

Is Off-Pump Coronary Artery Bypass Surgery Superior to On-Pump Coronary Artery Bypass Surgery on Postoperative Paradoxical Ventricular Septal Motion?

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ABSTRACT

Background: The aims of this study were to investigate the appearance of paradoxical ventricular septal motion (PSM) after coronary artery bypass graft (CABG) surgery and to identify factors that might be related to this abnormality.

Methods: This prospective study included 119 consecutive patients (38 women, 81 men) who underwent CABG. Patients who underwent on-pump surgery (22 women, 45 men) and patients who underwent off-pump surgery (16 women, 36 men) were studied separately. All subjects underwent preoperative angiographic septal perfusion evaluation, pre- and postoperative echocardiography, and standard electrocardiographic and laboratory investigations, including troponin I and CK-MB levels. Multivariate logistic regression analysis was also performed for a variety of related parameters.

Results: Significant differences in EuroSCORE, length of intensive care unit stay, length of hospital stay, PSM (assessed using echocardiography), septal perfusion (observed using preoperative angiography), postoperative pleural effusion, and intensive care unit recidivism were observed between the two groups ($P < .05$). Moreover, postoperative PSM was correlated with septal perfusion ($r = -0.687^{**}$, $P < .001$), type of operation ($r = -0.194^{*}$, $P = .035$), diabetes mellitus ($r = 0.273^{**}$, $P = .003$), carotid stenosis ($r = 0.235^{*}$, $P = .011$), the number of distal anastomoses ($r = 0.245^{**}$, $P = .008$), pleural effusion ($r = 0.193^{*}$, $P = .037$), and intensive care unit recidivism ($r = 0.249^{**}$, $P = .007$). However, multivariate analysis demonstrated that only preoperative septal perfusion (odds ratio: 0.037; 95% confidence interval: 0.011-0.128; $P < .05$) constitutes an independent risk factor for PSM ($P < .05$).

Conclusions: This study demonstrated that preoperative septal perfusion deficiency represents an independent risk factor for postoperative PSM in patients undergoing CABG. Further investigations addressing the timing of the appearance of PSM and the correlation of this finding with

perfusion imaging studies may provide new details concerning the mechanisms that underlie this abnormality.

INTRODUCTION

Septal wall motion abnormality or paradoxical septal motion (PSM) is defined as a motion of septum with normal thickness to the right ventricle during the systole [Choi 2010]. Although it usually develops in cases with septal ischemia/infarction, left bundle branch block, or constrictive pericarditis [Otto 2004], it can also be encountered after heart surgery [Joshi 2009]. As far as heart surgery is concerned, septal wall motion abnormality has been attributed to the displacement of the heart toward the anterior chest wall following pericardiectomy [Eslami 1979] or to the reduction of septal perfusion during cardiopulmonary bypass (CPB) [Righetti 1977]. It has been reported that in patients with a diagnosis of regional wall motion abnormality, the risk of a major adverse cardiac event increases in the long term [Swaminathan 2007].

As is well known, coronary artery bypass graft (CABG) surgery is performed either with on-pump or off-pump. However, in on-pump CABG, various types of cardioplegia were used. The optimal composition and temperature of these solutions have not yet been determined [Rosu 2012; Andrews 2012]. This study offers a prospective examination of the effects of on-pump and off-pump surgery on septal wall motion abnormality. Moreover, it investigates whether a septal branch obstruction overlooked in preoperative coronary angiography has any effect on the development of PSM in the postoperative period.

MATERIALS AND METHODS

Subjects and Study Design

The study included 119 patients (38 women, 81 men) who had undergone CABG consecutively. The patients who had undergone on-pump surgery were defined as group 1 (22 women, 45 men, $n = 67$); patients who had undergone off-pump surgery were defined as group 2 (16 women, 36 men, $n = 52$). Off-pump surgery was preferred in 40 patients who had only two or three vascular lesions on the front side of the heart that were surgically accessible and bypassable; in

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an additional eight patients because of respiratory reasons; in another three because of advanced aortic calcification; and finally in a patient with low ejection fraction (EF).

