TRANSIT-TIME FLOWMETRIC EVALUATION OF CORONARY ARTERY BYPASS GRAFT FLOW AFTER OFF- AND ON-PUMP MYOCARDIAL REVASCULARIZATION

Vladimir Kornovski[1], Plamen Panayotov[1], Atanas Angelov[2], Tsvetan Gradinarov[3]

[1]Department of Cardiac Surgery, St. Marina University Hospital of Varna
[2]First Department of Internal Medicine, St. Marina University Hospital of Varna
[3]Department of Anesthesiology, Emergency and Intensive Medicine, St. Marina University Hospital of Varna

ABSTRACT

INTRODUCTION: **Incorrect performance of anastomoses to the target coronary arteries often causes coronary artery disease and patient's death following myocardial revascularization. Coronary graft patency evaluation is obligatory for prevention of peri- and postoperative myocardial ischemia.**

AIM: **The objective of the present study was to comparatively assess the values of mean coronary flow and pulsatility index in arterial and venous grafts in patients after on-pump- and off-pump myocardial revascularization.**

MATERIALS AND METHODS: **During the period between January 1, 2014 and December 31, 2017, 143 coronary artery disease patients, 111 males at a mean age of 63.29±9.78 years and 32 females at a mean age of 66.43±9.58 years were operated on in the Department of Cardiac Surgery, St. Marina University Hospital of Varna. Myocardial revascularization was performed by using 92 arterial and 65 venous coronary grafts in the on-pump group (ONCAB) and 137 arterial and 45 venous grafts in the off-pump group (OPCAB). Coronary graft blood flow was assessed by means of coronary angiography and transit-time flowmetry (TTFM).**

RESULTS: **There were different values of the mean coronary flow and pulsatility index (PI) in arterial and venous conduits, both intervention types, as well as in males and females. The difference between male and female patients in terms of the mean values of venous grafts is statistically reliable (χ^2=11.410; p≤0.022 and r=-0.310; p=0.001). The PI values in arterial grafts differed statistically significantly between both intervention types (p=0.003). Much more revisions of arterial and venous conduits on the occasion of insufficient patency were performed in the ONCAB than in the OPCAB group.**

CONCLUSION: **Based on our results and literature data available, we could recommend the wide application of the method of TTFM for exact recognition of the circulatory disorders in the coronary graft following CAGB in Bulgaria.**

Keywords: *coronary artery bypass grafting, intraoperative transit-time flowmetry, coronary angiography, coronary blood flow assessment, graft revision*

Address for correspondence:
Vladimir Kornovski, MD
Department of Cardiac Surgery
St. Marina University Hospital of Varna
1 Hristo Smirnenski Blvd
9010 Varna
Phone: +359 52 363727
Mobile: 0899 126690
e-mail: kornovski@hotmail.com

Received: July 27, 2018
Accepted: September 19, 2018

INTRODUCTION

The main reason for mortality after myocardial revascularization is the incorrect performance of anastomoses to the target coronary arteries. Technical error in the construction of coronary bypass anastomoses may be the cause of myocardial infarction, postoperative angina pectoris, and death. The purposes of the intraoperative graft flow assessment are timely detection and immediate correction of a technical problem and effective prevention of a significant postoperative complication. Modern methods for intraoperative blood flow assessment include coronary angiography and transit-time flowmetry (TTFM).

TTFM is a reliable method to check the graft function intraoperatively in coronary surgery (1-4). This method is less invasive, more reproducible, and less time-consuming (5). Thus, it is a useful tool to investigate coronary artery bypass graft (CABG) flow characteristics and coronary circulation physiology. It is the most common intraoperative modality, but nowadays it is used by only about 20% of cardiac surgeons in North America (6). When combined with high-resolution epicardial ultrasonography, TTFM provides high diagnostic yield (6).

Coronary angiography is the gold standard when myocardial ischemia occurs after CABG (7). This serious complication is mainly due to graft dysfunction, coronary artery thrombosis and incomplete revascularization. Treatment strategy based on coronary angiography findings lessens the burden of the high mortality rate in such patients (8).

The main TTFM blood flow parameters are the following: i) shape of the curve - minimal systolic peak and primary blood flow during diastole (DF) ≥50%; ii) pulsatility index (PI) - absolute numbers with prescribed cut-off PI ≤5; iii) mean blood flow in mL/min - with prescribed cut-off ≥15 mL/min. A value extremely dependent on the quality of the target coronary vessel is not a good single factor determining the blood flow prior to and after surgery.

