echocardiography, scintigraphy, or myocardial biopsy. The Ethics Committee of the Pirogov National Medical and Surgical Center approved the study protocol.

There were no significant differences in the clinical characteristics between the two groups. Most patients were males. In groups I and II, 17 (37.7%) and 18 (36.0%) patients reported a previous history of MI, respectively. The mean left ventricular ejection fraction (LVEF) in groups I and II was 50.7%±5.4% and 49.1%±7.5%, respectively. The majority of patients were diagnosed with class III angina pectoris, with 38 (84.4%) in group I and 44 (88.0%) in group II (Table 1).

Two independent medical professionals assessed the preoperative radiographs obtained by selective coronary angiography in multiple projections using the Toshiba Infinix angiography system (Japan) in compliance with the standard protocol. There were no significant differences between the groups in the characteristics of coronary lesions. All the patients (100%) had significant ADA stenoses. The other angiographic findings reported Left Circumflex artery (LCx) stenoses for 17 (37.7%) and 20 (40.0%) patients; LMA stenoses for 15 (33.3%) and 17 (34.0%) patients; RCA stenoses for 30 (66.7%) and 31 (62.0%) patients; Posterior Descending Artery (PDA) stenosis for 9 (20%) and 10 (20%) with the left-dominant coronary circulation and 10 (22.2%) and 9 (18.0%) patients with the right-dominant coronary circulation, in groups I and II, respectively (Table 2).

All patients had an exercise stress test for the diagnosis of myocardial ischemia before revascularization. Gated myocardial perfusion Technetril ^{99m}Tc Single-Photon Emission Computed Tomography (gated SPECT) was performed in 78 (82.1%) patients using the standard one-day exercise-rest sequence. Stress echocardiograms were recorded in 17 (17.9%) patients.

Before the procedure, all the study patients started a dual antiplatelet therapy with lifelong acetylsalicylic acid at 100 mg once daily combined with a 300-mg clopidogrel loading dose for clopidogrel-naive patients, then at 75 mg once daily for 12 months. According to current clinical recommendations, postoperative medication includes statins, beta-blockers, and either angiotensin-converting enzyme inhibitors or angiotensin II receptor antagonists.

Table 1. Clinical characteristics.

Characteristic		Group I (n=45)	Group II (n=50)	P-value
Age, years (M±SD)		57.5±4.7	58.6±5.4	NS
Males, n (%)		31 (68.9)	35 (70.0)	NS
History of`MI, n (%)		17 (37.7)	18 (36.0)	NS
COPD, n (%)		12 (26.6)	13 (26.0)	NS
Smoking, n (%)		28 (62.2)	29 (58.0)	NS
Diabetes mellitus, n (%)		16 (35.5)	18 (36.0)	NS
LVEF (M±SD, %)		50.7±5.4	49.1±7.5	NS
Arterial hypertension, n (%)		38 (84.4)	41 (82.0)	NS
History of stroke, n (%)		4 (8.8)	3 (6.0)	NS
Class of angina pectoris	III. n (%)	38 (84.4)	44 (88.0)	NS
	IV. n (%)	7 (15.6)	6 (12.0)	NS

Note: AMI – Acute myocardial infarction, COPD – Chronic obstructive pulmonary disease, LVEF – Left ventricular ejection fraction.

Table 2. CA lesions.

Site of Stenosis		CA Stenosis, n (%)		P-value
		Group I (n=45)	Group II (n=50)	-
Left main CA		5 (11.1)	6 (12.0)	NS
ADA system	ADA	45 (100.0)	50 (100.0)	NS
	DA	13 (28.8)	15 (30.0)	NS
IMA		3 (6.7)	4 (8.0)	NS
LCx system	LCx	17 (37.7)	20 (40.0)	NS
	LMA	15 (33.3)	17 (34.0)	NS
	PLA	5 (11.1)	4 (8.0)	NS
	PDA	9 (20)	10 (20.0)	NS
RCA system	RCA	30 (66.7)	31 (62.0)	NS
	PLA	5 (11.1)	2 (4.0)	NS
	PDA	10 (22.2)	9 (18.0)	NS

Note: CA – Coronary artery, ADA – Anterior descending artery, DA – Diagonal artery, IMA – Intermediate artery, LCx – Left circumflex artery, LMA – Left marginal artery, PLA – Posterolateral artery, PDA – Posterior descending artery, RCA – Right coronary artery.

