

Intraoperative flow dynamic evaluation for single pedicled and composite arterial grafts in "off pump" coronary revascularization



Śródoperacyjna dynamiczna ocena przepływu w pojedynczych uszypułowanych i złożonych pomostach tętniczych w rewaskularyzacji wieńcowej w trybie „off pump”

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Abstract

Introduction: Currently, "off pump" arterial revascularization with T and Y grafts appears to be successful surgical treatment of coronary artery disease.

Aim of the study: Our objective was to compare adaptive capacities of arterial grafts with one source of inflow from a single internal thoracic artery.

Material and methods: Between October 2008 and July 2010, 200 patients underwent arterial revascularization without cardiopulmonary bypass. Four types of grafts were performed: single pedicled left internal thoracic artery – left anterior descending artery; single pedicled right internal thoracic artery – right coronary artery; Y grafts – two distal anastomoses; and T grafts – three or more distal anastomoses. The flow examinations were carried out with the transit-time method using VeriQ Medi Stim AS™ (Oslo, Norway). The registration of flow parameters was performed in basic conditions, and after dobutamine administration.

Results: Comparing mean values of the baseline flow no differences were identified between Y and T and between single pedicled grafts ($p > 0.05$). Dobutamine administration resulted in significantly increased mean flows for all configurations ($p < 0.005$). Linear regression analysis of flow with dobutamine administration as related to baseline flow showed that the smallest increases in flow values were present in the first configuration, followed by the second and then Y and T grafts. Coronary flow reserve ranged between 1.4 and 2.01.

Conclusions: Flow measurements at the basic level did not fully characterize the capability of blood flow in the arterial

Streszczenie

Wstęp: Obecnie rewaskularyzacja tętnicza wykonywana w opcji „off pump” wydaje się dobrą techniką chirurgicznego leczenia choroby wieńcowej.

Cel pracy: Porównanie zdolności adaptacyjnych pomostów tętniczych z jedną drogą napływu z pojedynczej tętnicy (t.) piersiowej wewnętrznej.

Materiał i metody: Od października 2008 do lipca 2010 r. 200 pacjentów przeżyło rewaskularyzację tętniczą bez użycia krążenia pozaustrojowego. Wykonano cztery rodzaje pomostów: uszypułowana t. piersiowa wewnętrzna lewa – lewa tętnica przednia zstępująca, uszypułowana prawa t. piersiowa wewnętrzna – prawa t. wieńcowa, pomosty typu Y – dwa zespolenia obwodowe i pomosty typu T – trzy lub więcej zespolień obwodowych. Pomiary przepływów wykonano przy użyciu aparatu VeriQ Medi Stim AS™ (Oslo, Norway) wykorzystującego metodę „transit-time”. Rejestrację przepływów przeprowadzono w warunkach podstawowych oraz po podaniu dobutaminy.

Wyniki: Porównując średnie wartości przepływu w warunkach podstawowych, nie wykazano istotnych statystycznie różnic pomiędzy pomostami Y i T ($p > 0,05$) oraz pomiędzy pojedynczymi tętniczymi pomostami uszypułowanymi ($p > 0,05$). Podanie dobutaminy spowodowało istotny wzrost średnich przepływu we wszystkich konfiguracjach ($p < 0,005$). Analiza, z zastosowaniem regresji liniowej, zależności przepływów po podaniu dobutaminy oraz przepływu podstawowego wykazała najmniejszy wzrost przepływu w konfiguracji pierwszej, następnie drugiej, a potem w pomostach Y i T. Zakres wieńcowej rezerwy przepływu zawierał się pomiędzy 1,4 a 2,01.

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grafts. The examined conduits had large adaptive capacities. Flow depended upon the baseline flow value and the number of distal anastomoses.

Key words: coronary artery bypass surgery, arterial revascularization, OPCAB, Y and T grafts, intraoperative TTF measurements, coronary flow reserve.