Patients with the following conditions were excluded from the study: basal PSM, emergency cases, patients with EF below 30%, redo CABG, coronary endarterectomy, combined heart valve surgery/aneurysmectomy patients with permanent pacemakers, patients with increased right ventricular diameter on account of tricuspid failure, patients with pulmonary hypertension (HT) (>40 mm Hg), patients with acute and chronic pericarditis or cardiomyopathy, and patients with left bundle branch block. This study was approved by the Ethics Board and the Institutional Review Board (Project no: KA07/193) of Baskent University, and supported by the Baskent University Research Fund. This study was conducted according to the recommendations contained in the Declaration of Helsinki on Biomedical Research Involving Human Subjects.

In the case of each patient, 12-lead electrocardiography was applied 24 hours before the operation, echocardiography was applied before the operation and postoperative 4-8 weeks, and troponin I, creatine kinase (CK) and MB (CK-MB) fractions were measured both before the operation and once during the postoperative 3 days period.

Surgical Procedure

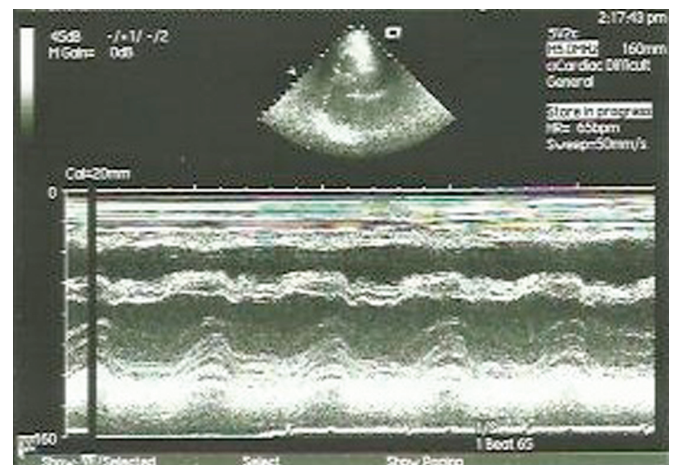
On-pump surgery: Median sternotomy was applied to all patients under general anesthesia. Systemic heparinization was performed to ensure an activated clotting time of 600-800 seconds. CPB was done via aorta-caval cannulation. Non-pulsatile CPB was used with a roller pump and a membrane oxygenator. The patients were routinely cooled to 28-30°C. After the installation of the cross-clamp, a crystalloid cardioplegic solution (St. Thomas' II solution) was applied every 20 minutes to protect the myocardium. Topical cooling was performed using a crystalloid ice slush solution in all patients. Using 7/0 propylene, distal anastomoses were made initially to the right coronary artery or to its posterior descending branch, subsequently to the circumflex coronary arterial system, and finally to the left anterior descending artery (LAD) and the diagonal arterial system. The left internal mammary artery was preferred as a graft for the anastomosis to the LAD artery. The proximal anastomoses were sewn onto the aorta, installing a side-clamp.

Off-pump surgery: Median sternotomy was performed on each patient. The arterial and venous grafts were prepared. The pericardium and heart were suspended with pericardial sutures. Then Octopus Tissue Stabilizers (Medtronic, Minneapolis, MN, USA) were used to immobilize the location where distal anastomosis was going to be applied. In cases that necessitated an anastomosis on the rear side of the heart, the heart was positioned using a Starfish (Medtronic). Following arteriotomy, the particular shunt (Medtronic) appropriate for the coronary diameter was placed. The distal and proximal anastomoses were carried out as described above. The pericardium was not closed in any of the patients, either in on-pump or off-pump surgery.

Echocardiographic and Angiographic Evaluation

During the preoperative and postoperative (ie, 4–8 weeks after the operation) periods, standard and tissue Doppler echocardiography were applied to each patient in the lateral decubitus position, using the Acuson Sequoia C256 Echocardiography System (Acuson, Mountain View, CA, USA). The echocardiographic images were recorded in video. Using M-mode imaging, the diastolic and systolic thicknesses of the intraventricular septum, the thickness of the posterior wall, and the end-diastolic and end-systolic diameters of the left and right ventricles were measured on the parasternal long axis. The EF was calculated. The mean of the three cardiac cycles was calculated. The echocardiographic assessments were made by the same cardiologists, with no information about the clinical data and echocardiographic analysis results of the patients. Positive PSM was defined as movement of the interventricular septum toward the right ventricle in systole with normal thickening in M-mode echocardiography (Figure).