AIM

The objective of the present study was to comparatively assess the values of mean coronary flow and PI in arterial and venous grafts in patients after on-pump and off-pump myocardial revascularization.

MATERIAL AND METHODS

During the period between January 1, 2014 and December 31, 2017, a total of 971 patients underwent cardiac surgery in the Department of Cardiac Surgery, St. Marina University Hospital of Varna.

The present study covered a total of 143 coronary artery disease patients, 111 males at a mean age of 63.29±9.78 years (range 38-84 years) and 32 females at a mean age of 66.43±9.58 years (range 49-81 years). They were hospitalized and operated on in the Department of Cardiac Surgery, St. Marina University Hospital of Varna and analyzed between January 1, 2014 and December 31, 2017. Myocardial revascularization was performed by using 92 arterial and 65 venous coronary grafts in the on-pump group (ONCAB) and 137 arterial and 45 venous grafts in the off-pump group (OPCAB). Coronary graft blood flow was assessed by means of coronary angiography and TTFM.

Patients' distribution according to gender and age groups is demonstrated on Fig. 1.

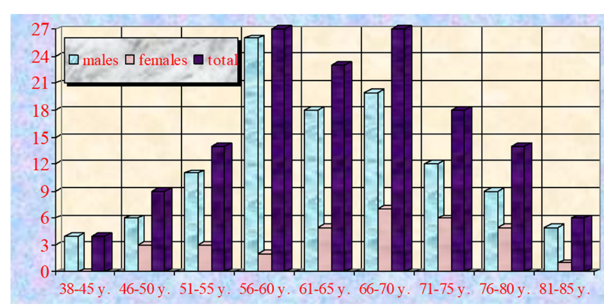

Fig. 1. Patients' distribution according to gender and age groups

RESULTS

Coronary blood flow values (in mL/min) in arterial and venous grafts following both intervention types in all the patients are presented on Table 1.

The total number of patients with examined blood flow in both intervention types with different number of arterial and venous conduits can be seen on Table 2 and Table 3.

Pearson's correlation coefficient is χ^2=11.410 ($p \leq 0.022$) and r=-0.310 (p=0.001), i.e. the difference between male and female patients in terms of the mean values of venous grafts is statistically reliable.

Table 1. Coronary graft blood flow values (in mL/min) in ONCAB and OPCAB

Grafts	n	Value/Method of Surgery			
		Minimal	Maximal	Mean	Standard Deviation
		ONCAB			
Arterial	92	9.00	88.00	36.717	19.188
Venous	65	4.00	99.00	32.185	18.176
		OPCAB			
Arterial	137	3.00	84.00	26.555	14.751
Venous	45	4.00	57.00	23.089	10.361

Table 2. Total number of patients with examined blood flow in ONCAB and OPCAB with a different number of arterial conduits

Graft Number	ONCAB		OPCAB		Total	
	n	%	n		n	%
0	2	3.12	0	0	2	1.40
1	29	45.31	23	29.11	52	36.36
2	8	12.50	18	22.78	26	18.18
3	15	23.44	29	36.71	44	30.77
4	10	15.63	8	10.13	18	12.59
5	0	0	1	1.27	1	0.70
Total	64	100.00	79	100.00	143	100.00

Table 3. Total number of patients with examined blood flow in ONCAB and OPCAB with a different number of venous conduits

Graft number	ONCAB		OPCAB		total	
	n	%	n	%	n	%
0	16	25.00	47	59.50	63	44.06
1	18	28.12	18	22.78	36	25.17
2	16	25.00	8	10.13	24	16.78
3	10	15.63	6	7.59	16	11.19
4	4	6.25	0	0	4	2.80
total	64	100.00	79	100.00	143	100.00

Table 4. Coronary blood flow values (in mL/min) in revised and non-revised grafts following both intervention types

Grafts	Revision	n	value/method of surgery		
			mean value	standard deviation	standard error
			ONCAB		
arterial	yes	9	4.0	3.055	9.538
	no	93	36.666	19.030	0.256
venous	yes	3	7.333	3.785	0.122
	no	66	32.070	19.161	0.061
			OPCAB		
arterial	yes	3	1.333	0.577	0
	no	137	26.822	14.693	0.570
venous	yes	1	4	-	-
	no	50	24.288	9.896	0.556