Introduction

Since its introduction in the early 1990s, total arterial revascularization in the T and Y graft configuration has gradually become a routine surgical treatment of coronary artery disease in numerous cardiovascular surgery centers [1]. It has many advantages in comparison to traditional surgical techniques and, particularly in the “off pump” mode, is much less invasive [2-4]. Operations that do not apply extracorporeal circulation reduce the systemic inflammatory response, degree of myocardial injury, and the incidence of stroke [5-7]. The use of arterial revascularization also extends the lifetime of implanted conduits [8]. Moreover, the application of the “aorta-no-touch” technique additionally reduces the amount of injuries to the central nervous system and complications connected with intraoperative aortic injury [9, 10]. However, there is still some controversy regarding inadequate inflow from a single pedicle internal thoracic artery (ITA) to revascularize multiple areas of the heart [11, 12]. In the last decade, a precise methodology of transit time flow (TTF) measurements has been developed and cut-off points for several parameters of these exami-

Wnioski: Pomiary przepływów przeprowadzane w warunkach podstawowych nie w pełni charakteryzują możliwości przepływu w pomostach tętniczych. Badane pomosty mają duże zdolności adaptacyjne zależne od przepływu podstawowego i liczby zespoleń obwodowych.

Słowa kluczowe: chirurgia naczyń wieńcowych, rewaskularyzacja tętnicza, pomostowanie tętnic wieńcowych bez zastosowania krążenia pozaustrojowego, pomosty Y i T, śródoperacyjne pomiary TTF, rezerwa przepływu wieńcowego.

nations have been presented, thus enabling the routine intraoperative verification of the performed anastomoses [13, 14]. Several reports highlight the adaptability of composite arterial grafts using various research methods for short and medium postoperative periods [11, 15-17]. Intraoperative examinations identifying the coronary flow reserve in such anastomoses have been performed using an intra-aortic balloon pump, comparisons of flow measured before and after performing distal anastomoses, and with dobutamine administration. However, they do not apply to patients operated on without use of cardiopulmonary bypass as its influence on flow has not been fully investigated. Moreover, these examinations do not adequately evaluate the dependencies between the flow rate and the number of distal anastomoses, or initial baseline flow, which is connected with the adaptive capacities of particular conduits [18-22]. The objective of our study was to compare adaptive capacities of arterial grafts with one source of inflow from a single internal thoracic artery and investigate factors that may affect the function of single pedicled and composite arterial conduits in “off pump” coronary revascularization.

Material and methods

Study population

From October 2008 to July 2010, a prospective study was carried out by taking TTF measurements in operated patients, both in basic conditions and after dobutamine administration. The study included 169 men and 31 women with a mean age of 61.1 years (Table I). The Ethics Committee of the Medical Faculty at the local university approved the study. All patients provided written informed consent.

Patient selection

Inclusion criteria were surgery for isolated coronary artery disease, left ventricular ejection fraction $\geq 35\%$, and informed consent. Exclusion criteria were acute myocardial infarction and the need for catecholamine or intra-aortic balloon pump administration before or during surgery due to hemodynamic instability. Based on these criteria, the examinations were performed in 200 patients.

Surgical technique

We followed our previously practiced revascularization technique; for multivessel coronary artery disease we applied T and Y grafts using the internal thoracic arteries and

Tab. I. Demographic data and preoperative clinical characteristics of 200 study patients

	Value
Number of patients	$n = 200$
Male	169 (84.5)
Female	31 (15.5)
Age	61.1 [37-81] ± 9.67
EuroSCORE	3.03 [0-12] ± 2.56
LVEF	52.82 [35-75] ± 9.36
Prior MI	86 (43)
Hypertension	109 (54.5)
Diabetes mellitus	59 (29.5)
COPD	2 (1)
PAF	16 (8)
PVD	20 (10)
CVA	10 (5)
Prior PCI	42 (20.5)

Values are expressed as number of patients or mean. (...) – percentage, [...] – range, \pm – standard deviation, COPD – chronic obstructive pulmonary disease, CVA – cerebrovascular accidents, LVEF – left ventricular ejection fraction, MI – myocardial infarction, PAF – paroxysmal atrial fibrillation, PCI – percutaneous coronary intervention, PVD – peripheral vascular disease.

radial arteries. The operations were carried out “off pump” with the Octopus Evolution (Medtronic Inc. Minneapolis, MN) and Starfish 2™ (Medtronic Inc. Minneapolis, MN) tissue and apex stabilizers. A detailed description of the surgical procedure is available [23].

