RESEARCH ARTICLE

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Coronary Flow Reserve Assessment Via Echocardiography in Patients with Coronary Bypass Surgery Undergoing LAD-LİMA Long Onlay-Patch Anastomosis without Endarterectomy

Esra ERTÜRK TEKİN [1,a]
Ayhan UYSAL [2, b]
Özden VEZİR [1, c]

[1] Mersin City Training and Research Hospital, Cardiovascular Surgery Department, Mersin, TURKIYE

[2] Fırat University, Faculty of Medicine, Cardiovascular Surgery Department, Elazig, TURKIYE

[a] ORCİD: 0000-0001-8335-5832
[b] ORCİD: 0000-0001-7526-5554
[c] ORCİD: 0000-0001-9948-0515

Objective: In severe calcified and diffuse coronary lesions, long onlay-patch anastomosis without endarterectomy is another technique to promote augmented blood flow especially to septal perforator branches of left anterior descending artery (LAD). In this study we aimed to demonstrate the efficacy of the long segment onlay-patch anastomosis without endarterectomy via using coronary flow reserve (CFR) measured by doppler echocardiography.

Materiasl and Methods: Fifty six patients who underwent Coronary artery bypass grafting (CABG) onlay-patch anastomosis technique without endarterectomy were evaluated by transthoracic echocardiography for CFR which represents the rates of blood flow both during resting and maximal hyperemia provided by dipyridamole. left anterior descending artery-left internal mammary artery (LAD-LIMA) along the long anastomosis line mid and distal flow patterns were examined, peak systolic and diastolic flow velocities and diastolic velocity time integral were registered.

Results: The mean onlay-patch length was 2.97±0.72 cm. When correlation of changes in coronary flow reserve and other echocardiographic findings were evaluated, there was a statistically significant however, for all patients (normal values: CFR>2, n: 9 and low values: CFR<2, n: 6) inverse correlation between onlay-patch anastomosis length and CFR (2.97±0.72 cm; 2.35±0.56 m/sec; P= 0.008, respectively). Coronary angiography was performed for the one patient with CFR<2. Angiography showed 80% stenosis in the post anastomosis segment.

Conclusion: We explained the reliability of the onlay-patch anastomosis technique without endarterectomy and the usability of CFR measurement with transthoracic echocardiography in the postoperative follow-up of patients who underwent coronary bypass.

Key Words: *Long onlay-patch anastomosis, endarterectomy, coronary flow reserve, coronary bypass, multi-vessel coronary artery disease*

Endarterektomisiz LAD-LIMA Uzun Onlay-Yama Anastomozu Yapılan Koroner Baypas Hastalarında Koroner Akım Rezervinin Transtorasik Ekokardiyografi ile Değerlendirilmesi

Amaç: Endarterektomisiz uzun onlay-yama anastomozu tekniği; yaygın ve ciddi koroner arter lezyonlarında, özellikle sol ön inen arterin (LAD) septal perforator dallarına da kan akımını sağlayan başka bir tekniktir. Bu çalışmada, endarterektomisin uzun segment onlay-yama anastomozu yapılan hastalarda, postoperatif transtorasik ekokardiyografi ile koroner akım rezervi (KAR) ölçümünün etkinliğini araştırdık.

Gereç ve Yöntem: Endarterektomisiz onlay-yama anastomozu tekniği uygulanarak koroner baypas yapılan 56 hasta hem istirahat sırasında hem de dipiridamol ile sağlanan maksimal hiperemi oranlarını temsil eden KAR ölçümü için transtorasik ekokardiyografi ile postoperatif değerlendirildi. Uzun anastomoz hattı boyunca LAD-LIMA orta ve distal akım paternleri incelendi, pik sistolik ve diyastolik akım hızları ve diyastolik hız zaman integrali kaydedildi.

Bulgular: Ortalama onlay-yama uzunluğu 2.97±0.72 cm idi. Koroner akım rezervindeki değişikliklerin (normal değerler: CFR>2, n: 49 ve düşük değerler: CFR<2, n: 6) ve diğer ekokardiyografik bulguların korelasyonu değerlendirildiğinde, tüm hastalar için onlay-yama anastomoz uzunluğu ile CFR arasında istatistiksel olarak anlamlı bir ters korelasyon vardı (sırasıyla 2.97±0.72 cm; 2.35±0.56 m/sn; P değeri: 0.008). CFR<2 olan bir hastaya koroner anjiyografi yapıldı. Anjiyografi anastomoz sonrası segmentte %80 darlık gösterdi.