The cardiology team agreed to attempt complete myocardial revascularization by targeting vessels with at least 70% stenosis and a diameter of 2.5 mm or greater in all patients. In the HMR group, the first step involved LITA grafting to the ADA, with the exception of using vein grafts for ADA revascularization in certain cases. Additionally, CABG was performed on the RCA and LCx. PCI was then performed as the second step within a month after surgical revascularization. Patients who underwent sequential CABG were not included in the study.

During the 755±286 day follow-up period after the surgery, patients underwent the examination with myocardial SPECT and/or coronary bypassography, if medically required, as well as a general clinical examination was performed to objectively assess myocardial ischemia. Patients for whom follow-up could not be achieved and completed were excluded from the study. The variables listed in the tables were collected from all patients included in the study (there were no patients with missing data).

All patients have signed an informed consent form for treatment

2.1. Inclusion Criteria

Class III or IV stable ischemic heart disease (IHD); myocardial ischemia confirmed by exercise testing; two- or three-vessel coronary artery (CA) disease with an intermediate or high SYNTAX risk score; and diffuse coronary artery disease.

2.2. Non-inclusion Criteria

IHD with a combined significant CA and heart valve stenosis; left ventricular aneurysm requiring surgical repair; severe renal or hepatic failure or malignancy.

The aim of this study was to compare the efficacy and safety of complete surgical myocardial revascularization *versus* staged repair of CA stenosis using CABG combined with PCI.

2.3. Statistical Analysis

Statistical analysis was conducted by testing for normal data distribution using the Statistica 12 software. The descriptive statistics included the following variables: the number of observations (n), mean (M), standard deviation (SD), and median (Me). The statistical significance of differences in quantitative variables for approximately normal distributions was assessed using Student's t-test. For non-normal distributions, we performed the analysis using non-parametric tests such as the Wilcoxon test and Mann-Whitney U-test. Kaplan-Meier curves were presented to show the 24-month occurrence of MACEs. Differences were considered statistically significant at $p<0.05$.

3. RESULTS

All the patients underwent CABG to achieve ADA revascularization (Table 3). LITA was anastomosed to the ADA in 42 (93.3%) and 48 (96.0%) patients from groups I and II, respectively (P=NS). In other cases, vein conduits were used. The proportion of patients who underwent Extracorporeal Circulation (ECC) bypass procedures in groups I and II was 55.6% and 28.0%, respectively (P=0.001).

To assess the extent of CABG objectively, we analyzed the revascularization rate for each group. This rate is the ratio of the number of distal anastomoses to significant CA stenoses to the total number of significant coronary lesions in the group. The overall revascularization rate in group I was significantly higher compared to group II (0.94 *vs*. 0.49; P=0.001).

Differences in the total procedure length were observed between the two groups, with 242.8±45.9 min for group I and 310±55.8 min for group II. It is important to note that the CABG stage in group II was shorter. The two groups exhibited significant differences in the mean volumes of intraoperative blood loss: 335.4±65.7 mL in group I and 215.0±64.1 mL in group II (P=0.001).

Group I required perioperative inotropic support significantly more often (11; 24.4%) than group II (4; 8.0%; P=0.028). In group I, mechanical ventilation lasted longer (460.3±45.1 min) compared to group II (335.1±39.2 min; P<0.001). However, when considering repeated hospitalizations, group I had fewer total patient days: 9.7±3.82 *vs*. 12.5±2.4 (P=0.01). There were no significant differences in the occurrence of MACEs: 1 patient in each group had a stroke, 2 patients in group I, and 1 patient in group II had a non-fatal MI and required urgent PCI. In group II, one death was reported (Table 4).

Table 3. Sites of distal anastomoses in CABG.

Site of Stenosis		Coronary Grafts, n (%)		P-value
		Group I (n=45)	Group II (n=50)	-
ADA system	ADA	45 (100.0)	50 (100.0)	NS
	DA	13 (28.8)	5 (10.0)	0.019
IMA		3 (6.7)	2 (4.0)	NS
LCx system	LCx	-	-	-
	LMA	15 (33.3)	9 (18.0)	NS
	PLA	5 (11.1)	1 (2.0)	NS
	PDA	6 (13.3)	1 (2.0)	0.035

(Table 3) contd.....