Classifications of composite arterial grafts

The classification of composite arterial grafts with a single source of inflow is often based on the manner in which the proximal anastomosis is performed and the spatial configuration of the arteries. Thus, there are many names and composition possibilities of such grafts [24]. In our institution, they are classified according to the number of distal anastomoses. Y grafts are defined as composite arterial conduits with a single source of inflow from the pedicled ITA and two distal anastomoses, whereas the T graft is defined as a composite arterial graft with the same source of inflow but with more than two distal anastomoses (T_3 , T_4 , T_5 , etc.). Therefore, the pedicled sequential left internal thoracic artery with two distal anastomoses is functionally considered to be a Y graft. Such a definition makes it possible for us to compare particular configurations in functional terms that depend on the size of the outflow tract, which includes the number of distal anastomoses. It also facilitates examinations of such grafts in terms of their ability to adapt the inflow.

Conduit preparation

All arteries were harvested in a skeletonized fashion. The radial artery (RA) was selected as the second conduit more often than the right internal thoracic artery as its harvesting is less time-consuming and entails fewer complications for post-sternotomy wound healing, particularly in diabetic patients.

Technique limitations

Limitations of this technique include the following: a free flow from the left internal thoracic artery, or alternatively the right one, of less than 40 ml/min; a small caliber of the internal thoracic artery (below 1 mm); and positive result of Allen’s test confirmed by saturation decrease detected by a pulse oximeter.

TTF measurements and data collection

The flow examinations were carried out with the transit-time method using a VeriQ Medi Stim AS™ (Oslo, Norway) device and Medi-Stim Quick Fit™ probes sized 1.5-4 mm, depending on the diameter of implanted vessels. The probes were placed at a distance of 1-2 cm from the examined anastomosis. The quality of flow in the grafts was assessed on the basis of three parameters: Q_{mean} – the mean flow; PI – the pulsatility index; and DF% – diastolic filling percentage. In each case we also performed occlusive maneuvers with the use of two snaring sutures set above and below the anastomotic site; this is standard practice in operations without cardiopulmonary bypass. Such a procedure enabled a separate assessment of anastomosis patency in the distal and proximal directions. The graft was considered “to be inspec-

ted” if it lacked flow and occlusive maneuvers eliminated the occurrence of a competitive flow from the patient’s native coronary vessels as the underlying case. Based on previous reports and our own experiences, in cases where the flow was detected in the conduit, the factors that determined inspection of the anastomosis included $PI \geq 5$ and the shape of the flow curve [13, 25]. Each time incorrect TTF parameters were recorded, we applied a papaverine solution externally, which eliminated vessel conduit spasm as a possible cause. TTF measurements were performed in quadruplicate in every patient: the first one (I) included the examination of the free flow from the left internal thoracic artery (LITA) and, optionally, from the right internal coronary artery (RITA); the second one (II) was a basic analysis, performed immediately after all anastomoses were completed (the measurements also included the occlusive maneuvers and were taken on all the anastomoses); the third one (III) was performed after the administration of dobutamine as a continuous infusion at a dose of 5 $\mu\text{g}/\text{kg}/\text{min}$ for 3 minutes; the fourth one (IV) was a control measurement taken after the administration of protamine sulfate, when the chest was about to be closed. To standardize the results of the investigated parameters, measurements I and II were performed during the patient’s hemodynamic stabilization at the “double product” (systolic blood pressure \times heart rate/100) > 100 . Obtaining the appropriate parameters for the “double product” included a physiological positioning of the heart, an increase of the preload, or atropine administration. Final analysis included only the flow parameters from measurement II, excluding results of the occlusive maneuvers, and parameters from measurement III. The coronary flow reserve (CFR) was calculated as the ratio of the mean flow after dobutamine administration to the mean baseline flow. All measurements were collected in the hard drive of the flow meter.

