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Original article

LEFT VENTRICULAR SYSTOLIC FUNCTION AFTER CORONARY ARTERY BYPASS GRAFTING: INSIGHTS FROM GLOBAL LONGITUDINAL STRAIN AND MYOCARDIAL WORK

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Abstract

Introduction. Patients with multivessel coronary artery disease (CAD) and preserved left ventricular ejection fraction (LVEF) may have subclinical systolic dysfunction. Advanced echocardiographic parameters, including global longitudinal strain (GLS) and myocardial work (MW) indices, provide additional insights into myocardial performance and recovery after coronary artery bypass grafting (CABG).

Aim. To assess changes in left ventricular systolic function using conventional echocardiography, GLS, and MW indices following CABG.

Material and methods. This prospective study included 21 patients with multivessel CAD undergoing CABG. Echocardiography, including GLS, and MW indices (global work index [GWI], global constructive work [GCW], global wasted work [GWW], and global work efficiency [GWE]) was performed preoperatively and at 6-8 months postoperatively. Percentage changes and correlations were analyzed.

Results. At baseline, patients demonstrated impaired GLS and abnormal MW parameters despite preserved LVEF, consistent with subclinical LV dysfunction. At follow-up, GLS showed a statistically significant but modest improvement (p=0.021), while LVEF showed a borderline increase (p=0.078). MW indices did not change significantly at the group level but demonstrated marked inter-individual variability. GLS increased by >5% in 42.9%, and >10% in 33.3% of patients, while LVEF increased by >5% in 52.4% of patients. Improvements in GWI, GCW, and GWE were observed in approximately half of the patients. Changes in MW indices correlated with improvements in both LVEF and GLS.

Conclusion. In patients with preserved LVEF undergoing CABG, subclinical LV dysfunction is detectable using GLS and MW analysis. While structural remodeling and modest improvement in GLS were observed, MW indices showed heterogenous responses. Combined GLS and MW assessment may improve postoperative functional evaluation.

Keywords: myocardial work, global longitudinal strain, echocardiography, coronary artery bypass graft

Introduction

Surgical myocardial revascularization through coronary artery bypass grafting (CABG) represents a standard therapeutic intervention in patients with coronary artery disease, aiming

to improve myocardial perfusion, reduce ischemic burden, and potentially enhance left ventricular (LV) systolic function[1].

In a substantial proportion of patients - particularly those with reduced preoperative ejection fraction or established LV dilation and remodeling - the assessment of systolic functional recovery is a key indicator of surgical success, postoperative risk, and long-term prognosis.

Conventional echocardiographic parameters such as left ventricular ejection fraction (LVEF) and global longitudinal strain (GLS) may lack sensitivity in detecting subtle functional improvements. Myocardial work (MW), derived from pressure–strain loop analysis, provides a noninvasive, afterload-adjusted assessment of effective myocardial contractility[2].

Furthermore, myocardial work indices - including global work index (GWI), global constructive work (GCW), global wasted work (GWW), and global work efficiency (GWE) - integrate myocardial deformation with estimated LV pressure, offering deeper physiological insight into myocardial performance and recovery following CABG[3,4].

The aim of this study was to evaluate changes in LV systolic function following CABG, with particular focus on GLS and myocardial work parameters as markers of subclinical systolic dysfunction.

Material and methods

This prospective observational study included patients of both sexes undergoing cardiac surgery at the University Clinic for Cardiac Surgery in Skopje. The study was approved by the Ethics Committee of the Faculty of Medicine, Ss. Cyril and Methodius University.

A total of 21 patients with angiographically and clinically indicated CABG, according to current guideline recommendations, were enrolled. All participants met inclusion criteria and provided written informed consent.

All patients underwent two-dimensional echocardiography before surgery and at 6–8 months postoperatively. In addition to conventional systolic parameters, LV global longitudinal strain (GLS) was assessed using speckle-tracking echocardiography from apical 2-, 3-, and 4-chamber views.

Myocardial work (MW) analysis was performed by integrating LV strain data with noninvasively measured brachial systolic blood pressure and valve timing events (mitral and aortic valve opening/closure), enabling construction of LV pressure–strain loops. This allowed calculation of: global work index (GWI), global constructive work (GCW), global wasted work (GWW), and global work efficiency (GWE)[5].

