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ABSTRACT

of the dissertation for the degree of Doctor of Sciences

**THE IMPACT OF MYOCARDIAL REVASCULARIZATION
ON THE PROGNOSIS OF PATIENTS WITH ISCHEMIC
HEART FAILURE**

Specialty: 3218.01- Cardiology

Science field: Medicine

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GENERAL CHARACTERISTICS OF THE RESEARCH

Relevance of the topic and degree of completion. Chronic heart failure is a distinct category of cardiovascular diseases, which, in terms of prevalence, unfavorable prognosis, mortality, recurrent hospitalizations, and the high financial costs required for treatment, has become a pressing issue for global healthcare over the past decades¹. Population aging and the decline in mortality from other forms of cardiovascular diseases have led to an increase in heart failure, continuing to exert a significant impact on public health². Over the last 30 years, particular attention has been given to left ventricular dysfunction, neurohumoral activation, and ventricular remodeling as the principal pathophysiological mechanisms underlying the progression of heart failure. However, during this period, a substantial shift in perspective has occurred regarding the cause of heart failure.

The Framingham Heart Study showed that the main cause of heart failure is ischemic heart disease, not hypertension and valvular heart disease, as was previously thought³. Ischemic etiology-related heart failure is the most prevalent form among heart failure cases and is associated with an unfavorable prognosis. In particular, patients with a left ventricular ejection fraction of $\leq 35\%$ have a significantly higher risk of mortality and recurrent hospitalizations⁴.

¹ Disease and Injury Incidence and Prevalence Collaborators. Global, regional, and national incidence, prevalence, and years lived with disability for 328 diseases and injuries for 195 countries, 1990-2016: a systematic analysis for the Global Burden of Disease Study 2016 [published correction appears in *Lancet*. 2017 Oct 28;390(10106):e38]. *Lancet*.2017;390(10100):1211 - 1259 doi:10.1016/S0140-6736(17)32154-2

² Ventura H.O., Mehra M.R., Böhm M. Observations and reflections on the burden of hospitalizations for heart failure // *Mayo Clinic Proceedings*. – 2017. – Vol. 92, № 2. – P. 175–178.

³ Tsao CW, Vasan RS. Cohort Profile: The Framingham Heart Study (FHS): overview of milestones in cardiovascular epidemiology. *Int J Epidemiol*. 2015;44(6):1800-1813. doi:10.1093/ije/dyv337

⁴ Savarese G. et al. Global burden of heart failure: A comprehensive and updated review of epidemiology // *Cardiovasc Res*. 2022. V. 118. P. 3272–3288.

Ischemic cardiomyopathy is observed in more than 60% of patients with a left ventricular ejection fraction of <40%, and it is associated with a poorer prognosis compared to non-ischemic heart failure^{5, 6}. The criterion of LVEF ≤ 35% has already been thoroughly substantiated by multiple studies (SOLVD, MADIT-II, SCD-HeFT, COMPANION, STICH, etc.) and guidelines (ESC, AHA/ACC), providing prognostic evidence related to sudden death, hospitalization, and survival outcomes^{7, 8, 9}. As a result of these processes, a condition known as “myocardial hibernation” develops in functionally inactive but still viable myocardial structures. Consequently, progressive fibrosis and structural remodeling occur in these myocardial segments.

The changes that occur clinically result in the progression of heart failure (HF) and worsening of the overall prognosis¹⁰. In this regard, many authors consider coronary revascularization—the restoration of blood supply to hypoperfused but still viable myocardium—as one of the main approaches to improving survival and clinical status in patients with IHD complicated by HF¹¹. According to current scientific sources, the impact of myocardial revascularization on disease progression and prognosis in patients

⁵ Canepa M. et al. Characterization of ischemic etiology in heart failure with reduced ejection fraction: a systematic review and meta-analysis // *Eur J Intern Med.* – 2025. – Vol. 134. – P. 51–58. doi: 10.1016/j.ejim.2025.02.004

⁶ Kodur Nandan, Tang W. H. Wilson et al. Management of Heart Failure With Improved Ejection Fraction: Current Evidence and Controversies // *JACC: Heart Failure.* – 2025. – Vol. 13, № 4. – P. 537–553. doi: 10.1016/j.jchf.2025.02.007

⁷ McDonagh TA, et al. 2021 ESC Guidelines for the diagnosis and treatment of acute and chronic heart failure. *European Heart Journal.* 2021;42(36):3599–3726.

⁸ Heidenreich PA, et al. 2022 AHA/ACC/HFSA Guideline for the Management of Heart Failure. *Circulation.* 2022;145(18):e895–e1032.

⁹ Patel MR, et al. ACC/AHA/SCAI Guideline on Coronary Revascularization. *J Am Coll Cardiol.* 2021;79:e21–e129.

¹⁰ Heusch G. Translational pathophysiology of ischemic heart disease: remodeling, scar formation and remote myocardial adaptation // *Eur Heart J.* – 2024. – Vol. 45, № 3. – P. 367–380. doi:10.1016/j.ehj.2023.12.015

¹¹ Gasior M., Gierlotka M., Hawranek M., Tajstra M., Zembala M.O., Gil R.J., Dudek D. Revascularization in Ischemic Heart Failure with Reduced Ejection Fraction: When and How? // *Current Cardiology Reports.* – 2023. – Vol. 25, № 5. – P. 449–458.

with ischemic etiology-related HF, depending on the method used (PCI or CABG), has not yet been fully clarified ¹².

Several studies have shown that CABG improves long-term survival in patients with ischemic-related reduced LVEF compared to conservative treatment ¹¹. The advantages of PCI remain a matter of debate. In the REVIVED-BCIS2 study, PCI was compared with optimal medical therapy, and no statistically significant differences were observed in outcomes such as mortality and frequency of recurrent hospitalizations ¹³.

In 2025, the results of the multicenter “RevascHeart” observational study, which included 408 patients with ischemic HF and LVEF \leq 40%, were published. The patients were divided into two groups: a revascularization group (PCI or CABG) and an optimal medical therapy (OMT) group. After a mean follow-up of 44.6 months (approximately 3.7 years), no significant differences were observed in the revascularization group compared to the OMT group in terms of both all-cause and cardiovascular mortality (HR 0.81; $p = 0.45$). On the other hand, both the revascularization and OMT patient groups showed positive changes in left ventricular functional and structural parameters; however, the revascularized group demonstrated a more pronounced improvement in terms of favorable remodeling ¹⁴.

In European guidelines, the strategy for revascularization in patients with ischemic severe LV dysfunction remains controversial.

¹² Filippo Gurgoglione, Giampaolo Niccoli, What is New from the 2024 European Society of Cardiology Congress on the Management of Chronic Coronary Syndromes? Updated Guidelines and Trials, European Cardiology Review 2024;19:e23. <https://doi.org/10.15420/ecr.2024.43>

¹³ Perera D., Clayton T., O’Kane P.D., Greenwood J.P., Weerackody R., Ryan M., Redwood S.R., Curzen N., Williams L., Oldroyd K.G., et al. Percutaneous revascularization for ischemic left ventricular dysfunction // *N Engl J Med.* – 2022. – Vol. 387, № 15. – P. 1351–1360. doi:10.1056/NEJMoa2206606

¹⁴ Moliner-Abós C., Calvo-Barceló M., Solé-Gonzalez E., Borrellas Martín A., Fluvià-Brugués P., Sánchez-Vega J., Vime-Jubany J., Ferré Vallverdú M., Taurón Ferrer M., Tobias-Castillo P.E., de la Fuente Mancera J.C., et al. Revascularization and outcomes in ischaemic left ventricular dysfunction after heart failure admission: the RevascHeart study // *Eur J Heart Fail.* – 2025. – Vol. 27, № 3. – P. 598–605. doi:10.1002/ejhf.3463

For example, the 2018 European Society of Cardiology (ESC) guidelines on myocardial revascularization recommend revascularization for patients with ischemic LV systolic dysfunction (LVEF \leq 35%) with a Class I recommendation and Level of Evidence B¹⁵. However, according to the 2021 ESC guidelines on the diagnosis and treatment of acute and chronic HF, coronary revascularization in these patients can only “be considered”.

It is classified as a Class II recommendation with Level of Evidence B and is recommended to be applied only after an individual risk/benefit assessment, taking into account coronary anatomy, comorbid conditions, factors affecting patient longevity, and overall clinical status.

Coronary revascularization via CABG or PCI is applied based on three main principles: 1) anatomical, 2) functional, and 3) physiological revascularization. In anatomical complete revascularization, all clinically significant stenoses identified on coronary angiography are targeted for revascularization. This principle is more commonly referenced during CABG procedures¹⁶. Functional complete revascularization is based on myocardial viability and ischemia indicators. The goal here is to eliminate only the stenoses causing ischemia. During PCI, especially in elderly patients and those with high surgical risk, the principle of functional complete revascularization is applied. In this patient group, revascularization provides clinical benefit only for ischemic and viable but dysfunctional myocardial regions¹⁷.

¹⁵ Neumann F.J., Sousa-Uva M., Ahlsson A., Alfonso F., Banning A.P., Benedetto U., et al. 2018 ESC/EACTS Guidelines on myocardial revascularization // *Eur Heart J.* – 2019. – Vol. 40, № 2. – P. 87–165. doi:10.1093/eurheartj/ehy394

¹⁶ Spadaccio C, Benedetto U. Coronary artery bypass grafting (CABG) vs. percutaneous coronary intervention (PCI) in the treatment of multivessel coronary disease: quo vadis? -a review of the evidences on coronary artery disease. *Ann Cardiothorac Surg.* 2018 Jul;7(4):506-515. doi: 10.21037/acs.2018.05.17. PMID: 30094215; PMCID: PMC6082779.

¹⁷ Babes EE, Tit DM, Bungau AF, Bustea C, Rus M, Bungau SG, Babes VV. Myocardial Viability Testing in the Management of Ischemic Heart Failure. *Life* (Basel). 2022 Nov 1;12(11):1760. doi: 10.3390/life12111760. PMID: 36362914; PMCID: PMC9698475.

Physiological complete revascularization, that is, targeting revascularization not only based on anatomical stenosis but also on hemodynamically significant lesions, is an approach that has recently attracted attention and been studied in cardiology. This concept is particularly implemented through the use of invasive physiological indicators such as FFR (Fractional Flow Reserve) and iFR (Instantaneous Wave-Free Ratio)¹⁸.

Thus, the current state of the problem in the international literature not only requires a thorough analysis of the results of studies such as REVIVED and STICH, as well as meta-analyses, but also necessitates the development of algorithms based on myocardial viability, which defines the relevance and importance of this scientific research.

Object of the Research. The study included 416 patients with ischemic HF, LVEF $\leq 35\%$, and multivessel coronary artery disease. The research aimed to assess the potential of viable myocardial tissue, to explore the feasibility of anatomically complete or functionally adequate revascularization strategies, and to evaluate the impact of the selected revascularization method (CABG or PCI) on early and long-term clinical outcomes.

Subject of the Research: To investigate the prognostic significance of assessing myocardial viability in patients with multivessel coronary artery disease and reduced LVEF.

Within the framework of this work, the following issues were addressed:

Comparative analysis of the differences between anatomical completeness and functional adequacy of revascularization performed via CABG and PCI, as well as the characteristics of myocardial contractile function recovery depending on the volume and method of revascularization;

¹⁸ Martino G, Quarta R, Greco F, Spaccarotella C, Indolfi C, Curcio A, Polimeni A. Physiology-Versus Angiography-Guided Complete Coronary Revascularization in STEMI Patients with Multivessel Disease: A Network Meta-Analysis. *J Clin Med*. 2025 Jan 9;14(2):355. doi: 10.3390/jcm14020355. PMID: 39860361; PMCID: PMC11766365.