Table 5. Graft PI values following both intervention types

Grafts	n	Value/Method of Surgery			
		Minimal	Maximal	Mean	Standard Deviation
		ONCAB			
Arterial	92	0.30	5.80	2.42	1.05
Venous	65	0.70	20.00	2.76	2.49
		OPCAB			
Arterial	137	1.20	16.30	3.21	1.59
Venous	45	1.20	11.90	3.26	2.03

Table 6. Revised- and non-revised-graft PI values following both intervention types

Grafts	Revision	n	value/method of surgery		
			mean value	standard deviation	standard error
			ONCAB		
arterial	yes	9	21.011	14.722	0.253
	no	93	2.430	1.070	0.161
venous	yes	3	21.866	20.929	0.317
	no	66	2.764	2.647	0.393
			OPCAB		
arterial	yes	3	23.766	6.807	0.531
	no	137	3.214	1.589	0.105
venous	yes	1	10	-	-
	no	50	3.260	2.030	0.306

Coronary blood flow values (in mL/min) in revised and non-revised arterial and venous grafts following both intervention types in all the patients are indicated on Table 4.

The PI values in the grafts following both intervention types in all the patients are systematized on Table 5, while those in the revised and non-revised grafts - on Table 6.

The results from the *t*-test for independent samples comparing PI values in arterial grafts display a statistically significant difference between both intervention types (p=0.003).

DISCUSSION

Our results indicated that both clinical effectivity and safety of OPCAB surgery can be compared to those of the ONCAP one in terms of postoperative graft patency, coronary graft blood flow and PI values.

There are several recent publications by foreign investigators testifying to the undisputed role of objective peri- and postoperative assessments of the coronary circulation by means of TTFM and/or coronary angiography.

The VeriQ™ system is one of the currently available systems, which detects imperfections that may be corrected by graft revision (9). Cardiac surgeons should bear in mind the limit of the system in distinguishing between graft failure and coronary spasm. Angiography is considered in case of decreased graft flow despite revision of anastomosis and vasodilatory treatment for the definitive diagnosis.

TTFM variables recorded early in failing grafts after CABG for chronic total occlusion present with a significantly lower mean flow and higher PI compared with patent grafts (10). Both mean flow and PI values are useful to detect early graft failure in conduits anastomosed to chronically totally occluded vessels. The collateral grade is not associated with graft failure. However, bypass grafting to such vessels with akinetic/dyskinetic wall motion should be carefully considered.

In a recent review, particular attention is paid on defining TTFM cutoff values for standard variables and correlating them with the ability to predict midterm and long-term graft patency for arterial and venous conduits (11).

Covariation of TTFM and free blood flows is evaluated in 60 patients undergoing CABG using the left internal mammary artery (LIMA) as conduit (12). TTFM is higher than free flow in 64% of measurements, with an overestimation by TTFM of 7.1±16.3% in the overall cohort (prevasodilation), statistically carried by measurements with 4-mm probes (overestimation by 13.3%±15.4%; both $p<0.01$). In a multiregression analysis, TTFM probe oversizing (odds ratio of 9.56; 2.03 to 45.10 at 95% confidence interval; $p=0.004$) and high flows (odds ratio of 1.02; 1.01 to 1.04 at 95% confidence interval; $p<0.001$) are independent determinants of flow overestimation by TTFM. Overestimation may be expected with flows greater than 68 mL/min, but most importantly, in situations with oversized TTFM probes.

Routine TTFM measurements are obtained in 167 saphenous vein grafts (SVGs) to the left and 134 ones to the right territory in 207 patients during CABG (13). There is no significant difference between coronary territories for mean graft flow and pulsatility index. There is a statistically significantly higher diastolic filling percentage in the left-sided SVGs in the overall cohort as well as in the on-pump (both $p<0.001$) and the off-pump cohorts ($p=0.07$) as well as a statistically reliably higher backward flow percentage in SVGs performed off-pump to the left territory (1.2±2.5 versus 2.3±3.0; $p=0.023$). In a multivariate regression analysis, anastomosing the SVG to the left territory is weakly associated with higher pulsatility index (odds ratio of 0.36; $p=0.026$) and strongly associated with higher diastolic filling percentage (odds ratio of 5.1; $p<0.001$).