Reference values were based on the EACVI NORRE study and subsequent meta-analyses[6,7]. All patients received guideline-directed medical therapy[8].

Statistical analysis

Data were expressed as mean±standard deviation or percentages. Categorical variables were compared using the Pearson chi-square test, while continuous variables were analyzed using Paired Student's t-test. Correlations were assessed using Pearson or Spearman correlation coefficients as appropriate. Statistical analyses were performed using SPSS, version 25 (IBM Corp., Armonk, NY, USA), with $p<0.05$ considered statistically significant.

Results

A total of 21 patients were evaluated before and after CABG. The mean age was 65 years, with a predominance of males (95.2%). Hypertension was present in all patients, dyslipidemia in 85.7%, and diabetes mellitus in 33.3%.

Most patients presented with acute coronary syndrome (76.2%) and myocardial infarction (MI) (66.7%), predominantly non-ST-elevation MI. Multivessel disease was present

in 81% of patients, while left main disease was identified in 57.1%. Urgent CABG was performed in 57.1% of patients. Chronic obstructive pulmonary disease, chronic kidney disease, and prior cerebrovascular stroke were each present in two patients, while peripheral vascular disease was present in one patient.

Before CABG, only five patients were receiving heart failure therapy, and six patients were on antiplatelet therapy.

Body mass index (BMI) averaged 28.84 kg/m² preoperatively and 28.60 kg/m² postoperatively, indicating that patients were, on average, overweight at both time points. Regarding NYHA functional class before CABG, 19% of patients were in class II, 28.6% in class III, and 52.4% in class IV.

Perioperative results are presented in Table 1. On average, more than two grafts were implanted per patient, predominantly arterial. The left internal mammary artery (LIMA) was used in all patients. Cardiopulmonary bypass time, myocardial ischemia time, and intubation duration were all within acceptable ranges. Vasopressors were administered in 19 (90.5%) patients. Regarding complications, one patient experienced myocardial infarction, and another experienced a stroke. Serum lactate levels at exit from the operating room averaged 2.07 mmol/L, while high-sensitivity troponin levels were 5515.63 pg/mL. Patients stayed in the ICU for approximately 5 days and had a total hospital stay of 16 days.

Table 1. Overview of perioperative cardiac surgical parameters

Parameters	n=21
Number of grafts	2.76± 0.70
Type of grafts (n/%)	
Arterial	16/76.2
Arterial+venous	5/23.8
LIMA used (n/%)	21/100
Cardiopulmonary bypass time (min)	127.90 ± 36.21
Myocardial ischemia time (min)	78.43 ± 27.86
Intubation time (min)	1869.76 ± 1800.67
Postoperative AF (n/%)	7/33.3
Perioperative MI (n/%)	1/4.8
Perioperative stroke (n/%)	1/4.8
Inotropes in OR (n/%)	6/28.6
Inotropes in ICU (n/%)	10/47.6
Vasopressors in ICU (n/%)	19/90.5
Heart failure therapy (n/%)	8/38.1
Lactate at OR exit (mmol/L)	2.07 ± 0.84
Postoperative hsTroponin (pg/ml)	5515.63 ± 5292.82
Total ICU stay (days)	5.19 ± 4.91
Total hospital stay (days)	15.76 ± 10.26

LIMA = left internal mammary artery graft; OR=operating room; ICU = intensive care unit.

Echocardiographic results

Echocardiographic assessment of systolic function before and after CABG is presented in Table 2, including percentage change.

Left ventricular (LV) internal dimensions in both systole and diastole were within reference ranges but showed significant reduction after CABG (p=0.017 and p=0.013, respectively). Indexed LV mass was above reference values, with a borderline reduction after CABG (p=0.075). End-diastolic and end-systolic volume indices were near normal both before and after CABG, with a non-significant trend toward reduction.

LVEF was slightly below the reference range preoperatively but remained within the preserved EF category (≥50%). After CABG, LVEF showed a trend toward improvement (p = 0.078), while tissue Doppler velocity increased significantly (p=0.010). An absolute increase

in LVEF was observed in 13 patients (61.9%), with an increase >5% in 11 patients (52.38%) (Figure 1).

Stroke volume index remained within normal limits, with a slight, non-significant increase postoperatively. Cardiac index remained below reference values at both time points, without significant change. Myocardial contraction fraction (MCF) remained within reference values, with a borderline increase after CABG.

