Research Article

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Surgical Remodeling of the Left Ventricle in Patients with Post-Infarction Dilation and Heart Failure

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INTRODUCTION The cause of heart failure in patients with coronary artery disease after anterior myocardial infarction may be dilatation of the cavity of the left ventricle (LV) with subsequent unfavorable course of the disease. In the case of early reperfusion, which prevents transmural myocardial necrosis, the damaged segment more often becomes akinetic than dyskinetic. Surgical remodeling of the left ventricle (SRLV) is aimed at reducing the volume and restoring its elliptical shape by eliminating scars in the akinetic and/or dyskinetic segments.

AIM OF STUDY To evaluate the survival of patients with chronic heart failure (CHF) who had anterior wall myocardial infarction in the early and late periods after surgical remodeling of the left ventricle, in combination with coronary bypass grafting and/or interventions on the mitral valve.

MATERIAL AND METHODS The study included 99 patients with coronary artery disease (CAD) who had myocardial infarction of the anterior LV wall and with severe heart failure, who underwent surgical LV remodeling in the period from 2002 to 2020. The analysis of early and long-term results was carried out. The risk factors influencing lethality were determined.

The mean age of the patients was 56.0±10.2 years (from 23 to 81 years). The vast majority of patients (90%) were men. LV ventriculoplasty was combined with coronary bypass grafting in 97 (98%) patients, with mitral valve repair in 2 (2%) patients, with mitral valve replacement in 2 (2%) patients.

RESULTS In the early postoperative period, all patients showed an improvement in global LV systolic function. The ejection fraction (EF) of the left ventricle increased from the average preoperative average value of 34.2±3.7% to 43±4.2% in the postoperative period (p<0,001). Left ventricular end systolic volume index (LVESV) decreased from 71.4±15.3 ml/m^2 to 43.8±9.6 ml/m^2, respectively (p<0,001). In the early postoperative period, 5 (5%) patients used the following means of mechanical hemodynamic support: intra-aortic balloon pump (IABP), non-implantable device for temporary support of the left ventricle (LVAD) and extracorporeal membrane oxygenation (ECMO). The 30-day mortality rate after LVESV was 6%. Prior to surgery, all patients had NYHA functional class (FC) III or IV. In the postoperative period, all patients experienced regression of heart failure symptoms and improved exercise tolerance. NYHA functional class improved to I and II in 100% of cases. Using univariate analysis, it was possible to determine that EF ⩽30%, LVESV ⩾80 ml/m^2 and pulmonary artery pressure (PAP) >60 mm Hg. were risk factors for hospital mortality. The overall fifteen-year survival rate was 59.8±0.13%. The absence of readmission to the hospital due to recurrent angina pectoris, mitral valve dysfunction and progression of heart failure (HF) was 72% among surviving patients.

CONCLUSION Surgical remodeling reduces the volume of the dilated left ventricle and restores its elliptical shape in patients with CAD after anterior myocardial infarction. The results of our study demonstrate an improvement in LV systolic function in all patients in the early postoperative period and low mortality, an acceptable fifteen-year survival rate, and a low readmission rate due to the progression of chronic heart failure (CHF).

Keywords: surgical reconstruction of the left ventricle, coronary artery disease, heart failure, myocardial infarction, coronary bypass grafting

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CABG — coronary bypass surgery
CHD — coronary heart disease
CHF — chronic heart failure
Echo-CG — echocardiography
EF — ejection fraction
FC — functional class
HF — heart failure
LV — left ventricle
LVESV — left ventricular end systolic volume
MV — mitral valve
PAP — pressure in the pulmonary artery

INTRODUCTION

Approximately two-thirds of cases of chronic heart failure are caused by coronary artery disease. Moreover, the vast majority of these patients suffer myocardial infarction [1]. Despite successful early reperfusion, late left ventricular dilatation leading to CHF develops in 20% of patients [2, 3]. Myocardial necrosis in transmural infarction, without timely restoration of blood flow through the occluded coronary artery, spreads sequentially from the endocardium to the epicardium [4]. Early reperfusion affects the formation of myocardial infarction, maintaining the viability of the epicardial layer and preventing the formation of thin-walled dyskinetic aneurysm. Despite early reperfusion, the necrotic area of the myocardium, while maintaining its thickness and normal-looking epicardium, undergoes varying degrees of fibrosis of the middle layer, which leads to the formation of an akinetic segment. Even an intact myocardium undergoes changes in volume and shape during subsequent pathological "ventricular remodeling". As the latter expands, its normal elliptical shape is replaced by a spherical one, and the overall systolic function deteriorates, which

leads to CHF [5]. Thus, the survival prognosis of patients with ischemic cardiomyopathy turned out to be more closely related to the LV volume, and not only to the ejection fraction [6].