Site of Stenosis		Coronary Grafts, n (%)		P-value
		Group I (n=45)	Group II (n=50)	-
RCA system	RCA	-	-	-
	PLA	3 (6.7)	0 (0)	NS
	PDA	31 (68.9)	12 (24.0)	<0.001

Note: CA – Coronary artery, ADA – Anterior descending artery, DA – Diagonal artery, IMA – Intermediate artery, LCx – Left circumflex artery, LMA – Left marginal artery, PLA – Posterolateral artery, PDA – Posterior descending artery, RCA – Right coronary artery.

Table 4. Perioperative characteristics.

Characteristic	Group I (n=45)	Group II (n=50)	P-value
Day-1 mean blood loss, mL (M±SD)	162.6±77.8	170.8±81.5	NS
Blood transfusion, n (%)	8 (17.7)	7 (14.0)	NS
Time of mechanical ventilation, min (M±SD)	460.3±45.1	335.1±39.2	<0.001
Mean ICU length of stay, hours (M±SD)	24.1±7.91	23.5±6.92	NS
Inotropic support, n (%)	11 (24.4)	4 (8.0)	0.028
Postoperative bleeding and resternotomy, n (%)	2 (4.4)	1 (2.0)	NS
Perioperative MI, n (%)	2 (4.4)	1 (2.0)	NS
Stroke, n (%)	1 (4.4)	1 (2.0)	NS
Early postoperative mortality, n (%)	0	1 (2.0)	NS
Postoperative patient days (M±SD)	9.7±3.82	12.5±2.4	0.01

Note: ICU – Intensive care medicine, AMI – Acute myocardial infarction.

Table 5. Postoperative coronary angiography.

Site of Stenosis		Uncorrected CA Stenoses, n (%)		P-value
		Group I (n=45)	Group II (n=50)	-
Left main CA		-	-	NS
ADA system	ADA	-	-	NS
	DA	1 (2.2)*	10 (20.0)	0.006
IMA		-	2 (4.0)	NS
LCx system	LCx	-	-	NS
	LMA	-	8 (16.0)	0.005
	PLA	-	3 (6.0)	NS
	PDA	3 (6.7)	10 (20.0)*	NS
RCA system	RCA	-	20 (40.0)	<0.001
	PLA	2 (4.4)	2 (4.0)	NS
	PDA	4 (8.9)	7 (14.0)	NS

Note: CA – Coronary artery, ADA – Anterior descending artery, DA – Diagonal artery, IMA – Intermediate artery, LCx – Left circumflex artery, LMA – Left marginal artery, PLA – Posterolateral artery, PDA – Posterior descending artery, RCA – Right coronary artery.
* Uncorrected stenosis is caused in part by vein graft failure.

The early postoperative examination (within a mean of 29±5.1 days) included clinical and functional assessments for myocardial ischemia. In group I, most patients had class 0-I angina pectoris (37; 82.2%), while class II was diagnosed in 8 (17.8%) patients. In group II, classes 0-I, II, and III were observed in 18 (36.0%), 23 (46.0%), and 9 (18.0%) patients, respectively. Myocardial gated SPECT showed 6.7±3.2% residual LV ischemia in group I and 12.4±4.1% in group II.

Follow-up coronary angiography demonstrated VGF of the DA or PDA in one patient from each group. In group II, significant stenoses requiring re-intervention were distributed as follows: 10 (20.0%) DA lesions, 2 (4.0%) intermediate artery (IMA) lesions, 21 (42.0%) LCx lesions, and 29 (58.0%) RCA lesions (Table 5).

During the mid-term follow-up (32.1±15.7 days), 62 (100%) CA stenoses required endovascular reintervention, 11 (17.7%) of which were bifurcation lesions, and 8 (12.9%) were chronic total occlusions (CTO). The planned extent of revascularization was achieved in 35 (70.0%) patients in the single-stage endovascular procedure. Sixteen (32.0%) coronary lesions were considered a severe B2/C stenosis. The quantitative analysis of pre-and post-PCI angiograms is presented in Table 6.

Table 6. Intraoperative angiography, group II (n=50).