Statistical analysis

Numerical data are presented as a percentage, range of means, average standard deviation, or parameters of a linear regression function. Results of significance tests with comparisons of the means and verification of the hypotheses on the structure of a linear function model are reported. Student’s t-test was used to identify the significance of differences in mean variables. $P < 0.05$ was considered statistically significant. The model of linear regression was used to investigate relations between the baseline flow and flow after dobutamine administration. Linear regression parameters were calculated with the method of least squares. The reliability of the linear models was verified using the coefficient of determination R^2 and the F criterion. All calculations were performed using SPSS 14.0 (SPSS Inc., Chicago, IL).

Results

Results and complications

All operations in the study cohort of 200 patients were carried out without extracorporeal circulation. The conduits were divided into four groups: single pedicle LITA-LAD (left

anterior descending artery), single pedicle RITA-RCA (right coronary artery), Y grafts, and T grafts. In 13 cases, apart from arterial anastomoses, we also used the traditional method by implanting the saphenous vein (SV) graft into the ascending aorta. We used the saphenous vein as grafting material only in situations in which arterial vessels were unsuitable for grafting. In this manner we anastomosed 1 PDA, 9 RCA and 3 OM arteries (Table II). The average number of conduits per patient was 2.1 (range 1-5, SD ± 0.9). **Fifteen patients (7.5%) were subjected to intraoperative surgical correction of the anastomoses due to poor TTF parameters in measurement.** When there was no flow through the anastomosis, we made surgical correction without performing intraoperative angiography. Angiography was performed in patients with preserved flow in the grafts and with the value of PI oscillating around 5 or more. If, after correction, the flow parameters were acceptable then control angiography was not performed. So in six patients, the need to revise the anastomoses was confirmed with intraoperative coronary angiography. There was one (0.5%) in-hospital death due to sudden cardiac arrest in the intensive care unit. The patient was re-operated on, connected to a cardiopulmonary bypass, and his TTF measurements were taken, which showed very good flows in his conduits. However, attempts to disconnect him from the extracorporeal circulation failed. In our opinion the main cause of fatal

outcome was incomplete revascularization because of intense distal changes in the RCA making this vessel unsuitable for grafting. Additionally he had a high risk of death calculated by EuroSCORE – 12 points. Six patients (3%) required re-exploration for bleeding in the early postoperative period. Fifty-three patients (26.5%) were administered low or moderate doses of catecholamines during the postoperative period and 1 patient (0.5%) was supported with IABP. No patient was diagnosed with perioperative myocardial infarction (creatin kinase MB < 50 U/L in all cases) or with intraoperative ischemic changes after dobutamine administration.

Follow-up

At postoperative 3-month follow-up (mean 78 days, SD ± 12 days), all patients were alive and free of angina. No myocardial infarctions occurred during this period and none of the patients required hospital readmissions for cardiac reasons. One hundred eighty-three patients (91.5%) were subjected to an exercise electrocardiogram with negative results.

TTF data analysis

The analysis included measurements taken in the main stems of the composite arterial grafts and measurements for the pedicled LITA-LAD and pedicled RITA-RCA. Measurements in the SV grafts were recorded but their results were not included in this study. The mean free flow of the LITA was 96.5 ml/min (range 44-283 ml/min; SD ± 42.5). Based on the measurement analysis, the differences in the baseline flow (measurement II) were identified for particular configurations of the coronary conduits. Comparing mean values of the baseline flow between the different configurations revealed statistically significant differences between pedicled LITA-LAD versus Y ($p < 0.005$) and pedicled LITA-LAD versus T ($p < 0.005$). No differences in mean flow values were identified between Y and T ($p > 0.05$) and between pedicled LITA-LAD versus pedicled RITA-RCA ($p > 0.05$). Dobutamine administration resulted in a very significant increase in flow in all examined configurations (Figure 1, Table III). Compa-