Sonuç: Endarterektomisiz onlay-patch anastomoz tekniğinin güvenilir ve koroner baypas yapılan hastaların postoperatif takiplerinde transtorasik ekokardiyografi ile KAR ölçümünün kullanılabilir olduğu kanaatindeyiz.

Anahtar Kelimeler: *Uzun onlay-yama anastomozu, endarterektomi, koroner akım rezervi, koroner baypas, çok damar koroner arter hastalığı*

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Correspondence
Yazışma Adresi

Esra ERTÜRK TEKİN

Mersin City Training and Research Hospital, Cardiovascular Surgery Department, Mersin, TURKIYE

dresraer@yahoo.com

Introduction

Patients undergoing cardiac surgery may be at an increased risk for neurological disorders due to symptomatic or asymptomatic carotid artery disease (CAD). Although many procedures are currently carried out under cardiopulmonary bypass (CPB), clinical neurological disorders can be encountered due to low blood flow and

thromboembolism-related cerebral ischemia and cerebral injury (1).

CABG has gained a valuable place in the treatment of obstructive coronary artery diseases in the past 50 years. In proximal and discrete type atherosclerotic lesions, life expectancy is prolonged, quality of life is improved, cardiac events and repetitive interventions are reduced with improvement of the surgery techniques. In contrast, diffuse coronary artery diseases are controversial as in disseminated atheromatous plaques and multıple stenosis are imposing operators to find appropriate lumen for bypass grafting and that causes the differences of the case selections compared to centers. It has been demonstrated that incomplete revascularization is one of the most significant parameter that affects both peri-operative and post-operative mortality rates. Especially, LAD with residual lesions, cause higher advert event rates than when other coronary arteries had incomplete revascularization.

When compared to conventional bypass, LIMA has more benefits in terms of mortality and morbidity compared to saphenous vein grafting (1).

In addition, significant differences were observed in the surgical techniques applied. Endarterectomy, patch plasty and jump bypass techniques are used to perform adequate and complete revascularization in diffuse coronary artery diseases. Coronary endarterectomy ensures appropriate lumen by mechanical removal of the atheromatous plaques however related with high peri-operative myocardial infarction (MI), increased early mortality rates as well as endarterectomy is a complicated and time consuming technique (2).

Coronary artery reconstruction with or without removal of plaque is another technique performed for diffusely diseased LAD. In severe calcified coronary lesions onlay-patch anastomosis without endarterectomy promotes augmented blood flow especially to septal perforator branches of LAD and obtains relief in angina. Various methods such as direct anastomosis with LIMA or saphenous vein are also applied in order to keep the anastomosis line long (3).

CFR is a physiologic non-invasive imaging technique that represents semiquantitative flow rates of epicardial coronary arteries and integrity of microvascular circulation. The decrease in CFR value indicates impairment of microvascular circulation and is early predictor of graft failure (4). The accuracy, sensitivity and specificity has been shown in a number of study and CFR is a reliable non-invasive unique test performed via transthoracic doppler echocardiography and feasible for post-operative bypass conduit assessment (5).

The purpose of the present study, via using CFR measured by doppler echocardiography to evaluate the efficacy of the LAD-LIMA long segment onlay-patch anastomosis without endarterectomy.

Materials and Methods

Research and Publication Ethics: The study protocol was approved by the ethical committee (Maltepe University, Faculty of Medicine Ethical Committee, Date: 01.06.2009/Decree No.2), and signed informed consent was obtained before the operation.