Strain values from all three apical views, as well as global longitudinal strain (GLS) were less negative than reference values both before and after CABG, indicating subclinical LV systolic dysfunction despite preserved LVEF. GLS showed a small but statistically significant improvement after CABG (p=0.021). Absolute improvement was observed in 11 patients (52.38%), with >5% improvement in 9 patients (42.86%) and >10% improvement in 7 patients (33.33%) (Figure 1). The number of segments with longitudinal strain (LS) <13% did not decrease significantly, although an absolute reduction was observed in 13 patients (52.38%).

Table 2. Echocardiographic parameters of dimensions, systolic function and longitudinal strain measured preoperatively and after CABG

Parameter	Preoperative n=21	Postoperative n=21	Percentage change n=21	p
LVEDd (mm)	55.76±5.17	53.24±5.23	-4.29±7.40	**0.017**
LVEDs (mm)	39.81±5.44	35.86±4.88	-9.01±13.35	**0.013**
IVSd (mm)	12.86±1.85	12.52±1.91	-2.25±10.81	0.297
PWd (mm)	10.43±1.39	10.19±1.28	-1.66±10.30	0.329
LVMi (g/m2)	140.78±42.52	127.21±24.35	-6.41±16.18	0.075
LVEDVi (ml/m2)	62.88±12.52	60.01±12.35	-2.45±21.43	0.255
LVESVi (ml/m2)	32.60±10.23	30.08±7.81	-1.55±31.65	0.225
LVEF (%)	49.81±9.98	53.33±8.38	9.58±19.78	0.078
SVI (ml/m2)	37.02±10.93	38.17±9.29	6.83±20.65	0.521
CI (L/min/m2)	1.37±0.42	1.36±0.42	1.87±20.88	0.856
s'TDI average (cm/s)	6.54±1.23	7.33±1.25	13.98±19.52	**0.010**
MCF (%)	29.31±9.93	32.36±8.72	18.85±39.21	0.092
GLS (%)	-14.30±3.06	-14.43±3.25	3.48±25.85	**0.021**
Nb. seg. LS < 13%	6.67±3.16	5.48±3.61	1.53±93.19	0.140

LVEDD=left ventricular end-diastolic diameter, LVESD=left ventricular end-systolic diameter, IVSd=interventricular septum thickness in diastole, PWd=posterior wall thickness in diastole, LVEDVI= left ventricular end-diastolic volume indexed to body surface area, LVESVI=left ventricular end-systolic volume indexed to body surface area, LVMI=left ventricular mass indexed to body surface area, SVI= stroke volume index, CI=cardiac index, s′ TDI=peak systolic tissue Doppler velocity measured at the level of the mitral annulus, MCF=myocardial contraction fraction, GLS=global longitudinal strain, Nb.seg= number of segments, LS=longitudinal strain

Myocardial work analysis

Myocardial work (MW) parameters are shown in Table 3. Values indicated reduced global work index (GWI) and global constructive work (GCW), decreased global work efficiency (GWE), and increased global wasted work (GWW), both before and after CABG. This profile is consistent with a population exhibiting preserved LVEF but impaired myocardial deformation (strain) and markedly abnormal MW.

No statistically significant group-level improvement in MW parameters was observed after CABG. However, individual patient analysis demonstrated heterogeneity of response, with increase in GWI in 42.9%, GCW in 47.6%, and GWE in 47.6%, and a reduction in GWW in 52.4% of patients (Figure 1).

Table 3. Echocardiographic parameters of left ventricular myocardial work measured preoperatively and after CABG

Parameter	Preoperative n=21	Postoperative n=21	Percentage change n=21	p
GWI (mmHg%)	1094.62±396.94	1045.00±327.71	10.21±52.87	0.627
GCW (mmHg%)	1668.10±463.40	1631.76±323.37	3.21±26.22	0.696
GWW (mmHg%)	277.95±101.39	291.52±178.32	13.80±69.77	0.704
GWE (%)	84.29±6.07	84.38±8.79	0.19±9.07	0.955

GWI=global work index, GCW=global constructive work, GWW=global wasted work, GWE=global work efficiency