Characteristic	Value
Radial approach, n (%)	39 (78.0)
Atherosclerotic CA sites, n (%)	62 (100)
Complex lesions (class B2/C), n (%) (of the total number of the involved CA sites)	16 (32.0)
Bifurcation stenosis, n (%) (of the total number of the involved CA sites)	11 (17.7)
Chronic coronary occlusive disease, n (%) (of the total number of the involved CA sites)	8 (12.9)
Number of stents implanted, n (M±SD)	2.8±0.9
Length of the stented segment, mm (M±SD)	25.2±8.1
Stent diameter, mm (M±SD)	2.74±0.48
Maximum balloon pressure, atm (M±SD)	15.8±0.7
Number of PCI stages, (M±SD)	1.4±0.5
Pre-PCI Quantitative Analysis	
Vessel reference diameter, mm (M±SD)	2.8±0.5
Minimum lumen diameter, mm (M±SD)	0.78±0.3
Degree of stenosis, % (M±SD)	81.9±19.5
Lesion length, mm (M±SD)	27.5±8.4
Post-PCI Quantitative Analysis	
Minimum lumen diameter, mm (M±SD)	2.6±0.5
Residual stenosis, % (M±SD)	6.7±8.4

Note: CA – Coronary artery, PCI – Percutaneous coronary intervention.

Table 7. One- and two-year endpoints (Kaplan-Meier).

Characteristic	Group I (n=45)	Group II (n=50)	P-value
Coronary grafts, n	121	80	NA
Arterial grafts, n	42	48	NA
Vein grafts, n	79	32	NA
Stented segments (2-year follow-up, including the graft), n	19	62	NA
Vein graft revascularization, n	5 (6.3)	2 (6.3)	NS
Recurrent myocardial ischemia			NS
1-year, n (%)	7 (15.5)	6 (12.0)	
2-year, n (%)	10 (22.2)	8 (16.0)	
All-cause mortality			NS
1-year, n (%)	1 (2.2)	1 (2.0)	
2-year, n (%)	2 (4.4)	1 (2.0)	
MI			NS
1-year, n (%)	1 (2.2)	1 (2.0)	
2-year, n (%)	2 (4.4)	2 (4.0)	
Stroke			NS
1-year, n (%)	1 (2.2)	1 (2.0)	
2-year, n (%)	2 (4.4)	1 (2.0)	
Restenosis			**0.016** **0.023**
1-year, n (%)	0 (0)	6 (12.0)	
2-year, n (%)	2 (10.5)	10 (16.1)	
Vein graft failure			NS
1-year, n (%)	13 (16.5)	5 (15.6)	
2-year, n (%)	18 (22.8)	6 (18.8)	

Note: MI – Myocardial infarction.

All 95 patients included in the study were analyzed in the remote follow-up period. The 1-year coronary angiography showed 16.5% VGF (13 of 79 cases) in group I. Nine of them required an endovascular repair of the target CA, while 4 failed grafts were stented. Over the 2-year follow-up, binary restenoses of the conduit stents and VGF were reported for 18 (22.8%) patients. Another three patients in this group underwent PCI.

At 12 months, there were 5 (15.6%) VGFs reported in group II. Two patients had a graft revascularization procedure, while 3 patients underwent PCI. One patient

experienced a graft occlusion by the end of the follow-up period, which required PCI to ensure the patency of the coronary bypass. At the 2-year follow-up, VGF was reported for 6 (18.8%) patients attesting no significant differences with group I (p=NS). At the 24-month follow-up, 2 restenoses (10.5%) were reported for group I with 19 stents. Group II, with 62 stenting procedures, had 6 restenoses (9.7%) at 12 months and 10 restenoses (16.1%) at 24 months (P=0.023). No significant differences were found between groups in the frequency of MACEs (P=NS) (Table 7).

4. DISCUSSION

In multivessel diffuse CA disease, PCI alone is known to be associated with higher rates of recurrence and repeat revascularization compared to CABG [26–28].

There appears to be a limited number of studies on the hybrid approach in both international and Russian literature, and the findings have not been entirely consistent. The initial stage of HMR can be accomplished through either PCI or CABG. It is worth noting that the quantity of endovascular interventions involved in HMR may vary.