Onlay-patch anastomosis without endarterectomy technique was performed a total of 56 patients who underwent coronary bypass surgery were included in this double-centered study. Between May 2005 and December 2010 41 patients in Maltepe University Medical Faculty Cardiovascular Surgery Clinic and between January 2015 and December 2017 15 patients in Mersin Training and Research Hospital Cardiovascular Surgery Clinic were operated with this same technique. Patients who underwent onlay-patch anastomosis and were fully recovered and discharged, were included consequently in this study. Patients who had documented proximal multi-vessel disease or left main arterial disease, admitted with stable angina and after the coronary angiography the significance of the lesions were assessed by fractional flow reserve or visually, were candidates for cardiac surgery. All the cases were evaluated by heart team and the surgery was performed according to decision. All the signed informed consents were obtained before the operation. All patients included in the study read and signed voluntary consent form. We measured postoperative CFR values in post-operative 6th month. Patients with dipyridamole allergy, severe chronic obstructive pulmonary disease, severe renal failure, pre or post-operative arrhythmias, addition cardiac surgery or valve pathology, acute coronary syndrome, and dilated cardiomyopathy were excluded from the study. Patients using vasospastic drugs and who had substance abuse other than cigarette were also excluded.

Surgical access was performed by median sternotomy in all patients. Cardiopulmonary bypass was performed in all cases using a membrane oxygenator. Moderate hemodilution, moderate hypothermia (28–30°C), and antegrade-retrograde hyperkalemic blood cardioplegia were obtained. The onlay-patch anastomosis technique was only done to diffuse long-segment or multıple stenotic LAD lesions, which is functionally significant and had necessity for revascularization. A small incision next to the distal plaque at mid portion of LAD and the incision was extended both in proximal and distal ways through the plain arterial wall. LIMA was prepared and distal anastomosis was done by continuous suture technique with 7/0 monofilament sutures. Blood samples including blood count, serum C reactive protein, electrolytes, blood urea nitrogen, creatinine, liver function tests and cardiac biomarkers were obtained in the 12^{th} hours, 48^{th} hours and 72^{th} hours at post-operative period. Invasive radial arterial catheter was used for close monitoring of hemodynamics.

Echocardiographic assessments were performed by both same physician and same device Vivid 7 dimension device (General Electric Waukesha, WI, USA) in the 6th months after surgery during follow ups. Mid-distal flow pattern was visualized on LAD-LIMA long anastomosis and native LAD in the anterior

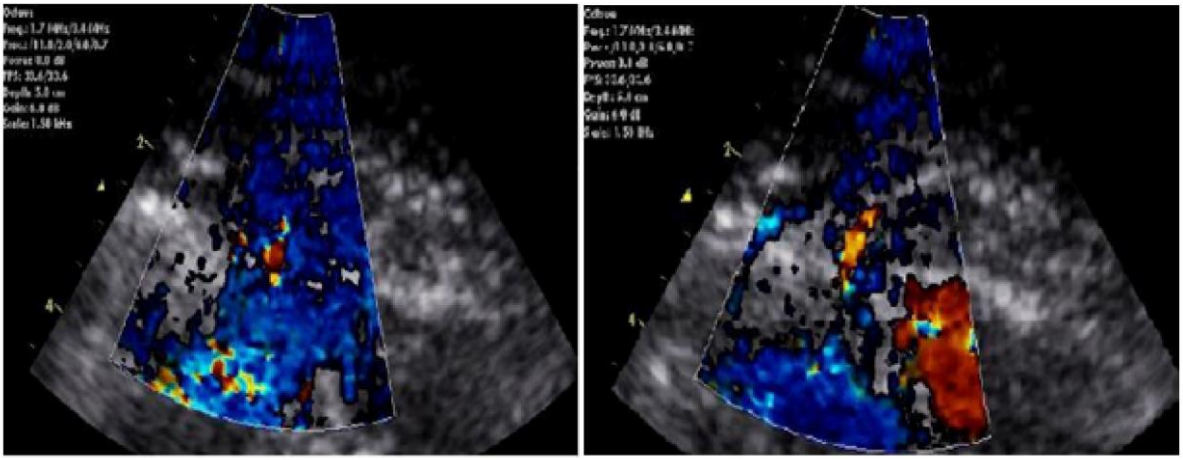

Figure 1. Basal LAD flow* sampling and post-dipyridamole hyperemia LAD flow** sampling with transthoracic echocardiography

interventricular sulcus (Figure 1). Peak systolic and diastolic flow velocities and systolic and diastolic velocity time integral (VTI) values were measured and recorded. Subsequently, dipyridamole was infused from the antecubital vein at a dose of 0.56 mg/kg over 4 minutes and the parameters mentioned above were measured again. Peak diastolic velocity and VTI values of 2.0 or more increased after dipyridamole infusion were considered as sufficient coronary flow reserve. Two dimension, M-mode, pulsed tissue doppler echocardiographic examinations were also performed and wall thicknesses, chamber dimensions, left ventricular ejection fraction (LVEF) by Teicholz method were noted.