The role of adenosine stress MRI in assessing the efficacy and safety of revascularization;

The significance of myocardial viability in predicting clinical outcomes and identifying risk factors contributing to adverse results;

In parallel with this approach, during the long-term follow-up, the dynamics of negative myocardial remodeling processes and changes in global contractile function were monitored, and the mechanisms by which revascularization interventions affect these processes were analyzed;

As a result of the study, selection criteria considering individual patient characteristics were established, and a new treatment algorithm applicable in clinical practice was developed.

Research Purpose: To develop a strategy for selecting the revascularization method (PCI or CABG) aimed at improving quality of life and clinical outcomes in patients with ischemic heart failure (LVEF \leq 35%).

Research Tasks:

In patients with ischemic HF and reduced LVEF (\leq 35%) with multivessel coronary artery disease:

1) To comparatively assess early clinical outcomes according to the revascularization method and the presence of viable myocardium;

2) To analyze factors limiting complete anatomical revascularization in patients with viable myocardium, regardless of the revascularization method;

3) To compare the early efficacy of different revascularization methods based on the volume of revascularization and the presence of viable myocardium;

4) To systematize the short-term and long-term clinical outcomes of revascularization and medical therapy according to the selected method and the presence of viable myocardium;

5) To investigate and comparatively assess the impact of the volume of revascularization on clinical outcomes during long-term follow-up;

6) To identify the factors preventing the achievement of functionally adequate revascularization in patients with incomplete

anatomical revascularization;

7) To study the long-term dynamics of myocardial functional recovery according to the volume and type of revascularization as well as the presence of viable myocardium;

8) To develop a practical treatment algorithm aimed at achieving complete and functionally adequate myocardial revascularization.

Main points submitted for defense:

1. In patients with ischemic chronic heart failure who had myocardial viability assessed and low LVEF, the outcomes of CABG and PCI were significantly better compared to those in whom myocardial viability was not assessed preoperatively. Within each group, no differences were observed in the effectiveness of the revascularization methods.

2. In patients of this type, when more than three coronary arteries are affected, coronary calcification is present, and one artery has a stenosis longer than 20 mm, the possibilities for anatomical revascularization are quite limited regardless of the revascularization method used, and the frequency of cardiological complications is high.

3. The subgroups with complete and incomplete anatomical revascularization did not differ statistically in terms of major cardiovascular complications, including bleeding. Among patients who underwent anatomically incomplete revascularization, functionally adequate myocardial revascularization was achieved in 81.8% of cases. Functionally adequate revascularization was observed at the same level in both the CABG and PCI revascularization groups.

4. Comparative analysis of the long-term outcomes in patients whose myocardial viability was assessed confirms that their quality of life is significantly better than in those without viability assessment. This is clearly reflected in lower rates of rehospitalization and repeat interventions, as well as higher survival free from cardiovascular complications. The frequency of major cardiovascular events (death, myocardial infarction, and repeat interventions) is higher in patients undergoing CABG compared to those treated with PCI.

5. In the absence of viable myocardium within the infarct zone, with involvement of more than three coronary arteries, wall motion abnormalities affecting more than four segments, and the presence of fibrosis exceeding 40% in the territory of the affected coronary artery, functional adequacy of myocardial revascularization is practically impossible regardless of the revascularization method applied.

6. The dynamics of viable myocardial functional recovery are significantly higher in patients who underwent complete anatomical and functionally adequate revascularization. Furthermore, when comparing patients who underwent CABG and PCI, the dynamics of myocardial functional recovery were similarly high in both groups.

7. Although a significant positive dynamic in myocardial systolic function was recorded at the end of the follow-up period within each group, no statistically significant difference in efficacy was observed between the revascularization methods (CABG and PCI).

8. In cases of a marked reduction in left ventricular ejection fraction and multivessel coronary artery disease, the assessment of myocardial viability is of paramount importance when making decisions regarding revascularization.

Scientific novelty of the research:

For the first time, in patients with ischemic heart failure characterized by reduced left ventricular ejection fraction (LVEF \leq 35%), multivessel coronary artery disease, and viable myocardium:

- The possibilities of performing complete anatomical myocardial revascularization by CABG and PCI were investigated, and the factors hindering its achievement were identified;

- The efficacy and safety of CABG and PCI in the early postoperative period were comparatively studied and evaluated, depending on the extent of revascularization, using adenosine stress cardiac MRI;

- It has been demonstrated that in the majority of patients with anatomically incomplete revascularization, CABG and PCI approaches allow achieving functionally adequate revascularization in approximately equal proportions, without the need for additional

intervention;

- In this group of patients, the factors preventing the achievement of functionally adequate revascularization were identified;

- Recovery of myocardial function was studied using the stress cardiac MRI method, depending on the extent and method of revascularization;

- The role of myocardial revascularization in preventing adverse remodeling has been clarified, and during long-term follow-up, the dynamics of changes in global myocardial contractile function, depending on the extent and method of revascularization, were studied and evaluated;

- An algorithm for treatment strategy has been justified based on the assessment of myocardial viability and the analysis of risk factors for an unfavorable prognosis of revascularization procedures.

Practical significance of the research:

- It has been established that in patients with LVEF $\leq 35\%$, multivessel coronary artery disease, and ischemic heart failure, the assessment of myocardial viability before surgery, regardless of the revascularization method, helps achieve favorable outcomes.

- The factors preventing complete revascularization (lesions of more than three coronary arteries, presence of calcification, and stenosis longer than 20 mm in a single artery) have been clarified.

- It has been proven that it is not the volume of revascularization but its functional adequacy that is decisive for clinical outcomes. Therefore, in the early postoperative period, the functional adequacy of perfusion should be assessed, and potential complications should be addressed in a timely manner.

- The high efficacy of adenosine stress MRI and the similar functional outcomes of CABG and PCI indicate that, regardless of the extent of revascularization, the alternative method can be successfully applied if one approach is contraindicated.

- Long-term observations indicate that in patients whose myocardial viability was not assessed, the frequency of rehospitalization and reintervention is higher, while survival rates

are lower. In addition, in these patients, the incidence of death, myocardial infarction, and repeat interventions is significantly higher in the CABG group compared to the PCI group.

– In patients who underwent anatomically and functionally inadequate revascularization, treatment outcomes are poorer compared to those who received adequate and complete revascularization; in these patients, the factors increasing the risk of cardiac complications have also been separately identified.

– Clinical, morpho-functional, and angiographic factors hindering functionally adequate myocardial revascularization were found to be equally significant in both the CABG and PCI groups.

– It has been noted that in patients with ischemic heart failure, low LVEF, and multivessel coronary artery disease, complete anatomical and functionally adequate revascularization of viable myocardium leads to a more rapid reversal of the adverse remodeling process.

Application of the research in scientific and experimental medicine. The obtained results have been applied in the clinical practice of the Educational-Surgical and Educational-Therapeutic Clinics of Azerbaijan Medical University, as well as in the teaching process of the Departments of 1st Internal Medicine, Anesthesiology-Reanimatology, and Intensive Care of Azerbaijan Medical University, and in the Cardiology and Cardiac Surgery departments of the Scientific-Surgical Center named after Topchubashov. Fragments of the dissertation have been published in various periodicals.

Approbation of the research. The main points of the dissertation were presented at national and international scientific-practical conferences and congresses, including: the 8th International Middle East Congress of the Emirates Cardiac Society in collaboration with the American College of Cardiology (UAE, Dubai, 2017); the 3rd International Caspian States Conference (“Topical Issues of Modern Medicine,” 2018); the 34th National Turkish Cardiology Congress (Antalya, 2018); the 7th National International Congress of the Azerbaijan Society of Cardiology (Baku, 2018); the Euro Heart Failure 2019 International Congress

(Athens, 2019); the European Society of Cardiology Congress (Paris, 2019); The International Academy of Young Cardiologists Congress (Northern Cyprus, 2024); the 20th International Congress of Update in Cardiology & Cardiovascular Surgery (Istanbul, 2024); the ESC Congress (London, 2024); the 25th Anniversary National Congress “Heart Failure 2024” with international participation (Moscow, 2024); and the SCMR Congress (USA, 2025), the 1st Young Cardiologists Forum (Baku, 2025)

Organization where the dissertation work was conducted.

The dissertation was carried out on the clinical bases of the Departments of 1st Internal Medicine, Anesthesiology-Reanimatology, and Intensive Care of Azerbaijan Medical University.

Publications. A total of 30 works have been published on the subject of the dissertation. Of the 17 scientific articles, 8 were published in journals included in international abstracting and indexing databases, and 2 were single-author articles, one of which appeared in a journal indexed in international abstracting and indexing systems. Of the 13 abstracts, 10 were presented abroad.

Volume and Structure of the Dissertation: The dissertation is written in 335.000 characters. It includes 3 Schemes, 32 graphics, 28 figures and 26 tables: The structure comprises an introduction (17.500 characters), a literature review (68.500 characters), materials and methods (64.000 characters), the results of the author’s research (30.900 + 27.500 + 17.100 characters), discussion, conclusions, practical recommenddations (109.500 characters), a bibliography of 291 local and international sources.

MATERIALS AND METHODS

Study Design and Methodology. The study was conducted as a prospective cohort observational design and aimed to evaluate the impact of myocardial revascularization, in addition to optimal medical therapy (OMT), on clinical outcomes and the long-term prognosis of patients with ischemic heart failure.

The study was conducted between 2016 and 2022 in Baku, at

Azerbaijan Medical University.

The research included 416 patients who had experienced myocardial infarction, developed post-infarction atherosclerosis, and had reduced left ventricular ejection fraction (LVEF \leq 35%).

The inclusion criteria for the study were as follows: confirmed coronary artery disease; presence of segmental wall motion abnormalities in the left ventricular myocardium based on echocardiography; angina of functional class II–III according to the Canadian Cardiovascular Society (CCS) classification; LVEF \leq 35%; QRS duration $<$ 120 ms on ECG, with no indications for cardiac resynchronization therapy (CRT) or pacemaker; and heart failure of functional class I–III according to the NYHA classification.

Exclusion criteria: acute coronary syndrome; QRS duration $>$ 120 ms on ECG and complete left bundle branch block; contraindications or technical impossibility for surgical or endovascular intervention; claustrophobia; presence of implantable cardiac devices (pacemaker, CRT) or patients requiring them; and contraindications to pharmacological testing or the use of contrast agents.

During patient selection and enrollment in the study, physical examination, electrocardiography, Holter ECG monitoring, transthoracic echocardiography, treadmill test, six-minute walk test, and coronary angiography to detect coronary artery disease were performed. Following coronary angiography, patients who underwent delayed-contrast cardiac MRI for the assessment of myocardial viability formed the first group ($n = 192$). The second group included patients who underwent PCI or CABG for complete anatomical revascularization without prior assessment of myocardial viability in the infarct zone ($n = 224$) (Scheme 1).