The concept of "surgical remodeling of the left ventricle" includes both volume reduction and restoration of the elliptical shape of the latter [7-9]. Excision of a thin-walled aneurysm with linear repair of the defect is the most historically early method of SRLV. The technique was first described by Cooley et al., and has been variously modernized over many years of use [4,5]. This technique is currently used in the treatment of LV aneurysms.

Left ventricular reconstruction with a circular patch was proposed in 1984 as a surgical method for the repair of aneurysms with asynergy after acute myocardial infarction. One of the developers of left ventricular plasty with a patch, V. Dor et al. analyzing the results of his experience, he noted that the type of aneurysm (dyskinesis or akinesis) depends on the type of infarction (transmural or not), and remodeling depends on the size of the asynergic scar. The technique, based on sewing in a circular patch, allows you to remove the scar without losing volume. Based on extensive experience in the treatment of 1100 patients, Dor confirms that this is a good method for treating patients with progressive heart failure. Dor [10] was the first to use LV repair with an endocardial patch for both morphologies. Dor operation [10] improves LV systolic function and New York Heart Association (NYHA) functional class [11]. However, this operation was not widely used in patients with ischemic cardiomyopathy because surgeons were unwilling to rule out akinetic, normal-looking myocardial segments that often occur after early reperfusion. Instead, coronary artery bypass grafting (CABG) was performed, and a non-functional akinetic muscle segment containing a hidden scar in its thickness was not subjected to surgical treatment.

There is still controversy regarding the choice of surgical technique for the surgical treatment of postinfarction aneurysms. After analyzing the results of two generally accepted methods, linear plasty and reconstruction with a patch for the treatment of aneurysms, foreign and domestic researchers came to the conclusion that the repair technique should be selected individually for each patient, depending on the size and shape of the left ventricle and scar. Both operations give good results in the form of reduced mortality, reduced functional class and improved survival.

MATERIALS AND METHODS

In the N.V. Sklifosovsky Research Institute for Emergency Medicine in the period from 2002 to 2020, SRLV was performed in 99 patients with coronary artery disease, postinfarction LV dilatation and severe heart failure. The criteria for selecting patients for the study were: previous myocardial infarction of the anterior wall, significant dilatation of the ventricle (end systolic volume index of the left ventricle ⩾ 50 ml / m2), regional asynergy and heart failure.

The age of patients ranged from 23 to 81 years and averaged 56.0±10.2 years. All patients were admitted to the hospital with a clinic of unstable angina or angina pectoris 3-4 FC. According to coronary angiography, the vast majority of patients had a critical multivessel lesion of the coronary arteries.

Echocardiography, ventriculography, and myocardial scintigraphy were used to detect the presence of asynergic segments and calculate EF values.

To assess the presence of myocardial viability, radioisotope research methods (technetium scintigraphy) were used, and in 11 patients, the ECHO-CG speckle-tracking method was also used. The global longitudinal LV systolic deformation was calculated. For this, in the gray scale mode at a frame rate of 60–100 per minute, images of the LV long axis, 2- and 4-chamber apical positions were recorded during breath holding, followed by a semi-automatic analysis of the degree of myocardial deformation. The study was carried out using the apparatus VIVID 9 (GENERAL ELECTRIC).

All patients had severe heart failure. 33% of patients were in NYHA functional class III and 67% of patients were in FC IV. The average functional class according to NYHA before surgery was 3.7+0.5. A small number of patients (4%), in addition to SRLV and CABG, underwent correction of insufficiency on the mitral valve. The main indication for surgical intervention in this category of patients, in addition to lesions of the coronary arteries and LV volume > 50 ml, was grade III mitral insufficiency.