In this study, statistical analysis was undertaken with SPSS 16.0 package program (SPSS Inc. Chicago, Illinois, USA). In the evaluation of data, descriptive statistical methods (mean, standard deviation, frequency distributions), as well as Mann-Whitney-U test for the comparison of binary groups, Wilcoxon test for measuring the changes before and after treatment, and Pearson correlation test were used to determine the relationship of variables. The results at $P<0.05$ level were considered statistically significant.

Results

On pump CABG surgery was performed in 56 patients by coronary long onlay-patch anastomosis without endarterectomy. Twenty of the patients were female (35.7%), 36 were male (64.2%) and the mean age were 58.58±9.4. The majority of patients were over 50 years old (70.7%). The risk factors and clinical characteristics of the patients for atherosclerotic coronary artery disease are described in Table 1. Preoperatively, all the patients were in sinus rhythm. Preoperative echocardiography finding of the patients were demonstrated in Table 2. Preoperative mean LVEF was invented 52.62±5.70%. Preoperative coronary angiography was revealed 32 (57.1%) patients had left main coronary disease, 48 (85.7%) patients had three vessel disease, 20 (35.7%) had two vessel disease and 14 (25%) patients underwent cardiac surgery on account of isolated diffuse LAD disease. Mean SYNTAX II score was 26.3±11.6. All patients underwent onlay-patch anastomosis without endarterectomy to the LAD. Patch anastomosis length was measured as 2.3-4.6 cm (mean= 2.97±0.72 cm). The median number off vessels grafted was 3.48±0.62 (1–4), mean cross–clamp time was 84.40±17.44 (55–110 min) and total bypass time was 108.12±22.1 min. Eight patients (14.2%) required positive inotropic and 3 patients (5.3%) required IABP support. Mean intubation time was 14.3±6.2 hours and there were two cases required prolonged intubation. There was not any re-intubated patient. The total drainages during follow ups were 540±215.2 mL. One patient underwent revision due to BARC 4 (The Bleeding Academic Research Consortium 4: CABG related-bleeding). Mean intensive care stay time was 2.10±1.27 days. Total hospital stay was 7.10±1.80 days. In our study, one patient died due to perioperative MI.

There was not any statistically significant difference when the preoperative and postoperative left ventricular mass index, interventricular septal thickness, left ventricular diameter and posterior wall thickness compared. However, postoperative LVEF was significantly higher compared with preoperative evaluation (52.62% vs 55.80%, P= 0.002, respectively).

CFR was measured as 1.29-3.6 (mean= 2.35±0.56) for all patients. CFR was normal (>2) in 49 (89.09%) patients and low (<2) in 6 (10.9%) patients. A statistically significant inverse correlation was found between CFR (1.29-3.6, mean= 2.35±0.56 m/sec) and onlay-patch anastomosis length (2.3-4.6, mean: 2.97±0.72 cm). CFR was positively correlated with mitral E/A-wave velocity ratio (r= 0.234; P= 0.02), however inversely correlated with severity of diastolic dysfunction. Correlation of CFR with examination and echocardiographic findings are described Table 3. There was not any statistical correlation between patients demographic characteristics and CFR levels. There was no statistical significance relationship regarding to the

number of vessels grafted. In patients with CFR values less than 2, the onlay-patch lengths found statistically significantly longer (3.4±0.41 cm vs 2.80±0.89 cm; P = 0.032, respectively). Postoperative LVEFs of patients with normal CFR (55.80±6.60%) were significantly increased compared to preoperative LVEF (53.83±7.90%). In the group of patients with low CFR (<2), postoperative LVEF did not show a significant increase when compared to the preoperative period.

According to the results of the echocardiography, CFR of the 6 patients who underwent CABG were insufficient (diastolic CFR<2; mean: 1.57±0.16). These patients were advised to undergo coronary angiography; however, three of them refused the angiography. Three patients underwent angiography. Post LAD-LIMA anastomosis 80% stenosis was observed at one patient (Figure 2).