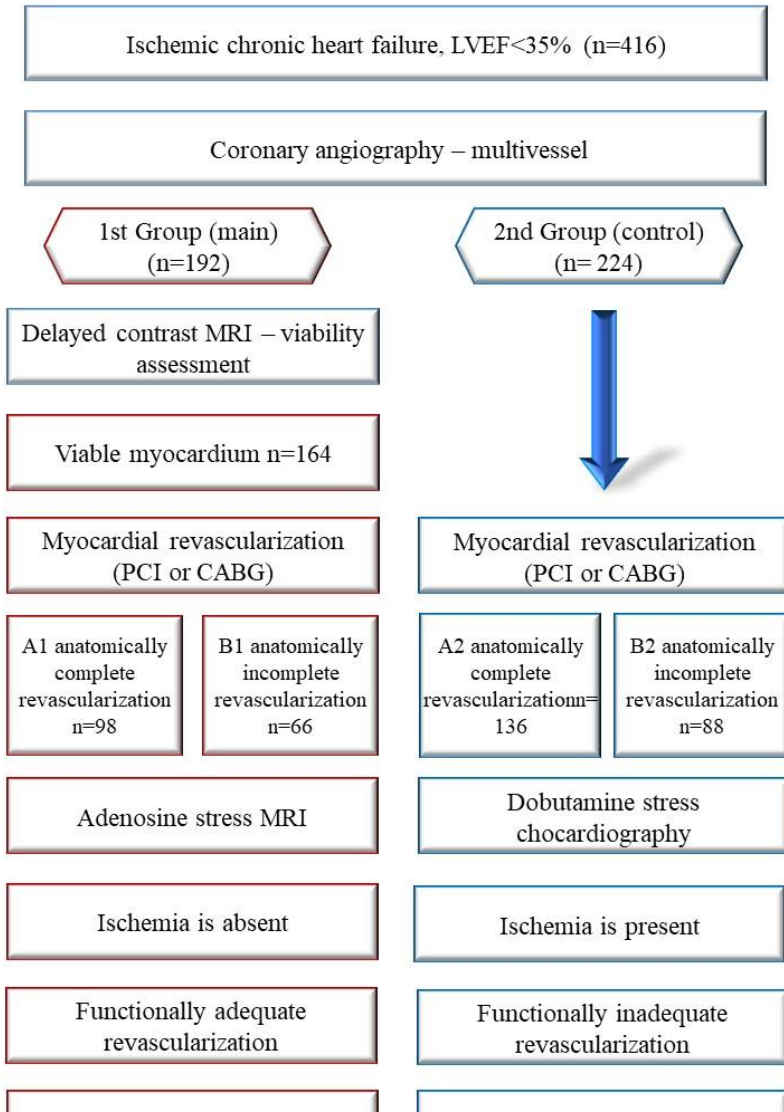
In Group I patients, the number of damaged myocardial segments and the viability of the myocardium in the infarct zone were determined using delayed-contrast cardiac MRI, based on the volume of fibrotic tissue in the coronary artery territory and the transmural index.

Based on the obtained results, myocardial revascularization was subsequently performed in 164 patients with viable myocardium:

PCI in 92 patients (56.1%) and CABG in 72 patients (43.9%).

In Group II (224 patients), PCI was performed in 122 patients (54.5%) and CABG in 102 patients (45.5%) without determining myocardial viability.

Myocardial revascularization was performed based on the anatomical characteristics of coronary stenoses, the patient's comorbid conditions, and clinical status, as well as in accordance with the SYNTAX Score I anatomical scale and the guidelines of the European Society of Cardiology on myocardial revascularization.



Scheme 1. Research Design.

All patients included in the study were receiving optimal medical therapy for IHD and HF in accordance with the current guidelines of the European Society of Cardiology (beta-blockers, ACE /ARB receptor inhibitors, ARNI, statins, aspirin, clopidogrel, spironolactone, and, when indicated, diuretics or cardiac glycosides).

Each patient included in the study was discussed at a multidisciplinary council involving a cardiologist, cardiac surgeon, anesthesiologist, and treating physician, and a joint decision regarding the appropriateness of the revascularization procedure was made based on the conducted investigations.

In all patients of Group I, revascularization of the coronary arteries supplying viable myocardial zones was performed using second- or third-generation drug-eluting stents, including Resolute Integrity (Medtronic), Promus (Boston Scientific), Xience V (Abbott Vascular), Coroflex ISAR (B. Braun), and Taxus (Boston Scientific). For this purpose, based on the results of coronary angiography performed at baseline, stenoses in the epicardial vessels were correlated with the myocardial segments identified as viable by cardiac MRI, and balloon angioplasty followed by stent implantation was carried out in vessels ≥ 2 mm in diameter with $> 50\%$ stenosis, when indicated. For this purpose, based on the results of baseline coronary angiography, stenoses in the epicardial vessels were correlated with the myocardial segments identified as viable by cardiac MRI, and in vessels ≥ 2 mm in diameter with $> 50\%$ stenosis, balloon angioplasty and stent implantation were performed when indicated.

In Group II, since myocardial viability was not assessed, revascularization was performed with an emphasis on achieving anatomical completeness whenever possible. In most cases, the

CABG operation was performed under artificial blood circulation conditions, with pharmacological-cold cardioplegia, without hypothermia. Patients scheduled for CABG were started on HF treatment according to protocols at least three months in advance, and were hospitalized 3 days before the operation for preparation. Antiplatelet agents were stopped 5 days before the operation, and the patients were operated on after the necessary laboratory tests and examinations were completed. Following myocardial revascularization, Group I patients underwent adenosine stress MRI during their hospital stay in order to confirm myocardial ischemia and to assess the effectiveness of the procedure.

In Group II, treatment outcomes were primarily assessed using pharmacological methods and dobutamine stress echocardiography. When ischemia was not detected, anatomical revascularization of the myocardium was considered functionally adequate (regardless of its volume). However, if ischemia was present, the revascularization was deemed functionally inadequate, and the patient was offered repeat coronary angiography and, if necessary, intervention via PCI.

To assess the long-term outcomes of the treatment, follow-up examinations of the patients were conducted at 12, 18, and 24 months post-surgery. During these follow-up visits, individual cardiovascular risk was evaluated and treatment adjustments were made as necessary. At each examination stage, all patients underwent a physical examination, electrocardiography (ECG), Holter ECG monitoring, transthoracic echocardiography (TTE), and a six-minute walk test. If a patient exhibited clinical exertional angina, a non-invasive stress test with ECG was performed, and if ischemia was confirmed, coronary angiography was recommended, and the need for repeat myocardial revascularization was reconsidered.

Evaluation of study results. The assessment of regional myocardial contractility was performed using cardiac MRI or dobutamine stress echocardiography on a 4-point scale based on a 17-segment model, and the regional wall motion abnormality index was calculated. The index was determined as the sum of scores for contractile impairment in each left ventricular segment divided by

the number of analyzed segments. The scoring was as follows: normokinesis – 1 point; hypokinesis – 2 points; akinesis – 3 points; dyskinesis – 4 points.

When assessing myocardial viability using cardiac MRI: a) Depth of myocardial damage – the transmural index was calculated as the ratio of the thickness of paramagnetic contrast uptake in the affected segment to the total thickness of the myocardium in that segment; b) Extent of myocardial fibrosis – the volume of contrast-enhanced myocardium in the affected arterial territory (%).

Myocardium was considered viable if the transmural index was less than 0.5 and the volume of fibrotic tissue did not exceed 50%.

The effectiveness of revascularization during the follow-up period was evaluated based on the following parameters: a) changes in the dynamics of segments with impaired contractility; b) changes in global myocardial contractile function (left ventricular ejection fraction (LVEF), end-systolic dimension (ESD), end-diastolic dimension (EDD), end-systolic volume (ESV), end-diastolic volume (EDV), stroke volume (SV)); c) incidence of cardiovascular complications (death, myocardial infarction (MI), repeat interventions).

Post-infarction myocardial recovery was assessed during the long-term follow-up period based on the dynamics of left ventricular regional wall motion, as well as the transmural index and the extent of myocardial fibrosis in each arterial territory (for patients who underwent repeated cardiac MRI examinations).

The criteria for technical success of PCI and stenting procedures were defined as: a) achievement of TIMI-3 blood flow, b) absence of signs of dissection in the artery, and c) residual stenosis of less than 10%.

A successful clinical outcome of the intervention was defined as a reduction of angina by at least two functional classes or complete resolution of angina symptoms, with no major adverse cardiac events (death, MI, repeat intervention).

Postoperative acute myocardial infarction was defined as

prolonged anginal pain accompanied by specific ST-segment changes on ECG, along with an elevation of cardiac-specific troponin levels to at least 5 times above the normal limit.

Late recurrence of angina was defined as the reappearance of angina symptoms after revascularization in patients who had previously been free of angina, or as progression of symptoms by at least one functional class in those with persistent angina.

Repeat stenting of the target vessel was performed in cases where residual myocardial ischemia was detected on adenosine stress-MRI, or when ischemia accompanied by recurrent angina was confirmed due to progression of the atherosclerotic process at the site of the previously implanted stent. Stent (or graft) thrombosis was defined, according to generally accepted criteria, as one of the following: complete or partial occlusion of the stent confirmed by digital coronary angiography within 30 days after revascularization; after 30 days, an acute ischemic event, sudden death, or myocardial infarction occurring after successful PCI or CABG, confirmed by digital angiography.

CONTENT OF THE WORK

The study groups were compared in terms of their clinical and demographic characteristics. A statistically significant difference between the groups was observed in the mean age of patients and in the incidence of hypercholesterolemia, which was more frequently noted in Group II (Table 1).

Table 1. Baseline clinical and demographic characteristics of the patients

Parameters	Group 1 (n = 164)	Group 2 (n = 224)	p-value
Sex:			
Male, n (%)	148 (9.8)	182 (81.3)	
Female, n (%)	16 (90.2)	42 (18.8)	0.0082
Mean age, years	63.55±10.4	68.4±12.6	0.0001
Mean BMI, kg/m ²	28.58±5.2	28.46±4.1	0.7878

Obesity, n (%)	77 (40.1)	85 (37.9)	0.0914
Smoking, n (%)	100 (52.1)	155 (69.2)	0.2123
Hypercholesterolemia, n (%)	93 (48.4)	167 (74.6)	0.0001
History of cerebrovascular disorder, n (%)	20 (10.4)	31 (13.8)	0.6612
Atherosclerosis of brachiocephalic arteries, n (%)	75 (39.1)	99 (44.2)	0.5541
Tension angina:			
FS II, n (%)	82 (50.0)	92 (41.1)	
FS III, n (%)	82 (50.0)	132 (58.9)	0.0618
Cardiac rhythm and conduction disorders, n (%)	35 (18.2)	46 (20.5)	0.5279
Arterial hypertension, n (%)	112(58.3)	157 (70.1)	0.8318
Peripheral artery atherosclerosis, n (%)	46 (24.0)	73 (32.6)	0.4597
Type II diabetes mellitus, n (%)	41 (21.4)	42 (18.8)	0.0601
Renal dysfunction, n (%)	36 (22.0)	39 (17.4)	0.8121

It should be noted that all examined patients had a severe comorbid background. Approximately 40% of the patients were overweight, more than half were smokers, and had arterial hypertension. About 20% of the patients suffered from type II diabetes mellitus, as well as various forms of cardiac rhythm disorders and renal dysfunction. Multifocal atherosclerosis, with involvement of the brachiocephalic arteries and lower limb arteries, was observed in 30–40% of the patients.

The condition of the coronary bed, as determined by the quantitative results of digital coronary angiography, is presented in Table 2.