Surgical remodeling by removing or eliminating the scar and reducing the volume of the LV cavity was achieved using an intracardiac patch or linear plasty. The majority of patients (89%) underwent surgery using an intracardiac patch according to the Dor method (Fig.1).

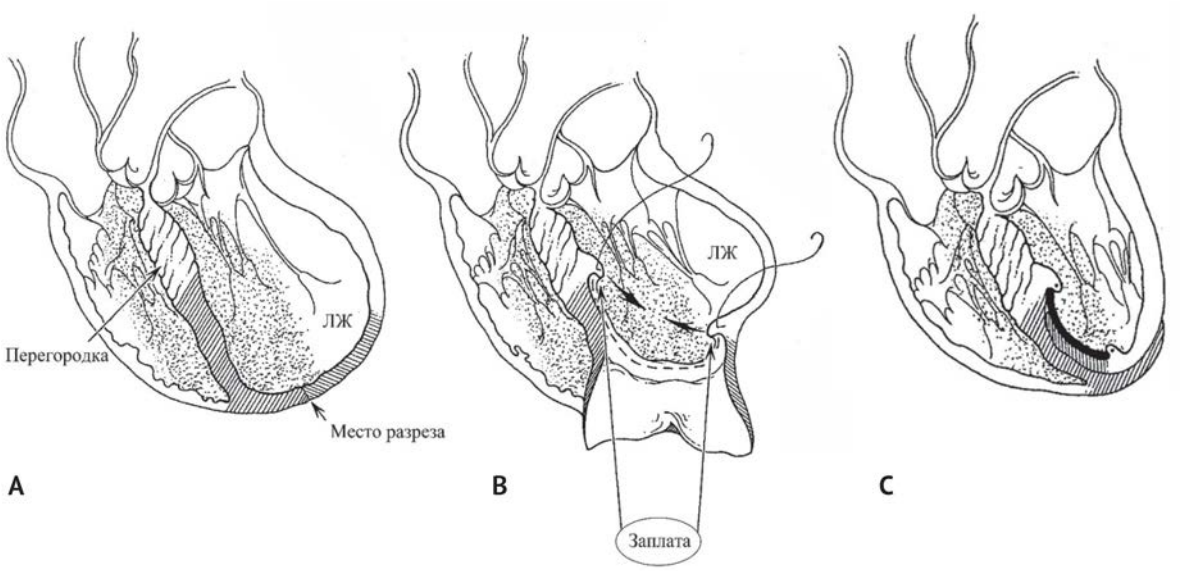

Fig. 1. A — incision in the cicatricial zone of the dilated left ventricle; B — the purse-string suture along the perimeter of the scar segment; C — implantation of a patch in a partially reduced left ventricular (ЛЖ) wall defect with restoration of its integrity

All operations were performed using a heart-lung machine under conditions of moderate hypothermia or normothermia. Myocardial protection in some patients was carried out with the help of a pharmaco-cold solution "Consol" and with the use of "ice slurry" from saline for local hypothermia of the myocardium. В последние 6 лет для защиты миокарда используется тепловой кровяной раствор. In the postoperative period, the control measurement of the size of the heart cavities, EF values, assessment of the function of the prosthesis on the MV after the correction of the defect was performed before discharge.

All results were collected prospectively in standard forms and entered into a computerized database. Statistic 10 software was used for statistical analysis. All data were expressed as mean ± standard deviation and compared using a chi-square test and an independent t-test. Survival and readmission analyzes were performed using the Kaplan-Meier method to properly account for patients lost to follow-up. Value of $p < 0.05$ was considered statistically significant.

RESULTS

The interval between the development of myocardial infarction and SRLV was on average 3.4+4.2 years.

According to ECHO-CG data, the mean LV ejection fraction (EF) before surgery was 34.2±3.7%. EF ⩽ 30% was noted in 12 (12%) patients, LVESV ⩾ 80 ml/m2 in 34 (34%) patients, and pulmonary artery pressure (PAP) > 60 mm Hg in 3 (3%) patients. Akinetic LV segments were detected in 54% of patients (Fig. 2) and dyskinetic segments in 46% of patients. Most of the 34 patients with LVESV ⩾ 80 ml/m2 were with akinetic segments (56%) and 44% of patients had dyskinetic segments.