In previous studies [29, 30], 12,591 patients were followed up for 5 years. There were no differences found in the treatment outcomes between the group of CABG patients with prior PCI (>14 days before CABG) and the group of CABG alone, *i.e.*, 1.1% *vs*. 1.5% for 30-day mortality, P=0.432; 41% *vs*. 40%, for hospital morbidity, including reoperations for bleeding, the number of blood transfusions, perioperative MI, ventilation time, length of hospital stay, P=0.385, and overall survival (OR, 0.93; 95% CI, 0.74–1.18; P=0.555). In the group of patients with a history of recent PCI (<14 days before CABG), only hospital morbidity was higher (59% *vs*. 45% in the control group; *P*<0.001).

Previous studies [31, 32] analyzed 308,284 patients, of whom 40,892 (13.3%) had previous PCI. They demonstrated that CABG with prior PCI was associated with a higher risk of early (in the hospital or within 1 month) all-cause mortality (OR, 1.26; 95% CI, 1.11–1.44, P=0.003) and MACEs (OR, 1.36; 95% CI, 1.12–1.66; P=0.002), but not with late (1–13 years of the follow-up) mortality (OR, 1.03; 95% CI, 0.95–1.13; P=0.44) and MACEs (OR, 1.03; 95% CI, 0.97–1.09; P=0.38).

In this study, all patients had a history of initial standard CABG *via* median sternotomy. During the intraoperative period, the groups differed in the total duration of the procedure, with 242.8±45.9 min in group I and 310±55.8 min in group II, including subsequent stages of PCI. Due to minimal surgical invasiveness and reduction in ECC procedures, the volume of intraoperative blood loss was significantly lower in group II (335.4±65.7 mL) compared to group I (215.0±64.1 mL; P=0.001). The proportion of patients who needed perioperative inotropic support was significantly higher in the CABG group (22.2%) than in the HMR group (10%; P=0.001). The time of mechanical ventilation in group I increased significantly to 460.3±45.1 min *vs*. 335.1±39.2 min in group II (P=0.001). There were no significant differences between the two groups in terms of the length of stay in the intensive care unit (ICU), the number of blood transfusions, and the frequency of MI, postoperative bleeding, or strokes.

Intraoperative and postoperative characteristics, in general, correlated with the data presented in domestic studies. In particular, the authors of a previous study [33] compared the effectiveness and safety of Minimally Invasive Myocardial Revascularization (MIMR) with the standard CABG performed with or without extracorporeal circulation. They showed that the volume of intraoperative blood loss in patients with standard CABG at the beating heart (BH) was significantly higher compared to patients who underwent CABG with ECC and MIMR amounting to 483.5±75.8 ml versus 310.5±60.5 ml and 295.4±60.1 ml ($p<0.05$), respectively. The need for inotropic support was significantly higher among patients in the CABG group without ECC in comparison to that with MIMR, while in comparison to patients with CABG at BH, it was insignificantly higher, amounting to 18.2% versus 9.29% ($p<0.05$) and 13.5% ($p>0.05$), respectively. The incidence of postoperative MACE, according to the authors, did not differ significantly between groups similar to data obtained in our study.

With an average follow-up period of 755±286 days, there was no significant difference in the frequency of MACEs between the two groups. The incidence of VGF did not differ significantly between both groups, amounting to 18 (22.8%) in Group I versus 6 (18.8%) in Group II (P=NS). Meanwhile, group II had a higher incidence of restenoses (2 [10.5%] *vs*. 10 [16.1%]) over the 24-month follow-up (P=0.023). The groups exhibited no significant differences in early or long-term postoperative mortality. Therefore, it can be concluded that the results obtained are consistent with the findings of previous Russian and international studies. The perioperative characteristics were found to be similar in both groups, and the frequency of early postoperative MACEs was also comparable.