Table 1. Demographic and clinical features of patients with long onlay-patch anastomosis

	Mean	**± SD**
Age (years)	58.58	9.4
Male/Female (n/n)	36/20	
Body mass index (kg/m^2)	25	4
Systolic blood pressure (mmHg)	132	20
Diastolic blood pressure (mmHg)	71	10
Heart rate (beats/min)	64	11
Fasting plasma glucose concentration (mg/dL)	102	30.8
Total serum cholesterol concentration (mg/dL)	193.3	36.6
Serum triglyceride concentration (mg/dL)	224.8	167.8
Serum high density lipoprotein cholesterol concentration (mg/dL)	42.4	15.5
Serum low density lipoprotein cholesterol concentration (mg/dL)	106.8	31.1
Haemoglobin concentration (mg/dL)	13.2	4.1
Serum C – reactive protein concentration (mg/dL)	7	12
LVEF (%)	52.62	5.7
Number of vessels grafted (n)	3.48	0.62
LMCA lesions (n)	32 (57.1%)	
Cardiopulmonary bypass duration (min)	108.12	22.1
Intubation time (hours)	14.3	6.2
Stay in intensive care unit (days)	2.1	1.27
Hospital stay (days)	7.1	1.8
Inotropic agent usage (n)	8 (14.2%)	
Postoperative exitus (n)	1 (1.7%)	
Length of onlay-patch anastomosis (cm)	2.97	0.72

Table 2. Hemodynamic and coronary blood flow measurements and echocardiographic findings

	Pre-operative	**Post-operative**	**P value**
Left ventricular end diastolic diameter (mm)	4.76±0.63	4.83±0.56	0.86
Left ventricular end systolic diameter (mm)	3.33±0.56	3.27±0.62	0.75
Interventricular septal thickness (mm)	1.19±0.23	1.14±0.15	0,49
End diastolic posterior wall thickness (mm)	1.14±0.19	1.14±0.15	0.92
LVEF by Teicholz method (%)	52.62±5.70	55.80±6.98	0.002
Left atrial diameter (mm)	3.65±0.46	3.84±0.92	0.18
Baseline diastolic peak flow velocity (cm/s)	-	23.8±4.9	-
Hyperemic diastolic peak flow velocity (cm/s)	-	50.5±12.6	-
Coronary flow reserve (m/sec)	-	2.35±0.56	-
Mitral E-wave max (cm/s)	0.7±0.1	0.7±0.2	0.69
Mitral A-wave max (cm/s)	0.5±0.09	0.6±0.1	0.34
E/A ratio	1.4±0.3	1.2±0.4	0.26

Table 3. Correlation of CFR with examination and echocardiographic findings (n= 55)

		Diastolic CFR	Systolic CFR
Age	Pearson Correlation	0.253	0.350
	Sig. (2-tailed)	0.100	0.026
Systolic blood pressure before CFR (mmHg)	Pearson Correlation	-0.20	0.179
	Sig. (2-tailed)	0.239	0.287
Diastolic blood pressure before CFR (mmHg)	Pearson Correlation	0.061	0.257
	Sig. (2-tailed)	0.670	0.129
Systolic blood pressure after CFR (mmHg)	Pearson Correlation	-0.270	-0.130
	Sig. (2-tailed)	0.09	0.401
Diastolic blood pressure after CFR (mmHg)	Pearson Correlation	-0.39	-0.380
	Sig. (2-tailed)	0.021	0.018
Patch anastomosis length (cm)	Pearson Correlation	-0.403	-0.39
	Sig. (2-tailed)	0.007	0.97
Left ventricular end diastolic diameter (cm)	Pearson Correlation	-0.210	-0.170
	Sig. (2-tailed)	0.157	0.27
Left ventricular end systolic diameter (cm)	Pearson Correlation	-0.242	-0.412
	Sig. (2-tailed)	0.110	0.004
Interventricular septum thickness end diastolic (cm)	Pearson Correlation	-0.111	-0.125
	Sig. (2-tailed)	0.399	0.405
EF (TEICHOLZ) (%)	Pearson Correlation	0.156	0.099
	Sig. (2-tailed)	0.304	0.74