All patients were assessed angiographically prior to surgery.



The image of septal wall motion abnormality in M-mode echocardiography.

Statistical Analyses

SPSS software version 10.0 (SPSS Inc, Chicago, IL, USA) was used to perform the statistical analyses. The numeric values were expressed as the mean $\pm$ SD. The independent-samples *t* test or the Mann-Whitney *U* test was used for continuous variables, and the χ^2 test was used for categorical variables. Continuous variables were tested for normal distribution using the Kolmogorov-Smirnov test. In the correlation analysis, the Pearson correlation coefficient was used for the parametric values and the Spearman correlation coefficient for the nonparametric values. Values of $P < .05$ were accepted as statistically significant. Multivariable logistic regression analyses were used to determine the independent risk factors of PSM. According to the power analysis, if a 20% change in a certain variable was considered clinically significant with a two-tailed $\alpha = 0.05$ and a statistical power of 80%,

the adequate subject count was 86. This result indicated that a sample size of 119 participants would be sufficient. With this sample size, the statistical power was 0.6.

RESULTS

The average age was 63.05 ± 10.27 for group 1 and 63.81 ± 10.24 for group 2. We did not encounter mortality in any of the patients who took part in our research. There was no statistically significant difference between the two groups in regard to average age, preoperative troponin I, preoperative CK-MB, postoperative CK-MB, height, weight, the average body mass index, EF, distal anastomosis number, preoperative septal thickness, postoperative septal thickness, gender, diabetes mellitus, HT, hyperlipidemia, chronic renal failure, smoking, peripheral vascular disease, and carotid stenosis ($P > .05$) (Tables 1, 2).

Significant differences in EuroSCORE, postoperative troponin I, length of intensive care unit stay, length of hospital stay, PSM (assessed using echocardiography), septal perfusion (observed using preoperative angiography), postoperative pleural effusion, and intensive care unit recidivism were observed between the two groups ($P < .05$) (Tables 1-3).

Moreover, postoperative PSM was correlated with septal perfusion ($r = -0.687^{**}$, $P < .001$), type of operation ($r = -0.194^*$, $P = .035$), diabetes mellitus ($r = .273^{**}$, $P = .003$), carotid stenosis ($r = 0.235^*$, $P = .011$), the number of distal anastomoses ($r = 0.245^{**}$, $P = .008$), pleural effusion ($r = 0.193^*$, $P = .037$), and intensive care unit recidivism ($r = 0.249^{**}$, $P = .007$). However, multivariate analysis demonstrated that only preoperative septal perfusion (odds ratio: 0.037; 95% confidence interval [CI]: 0.011-0.128; $P < .05$) constitutes an independent risk factor for PSM ($P < .05$) (Table 4).

DISCUSSION

In this prospective study, we detected PSM more frequently after on-pump CABG than off-pump surgery. Moreover, we observed that regardless of the type of operation, there was a link between PSM and cases in which septal perfusion was anatomically inadequate prior to surgery (for reasons such as stenosis of 70% or more in the first septal branch or the issuing of the septal branch from a coronary lesion). Moreover, in multivariate analysis, inadequate septal perfusion before surgery turned out to be an independent risk factor for postoperative PSM. To our knowledge, this link has not been reported in previous literature.

PSM can be detected at an early stage by postoperative echocardiography [Burggraf 1975]. Although it may be encountered in different clinical situations, the echocardiographic image obtained is similar in all of them [Joshi 2009]. PSM has also been linked to abnormalities in septal perfusion (ischemia/infarction), even though this disturbance may be clinically unimportant [Righetti 1977; Comunale 1998]. PSM upsets the performance of the ventricle, and therefore may lead to an increase in the morbidity and mortality of patients with a malfunction in the left ventricle [Sellier 2003].