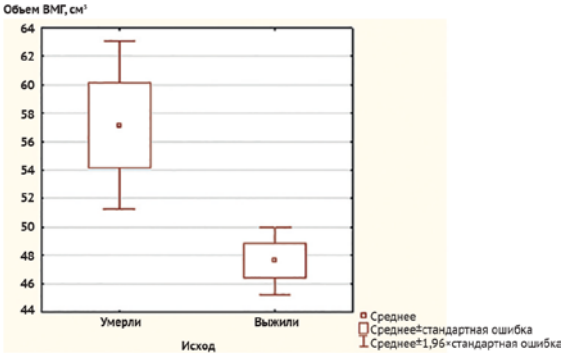

Fig. 2. Fibromuscular aneurysm of the left ventricle

SRLV was combined with CABG in 98% of patients, mitral valve repair in 2% of patients, and mitral valve replacement, also in 2% of patients. During myocardial revascularization, the average number of distal anastomoses per 1 patient was 3.03±1.09. According to coronary angiography, the majority of patients (69%) had stenotic lesions of three coronary arteries, lesions of two vessels in 26% of patients, and isolated lesions of one artery in 5% of patients. LCA trunk stenosis and its equivalent were detected in 43% of patients. Mitral valve interventions have been performed in patients with severe mitral regurgitation.

In the early postoperative period, there was an improvement in global LV systolic function. LV EF increased from mean values of 35.3±3.6% before surgery to 43±4.2% after surgery (p<0.001) (Table 1), and LVESV decreased from 71.4±15.3 ml/m2 to 43 .8±9.6ml/m2, respectively (p<0,001).

Perioperative mechanical hemodynamic support was required in 5% of patients. Intra-aortic balloon pumping was used in 2% of patients, mechanical left ventricular support devices in 2% of patients, and extracorporeal membrane oxygenation in 1 patient.

Table 1

Ejection Fraction and End Systolic Volume Index, Mean Value

Parameter	Before surgery	After surgery	p
EF, %	35.3±3,6	43±4.2	<0.001
LVESV, ml/m^2	71.4±15.3	43.8±9.6	<0.001

Hospital mortality was 6% (6 patients), and the need for long-term cardiotonic support was noted in 6 (6%) patients. Risk factors such as EF ⩽ 30%, LVESV ⩾ 80 ml/m2 and PAP > 60 mm Hg., correlated with the level of postoperative mortality (p<0,001) (Table 2).

Table 2

Postoperative Morbidity and Mortality Rates in Univariate Analysis

Parameter	Morbidity (P)	Mortality (P)
Age	0.09	0.417
Preoperative ejection fraction	0.346	0.002
LVESV	0.028	0.005
PAP	0.782	<0.001

The overall 15-year survival rate calculated using the Kaplan-Meier method was 59.8 ± 0.13% (Fig. 3). Mean time to death or time lost to follow-up was 3.2+3.9 years.

Long-term survival of patients with akinetic and dyskinetic morphologies did not differ statistically (p>0.05) (Fig.4).

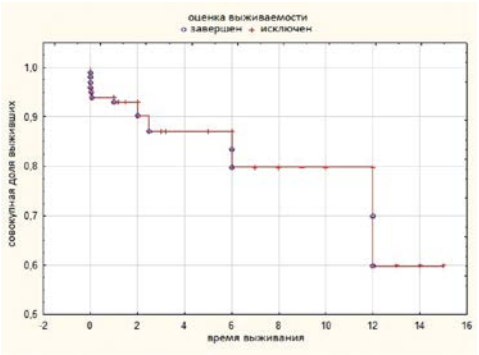

Fig. 3. Overall 15-year survival by the Kaplan-Meier method

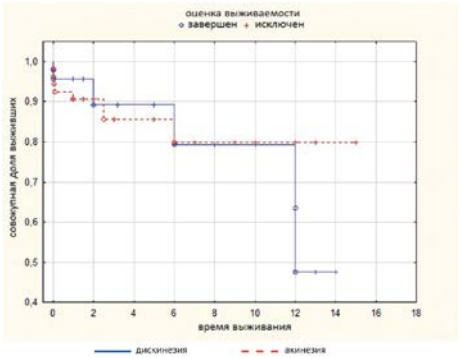

Fig. 4. Survival based on left ventricular wall morphology: dyskinesia versus akinesia in patients with postinfarction left ventricular dilatation