In a previous study [34], the authors compared the long-term results of minimally invasive robot-assisted HMR in 147 patients with the formation of the LITA – ADA anastomosis and subsequent PCI and the results of the standard CABG with ECC in 682 patients. The follow-up periods differed from those in our study, with 96 months for patients with HMR and 70 months for patients with CABG at ECC. Similar to our findings, no significant differences were observed in MACEs between the two groups, with overall mortality rates of 3.0% in the HMR group versus 8.0% in the CABG group (P=0.130). The frequency of repeat revascularization also did not differ significantly between the studies, though it was slightly lower than in our study: 7.0% in the CABG group versus 9.0% in the HMR group (P = 0.270). These differences may be attributed to variations in the initial clinical and angiographic characteristics of the patient cohorts. Moreover, in the presented study, a significantly lower incidence of recurrent myocardial ischemia was reported in the HMR group compared to the CABG group, at 9.0%

versus 30.0% (p<0.001). In our study, we also observed a trend toward a higher incidence of recurrent myocardial ischemia in the CABG group compared to the HMR group, though the differences were not statistically significant, likely due to a shorter follow-up period.

The randomized HREVS study has analyzed 5-year results on safety and efficacy outcomes of CABG (n=50), HMR (n=52), and PCI (n=53) [35]. After 12 months, the median residual ischemia, according to SPECT, did not differ significantly in the CABG, HMR, and PCI groups with rates of 6.7 (4.6; 8.8)%, 6.4 (4.3; 8.5)%, and 7.9 (5.9; 9.8)%, respectively (p=0.45). The average follow-up period was 76.5 months (minimum 60 months). There were no statistically significant differences in all-cause mortality among the CABG, HMR, and PCI groups, with rates of 10.6, 12.8, and 8.2%, respectively (p=0.23). Additionally, no significant differences were observed between the CABG, HMR, and PCI groups in terms of MI incidence (12.8, 8.5, and 16.3%; p=0.12), stroke (4.2, 6.4, and 10.2%; p=0.13), or repeat revascularization due to clinical indications (23.4; 23.4, and 34.7%; p=0.11). Over 5 year follow-up period, the cumulative MACE rate in patients after HMR was similar to that in the CABG group.

In general, the results obtained correlated with the data of both domestic and international studies. The characteristics of the perioperative period did not differ significantly in patients of both groups, and the frequency of MACE in the early postoperative period was also comparable. Additionally, during long-term follow-up, no significant differences were observed in the incidence of acute cerebrovascular accidents, MI, or fatal outcomes between patients who underwent CABG and HMR. The frequency of registration of bypass dysfunction and recurrence of myocardial ischemia did not differ significantly in both groups.

This study was limited by the retrospective, single-center, and non-randomized design, a short follow-up period, and a small number of patients.

CONCLUSION

The efficacy and safety of standard CABG with extensive myocardial revascularization and the staged hybrid approach are comparable in the surgical treatment of patients with CAD. HMR combined incomplete revascularization CABG with PCI performed within one month of the initial stage. HMR has been shown to achieve favorable outcomes in terms of MACE occurrence, VGF, recurrent ischemia, and reduction of surgical invasiveness. Developing a unified HMR technique holds promise as an optimized strategy for surgical staging and a more effective balance between surgical and endovascular revascularization.

LIST OF ABBREVIATIONS

IHD	=	Ischemic Heart Disease
CABG	=	Coronary Artery Bypass Grafting
HCR	=	Hybrid Coronary Revascularization
HMR	=	Hybrid Myocardial Revascularization
PCI	=	Percutaneous Coronary Intervention
CAD	=	Coronary Artery Disease
CVDs	=	Cardiovascular Diseases

AUTHORS' CONTRIBUTION

It is hereby acknowledged that all authors have accepted responsibility for the manuscript's content and consented to its submission. They have meticulously reviewed all results and unanimously approved the final version of the manuscript.

ETHICS APPROVAL AND CONSENT TO PARTICIPATE

The study protocol was approved by the Ethics Committee of the Pirogov National Medical and Surgical Center, Russia (Protocol number: 2. Date: March 5, 2024).

HUMAN AND ANIMAL RIGHTS

All procedures performed in studies involving human participants were in accordance with the ethical standards of institutional and/or research committees and with the 1975 Declaration of Helsinki, as revised in 2013.

CONSENT FOR PUBLICATION

All patients have signed an informed consent form for treatment.

STANDARDS OF REPORTING

STROBE guidelines were followed.

AVAILABILITY OF DATA AND MATERIALS

The data and supportive information will be available for corresponding author [D.E] upon reasonable request.

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None.

CONFLICT OF INTEREST

The authors declare no conflict of interest, financial or otherwise.

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