Table 1. Comparison of the Parametric Data between the Two Groups*

	Group 1	Group 2	P
Mean age, y	63.05±10.27	63.81±10.24	.692
EuroSCORE	3.92±2.54	2.90±2.02	.017†
Preoperative troponin I (ng/mL)	0.26±0.47	0.44±0.97	.246
Preoperative CK-MB (U/L)	27.37±18.35	27.85±18.37	.899
Postoperative troponin I (ng/mL)	9.36±32.67	10.20±32.65	.022†
Postoperative CK-MB (U/L)	74.77±146.35	48.41±50.87	.405
Cross-clamp time, min	46.78±15.09	0	
CPB duration, min	102.14±34.97	0	
Height, cm	162.71±10.15	162.85±9.43	.939
Weight, kg	78.64±15.21	75.20±13.77	.211
BMI, m ²	1.87±0.21	1.83±0.19	.285
Ejection fraction, %	55.79±11.49	58.74±9.44	.145
Distal anastomosis, n	3.38±0.99	3.12±0.62	.079
Preoperative septal thickness	1.10±0.14	1.13±0.14	.395
Postoperative septal thickness	1.09±0.12	1.13±0.15	.335
Length of ICU stay, d	2.56±1.11	1.94±0.64	<.001†
Length of hospital stay, d	8.88±4.86	6.69±2.53	<.001†

*Data are presented as the mean $\pm$ SD where indicated. CK-MB indicates creatine kinase MB; CPB, cardiopulmonary bypass; BMI, body mass index; ICU, intensive care unit.

† $P < .05$.

Table 2. Comparison of the Non-Parametric Data between the Two Groups

	Group 1, %	Group 2, %	P
Septal perfusion in preoperative angiography	32.4	62.5	.023*
Postoperative paradoxical septal motion	71.4	23.5	.036*
Sex, male versus female	68.6	72.2	.811
Diabetes mellitus	68.6	33.3	.07
Hypertension	85.7	77.8	.312
Hyperlipidemia	62.9	66.7	.768
Chronic renal failure	5.7	5.6	.809
Smoking	42.9	27.8	.075
Peripheral vascular disease	8.6	5.6	.947
Carotid stenosis	14.3	11.1	.573

* $P < .05$.

Table 3. Postoperative Morbidity*

	Group 1	Group 2	P
Atrial fibrillation	14	10	.470
Pleural effusion	11	4	.045†
Postoperative ARF	1	1	.865
ICU recidivism	5	0	.043†
Infection of saphenous vein location	2	2	.809
Sternum wound infection	4	0	.072
Pulmonary infection	6	5	.923
Stroke	0	1	.256
Revision due to bleeding	1	0	.375
Mediastinitis	1	0	.375

*ARF indicates acute renal failure; ICU, intensive care unit.

†P < .05.

Echocardiography is a practical, reliable, and well-defined non-invasive diagnostic method used in the examination of the systolic and diastolic functions of the left and right ventricles. It is widely used in assessing the functions of the septum and other parts of the heart. However, the image quality it provides in the early postoperative period is not satisfactory. For this reason, various studies on septal wall motion abnormality have instead used magnetic resonance (MR) [Joshi 2009], thallium scintigraphy [Okada 1992], or gated single-photon emission computed tomography [Aljaroudi 2012].

In the literature, there are various studies on the etiology of septal wall motion abnormality. The first theory that has come to the fore in this context suggests that it is caused by the forward displacement of the heart as a result of the opening of the pericardium during heart surgery, which eliminates the constraining force of the pericardium [Joshi 2009]. This

theory seems to be supported by the fact that septal wall motion abnormality is typical in cases involving a congenital absence of the pericarditis [Connolly 1995]. The other theory is that septal wall motion abnormality is caused by a reduction in septal perfusion during CPB. There is conflict within these two theories. Choi et al, who used MR, encountered paradoxical anterior septal wall motion frequently after CABG, but in researching the etiology, they were unable to detect an infarction in the septum or a reduction in septal perfusion. Due to the fact that the examinations were carried out three months after open heart surgery, it was not possible to detect any early postoperative abnormalities in septal perfusion, and thus this is a limitation of the study. Okada et al also found that septal perfusion was normal in most of the 16 patients examined with thallium scintigraphy after CABG. Akins et al [Akins 1984] attributed PSM to an abnormal septal perfusion that was caused by inadequate protection of the myocardium during surgery. But eight years later the same researchers detected normal septal perfusion in 11 of the 16 patients who had septal wall motion abnormality. Ribeiro et al reported that PSM developing after CABG was linked to intrapericardial adhesions, while myocardial ischemia or cell necrosis did not play a role in its etiology [Ribeiro 1985]. On the other hand, Swaminathan et al [2007] observed septal wall motion abnormality in intraoperative transesophageal echocardiography (TEE). It is difficult to argue about their theory belonged postoperative adhesions. Wranne et al detected tricuspid failure in all patients diagnosed with PSM by using intraoperative TEE, and reported that the cause was inadequate perfusion of the right ventricle during CPB [Wranne 1993]. Other rare causes of septal wall motion abnormality are primary or secondary pulmonary HT, primary tricuspid failure, and volume overload in the right ventricle on account of congenital heart diseases with a shunt from the left to right. In this study we didn't include the patients with the above.