Risk factors for death identified in the early postoperative period were also identified in the late postoperative period. These include EF⩽30% and LVESV ⩾80 ml/m2 before surgery. Thus, an 8-year follow-up showed that patients with an EF>30% had a survival rate of 80.2±0.21% compared with 59.2±0.21% in patients with an EF⩽30% (p<0.001), and patients with LVESV <80 ml/m2 had a survival rate of 88.4±0.22% compared with 51.3±0.22% for patients with LVESV >80 ml/m2 (p<0.001) (Fig. 5, 6).

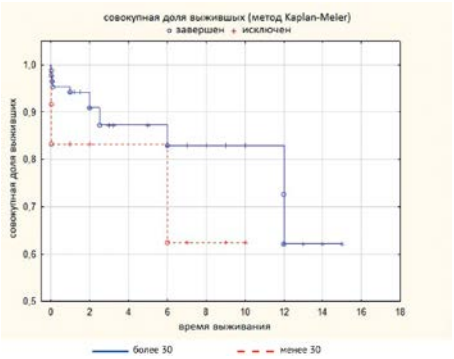

Fig. 5. Survival based on preoperative left ventricular ejection fraction values in patients with postinfarction left ventricular dilatation

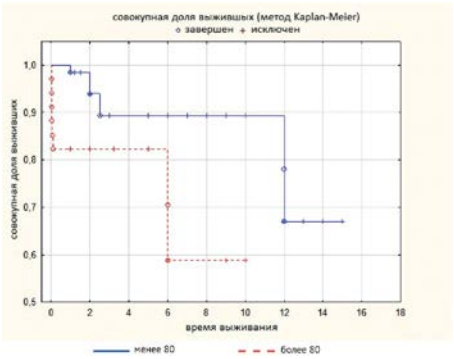

Fig. 6. Survival based on the values of the index of the end systolic volume of the left ventricle before surgery in patients with postinfarction dilatation of the left ventricle

Freedom from re-hospitalization, due to the increase in the phenomena of CHF, was 73%. NYHA functional class improved from an average of 3.7+0.5 to 1.0+0.2 after surgery. In the postoperative period, 100% of patients had a functional class I or II (94% - I FC, 6% - II FC).

In 11 (11%) patients, speckle-tracking Echo-CG was performed before and 18 months after SRLV surgery. In all patients, the indicators of global longitudinal systolic deformity in the postoperative period significantly increased in comparison with preoperative indicators: -6.48+1.23% and -9.2+0.86% (p<0.001), respectively, which makes it possible to judge about improvement of LV myocardial function in patients after SRLV.

CONCLUSION

Postinfarction remodeling of the LV cavity leads to an increase in diameter and an increase in wall stress according to Laplace's law. Increased wall loading leads to an increase in oxygen consumption, a decrease in subendocardial blood flow and a decrease in systolic shortening. White et al. reported that when analyzing the causes of mortality after myocardial infarction, LV volume was more prognostic than EF. In patients with an LVESV > 60 ml/m2, mortality is about five times higher than in patients with an unchanged LV volume, given that the normal LVESV is 24±10 ml/m2 [6, 12].

Studies of the global use of streptokinase (GUSTO I) and t-PA in patients with coronary artery occlusion after myocardial infarction showed that LVESV ⩾ 40 ml/m2 was associated with increased development of CHF and poor long-term survival. Thus, mortality among patients within one year with LVESV from 40 to 50 ml/m2 was 16%, with LVESV from 50 to 60 ml/m2 - 21% and with LVESV > 60 ml/m2 - 33% [13].