Table 2. Initial angiographic characteristics of patients

Parameters	Group 1 (n = 164)	Group 2 (n = 224)	p-value
Two-vessel disease, n (%)	16 (9.8)	12 (5.4)	
Three-vessel disease, n (%)	131 (80.0)	174 (77.6)	
Four-vessel disease, n (%)	17 (10.2)	38 (17.0)	0.0332
Mean number of affected vessels	3.01±0.45	3.12±0.46	0.0095
Left main coronary artery involvement, n (%)	35 (21.3)	50 (22.3)	0.3972
Chronic occlusion, n (%)	44 (26.8)	66 (29.5)	0.5852
Bifurcation stenoses (outside left main), n (%)	43 (26.2)	43 (19.2)	0.2503
Mean SYNTAX I score	27.82±4.4	27.73±3.98	0.8266
Lesion length > 20 mm in one artery, n (%)	57 (34.8)	81 (36.2)	0.8374

Mean diameter of target major arteries, mm	2.82±0.44	2.89±0.23	0.7172
Mean diameter of target major arteries in distal segment, mm	2.28±0.65	2.31±0.63	0.9545
Calcification, n (%)	73 (44.5)	110 (49.1)	0.3752
Vessel tortuosity, n (%)	35 (21.3)	52 (23.2)	0.7232

Overall, the study groups can be considered comparable in terms of initial angiographic characteristics. Differences were observed in the quantitative indicators of affected vessels. Thus, patients with three-vessel disease predominated, accounting for approximately 80% in each group. Two-vessel coronary artery disease was detected in 9.8% and 5.4% of patients in Groups I and II, respectively, while four-vessel disease was observed in 10.2% and 17% of cases, respectively. Chronic total occlusions were identified in approximately one-third of patients in each group.

Left main coronary artery involvement was observed in 20% of patients, and bifurcation stenoses outside the left main were observed at approximately the same frequency.

According to the SYNTAX I score, the severity of coronary lesions averaged 27.82±4.4 in Group I and 27.73±3.98 in Group II, indicating that the coronary lesions were predominantly multi-vessel and complex in nature. It should be noted that almost all patients with a SYNTAX score above 32 underwent coronary artery bypass grafting.

It should also be noted that calcification of the affected coronary arteries was observed in nearly half of the patients in each group, and excessive tortuosity was detected in 20% of cases. In approximately one-third of the patients, atherosclerotic lesions in a single artery exceeded 20 mm in length. The mean diameter of the target artery in the distal segment was 2.28±0.65 mm in Group I and 2.31±0.63 mm in Group II, indicating that performing coronary artery bypass grafting in these patients did not present technical difficulties.

When assessing the global contractile function of the myocardium, it should be noted that the mean LVEF values were 31.18±2.58% in Group I and 31.08±2.53% in Group II, with no statistically significant difference observed ($p = 0.7087$).

In all patients, end-diastolic and end-systolic volumes, as well as

end-systolic and end-diastolic dimensions, were elevated. However, no significant differences were observed in any morphofunctional parameters of the heart between the two groups. The mean number of segments with impaired contractility was 4.76 ± 1.3 in Group I and 4.54 ± 1.21 in Group II, with no statistically significant difference ($p = 0.7799$) (Table 3).

In Group I patients, a total of 913 segments with impaired local contractility were identified, of which 667 were hypokinetic and 246 akinetic. In Group II, among 1,016 segments, these indicators were 711 and 305, respectively ($p > 0.05$).

Table 3. Initial morphofunctional parameters of the heart based on transthoracic echocardiography

Parameters	Group 1 n = 164	Group 2 n = 224	p- value
Mean left ventricular end-diastolic dimension, cm	4.73 ± 0.71	4.70 ± 0.7	0.8588
Mean left ventricular end-systolic dimension, cm	4.18 ± 0.37	4.17 ± 0.37	0.8324
Mean left ventricular end-diastolic volume, ml	151.1 ± 12.15	158.80 ± 17.85	0.7218
Mean left ventricular end-systolic volume, ml	104.2 ± 8.07	109.60 ± 7.87	0.1861
Mean left ventricular ejection fraction (LVEF), %	31.18 ± 2.58	31.08 ± 2.53	0.7087
Mean interventricular septum thickness (IVS), mm	1.2 ± 0.20	1.2 ± 0.23	0.5030
Mean left ventricular posterior wall thickness (LVPW), mm	1.2 ± 0.18	1.2 ± 0.19	0.7751
Mean number of segments with impaired contractility	4.76 ± 1.34	4.54 ± 1.21	0.7799

After contrast-enhanced cardiac MRI, 164 patients in Group I with detected myocardial viability were included in the subsequent stages of the study.

The images obtained after administration of the paramagnetic contrast agent were analyzed in detail. Using these images, the

transmurality index was calculated for each individual segment of the left ventricle. For ease of statistical analysis, patients were grouped into the following subcategories according to the transmural index: 0.2–0.29; 0.3–0.39; 0.4–0.49.

In addition, for all patients, the volume of the affected myocardium corresponding to a single (damaged) coronary artery territory was calculated based on the contrast-enhanced area. Furthermore, for the convenience of statistical data processing, patients were stratified into the following subgroups according to the extent of myocardial fibrosis: 10–19%, 20–29%, 30–39%, and 40–49%.

In nearly half of the patients in the group, the transmural index ranged between 0.3 and 0.39, while the volume of myocardial fibrosis varied from 30% to 39%.

In Group II patients, revascularization was performed without prior assessment of myocardial viability in the post-infarction zone.

Overall, 388 patients from both groups underwent revascularization: 174 patients (72 in Group I and 102 in Group II) underwent coronary artery bypass grafting (CABG), and 214 patients (92 in Group I and 122 in Group II) underwent PCI (Table 4).

Table 4. Characteristics of the Performed Revascularization

Parameters	Group 1 n = 164	Group 2 n = 224	p-value
	<i>PCI (n = 92)</i>	<i>PCI (n = 122)</i>	
1 stent, n (%)	4 (4.3)	6 (5.0)	0.3342
2 stent, n (%)	40 (43.5)	47 (38.5)	
3 stent, n (%)	40 (43.5)	68 (55.7)	
4 stent, n (%)	8 (8.7)	1 (0.8)	
Total number of implanted stents	236	308	0.0063
Stent coatings:			0.3983
Bare metal, n (%)	25 (10.6)	42 (13.6)	
Zotarolimus, n (%)	25 (10.6)	23 (7.5)	
Paclitaxel, n (%)	47 (19.9)	84 (27.3)	
Everolimus, n (%)	101 (42.8)	127 (41.2)	
Sirolimus, n (%)	38 (16.1)	32 (10.4)	
Mean number of implanted stents	2.56±1.45	2.52±1.46	0.3495

	<i>CABG (n = 72)</i>	<i>CABG (n = 102)</i>	
1 graft, n (%)	1 (1.4)	0	0.3972
2 graft, n (%)	28 (38.9)	41 (40.2)	
3 graft, n (%)	38 (52.8)	31 (30.4)	
4 graft, n (%)	5 (6.9)	30 (39.4)	
Total number of grafts	191	295	0.0657
Mean number of grafts	2.65±1.25	2.89±1.62	0.0487
Types of grafts:			
Internal mammary artery, n (%)	72 (100.0)	100 (98.0)	0.2314
Radial artery, n (%)	27 (37.5)	16 (15.7)	0.0246
Saphenous vein, n (%)	71 (98.6)	102 (100)	0.1616

As shown in the table, the groups did not differ significantly in terms of the mean number of implanted stents among patients who underwent PCI (2.56±1.45 in Group I and 2.52±1.46 in Group II; $p = 0.3495$). In the majority of patients included in the study, drug-eluting stents were implanted (89.4% in Group I and 86.4% in Group II). Patients in the CABG groups differed in terms of the mean number of grafts (2.65±1.25 and 2.89±1.62 in Groups I and II, respectively; $p = 0.0487$). Notably, among patients in Group I, 52.8% underwent three-vessel and 38.9% underwent two-vessel CABG, whereas in Group II, 30.4% underwent three-vessel and 40.2% underwent two-vessel CABG. In almost all CABG patients, the internal thoracic artery was used as the primary conduit. Radial artery grafts were used more frequently in Group I compared with Group II.

In Group I, out of 164 patients, 92 (56.1%) underwent PCI and 72 (43.9%) underwent CABG. Depending on the extent of revascularization performed, 98 patients were included in the A1 subgroup, in whom anatomically complete myocardial revascularization was achieved (60 patients with PCI, 38 patients with CABG), and 66 patients were included in the B1 subgroup, in whom anatomically incomplete myocardial revascularization was performed (32 patients with PCI, 34 patients with CABG).

In Group II, out of 224 patients, 122 (54.5%) underwent PCI and 102 (45.5%) underwent CABG. Depending on the extent of revascularization performed, 136 patients were included in the A2 subgroup, in whom anatomically complete myocardial

revascularization was achieved (84 patients with PCI, 52 patients with CABG), and 88 patients were included in the B2 subgroup, in whom anatomically incomplete myocardial revascularization was performed (38 patients with PCI, 50 patients with CABG).

Thus, anatomically complete revascularization was performed in 98 patients (59.8%) in Group I and 136 patients (60.7%) in Group II. The frequency of anatomically incomplete revascularization was 40.2% and 39.3%, respectively. Notably, these indicators did not differ significantly between Groups I and II ($p = 0.3453$).

In the A1 and A2 subgroups, the frequency of anatomically complete revascularization using PCI was 61.2% and 61.8%, respectively ($p = 0.4233$), while using CABG it was 38.8% and 38.2%, respectively ($p = 0.3352$).

In the B1 and B2 subgroups, anatomically incomplete revascularization was performed using PCI in 48.5% and 43.2% of patients, respectively ($p = 0.8234$), and using CABG in 51.5% and 56.8% of patients, respectively ($p = 0.7342$).

Comparison of these indicators between the subgroups revealed that the frequency of anatomically complete revascularization was significantly lower in patients who underwent CABG ($\chi^2 = 6.637$; $p = 0.009$).

Factor analysis of clinical, demographic, angiographic, and morphofunctional characteristics revealed that the presence of stenosis in more than three coronary arteries ($\chi^2 = 13.833$; $p = 0.0001$), the presence of calcification ($\chi^2 = 4.658$; $p = 0.039$), and a stenosis length exceeding 20 mm in a single artery ($\chi^2 = 4.640$; $p = 0.009$) significantly reduced the frequency of anatomically complete myocardial revascularization, regardless of the revascularization method used.

The statistical analysis of the results was carried out using the Statistica 12.0 software package for MS Windows. Methods of variation statistics were applied by calculating the arithmetic mean (M), the standard deviation (δ), and the standard error of the mean (m). Qualitative characteristics were described in terms of absolute numbers and proportions, with percentage values provided for each category. The normality of the distribution of quantitative indicators

was tested using the Shapiro–Wilk criterion.

RESULTS OF THE RESEARCH

Initial (in-hospital) outcomes of treatment. In Group I, 4 patients (2.4%) and in Group II, 13 patients (5.8%) ($\chi^2 = 5.245$; $p = 0.0467$) died due to myocardial infarction caused by acute thrombosis of a graft or stent. Thus, the rate of cardiac death due to myocardial infarction was significantly higher in Group II compared with Group I. At the same time, no significant difference was observed between Groups I and II in the incidence of acute cerebrovascular events, which occurred in 2.4% and 7.1% of patients, respectively ($\chi^2 = 3.821$; $p = 0.1017$). A similar pattern was observed for the incidence of bleeding, which was 6.7% in Group I and 6.25% in Group II ($\chi^2 = 2.915$; $p = 0.1637$). This finding can be explained, on one hand, by the heterogeneity of the study groups including both CABG and PCI patients, and on the other hand, by the lack of myocardial viability assessment in Group II patients, which directly affects surgical outcomes.