Flowmetric and angiographic assessment of 235 autoarterial and 117 autovenous bypass grafts are performed in 141 patients undergoing CABG (14). During the follow-up period of up to 42 months, there are 33 (14.04%) occluded arterial conduits and 30 (25.64%) venous ones. The probability of absent occlusions of venous grafts amounts to 74.4±5.8% and that of arterial ones equals 86±3.3%, i. e. during the follow-up period of up to 42 months, the probability of occlusion of venous grafts is reliably higher than that of arterial ones (Log Rank=0.006). Graft occlusion is influenced by an increased peripheral resistance index (hazard ratio of 1.374; $p=0.03$), a decreased volumetric blood flow velocity in the graft (hazard ratio of 0.981; $p=0.005$), and venous graft type (hazard ratio of 2,587; $p=0.001$).

In 1240 patients, 856 males and 384 females at a mean age of 57.4±12.1 years (range, 47 to 74 years), a total of 3596 isolated on-pump CABGs performed by median sternotomy grafts are evaluated in the perioperative period using TTFM (15). Anastomosis/graft revision, new anastomosis/patch plasty to distal native artery or free LIMA graft is done in 146 grafts of 143 patients presenting with insufficient patency. The coronary flow in four grafts with insufficient TTFM is successfully corrected by extending the short graft length.

Preserved coronary flow autoregulation contributes to a lower impact on the heart and early functional recovery, and consequently, greater perioperative safety of OPCAB (16).

TTFM 9-polynomial maximal graft flow acceleration in the early diastolic phase is a promising predictor of future graft failure for aortocoronary artery bypass grafts in CABG patients, particularly in abnormal TTFM grafts (17).

Based on the meta-analysis of nine studies published since 1990 and retrieved from *PubMed*, *Scopus*, *ScienceDirect* and *Google Scholar* concerning the evaluation of the outcome of perioperative myocardial ischemia after CABG, it has been concluded that control coronary angiography is a valid life-saving strategy to guide repeat revascularization in hemodynamically stable patients (18).

Postoperative coronary angiography is performed in 168 patients with perioperative myocardial ischemia following CABG (19). Of them, 74.4% undergo this examination within 24 hours of surgery. There are 263 venous, 196 internal mammary artery and 17 radial artery grafts. Normal angiographic findings, graft failure and new native vessel occlusion are observed in 23.2%, 52.4% and 24.4% of the cases, respectively. Thirty patients (17.86%) undergo surgical revision of grafts, while 60 ones (35.71% of the cases) are treated with percutaneous coronary intervention.

Post-CABG urgent coronary angiography is performed in 106 out of 6025 patients (in 1.76% of the cases) having undergone isolated or combined surgery for coronary artery disease between January 2005 and June 2011 (20). The average time between the cardiac operation and the coronary angiography is 3.41±5.68 days. The rates for this examination are 1.3% (n=25), 2% (n=65), and 1.8% (n=16) for total arterial, combined arterial and venous, and venous CABG alone, respectively. Twenty-four percent of the patients undergo CABG revision, while 32% of them - percutaneous transluminal coronary angioplasty, stenting, or both.

CONCLUSION

Our results with OPCAB application are encouraging. The method of TTFM enables timely identification of the circulatory disorders leading to reduced or even missed coronary graft patency following CAGB for myocardial revascularization. Along with routine coronary angiography, it should be more widely applied in the cardiac surgical practice in our country.