The shape of the left ventricle is an important determinant of its function. The transition from the elliptical shape of the left ventricle to the spherical one reduces the normal systolic torsion. Myofibrils in the spherical shape of the left ventricle are displaced from their inclined axis towards the transverse. A spherical ventricular myofibril with 15% shortening generates 30% EF, compared to a 60% elliptical ventricular myofibril with natural torsion of the myofibrils [14]. The radius of myocardial curvature increases after myocardial infarction with loss of regional EF [15]. The Dor procedure improves overall LV systolic function by increasing regional function in non-infarcted segments [16]. After surgery, the left ventricle becomes elliptical [8].

In the present study, SRLV was performed to restore normal LV geometry in all cases. Concomitant operations included CABG in 98% of patients and interventions on the mitral valve in 4% of patients. Thus, three pathological components influencing the development of CHF: the shape of the left ventricle, coronary vessels and valve were surgically corrected.

Coronary artery bypass grafting can be safely performed in patients with reduced LV systolic function [17, 18–20]. Isolated CABG is not very effective when excessive ventricular expansion occurs. In one study, mortality from CABG was 27% if LV end-diastolic diameter ⩾81 mm [21]. Survival of patients with EF ⩽30% after CABG correlated with LVESV [17]. Five-year survival was 54% if preoperative LVESV ⩾100 ml/m2 and 85% if LVESV ⩽100 ml/m2, and congestive heart failure was observed in 69% of patients and 15%, respectively [22]. Luciani et al. studied 167 patients with EF 28% who underwent CABG. Five years later, 60% of patients still had CHF, which was the most common cause of death. All this testifies to the limitations of using only isolated CABG in these patients [19, 23].

Expansion of the left ventricular cavity is often accompanied by dysfunction of the mitral valve of a functional nature [24]. Patients with mitral regurgitation in CHF after mitral valve surgery have a five-year survival of approximately 50% [19, 25]. Recurrent CHF occurs in one third of patients and is presumably associated with continued dysfunction of the unchanged ventricular myocardium, which is the most common cause of death [19, 26]. Restoration of normal mitral valve function is integral in addition to LV cavity volume reduction and myocardial revascularization. Surgical intervention on the mitral valve was performed in 4% of patients with a pronounced decrease in systolic function and a significant expansion of the LV cavity. Regurgitation in 2 patients was central and both were able to undergo suture annuloplasty. In two patients, it was impossible to perform MV annuloplasty, and therefore mitral valve replacement was performed. Di Donato et al., [27] described a reduction in patient survival at two years (52%) if the removed segment of the anterior wall was asynergic. These data illustrate the importance of preoperative assessment of LV wall segments supplied by the right and circumflex arteries. SRLV should be avoided if segments of the inferior and lateral wall of the left ventricle are asynergic after myocardial infarction [16]. At the same time, LV wall hypokinesia is not always a contraindication to surgery, since local contractility may improve after myocardial revascularization. In these cases, myocardial scintigraphy and ECHO-CG speckle tracking during the preoperative examination is an important prognostic study to determine myocardial viability in these patients. The analysis showed that in patients with coronary artery disease, severe mitral valve insufficiency and large LV volume, LVLC with CABG in combination with mitral valve repair or replacement leads to an improvement in the values of LVESV.

Other surgical approaches in the treatment of ischemic cardiomyopathy include implantation of an artificial left ventricle (LVAD) and donor heart transplantation. The Randomized Evaluation of Mechanical Assistance in Congestive Heart Failure (REMATCH) study examined the use of LVAD as a long-term myocardial replacement treatment in patients with CHF. Fewer than 10% of patients survived to three years in the LVAD group, compared with no survivors among patients treated with medication alone [3]. The five-year survival rate after heart transplantation is 70%, but few patients manage to receive a heart due to a lack of donors [28]. Surgical remodeling of the left ventricle should be considered as an alternative option.

Our logistic regression analysis shows that the main factors influencing the survival of patients after SRLV were EF ⩽ 30% and LVESV ⩾ 80 ml/m2 before surgery.

FINDING

Surgical remodeling reduces the volume of the dilated left ventricle and restores its elliptical shape in CAD patients with anterior myocardial infarction. The results of our study demonstrate an improvement in LV systolic function in all patients in the early postoperative period and low mortality, an acceptable fifteen-year survival rate, and a low rehospitalization rate due to the progression of chronic heart failure.

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