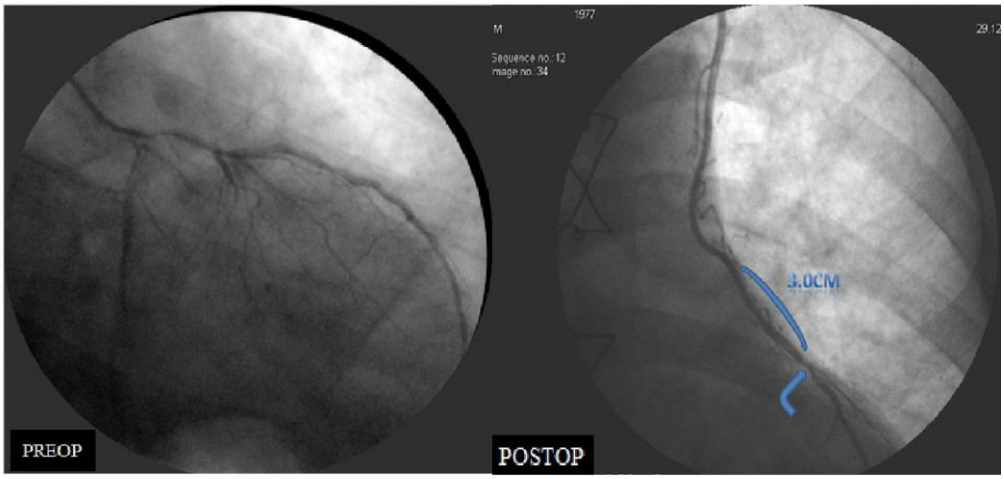

Figure 2. The preoperative and postoperative coronary angiography images of the patient with low CFR who underwent LAD-LIMA long-onlay patch anastomosis without endarterectomy. The curved arrow shows the critical stenosis at the post anastomosis segment.

Discussion

Despite all the advances in cardiac surgery, morbidity and mortality after coronary heart surgery is the most important problem. Diffuse coronary artery disease is defined as multiple stenosis in one or more coronary arteries, distal or partial obstruction of the lumen with the atheromatous material, along the entire length of the vessel (6). In case of diffuse coronary artery disease, it is not possible to anastomose the graft by conventional bypass techniques in such region and even if anastomosed it is often impossible to be beneficial at the distal portion. Therefore, more complex should be applied in such cases (7).

The usage of arterial conduits provides prolonged graft patency and reduce re-intervention necessity (8). In the lesions that partially or completely obstruct the vessel lumen and progress along to distal, the removal of atheromatous material, which is called endarterectomy, is one of the techniques that can be applied. Other technique, in cases where the vessel lumen is partially narrowed is patch plasty in which the arteriotomy is extended to the healthy lumen and the graft is spread over this long arteriotomy area and anastomosis with patch plasty. In cases of multiple stenosis, the arteriotomy can be extended from the proximal along the end of the stenosis or strictures and afterwards the graft is anastomosed to this long arteriotomy (9-10).

The frequency of endarterectomy and reconstruction due to diffuse coronary disease varies according to the clinics, and in some centers, 50% of the cases with coronary revascularization are present (11). According to previous studies, endarterectomy increased peri-operative MI and hospital mortality by 2 fold. Results of the studies from the era of vein grafts, endarterectomy had no benefits regarding to myointimal hyperplasia (12). In a study of Livesay et al. (13) 3369 patients were randomized in CABG with endarterectomy or conventional surgery. Mortality and peri-operative MI rates were significantly higher in the endarterectomy group (2.6%, 2.6% vs 4.4%, 5.4%; respectively). The benefits or harms of the endarterectomy is still questionable. The histopathological study of the pathologist Roberts et al. (14) on 35 coronary endarterectomy specimen performed by 7 different surgeons in a single center and 7 years period indicated from Texas that intima and media layer were seen together in all of the samples. He told surgeons that the procedure might better be called “endomediaectomy” rather than endarterectomy, which determined that the wall of the artery also includes the media layer. There is not any consensus whether to perform or avoid from endarterectomy. Contemporary studies were demonstrated that endarterectomy may beneficial and feasible for selected patients in mid-term survival rates and graft patency. Recent mid-term follow-up studies, in patients with advanced atherosclerosis and severe diffuse atheromatous plaque formation, endarterectomy had favorable effects on preserving myocardial viability and precipitated lesser major cardiac adverse events rather than former studies (15). Wang et al. (16) demonstrated poor short term outcomes for high risk patients with diffuse LAD disease that underwent endarterectomy with CABG while long term results are comparable to conventional CABG. The other study noted increase of cerebrovascular events in CABG with endarterectomy when compared to conventional surgery (17).