REFERENCES

1. Lobo HG Filho, Lobo JG Filho, Pimentel MD, Silva BG, Souza CS, Montenegro ML, et al. Intraoperative analysis of flow dynamics in arteriovenous composite Y grafts. Braz J Cardiovasc Surg. 2016;31(5):351-7. doi: 10.5935/1678-9741.20160053.
2. Leon M, Stanham R, Soca G, Dayan V. Do flow and pulsatility index within the accepted ranges predict long-term outcomes after coronary artery bypass grafting? Thorac Cardiovasc Surg. 2017 Apr 12. doi: 10.1055/s-0037-1600116.
3. Di Giammarco G, Marinelli D, Foschi M, Di Mauro M. Intraoperative graft verification in coronary surgery. J Cardiovasc Med (Hagerstown). 2017;18(5):295-304. doi: 10.2459/JCM.0000000000000401.
4. Niclauss L. Techniques and standards in intraoperative graft verification by transit time flow measurement after coronary artery bypass graft surgery: a critical review. Eur J Cardiothorac Surg. 2017;51(1):26-33. doi: 10.1093/ejcts/ezw203.
5. Takami Y, Takagi Y. Roles of transit-time flow measurement for coronary artery bypass surgery. Thorac Cardiovasc Surg. 2018 Jan 19. doi: 10.1055/s-0037-1618575.
6. Ohmes LB, Di Franco A, Di Giammarco G, Rosati CM, Lau C, Girardi LN, et al. Techniques for intraoperative graft assessment in coronary artery bypass surgery. J Thorac Dis. 2017;9(Suppl 4):S327-S32. doi: 10.21037/jtd.2017.03.77.
7. Hultgren K, Andreasson A, Axelsson TA, Albertsson P, Lepore V, Jeppsson A. Acute coronary angiography after coronary artery bypass grafting. Scand Cardiovasc J. 2016;50(2):123-7. doi: 10.3109/14017431.2016.1143112.
8. Szavits-Nossan J, Stipić H, Sesto I, Kapov-Svilicić K, Sipić T, Bernat R. Angiographic control and percutaneous treatment of myocardial ischemia immediately after CABG. Coll Antropol. 2012;36(4):1391-4.
9. Kassimis G, Krasopoulos G. False positive transit time flowmetry graft failure in multivessel coronary spasm following off-pump coronary artery bypass grafting. Case Rep Cardiol. 2017;2017:3186047. doi: 10.1155/2017/3186047.
10. Oshima H, Tokuda Y, Araki Y, Ishii H, Murohara T, Ozaki Y, et al. Predictors of early graft failure after coronary artery bypass grafting for chronic total occlusion. Interact Cardiovasc Thorac Surg. 2016;23(1):142-9. doi: 10.1093/icvts/ivw084.
11. Amin S, Pinho-Gomes AC, Taggart DP. Relationship of intraoperative transit time flowmetry findings to angiographic graft patency at follow-up. Ann Thorac Surg. 2016;101(5):1996-2006. doi: 10.1016/j.athoracsur.2015.10.101.
12. Amin S, Werner RS, Madsen PL, Krasopoulos G, Taggart DP. Intraoperative bypass graft flow measurement with transit time flowmetry: a clinical assessment. Ann Thorac Surg. 2018;106(2):532-8. doi: 10.1016/j.athoracsur.2018.02.067.
13. Amin S, Werner RS, Madsen PL, Krasopoulos G, Taggart DP. Influence of coronary territory on flow profiles of saphenous vein grafts. J Cardiothorac Surg. 2018a;13(1):23. doi: 10.1186/s13019-018-0709-6.
14. Bazylev VV, Nemchenko EV, Rosseĭkin EV, Mikuliak AI. Flowmetric and angiographic predictors of occlusion of coronary bypass grafts. Angiol Sosud Khir. 2018;24(2):49-55 (in Russian).
15. Kaya U, Çolak A, Becit N, Ceviz M, Koçak H. Intraoperative transit-time flow measurement in on-pump coronary artery bypass graft surgery: Single center experience. Turk J Thorac Cardiovasc Surg. 2018;26(2):167-76.
16. Nakajima H, Iguchi A, Tabata M, Kambe M, Ikeda M, Uwabe K, et al. Preserved autoregulation of coronary flow after off-pump coronary artery bypass

grafting: retrospective assessment of intraoperative transit time flowmetry with and without intra-aortic balloon counterpulsation. J Cardiothorac Surg. 2016;11(1):156. doi: 10.1186/s13019-016-0550-8.

17. Handa T, Orihashi K, Nishimori H, Yamamoto M. Maximal blood flow acceleration analysis in the early diastolic phase for aortocoronary artery bypass grafts: a new transit-time flow measurement predictor of graft failure following coronary artery bypass grafting. Surg Today. 2016;46(11):1325-33. doi: 10.1007/s00595-016-1325-5.

18. Biancari F, Anttila V, Dell'Aquila AM, Airaksinen JKE, Brascia D. Control angiography for perioperative myocardial Ischemia after coronary surgery: Meta-analysis. J Cardiothorac Surg. 2018;13(1): 24. doi: 10.1186/s13019-018-0710-0.

19. Preußer MJ, Landwehrt J, Mastrobuoni S, Biancari F, Dakkak AR, Alshakaki M, et al. Survival results of postoperative coronary angiogram for treatment of perioperative myocardial ischaemia following coronary artery bypass grafting: a single-centre experience. Interact Cardiovasc Thorac Surg. 2018;26(2):237-42. doi: 10.1093/icvts/ivx317.

20. Fleißner F, Issam I, Martens A, Cebotari S, Haverich A, Shrestha ML. The unplanned postoperative coronary angiogram after CABG: Identifying the patients at risk. Thorac Cardiovasc Surg. 2017;65(4):292-5. doi: 10.1055/s-0035-1564927.