Among patients who underwent PCI, life-threatening dissections occurring during the procedure and requiring additional stent placement were observed in 5.4% of Group I and 4.9% of Group II patients ($\chi^2 = 1.726$; $p = 0.2884$), while non-life-threatening dissections were observed in 14.1% and 17.2% of patients, respectively ($\chi^2 = 2.516$; $p = 0.2334$).

It should be noted that for this group of patients with severe multivessel coronary artery disease, the treatment method of choice, CABG, was associated with a significantly higher incidence of graft thrombosis leading to fatal myocardial infarction, as well as a higher incidence of acute cerebrovascular events, compared with PCI.

At the same time, an increased trend in the incidence of bleeding was observed in patients who underwent CABG; however, these rates did not differ significantly from those in the PCI group.

Thus, regarding the incidence of major cardiovascular complications and bleeding events, the subgroups of patients who underwent anatomically complete revascularization (A1 and A2) and

anatomically incomplete revascularization (B1 and B2) did not differ significantly. This may be explained by the fact that in certain patients, anatomically incomplete myocardial revascularization can be functionally adequate.

To assess the immediate outcomes of treatment, based on adenosine stress MRI performed in each patient of Group I and dobutamine stress echocardiography performed in Group II, functionally adequate myocardial revascularization was achieved in 154 patients (93.9%) in Group I and 206 patients (92.0%) in Group II. The overall frequency of functionally inadequate revascularization was 6.1% and 8.0%, respectively ($\chi^2 = 1.053$; $p = 0.3047$), with no significant differences observed between the study groups according to these parameters.

It should be noted that residual myocardial ischemia was detected only in patients who underwent anatomically incomplete revascularization—specifically, in the B1 and B2 subgroups (10 and 18 patients, respectively).

Based on the results of post-operative stress testing, residual ischemia was more frequently diagnosed in Group II, where myocardial viability had not been assessed prior to surgery, and correspondingly in the B2 subgroup, in which functionally inadequate revascularization had been performed. All patients in whom residual ischemia was detected underwent repeat interventions using PCI at various time intervals.

Using this approach, functionally adequate myocardial revascularization was observed in 100% of patients who underwent anatomically complete revascularization, whereas in patients with anatomically incomplete revascularization, functional adequacy was achieved in 81.8% of cases ($\chi^2 = 26.153$; $p = 0.0001$).

Factor analysis of clinical, demographic, angiographic, and morphofunctional characteristics, as well as the revascularization method used to achieve functionally adequate myocardial revascularization, revealed that the likelihood of achieving functional adequacy was significantly reduced, regardless of the method employed, when there was nonviable myocardium ($\chi^2 = 13.638$; $p = 0.009$), stenosis in more than three coronary arteries ($\chi^2 = 13.331$; $p =$

0.0111), more than four segments with impaired local contractility ($\chi^2 = 23.37$; $p = 0.025$), or myocardial fibrosis exceeding 40% in the affected coronary artery territory ($\chi^2 = 9.881$; $p = 0.0001$). At the same time, CABG and PCI allowed achievement of functionally adequate revascularization at approximately equal rates.

In most patients, a clear and favorable dynamic of reduction in the functional class of exertional angina was observed by the end of hospitalization. Thus, a decrease was observed in 88.4% of patients in Group I, with no change in 11.6%, whereas in Group II, these figures were 81.2% and 18.8%, respectively ($\chi^2 = 2.837$; $p = 0.0987$).

Thus, in Group I, a reduction of one functional class was observed in 112 patients (68.3%), and a reduction of two functional classes in 33 patients (20.1%). In Group II, a reduction of one functional class was observed in 158 patients (70.5%), and a reduction of two functional classes in 24 patients (10.7%), which was notably less frequent.

Even at the early stage of treatment, by the time of hospital discharge, patients demonstrated a significant increase in exercise tolerance compared with pre-revascularization levels. Moreover, comparison of the mean physical performance indicators between the groups revealed that this improvement was significantly greater in Group I than in Group II ($\chi^2 = 5.136$; $p = 0.0472$).

The dynamics of chronic heart failure were assessed using the six-minute walk test. It should be noted, however, that when patients within the study groups were stratified according to functional class, no differences were observed between them.

Despite the observed improvement in the functional class of heart failure in both groups at this stage of treatment, it should be noted that in Group II, 87.1% of patients experienced an increase of only one functional class, and no patients showed an increase of two classes. In contrast, in Group I, an increase of two functional classes was observed in 33 patients (20.1%). Additionally, in Group II, 29 patients (12.9%) showed no change in functional class during the hospital stay, whereas in Group I, no patients remained without improvement in functional class.

When patients were divided into functional classes according to

the type of revascularization performed (CABG or PCI), no differences were observed between the groups. The dynamics of functional class in heart failure showed that regression of the clinical manifestations occurred similarly after both CABG and PCI. Moreover, changes of one or two functional classes were comparable following either revascularization method.

A similar pattern was observed when comparing the study groups. Thus, at this stage of treatment, improvement in the functional class of heart failure was observed in patients who underwent both anatomically complete and anatomically incomplete revascularization. However, in patients with anatomically incomplete revascularization, no cases of a two-class improvement were observed, whereas in the anatomically complete revascularization group, an improvement of two functional classes was observed in 33 patients (14.1%).

In addition, among patients in the anatomically incomplete revascularization group, 29 patients (18.8%) showed no change in the functional class of heart failure during their hospital stay.

At the time of hospital discharge, imaging studies showed no significant reduction in the number of myocardial segments with impaired contractile function. Thus, in Group I, 913 pathological segments were identified before surgery, and this number decreased to 898 at discharge ($p = 0.2714$). In Group II, the number of segments with impaired contractile function decreased from 1016 to 1006 ($p = 0.3168$).

A similar pattern was observed when analyzing the recovery of myocardial function according to the type of contractile dysfunction. The recovery dynamics of initially hypokinetic segments did not differ from those of akinetic segments. At the same time, the increase in the number of normokinetic segments at this stage of treatment was insignificant.

The mean number of segments with impaired contractility did not differ significantly between the groups when compared with preoperative values. In Group I, the numbers were 4.76 ± 1.34 before surgery and 4.74 ± 1.29 at discharge ($p > 0.05$), while in Group II, the numbers were 4.54 ± 1.21 and 4.53 ± 1.64 , respectively ($p > 0.05$).

Long-term outcomes of treatment. To assess the long-term

outcomes of treatment, patients were re-evaluated at 12, 18, and 24 months after surgery.

Taking into account peri-procedural and early post-procedural deaths, 160 patients in Group I and 211 patients in Group II were observed at 12 months.

At this stage of follow-up, 2 patients (1.2%) in Group I and 7 patients (3.3%) in Group II had died ($p = 0.3251$).

Taking into account deaths during the 12-month follow-up, 158 patients in Group I and 204 patients in Group II proceeded to the 18-month follow-up. At this stage, 2 patients (1.3%) in Group I and 2 patients (0.9%) in Group II had died ($p = 0.3652$).

At the 24-month follow-up, 156 patients in Group I and 202 patients in Group II were observed. At this stage, 2 patients (1.3%) in Group I and 6 patients (3.0%) in Group II had died ($p = 0.2662$) (Figure 1).

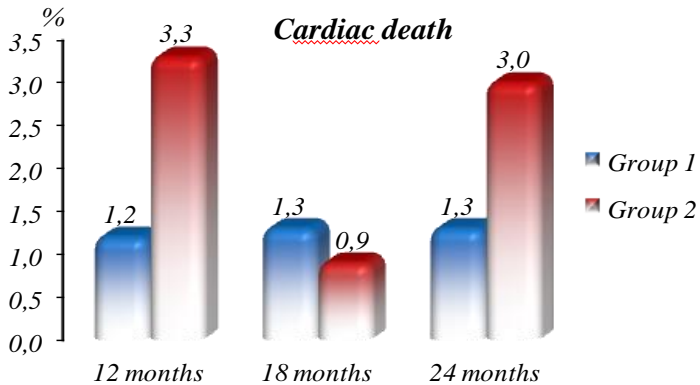


Figure 1. Incidence of cardiac death during long-term follow-up.

Comparative analysis of this parameter between the study groups revealed no significant differences at any stage of follow-up.

At 12 months after surgery, all deaths in Group I were due to myocardial infarction, whereas in Group II, 4 patients (1.9%) died

from myocardial infarction and 3 patients (1.4%) died from other causes ($p = 0.218$).

The 18-month follow-up showed that the cause of death in both Group I and Group II patients was myocardial infarction, with an incidence of 1.3% and 0.9%, respectively ($p = 0.4241$). It should be noted, however, that two patients in Group II experienced non-fatal myocardial infarctions.

At the 24-month follow-up, in Group I, 2 patients (1.3%) died due to myocardial infarction, while another patient experienced a non-fatal myocardial infarction. In Group II, 6 patients (3.0%) died from myocardial infarction, and 4 other patients experienced non-fatal myocardial infarctions. Thus, at this stage of follow-up, the overall incidence of myocardial infarction was 1.9% in Group I and 4.5% in Group II ($p = 0.1456$) (Figure 2).

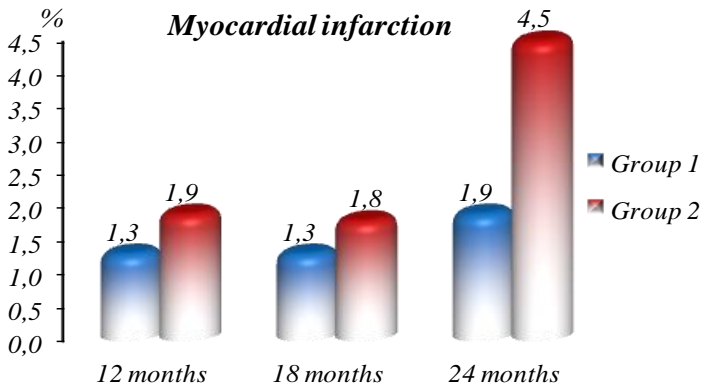


Figure 2. Incidence of myocardial infarction during the long-term follow-up period.

It should be noted that the comparative analysis of the study groups for this parameter did not reveal any significant differences at any stage of follow-up.

The groups differed significantly in terms of the incidence of

repeat interventions. Thus, at 12 months postoperatively, repeat interventions were performed in 4.9% of patients in Group I and in 8.1% of patients in Group II ($p = 0.0248$).

At the 18-month follow-up, no significant difference was detected between the groups for this parameter, with the incidence of repeat interventions being 5% and 8.3%, respectively ($p = 0.2632$). However, at 24 months of follow-up, the groups differed significantly in the incidence of repeat interventions, accounting for 3.8% and 15.8%, respectively ($p = 0.0001$).

The obtained results demonstrate that patients in Group II had a poorer quality of life, as reflected in the higher frequency of rehospitalizations and repeat interventions. This can be explained, on the one hand, by the absence of myocardial viability assessment in Group II patients and, on the other hand, by the performance of anatomically incomplete and functionally inadequate revascularization. This assumption is supported by the results of Kaplan-Meier analysis, which showed a significantly better prognosis in patients with documented myocardial viability.

The survival curves free from cardiac complications began to diverge significantly after 12 months of follow-up and maintained this trend clearly until the end of the study.

The treatment outcomes, depending on the method of myocardial revascularization applied, were analyzed in Table 5.