Tab. II. Number of grafts and their configurations in 200 patients

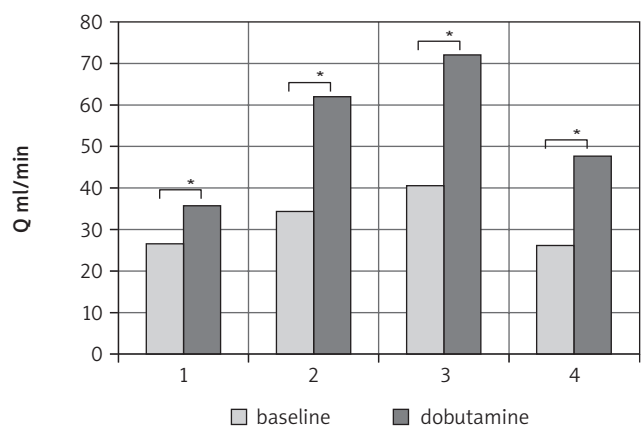
Configurations	Number (%) of conduits
ped. LITA – LAD	62 (31)
Y grafts	103 (51.5)
LITA seq.	1 (0.5)
(LITA, RA)	96 (48)
(LITA, f. RITA)	6 (3)
T grafts	35 (17.5)
(LITA, RA)	35 (17.5)
(LITA, f. RITA)	0 (0)
ped. RITA – RCA	27 (13.5)
SVG	13(6.5)

ped. – pedicled, LITA – left internal thoracic artery, RITA – right internal thoracic artery, ped. LITA seq. – pedicled LITA in sequential configuration, f. RITA – free segment of RITA, (... ..) – arteries creating T or Y graft, RA – radial artery, RCA – right coronary artery, SVG – aortocoronary saphenous vein graft.

Tab. III. Comparison of baseline flow and flow after dobutamine administration in the analyzed graft configurations

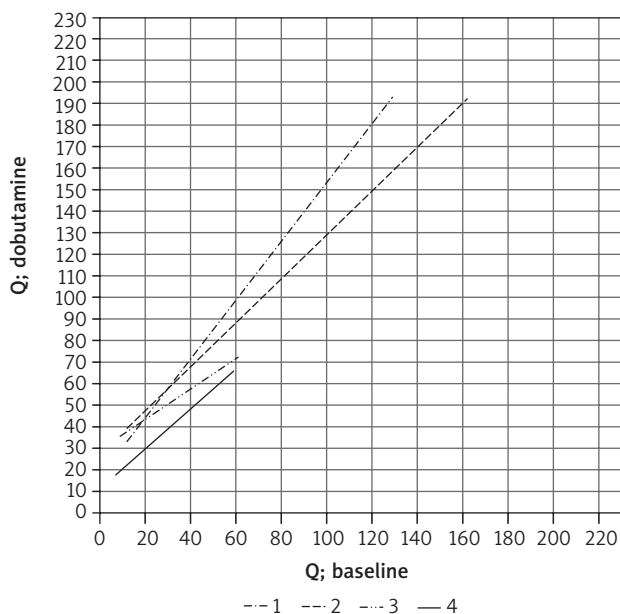
Graft configuration	Mean (Q - ml/min)	Range (Q - ml/min)	SD
ped. LITA – LAD	26.55	7-59	± 12.54
ped. LITA – LAD dob.	35.73	10-103	± 19.05
Y graft	34.35	12-162	± 21.97
Y graft dob.	61.95	19-172	± 31.83
T graft	40.54	12-129	± 24.15
T graft dob.	72.06	25-211	± 38.15
ped. RITA – RCA	26.14	9-69	± 15.95
ped. RITA – RCA dob.	46.56	18-111	± 21.26

Q – flow, ped. – pedicled, dob. – flow after dobutamine administration, SD – standard deviation.