In conclusion, it should be noted that we have not encountered a prospective study made on this topic to date. Our study

Table 4. Multivariate Analysis for Postoperative Paradoxical Septal Motion*

	B	S.E.	Wald	df	P	Exp(B)	95% CI for Exp(B)	
	Lower	Upper	Lower	Upper	Lower	Upper	Lower	Upper
Septal perfusion in preoperative angiography	-3.289	0.628	27.470	1	<.001†	0.037	0.011	0.128
Type of operation	-.299	0.587	0.260	1	.610	0.742	0.235	2.342
Diabetes mellitus	0.884	0.607	2.120	1	.145	2.421	0.736	7.960
Carotid stenosis	0.785	1.255	0.392	1	.531	2.193	0.187	25.679
Distal anastomosis number	0.197	0.364	0.293	1	.588	1.218	0.597	2.485
Pleural effusion	1.607	0.919	3.059	1	.080	4.990	0.824	30.226
ICU recidivism	18.714	17456.905	0.000	1	.999	134031397.278	0.000	.
Constant	.538	1.475	0.133	1	.715	1.712		

*B indicates coefficient of regression; S.E., standard error; Wald, the index of regression effect; df, degrees of freedom; Exp(B), odds ratio; CI, confidence interval; ICU, intensive care unit.

†P < .05.

conflicts with the first theory because in our prospective study the pericardium was opened, and the heart was displaced toward the anterior in both groups during the postoperative period. If this theory had been true, we would have encountered PSM in all patients after heart surgery. However, we observed a statistically significant difference in the frequency of PSM between the two groups; PSM was encountered more frequently in the patients who underwent on-pump surgery than in the patients who underwent off-pump surgery. For this reason, we consider that the etiology of PSM might be linked to inadequate perfusion of the septum during surgery. In our study we found a correlation between PSM and reduced septal perfusion ($r = -0.687^{**}$, $P < .001$), type of operation ($r = -0.194^*$, $P = .035$), diabetes mellitus ($r = 0.273^{**}$, $P = .003$), carotid stenosis ($r = 0.235^*$, $P = .011$), the number of distal anastomoses ($r = 0.245^{**}$, $P = .008$), pleural effusion ($r = 0.193^*$, $P = .037$), and intensive care unit recidivism ($r = 0.249^{**}$, $P = .007$).

Clinically, the positive correlation with carotid stenosis, number of distal anastomoses, and diabetes mellitus, as well as the negative correlation with septal perfusion seem to corroborate the view that ischemia plays a role in the etiology. For this reason, as clinicians, perhaps we should give preference to off-pump surgery in diabetic patients with carotid stenosis in multiple vessels, so that the development of PSM may be prevented. Nevertheless, we believe that the cases of return to the intensive care unit and pleural effusion are not very important, and that its use in the clinic will remain limited. Moreover, in multivariate analysis for postoperative septal perfusion, only the septal perfusion in preoperative angiography (odds ratio: 0.037; 95% CI: 0.011–0.128; $P < .05$) was determined to be an independent risk factor.

In other words, regardless of the type of surgery, an occlusion in the septal branches that had not caused any PSM prior to surgery aggravated the septal perfusion abnormality with CPB. To date in the literature we have not seen the results of a comparison between on-pump and off-pump CABG.

We suggested that off-pump CABG is a better choice for preventing postoperative PSM in patients with preoperative septal branch occlusion or stenosis.

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