Table 5. Long-term outcomes of interventions depending on the method of revascularization

Complications	CABG, n = 174	PCI n = 214	p - value
	12 months		
Death, n (%)	2.9	4.2	0.0123
Myocardial infarction, n (%)	2.3	2.8	0,0133
Repeat interventions, n (%)	9.8	5.6	0.0032
	18 months		
Death, n (%)	1.7	0.5	0.0091
Myocardial infarction, n (%)	1.7	1.4	0.0082
Repeat interventions, n (%)	9.2	5.1	0.0024
	24 months		

Death, n (%)	2.9	1.4	0.0054
Myocardial infarction, n (%)	4.0	2.8	0.0061
Repeat interventions, n (%)	13.2	8.8	0.0023

Although the previous analysis of results by groups at 12 and 18 months did not reveal any significant differences in terms of cardiac complications, the outcomes obtained depending on the revascularization method showed a clear and significant difference across all follow-up periods for the patients under observation. Thus, the incidence of cardiac complications (death, myocardial infarction, and repeat interventions) was higher with CABG compared to PCI.

The Kaplan-Meier analysis, which shows that the prognosis of patients who underwent PCI is significantly better compared to those who had CABG, also confirms the data obtained at various stages of follow-up. The survival curves without cardiac complications begin to diverge significantly from almost the earliest stages of patient observation and clearly maintain this pattern until the end of the study, with the difference reaching its peak at the 24th month of follow-up.

The analysis of treatment outcomes depending on the extent of myocardial revascularization performed is presented in Table 6.

Table 6. Long-term outcomes of surgical interventions depending on the extent of revascularization

Complications	A1+A2 n = 234	B1+B2 n = 154	p - value
	12 months		
Death, n (%)	2.6	1.9	0.4211
Myocardial infarction, n (%)	2.2	3.1	0.4201
Repeat interventions, n (%)	8.3	6.3	0.3403
	18 months		
Death, n (%)	1.3	0.6	0.3412
Myocardial infarction, n (%)	0.9	2.5	0.1657
Repeat interventions, n (%)	7.9	5.6	0.2154
	24 months		
Death, n (%)	1.7	2.5	0.3145
Myocardial infarction, n (%)	3.5	3.1	0.3343

Repeat interventions, n (%)	11.4	10.0	0.2954
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The subgroups that underwent anatomically complete myocardial revascularization and those that underwent anatomically incomplete revascularization did not differ significantly in terms of the frequency of cardiac complications at any stage of long-term follow-up. This indicates that the extent of revascularization is not the main factor affecting patients' prognosis after the procedure, as incomplete anatomical revascularization can be functionally adequate, which is likely reflected in the presented results.

One of the primary objectives of the presented study was to investigate the dynamics of LVEF in a sufficiently severe patient group with heart failure following myocardial infarction through the revascularization of viable myocardium. When comparing preoperative values with the data obtained at the end of the study, a significant overall increase in LVEF can be observed.

Thus, compared with the echocardiographic data obtained during hospitalization, an increase in LVEF was observed in both patient groups only after 12 months of follow-up. In Group I patients, the values were $31.18 \pm 2.58\%$ and $34.74 \pm 3.98\%$, respectively ($p = 0.6533$), while in Group II patients, they were $31.08 \pm 2.53\%$ and $34.97 \pm 5.61\%$, respectively ($p = 0.12$).

In Group I patients, a significant increase in LVEF was observed at 18 months compared with the 12-month follow-up ($34.74 \pm 3.98\%$ vs. $41.91 \pm 4.16\%$, respectively; $p = 0.0009$), whereas the increase in LVEF in Group II patients was not statistically significant ($34.97 \pm 5.61\%$ vs. $39.11 \pm 5.87\%$, respectively; $p = 0.0897$). This trend was maintained up to the 24th month of follow-up. A clear increase was observed only in Group I when comparing the 18-month LVEF with baseline values ($41.91 \pm 4.16\%$ vs. $46.8 \pm 2.92\%$, respectively; $p = 0.00001$). In Group II, no significant increase was recorded over this observation period ($40.11 \pm 5.87\%$ vs. $42.71 \pm 4.99\%$, respectively; $p = 0.0727$).

Thus, among patients in whom myocardial viability was determined, a significant increase in LVEF was observed at all stages of follow-up, unlike in Group II patients.

When comparing the preoperative data with the results obtained after 12 months of follow-up, LVEF in CABG patients was $31.17 \pm 2.5\%$ and $34.90 \pm 4.97\%$, respectively ($p > 0.05$), while in the PCI group it was $31.10 \pm 2.59\%$ and $34.83 \pm 4.99\%$, respectively ($p > 0.05$). At this stage of follow-up, no significant increase in LVEF was observed either between CABG and PCI patients ($p = 0.8996$) or within each group.

The results of the 12- and 18-month follow-ups showed that LVEF in CABG patients was $34.90 \pm 4.97\%$ and $40.95 \pm 5.33\%$, respectively, while in PCI patients it was $34.83 \pm 4.99\%$ and $40.82 \pm 5.5\%$, respectively. No significant differences were observed either between CABG and PCI patients or within each group ($p = 0.7299$).

The comparison of the 18- and 24-month results showed that LVEF in CABG patients was $40.95 \pm 5.33\%$ and $44.48 \pm 4.64\%$, respectively ($p = 0.6824$), while in PCI patients it was $40.88 \pm 5.25\%$ and $44.71 \pm 4.12\%$, respectively ($p = 0.6294$). No significant differences were observed when comparing the values between CABG and PCI patients ($p = 0.2399$).

Thus, the analysis of LVEF, depending on the type of revascularization performed, demonstrated a clear improvement in myocardial systolic function within each group compared with preoperative values by the end of follow-up. However, no significant superiority was observed between CABG and PCI, confirming the equivalent efficacy of these procedures.

A comparative analysis of long-term systolic function of the heart, depending on the extent of revascularization, is presented in Figure 3.

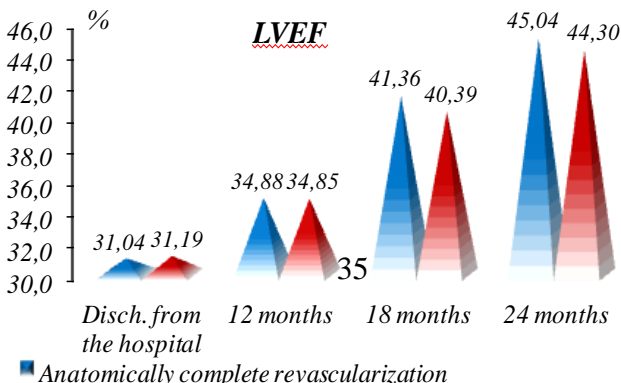


Figure 3. Dynamics of left ventricular ejection fraction during long-term follow-up depending on the type of revascularization.

As seen in the figure, by the end of the study, a significant increase in LVEF was observed in both subgroups compared with the values at hospital discharge ($p = 0.0001$). However, no significant differences related to the increase were observed at any stage of follow-up within the subgroups. Additionally, comparisons between the anatomically complete and incomplete revascularization subgroups did not reveal any significant differences at any stage of observation. This finding further confirms that anatomically incomplete revascularization can be functionally adequate.

In patients who underwent functionally inadequate revascularization, no significant increase in LVEF was observed at the end of the study compared with the values at hospital discharge ($p > 0.05$). At the same time, after 18 months of follow-up, a comparison of LVEF between patients who underwent functionally adequate and inadequate revascularization revealed a significant advantage in favor of the functionally adequate revascularization subgroup.

It should be noted that, alongside the increase in LVEF, a clear positive trend was also observed in the reduction of natriuretic peptide levels when comparing preoperative values with the data obtained at the end of the study.

However, in Group I, a significant decrease in natriuretic peptide levels was already observed at the 12th month of follow-up compared with preoperative values (3030.15 ± 603.68 and 2473.13 ± 489.37 pg/ml, respectively; $p = 0.0016$), whereas in Group II, no significant difference was detected at this stage of follow-up (3087.10 ± 619.45 and 2682.05 ± 716.59 pg/ml; $p = 0.3885$).

In Group I, the decreasing trend of natriuretic peptide levels continued at the 18- and 24-month follow-ups, whereas in Group II, a significant reduction was observed only at the 24th month compared with the data after 18 months of follow-up (2023.16 ± 726.18 vs. 1376.3 ± 768.66 pg/ml, respectively; $p = 0.001$). It should also be noted that natriuretic peptide levels in Group II patients remained higher compared with those in Group I ($p = 0.0092$).

In patients who underwent functionally inadequate myocardial revascularization, the decrease in natriuretic peptide levels occurred much more slowly compared with those who underwent functionally adequate revascularization. Moreover, by the end of the study, a negative trend could be observed, with natriuretic peptide levels increasing in patients with functionally inadequate revascularization.

In patients from both study groups, a significant reduction in the number of dysfunctional wall motion segments was observed at the later follow-up stages compared with the data recorded at hospital discharge after surgery (Figure 4).

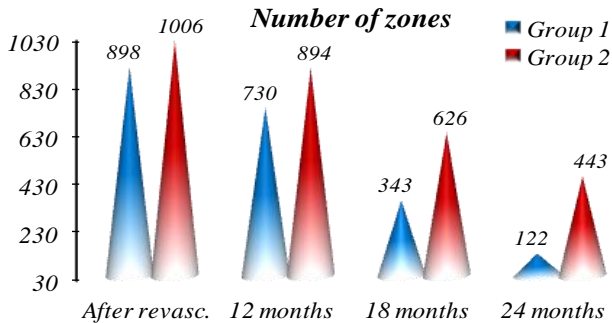


Figure 4. Dynamics of myocardial function recovery in the study groups during the long-term postoperative period.

As can be seen from the figure, in Group I patients with identified myocardial viability, the recovery of myocardial

contractile function in the post-infarction damaged zone was significantly better compared with Group II patients. Thus, in Group I, a significant difference in the number of recovered segments was observed by the 18th month of follow-up compared with the values recorded at hospital discharge. In contrast, in Group II, a significant reduction in the number of dysfunctional wall motion segments was observed only at the 24th month of follow-up. It should be noted that in the postoperative period, recovery of motion was observed in segments previously characterized by both hypokinesia and akinesia.

The recovery dynamics of segments initially identified as hypokinetic were considerably better than those assessed as akinetic. At the same time, in Group I patients, recovery was clearly observed by the 18th month and was significantly faster compared with Group II patients ($p < 0.001$).

Segments identified as akinetic recovered significantly faster in Group I patients compared with Group II patients. At the same time, in Group II, a significant reduction in the number of akinetic segments compared with the data recorded at hospital discharge was observed only at the 24th month of follow-up.

When conducting a comparative analysis of myocardial function recovery in the previously infarcted zone depending on the method of revascularization, no significant difference was found between the patient groups.

Compared with the data obtained at hospital discharge, a clear reduction in the mean number of dysfunctional wall motion segments was observed at the 12th month of follow-up after both CABG and PCI, and this trend continued until the end of the study, confirming the equal effectiveness of both methods of myocardial revascularization.

When assessing the dynamics of the number of segments at different extents of revascularization, no significant difference was observed between the subgroups that underwent anatomically complete and anatomically incomplete revascularization.

In both subgroups, a clear reduction in the mean number of previously dysfunctional segments was observed by the 12th month of follow-up, and this decreasing trend continued until the end of the

study.

However, analysis of segment dynamics depending on the effectiveness of revascularization revealed a significant difference. In patients who underwent functionally inadequate myocardial revascularization, no significant reduction in the mean number of dysfunctional segments was observed. At the same time, in patients who underwent functionally adequate revascularization, a clear recovery of myocardial function was observed 12 months after surgery, and this trend continued until the end of the study.