Q – flow, 1 – pedicled LITA – LAD, 2 – Y grafts, 3 – T grafts, 4 – pedicled RITA-RCA, *p value < 0.005.

Fig. 1. Baseline flow and flow after dobutamine administration in four analyzed configurations



Q – flow, 1 – ped. LITA-LAD, 2 – Y grafts, 3 – T grafts, 4 – ped. RITA – RCA.

Fig. 2. Regression lines showing the dependence of flow after dobutamine administration on the baseline flow in each graft configuration

ring mean values of flow after dobutamine administration also showed very significant differences between the configurations of pedicled LITA-LAD versus Y and pedicled LITA-LAD versus T ($p < 0.005$) as well as a statistically significant difference between pedicled LITA-LAD and pedicled RITA-RCA ($p < 0.05$). There was no statistically significant difference in mean flow rates after dobutamine administration for the T and Y configuration ($p > 0.05$). Linear regression for the dependency of flow after dobutamine administration as related to the baseline flow revealed additional correlations for the four configurations. The linear regression angles were 42.8° for LITA-LAD, 35.2° for RITA-RCA, 45.6° for Y, and 53.8° for T (Figure 2). Moreover, the increase in flow in the Y and T configurations were statistically significant ($p < 0.05$) when above 65 ml/min of baseline flow. Mean coronary flow reserve for the LITA-LAD configuration was 1.4 (SD ± 0.73), for the Y configuration 1.99 (SD ± 0.83), for the T configuration 1.91 (SD ± 0.56), and for the pedicled RITA-RCA the value was greatest at - 2.01 (SD ± 0.93). Compared to the LITA-LAD configuration, mean CFR values were significantly different for the Y ($p < 0.001$), T ($p < 0.001$), and RITA-RCA ($p < 0.01$) configurations. No statistically significant difference was identified for the mean CFR values for the configurations Y versus T ($p > 0.05$), Y versus pedicled RITA-RCA ($p > 0.1$), and T versus pedicled RITA-RCA ($p > 0.1$).

Discussion

Currently, revascularization based on the “off pump” technique and total arterial revascularization with T and Y grafts seems to be a good option for the surgical management of coronary artery disease [2-4, 7, 8]. The intraoperative period has a significant direct effect on the later

phases of treatment. It should be noted that using the TTF method for routine intraoperative verification of coronary grafts detects technical failures that occur in 4 to 9.9% of cases [13, 25]. Discovering the adaptive capabilities of the grafts in intraoperative conditions may be useful in predicting the final therapeutic effect. It may also contribute to a deeper understanding of functional and morphological changes occurring in such grafts over medium and long time periods. Bypasses supply blood to ischemic areas of myocardium both during rest and exercise. Therefore, we compared three flow parameters measured with the TTF method for two types of single pedicled arterial graft as well as the Y and T grafts in basic conditions and with an increased oxygen demand by the myocardium. Under routine conditions, comparison of the mean flow values between different bypass configurations was not statistically significant, with the exception of LITA-LAD when compared to all others. This may indicate that the TTF examination in routine conditions does not fully characterize the capability of blood flow in the arterial grafts nor demonstrate differences between them. Dobutamine administration resulted in a statistically significant flow increase in every examined configuration. This proves that the examined conduits had large adaptive capacities in the situation of an increased myocardial oxygen demand, regardless of the number of distal anastomoses. The LITA-LAD configuration had the smallest CFR. Its flow increased by 40% on average and differed significantly from the other configurations, where the mean flow for the Y and T ones increased by 99% and 91%, respectively, and for the RITA-RCA increased by 101%. This may be explained by the position of the LAD in coronary artery surgery. It is the primary artery in coronary revascularization and very often the qualification for an operation is based on the feasibility of implanting a conduit to it. Thus, it can be more often subjected to grafting even if there are changes in it or its periphery, in situations when it is nearly ungraftable. This results in reduced outflow possibilities from the implanted graft, which is connected with increased vascular resistance of the area supplied by the LAD.