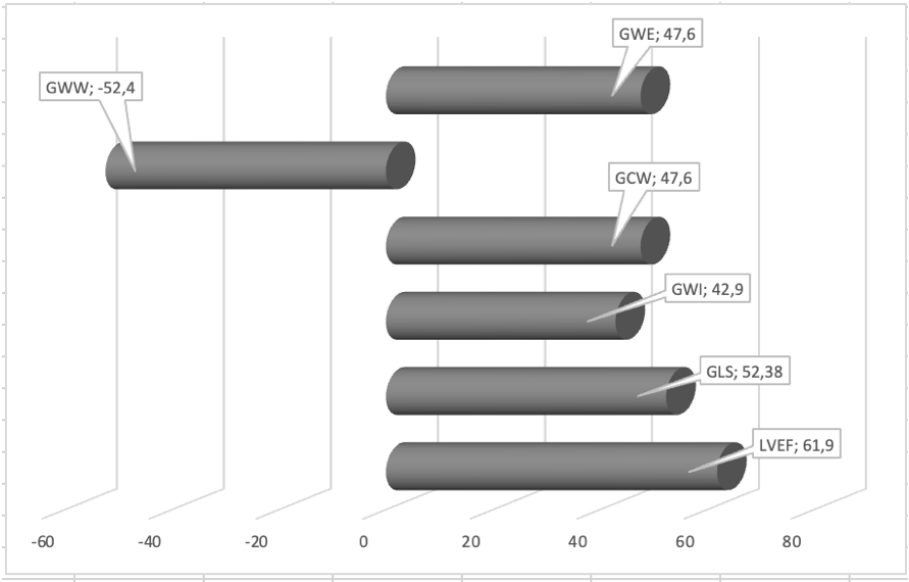

Fig. 1. Percentage change in left ventricular systolic function and myocardial work parameters after CABG. LVEF showed mild increase, GLS showed significant improvement and MW indices showed heterogeneous response/no clear group shift.

Percentage change in left ventricular ejection fraction (LVEF), global longitudinal strain (GLS), and myocardial work indices (global work index, GWI; global constructive work, GCW; global wasted work, GWW; global work efficiency, GWE) measured 6-8 months after CABG compared with baseline values.

Correlations of the changes in systolic function parameters after CABG

Correlations between improvements in postoperative LV systolic parameters (LVEF, GLS) and MW indices (GWI, GCW, GWW, GWE), as well as their relationships with pre-, peri-, and postoperative variables, are displayed in Table 4.

An increase in LVEF after CABG was significantly associated with lower lactate levels at exit from the operating room, as well as with an increase in SVI and GWI. Improvement in GLS was significantly associated with the absence of LM disease and with an increase in GWI. The increase in GWI after CABG was significantly associated with improvements in both LVEF and GLS, as well as with increases in GCW and GWE. Additionally, an increase in GCW was significantly associated with improvement in GLS% and GWI.

A reduction in GWW after CABG was significantly associated with an increase in GWE. Conversely, improvement in GWE was significantly associated with the absence of LM disease, as well as an increase in GWI and a reduction in GWW.

Table 4. Overview of correlations between the analyzed echocardiographic parameters and postoperative improvement in left ventricular systolic function

	Postoperative		
	Increase in LVEF%	**Increase in GLS%**	**Increase in GWI**
Lactate in OR (mmol/L)	r=-0.453. p=0.039	-	-
Presence of LM disease	-	r=-0.440. p=0.046	-
Increase in LVEF (%)	-	-	r=0.481. p=0.027
Increase in SVI (ml/m2)	r=0.596. p=0.004	-	-
Increase in GLS (%)	-	-	r=0.440 p=0.046
Increase in GWI (mmHg%)	r=0.481. p=0.027	r=0.440. p=0.006	-
Increase in GCW (mmHg%)			r=0.716. p=0.0001
Increase in GWE (mmHg%)			r=0.523 p=0.015
	Increase in GCW	**Decrease in GWW**	**Increase in GWE**
Presence of LM disease	-	-	r=-0.523. p=0.015
Increase in GLS (%)	r=0.526. p=0.014	-	-
Increase in GWI (mmHg%)	r=0.716. p=0.0001	-	r=0.523 p=0.015
Decrease in GWW (mmHg%)			r=0.718. p=0.0001
Increase in GWE (mmHg%)	-	r=0.718. p=0.0001	-

OR=operating room, LM=left main, LVEF=left ventricular ejection fraction, GLS=global longitudinal strain, GWI=global work index, GCW=global constructive work, GWW=global wasted work, GWE=global work efficiency

Due to the limited sample size, multivariable regression analysis was not performed to avoid model overfitting.