Considering that patients in Group I underwent stress MRI to evaluate the effectiveness of revascularization, it was possible to assess the recovery of myocardial function based on the dynamics of the transmural index.

Thus, while the mean transmural index was 0.4 ± 0.07 at the time of discharge, it decreased to 0.38 ± 0.06 at 12 months of follow-up ($p = 0.2117$), to 0.35 ± 0.05 at 18 months ($p < 0.001$), and continued to decline to 0.32 ± 0.03 at 24 months of follow-up ($p < 0.001$).

The marked reduction in the area of myocardial fibrosis within the affected arterial territory after revascularization occurred more rapidly compared to the changes in the transmural index. Thus, while the extent of myocardial fibrosis in the affected coronary artery territory was $33.29 \pm 7.47\%$ at the time of hospital discharge, it decreased to $31.93 \pm 6.58\%$ at 12 months of follow-up ($p = 0.0002$).

At 18 months of follow-up, the mean extent of myocardial fibrosis was $29.35 \pm 5.56\%$, and at 24 months it further decreased to $27.52 \pm 4.36\%$. Besides, when compared with the data obtained at the time of hospital discharge, these values were significantly different ($p < 0.001$).

The reduction in the number of pathological segments was also reflected in cardiac remodeling, particularly in the left ventricle. It should also be noted that the remodeling process occurred differently in each study group, which in Group II patients was especially unfavorable, possibly as a consequence of the lack of confirmed myocardial viability.

In Group I patients, a significant reduction was observed in the

mean values of left ventricular end-diastolic volume, end-systolic volume, and end-systolic dimension at 18 months of follow-up. Thus, while the mean EDV at the time of hospital discharge was 151.1 ± 12.15 ml, by the 18th month it had decreased to 143.8 ± 9.01 ml ($p = 0.0009$). By the 24th month of follow-up, this parameter continued to decline, reaching 137.5 ± 6.6 ml ($p = 0.0001$). At the time of hospital discharge, the mean ESV was 104.2 ± 8.07 ml, whereas at the 18th month of follow-up, it decreased to 90.6 ± 5.66 ml ($p = 0.05$). By the 24th month, this parameter further declined to 80.1 ± 3.81 ml, which was significantly lower compared to the value at hospital discharge ($p = 0.0001$). While a significant reduction in EDD was observed only at the 24th month of follow-up, the ESD values showed a significant decrease as early as the 18th month.

In patients of Group II, the process of myocardial remodeling progressed significantly more slowly, and compared to the data recorded at the time of hospital discharge, no significant decrease was observed in most parameters. Specifically, a significant reduction was noted only in the mean value of EDV, which was 158.8 ± 17.85 ml at the time of hospital discharge and 146 ± 16.04 ml at the 24th month of follow-up ($p = 0.0001$). For the other parameters (ESV, EDD, ESD), only a decreasing trend was observed.

Thus, the results of the assessment of the morphofunctional parameters of the heart after myocardial revascularization demonstrate the significant role of revascularization in preventing adverse remodeling of the heart, particularly in patients in whom myocardial viability was detected.

Thus, in the early stages of treatment, a significant increase in exercise tolerance was observed in patients compared to their preoperative values before hospital discharge. However, in the long-term phase, the dynamics of improvement in exercise tolerance were relatively slow in both groups. Although a tendency toward increased exercise tolerance was noted at the 12- and 18-month follow-ups, a significant improvement was recorded only at the 24th month of observation.

The dynamics of the clinical course of chronic heart failure, assessed using the six-minute walk test, are presented in Figure 5.

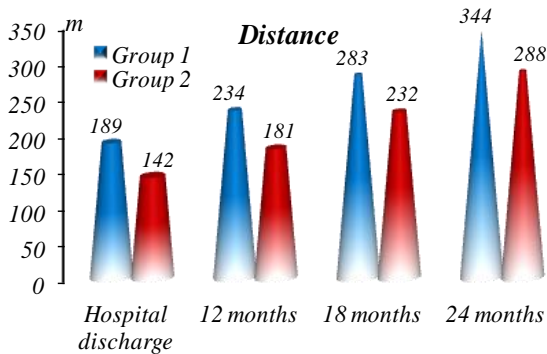


Figure 5. Results of the six-minute walk test at different observation stages in the study groups.

In patients of Group II, the walking distance was initially shorter compared to patients of Group I. However, the mean values of the six-minute walk test showed a significant increase in distance in patients of both groups. At the same time, by the 12th month of observation, a significant difference was already noted, and a steady increase continued until the end of the study. The dynamics of the mean values of the six-minute walk test indicated that the regression of the clinical manifestations of heart failure was similar both after CABG and PCI. At the same time, a significant difference was already observed by the 12th month of follow-up, and the values reached their maximum by the end of the study. According to the results of the six-minute walk test, no significant difference was found between the groups with complete and incomplete anatomical revascularization.

The regression of the clinical manifestations of heart failure was observed to the same extent in patients who underwent both complete and incomplete anatomical revascularization. At the same time, at each stage of the study, the increase was significant, with a notable difference recorded at the 12th month of observation, and the values reached their maximum by the end of the study.

A further confirmation of the importance of achieving functional

effectiveness of the applied treatment is provided by the analysis of the dynamics of heart failure in the group of patients who underwent functionally adequate and inadequate revascularization.

In patients who underwent functionally inadequate revascularization, no significant increase in distance was observed based on the results of the six-minute walk test. A significant improvement was noted only at the 24th month of observation compared to the values recorded at hospital discharge. At the same time, in patients who underwent functionally adequate revascularization, a significant increase in distance was observed at each stage of the follow-up.

Factor analysis of the influence of clinical-demographic, angiographic, laboratory, and morphofunctional parameters on the incidence of major cardiac complications in the long-term follow-up stage showed that, regardless of the revascularization method used, the frequency of major cardiovascular events was significantly higher in patients with: functionally inadequate revascularization ($\chi^2 = 36.771$; $p = 0.0001$), a history of type 2 diabetes mellitus ($\chi^2 = 5.177$; $p = 0.0014$), bifurcation stenosis outside the left main coronary artery ($\chi^2 = 5.866$; $p = 0.020$), involvement of more than three coronary arteries ($\chi^2 = 16.731$; $p = 0.001$), stenosis length exceeding 20 mm ($\chi^2 = 6.312$; $p = 0.025$), and coronary artery calcification ($\chi^2 = 4.561$; $p = 0.0001$).

The main distinguishing feature of the present study is the direct comparison of the outcomes of two methods of myocardial revascularization-coronary artery bypass grafting and percutaneous coronary intervention. This comparison was carried out exclusively in patients with post-infarction left ventricular dysfunction and reduced ejection fraction, in whom the presence of viable myocardium had been confirmed by MRI. In all patients of the main group, cardiac MRI with late gadolinium enhancement was employed to precisely determine myocardial viability.

During the two-year follow-up period, not only clinical outcomes but also the recovery of hibernating myocardium function was monitored using objective imaging methods, including cardiac stress MRI and dobutamine stress echocardiography. In the analysis

of treatment outcomes, both the extent and nature of revascularization were taken into account, with special attention given to the identification of adverse prognostic factors. Within this framework, alongside complete anatomical revascularization, the concept of “functional adequate revascularization” was applied in patients with incomplete anatomical revascularization. This term refers to the absence of myocardial ischemia, as confirmed by non-invasive stress imaging tests (adenosine stress MRI, dobutamine stress echocardiography).

The results of the study have shown that in the management of complex clinical cases characterized by low LVEF and multivessel coronary artery disease, there is a need for a new approach. This approach is based on the use of modern imaging methods for dysfunctional myocardium and involves the development of an improved algorithm that ensures a more optimal selection of patients for revascularization and a more objective assessment of the effectiveness of the applied treatment.

However, the study has certain limitations. First of all, it should be noted that the work was conducted with a single-center design and that intracoronary physiology methods were not applied in the evaluation of long-term outcomes. Yet, intracoronary physiology methods could have allowed a more objective assessment of residual ischemia after revascularization. At the same time, the use of non-invasive stress tests (cardiac MRI and dobutamine stress echocardiography) is not a factor that diminishes the scientific value of the study or the reliability of the obtained results. On the contrary, this work is one of the few studies confirming the effectiveness of revascularization by stress MRI in large patient groups, thereby demonstrating the feasibility of revascularization in complex clinical cohorts.

Cardiac MRI, as one of the most informative methods in the diagnosis of dysfunctional myocardium, demonstrates the feasibility of its inclusion in standard examination protocols for patients with a history of myocardial infarction and those scheduled for revascularization.

For the first time, we evaluated the impact of achieving complete

revascularization on clinical outcomes in a large patient cohort. Analysis of patients with incomplete anatomical revascularization showed that complete anatomical revascularization is not always necessary, and the functional significance of revascularization carries greater importance in the context of restored myocardial perfusion. In addition, the study identified the main factors that hinder the achievement of complete anatomical revascularization, which should be carefully considered during the patient selection process for surgery.

The obtained results also highlighted the specific role of PCI in patients with post-infarction heart failure and reduced LVEF. PCI often facilitated more complete myocardial revascularization and was accompanied by a lower incidence of perioperative complications. This provides a rationale for recommending endovascular interventions more broadly in patients with left ventricular dysfunction.

Medical therapy of viable myocardium. Recent studies have shown that global longitudinal strain (GLS) precedes both the onset of clinical symptoms and the deterioration of global ventricular function, reflecting early pathological changes in the heart. Strong scientific evidence supports the prognostic value of GLS assessed by echocardiography, demonstrating that it has superior predictive power for major adverse cardiac events (MACE) compared to left ventricular ejection fraction and may serve as an optimal method for evaluating global left ventricular systolic function. GLS of the left ventricle is a more sensitive marker of ventricular dysfunction than LVEF. This is related to the orientation of myocardial fibers in the left ventricle, which are particularly susceptible to subendocardial ischemia; in the presence of longitudinal dysfunction, circumferential fiber function compensatorily increases, thereby maintaining LVEF within the normal range.

In our study, we investigated the effect of short-term trimetazidine administration on global longitudinal strain (GLS) measured by cardiac MRI in patients with ischemic origin reduced ejection fraction (LVEF \leq 35%) and stable angina who had viable myocardium. For this purpose, 52 patients were enrolled: 30 patients

in Subgroup I (24 revascularized, 28 non-revascularized) received trimetazidine once daily for 8 weeks in addition to optimal medical therapy, forming the main study group, while 22 patients receiving only optimal medical therapy served as the control subgroup. The mean age of patients in the subgroup was 62 ± 7 years, with 69% male and 31% female. Among the participants, 63% were active tobacco users, 48% had a family history of CAD, 60% had arterial hypertension, 60% had type 2 diabetes mellitus, 12% experienced typical angina attacks, and 88% reported atypical symptoms such as palpitations and dyspnea. Additionally, 6% of patients had concomitant peripheral arterial disease (PAD). Almost all patients received treatment with ARNI/ACE inhibitors, SGLT2 inhibitors, beta-blockers, MRA, aspirin, and statins (Table 7).