We performed long onlay-patch anastomosis without endarterectomy because many aspects remain uncertain about endarterectomy, and there is not a clear recommendation. We did not perform endarterectomy to protect the endothelium and preferred onlay-patch anastomosis also being safe and less complex technique of the onlay-patch anastomosis influenced our choice. LAD-LIMA onlay-patch anastomosis was performed to patients because the distal LAD did not allow for conservative anastomosis due to atherosclerosis. After long segment arteriotomy LIMA graft was directly anastomosed to the LAD and we called it onlay-patch anastomosis (18). During the operation, we experienced that onlay-patch anastomosis technique without endarterectomy was performed easier than endarterectomy technique. Therefore, onlay-patch anastomosis without endarterectomy technique may be better than endarterectomy in patients who would lose the chance of surgery due to diffuse atherosclerosis and multıple stenosis. Also, this technique, facilitate blood flow to the septal perforators and diagonal coronary arteries thus, perioperative MI and related death, the most important complication of endarterectomy (13), can be prevented. In our study, one patient (1.7%) died due to perioperative MI. The mortality rate of our patients who underwent onlay-patch anastomosis without endarterectomy were lower than that of endarterectomy (13, 15, 16).

There is some limited evidence to demonstrate microcirculation and blood flow in microvascular bed. CFR measurement after pharmacological vasodilatation is an effective way that supported with studies. CFR values were adequate to estimate hemodynamic significancy at LAD lesions (19). CFR is evaluates the severity of coronary stenosis (20). The determination of CFR by non-invasive method indicates a wide range of pathophysiological conditions, indicating changes in endothelial function in patients with risk factors and in treated patients. Low CFR values (<2) predict epicardial vascular disease associated with microcirculation and multiple cardiovascular, metabolic risk factors may be present (21). In our study, we measured CFR by doppler echocardiography to investigate the presence of epicardial stenosis in patients who had onlay-patch anastomosis without endarterectomy with LIMA after long LAD arteriotomy. As far as we know, investigation of the presence of epicardial stenosis in this long anastomosis line with doppler echocardiography has not been previously described. One of the important results we found; there is a statistically significant inverse correlation between onlay-patch anastomosis length and CFR values (P: 0.008). We evaluated this result as follows; the patch length shows us the presence of intra-coronary lesion that is surgically involved in the more common and longer segment. In such a case, however, the arteriotomy segment is kept longer. More common vascular disease is also compatible with worse coronary microvascular circulation. We think that the cause of lower coronary flow reserve in patients with longer patch anastomosis is due to worse intravascular disease and worse microvascular bed reserve. We performed a more accurate method to confirm graft patency by coronary angiography in a patient with low CFR. In this patient; we believe that CFR is low due to the critical post-anastomotic stenosis.

This study demonstrated the reliability of CFR in detecting graft patency and lower CFR levels are directly

associated with impaired viability that represents as decrease in LVEF in echocardiography. Onlay-patch anastomosis technique increases the blood flow in microvascular bed especially in patients with severe diffuse atheromatous plaque at distal vessel. Better results of microcirculation lead to better CFR measurements at LAD flow and directly related with myocardial contraction that presented in echocardiography. It is believed that these results have the clinical strength and meaning to trigger important studies in the near future.

This study had limitations because of restricted and short follow ups that omit long term survival, mortality and graft patency rates. Despite CFR is an accurate and reliable parameter, we could only measure changes in coronary blood flow velocity without coronary artery diameter, but we cannot measure itselves in coronary blood flow. However, it is closely related to the CFR measured using both parameters (22, 23). Also, the sample size was relatively small. Randomized cohorts and a control group would increase the statistical power. A long patch plasty with endarterectomy group can be added to demonstrate incontestable results. Finally, coronary angiography was performed in only one patient.

In conclusion, onlay-patch anastomosis without endarterectomy is a relatively safe, feasible and easily applicable technique in patients with severe distal atheromatous plaques. Onlay-patch anastomosis is superior for other conventional methods and more safe than endarterectomy. CFR is a noninvasive and sensitive parameter easily and cost-effectively performed to evaluate bypass grafts.

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