Discussion

In this prospective study, changes in LV systolic function in patients undergoing CABG were analyzed, using conventional echocardiography, tissue Doppler imaging, LV longitudinal deformation, and MW indices. Although the mean LVEF was within the normal range preoperatively, patients exhibited subclinical systolic dysfunction manifested as reduced GLS and decreased MW values, which is consistent with the results reported by Roemer et al. and Trimarchi *et al*.[9,10].

After CABG (6-8 months), structural reverse remodeling and improvement were observed in a subset of patients. The change after CABG was statistically significant only for GLS. Changes in MW parameters did not reach statistical significance, although improvement was observed in some patients, as expected in patients with coronary artery disease[11].

The profile of our cohort was characterized by older patients, with a mean age of 65 years, predominantly male, with multivessel and/or left main (LM) disease, and a high proportion of urgent procedures, which is typical for a population referred for surgical revascularization[12]. Although a large proportion of patients required inotropic and vasopressor support in the ICU, the incidence of major perioperative events was low, and the duration of hospitalization corresponded to what is expected for this high-risk group[13].

In our study, we observed a significant reduction in LV dimensions (LVEDd/LVEDs) and LVMi after CABG, suggesting early reverse remodeling, as previously reported in several studies, including that of Papestiev *et al.*[3,5,10]. Although LV volumes did not show statistical significance at the level of mean values, percentage analysis revealed a clear individual reduction - most pronounced for LVESVI, where postoperative reduction was present in all patients. This is consistent with the literature demonstrating that successful revascularization may lead to a reduction in LV volume and mass, even in patients with normal preoperative LVEF[10.14].

Left ventricular ejection fraction increased postoperatively with borderline statistical significance, with an increase >5% observed in 52.38% of patients. This is expected in patients with preserved LVEF, where ejection fraction has limited sensitivity for detecting subtle

changes compared to newer advanced techniques[15,16]. Stroke volume and cardiac output remained within normal ranges. Importantly, the increase in LVEF statistically correlated with the increase in stroke volume index and GWI, and inversely with lower preoperative MCF, suggesting that patients with more impaired baseline contractility have greater potential for recovery[9,17,18].

Peak systolic velocity (s′ TDI) increased significantly after CABG, indicating improvement in longitudinal contractility. GLS%, although reduced across the entire cohort (≈ -14%), showed a significant group-level change after surgery, with a non-significant reduction in the number of segments with LS <13%, findings that have already been reported in studies by Lustosa *et al*.[19] and Olsen *et al.*[20]. These results are consistent with the known heterogeneity of the post-revascularization response, which depends on myocardial viability, the extent of ischemic injury, and follow-up duration, as concluded in the studies by Spetsotaki *et al*.[21] and Perone *et al*.[22].

Several studies have demonstrated that myocardial work parameters (GWI, GCW, GWE, GWW) provide additional value in the assessment of LV deformation and function[11,14,21]. Accordingly, a reduction in constructive work and an increase in wasted work were already present preoperatively, indicating energetically inefficient myocardial function despite preserved LVEF. Postoperatively, MW values did not show significant changes at the group level; however, inter-individual variability was substantial: in some patients, GWI, GCW, and GWE improved, while in others they worsened. The increase in GWI correlated with increases in LVEF%, GLS%, GCW, and GWE, supporting the concept that myocardium with greater functional reserve and reversible ischemia derives the greatest benefit from revascularization[16,22]. Correlation analyses further strengthened this interpretation: lower postoperative lactate levels were associated with greater functional recovery[23].

Study limitations

The main limitation of this study is the small sample size, which may affect the precision of the results and precluded regression analysis.

Conclusion

In patients with multivessel coronary artery disease and preserved LVEF undergoing CABG, subclinical LV systolic dysfunction was present, as evidenced by impaired GLS, myocardial contraction fraction, and myocardial work parameters.

Although structural remodeling and improvement in GLS were observed, myocardial work parameters did not demonstrate statistically significant changes at the group level.

Myocardial work indices in combination with GLS, provide additional clinically relevant information for evaluating the effects of surgical revascularization and may improve risk stratification and postoperative follow-up.

Conflict of interest statement. None declared.

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