Table 7. Baseline Echocardiographic and Cardiac MRI Parameters of LVEF

Parameters	TRIM+ (N=30)	TRIM-(N=22)	p value
LVEF (Echocardiography)	29.8%±3.2	31.3%±2.7	0.0547
LVEF (Cardiac MRI)	25.9%±3.1	29.6%±4.1	0.05

All patients underwent contrast-enhanced cardiac MRI with gadolinium to assess left ventricular global longitudinal strain at baseline and after 8 weeks. At the same time, transthoracic echocardiography was performed to evaluate the morphological and functional parameters of the heart. The groups did not differ statistically in terms of clinical characteristics or the medical therapy they received. After 8 weeks, no statistically significant change was recorded in overall systolic function as measured by echocardiography and cardiac MRI. However, the global longitudinal strain significantly improved in the trimetazidine group: from $9.9\% \pm 1.1\%$ to $-12.7\% \pm 1.2\%$ ($p = 0.0001$), while no significant change was observed in the control group: $9.3\% \pm 1.3\%$ vs $-10.3\% \pm 1.4\%$ ($p = 0.3$).

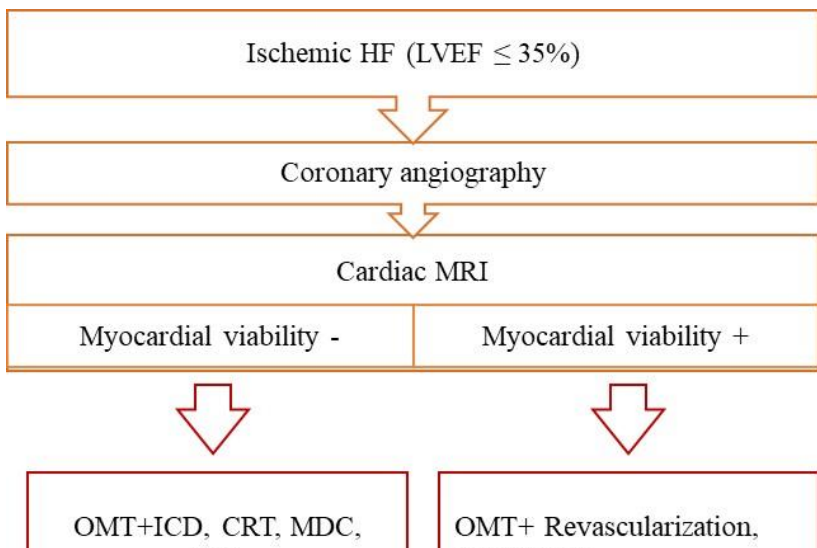
The results of our observation in the subgroup of patients receiving medical therapy for viable myocardium, in whom

trimetazidine was administered for 8 weeks in addition to optimal medical therapy, demonstrated that in patients with a history of myocardial infarction, stable angina, and viable myocardium, the use of trimetazidine improves the left ventricular global longitudinal strain as assessed by cardiac MRI.

The superiority of global longitudinal strain over LVEF as an earlier and more sensitive marker is explained by the high susceptibility of subendocardial longitudinal muscle fibers to ischemia. Against this background, due to the compensatory activity of the circumferential fibers, LVEF may remain within normal limits; however, changes in global longitudinal strain already indicate the presence of dysfunction.

Thus, the analysis of our study subgroup demonstrated that treatment with trimetazidine as a metabolic therapy can induce short-term functional improvement by influencing intracellular metabolic adaptation of the myocardium without affecting hemodynamic parameters. This is particularly important in patients with dysfunctional but viable myocardial regions.

Based on the results of the study, a treatment algorithm was proposed (Scheme 2) for patients with ischemic heart failure, multivessel coronary artery disease, and reduced left ventricular ejection fraction ($LVEF \leq 35\%$), aimed at achieving diagnosis, complete anatomical, and functionally adequate revascularization.



Scheme 2. Diagnostic and treatment algorithm for patients with ischemic heart failure.

According to the proposed algorithm, patients with reduced LVEF, a history of myocardial infarction, and heart failure should undergo coronary angiography after optimization of their medical therapy. In patients in whom multivessel coronary artery disease is detected during coronary angiography, cardiac MRI with late gadolinium enhancement should be performed to assess myocardial viability.

Patients in whom myocardial viability is not detected are considered unsuitable for revascularization and should be evaluated for additional options alongside OMT, such as ICD, CRT, MDC, or transplantation. In patients with viable myocardium detected by cardiac MRI, the current state of the coronary vessels should be

correlated with the localization of the viable myocardial segments to determine suitability for revascularization. Patients considered suitable for revascularization should be discussed by the heart team to determine the method and extent of revascularization. In making this decision, factors such as patient age, comorbidities, physical condition and prognosis, surgical risk and duration, and coronary anatomy (location and length of stenoses, degree of calcification) should be considered. Even in this high-risk patient group, after revascularization, patients should be clinically re-evaluated for ICD/CRT in addition to OMT. According to the algorithm, in patients with $LVEF \leq 35\%$ and ischemic heart failure, functional recovery is always the primary criterion during revascularization. Such an approach is expected to be beneficial for patients' quality of life and clinical outcomes.

CONCLUSIONS

In patients with ischemic heart failure and multivessel coronary artery disease with reduced left ventricular ejection fraction (LVEF \leq 35%):

1. In patients whose myocardial viability was assessed prior to revascularization, the early clinical outcomes of CABG and PCI were more favorable compared to those without viability assessment; however, within each group, no statistical superiority of one method over the other was observed [2,3,6,17].

2. The presence of more than three coronary artery lesions ($\chi^2 = 13.833$; $p = 0.0001$), calcification ($\chi^2 = 4.658$; $p = 0.039$), and long stenoses (> 20 mm) ($\chi^2 = 4.640$; $p = 0.009$) significantly reduces the likelihood of achieving complete anatomical revascularization with any method [13,14].

3. The subgroups of complete and incomplete anatomical revascularization did not differ in terms of the incidence of major cardiovascular complications and bleeding in the early period. In the majority of patients who underwent anatomically incomplete revascularization, functionally adequate revascularization was achieved (81.8%), and this outcome was attained at an equal rate through both CABG and PCI [26,28].

4. In patients with viable myocardium receiving “ischemia-guided” medical therapy, no marked increase in left ventricular ejection fraction was observed during the short-term follow-up; however, global longitudinal strain significantly improved (from $-9.9\% \pm 1.1\%$ to $-12.7\% \pm 1.2\%$, $p = 0.001$). In the long-term follow-up, patients with confirmed myocardial viability demonstrated better quality of life and fewer rehospitalizations compared to those without viability. Nevertheless, major cardiovascular complications were recorded more frequently in CABG patients compared to PCI [27, 28].

5. Incomplete and functionally inadequate revascularization worsens long-term outcomes. Type 2 diabetes mellitus ($\chi^2 = 5.177$; p

= 0.0014), bifurcation stenosis outside the left main coronary artery ($\chi^2 = 5.866$; $p = 0.020$), stenosis involving more than three coronary arteries ($\chi^2 = 16.731$; $p = 0.001$), long coronary artery stenoses (> 20 mm) ($\chi^2 = 6.312$; $p = 0.025$), and coronary calcification ($\chi^2 = 4.561$; $p = 0.0001$) increase the risk of cardiovascular complications [13, 14, 29].

6. The absence of viable myocardium ($\chi^2 = 13.638$; $p = 0.009$), involvement of more than three coronary arteries ($\chi^2 = 13.331$; $p = 0.0111$), wall motion abnormalities in more than four segments ($\chi^2 = 23.37$; $p = 0.025$), and fibrosis exceeding 40% in the affected coronary artery territory ($\chi^2 = 9.881$; $p = 0.0001$) significantly reduce the likelihood of achieving functionally adequate myocardial revascularization, regardless of the revascularization method used [12].

7. In each group, myocardial systolic function improved by the end of the follow-up period compared to pre-revascularization values; however, when comparing CABG and PCI, no method was found to be superior to the other ($31.17\% \pm 2.5$ to $44.48\% \pm 4.64$; $31.10\% \pm 2.59$ to $44.71\% \pm 4.12$, respectively; $p = 0.2399$) [17, 28].

8. In patients with reduced left ventricular ejection fraction (LVEF $\leq 35\%$) and multivessel coronary artery disease, the assessment of myocardial viability and consideration of individual risk factors before deciding on revascularization are regarded as an important diagnostic and therapeutic step that enhances the effectiveness of the intervention [1,6,10,23] (Scheme 2).

PRACTICAL RECOMMENDATIONS

1. In patients with left ventricular ejection fraction $\leq 35\%$, the assessment of myocardial viability prior to revascularization is essential. This approach, regardless of the selected revascularization method, reduces perioperative complications and facilitates improvement in clinical outcomes, including enhanced long-term quality of life, increased event-free survival, and protection against cardiovascular complications.

2. In clinical practice, complete anatomical revascularization in patients with LVEF $\leq 35\%$ and multivessel coronary artery disease may sometimes carry additional risks and may not be clinically necessary. Therefore, it is recommended that decisions regarding the revascularization strategy be made collegially by a “heart team.”

3. Even in cases where complete anatomical revascularization is not achieved, incomplete anatomical revascularization can still lead to improved clinical outcomes. The assessment of revascularization results should not be limited to anatomical completeness alone but should also take functional adequacy into account.

4. In the presence of more than three coronary artery lesions, calcified or long coronary stenoses, and complex coronary anatomy, revascularization should prioritize functional adequacy rather than anatomical completeness, taking into account the presence and localization of viable myocardium, regardless of the chosen revascularization method.

5. Coronary artery bypass grafting and percutaneous coronary intervention may provide similar benefits in terms of restoring myocardial systolic function. Therefore, when selecting a specific revascularization method, factors such as the patient’s age, prognosis, comorbidities, characteristics of the coronary anatomy, and the degree of surgical risk should be taken into consideration.

6. In elderly and high-risk patients, regardless of the revascularization method, priority should be given to functional revascularization in order to shorten the duration of the procedure

and minimize procedure-related complications. In patients with a history of type II diabetes mellitus, bifurcation stenosis outside the left main coronary artery, involvement of more than three coronary arteries, stenosis length greater than 20 mm, and coronary artery calcification, the frequency of major cardiovascular complications is high when functionally inadequate revascularization is performed, irrespective of the method used.

7. In patients with reduced LVEF and severe heart failure, the anatomical completeness and functional adequacy of revascularization should be regarded as an essential diagnostic step. This approach, regardless of the chosen revascularization method, enhances treatment effectiveness and makes a significant contribution to the rapid and meaningful improvement of left ventricular systolic function in severe forms of ischemic heart failure (Scheme 2).

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Abbreviations

CABG	– Aorto-Coronary Bypass Grafting
CHF	– Chronic Heart Failure
CVE	– Cerebrovascular Event
CRT	– Cardiac Resynchronization Therapy
DSE	– Dobutamine Stress Echocardiography
ECG	– Electrocardiography
Echo	– Echocardiography
EDM	– End-Diastolic Measurement
EDV	– End-Diastolic Volume
EF	– Ejection Fraction
ESC	– European Society of Cardiology
ESM	– End-Systolic Measurement
ESV	– End-Systolic Volume
HF	– Heart Failure
HFrEF	– Heart Failure with Reduced Ejection Fraction
ICD	– Implantable cardioverter-defibrillator,
IHD	– Ischemic Heart Disease
LV	– Left Ventricle
LVEF	– Left Ventricular Ejection Fraction
MDC	– mechanical support device
MI	– Myocardial Infarction
MRI	– Magnetic Resonance Imaging
OMT	– Optimal Medical Therapy
PCI	– Percutaneous Coronary Intervention
PET	– Positron Emission Tomography
SPECT	– Single-Photon Emission Computed Tomography
TPL	– Transplantation

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