Our results concerning CFR in composite arterial grafts have higher values than those presented by Delatore and Affleck et al., who compared the free flow from T grafts with the flow after performing distal anastomoses (mean CFR 1.7 and 1.6, respectively) [18, 22]. They are consistent or slightly lower than the results reported by other authors who intraoperatively identified CFR in composite arterial grafts. Royse and Onorati et al. found that flow was 2.3 and 1.9 times higher, respectively, when using intra-aortic balloon pumping [19, 20]. Gaudino et al. identified the flow reserve to be 2.1 after dobutamine injection [21]. Postoperative examinations of the arterial graft flow performed with various recording methods in the short and medium terms show an increase in the flow reserve reaching up to 2.8 [15-17]. This is related to remodeling of the implanted arterial vessels, which occurs later. The CFR is a very important parameter indicating the possibility of increased flow rates connected with coronary grafts. However, it is a factor applying only the average

values from the measured parameters and it does not illustrate certain dependencies in detail. The use of linear regression clearly reveals two additional factors that influence the flow increase in both single and composite arterial grafts. First, the baseline flow is an element that directly affects the potential to increase flow in the examined grafts. The greater the baseline flow is in the examined arterial grafts, the greater the flow during the increased oxygen demand by the myocardium. Second, the flow increase depends on the number of distal anastomoses. The angles of inclination for the regression curves differ depending on the number of anastomoses. It clearly indicates that, for the same baseline flow, the highest flow rate is in the T grafts, then the Y grafts, and finally single arterial grafts. However, this difference is not apparent until the baseline flow exceeds 40 ml/min, and in the cases of the T and Y grafts it is not until 65 ml/min that flows are significantly different (Figure 2). These data demonstrate that the baseline flow rate plays a very important role in identifying the adaptive capacities of the examined arterial grafts. There are many factors influencing baseline flow. Firstly, the effect of the degree of stenosis in the coronary arteries was shown by Markwirth and co-workers [15]. This factor affects the patients' native flow in their coronary vessels, which creates the competition flow; the effect of competitive flow was reported by Royse and co-workers [19]. The size of the myocardium area supplied by the revascularized vessel, the occurrence of infarction scars, and the diameters of coronary arteries resulting from advancement of peripheral atherosclerosis produce peripheral resistance, which is another factor influencing flow in the grafts by limiting the outflow. All these factors, together with the collateral flow, affect baseline flow, which, as our study presents, significantly influences the adaptive capacities of arterial grafts. The better baseline flow is, the higher the reaction to the metabolic demand by cardiomyocytes, which manifests as flow increase. The pedicled RITA-RCA configuration works in a slightly different way. On the one hand, it has a very high mean CFR, even slightly above the mean CFR in the Y and T configurations, and on the other hand, the inclination of the linear regression curve is the weakest. This suggests a significantly greater potential flow increase when compared to the LITA-LAD configuration. It may be that these results are also connected with the differences in the anatomical position of the right coronary artery. Doubtlessly, this phenomenon requires further investigation. When comparing regional myocardial blood flow at rest and after dipyridamole infusion using positron emission tomography two weeks after coronary artery bypass graft, Sakaguchi et al. found that composite arterial grafts facilitate flow in basic conditions but have a smaller flow reserve than independent arterial grafts. He also suggested that composite arterial grafts may not be efficient enough to provide satisfactory flow in the whole left coronary system during the immediate postoperative period [11]. This disagrees with our observations showing good adaptive capabilities of the T and Y grafts immediately after implantation. Comparing the mean numerical values for the CFR pre-

sented in the discussed article with our data on the T and Y grafts, we can see that our results are even higher than the ones obtained by Sakaguchi, not only for the composite arterial grafts but also for the independent arterial grafts. Naturally, it should be stressed that the method of measurement is completely different and refers to the measurement of tissue flow. The intraoperative dobutamine test used to characterize the flow in the arterial grafts is not yet a frequently used method; however, it may provide some important information on graft functioning. The impact of this method on the possibilities of predicting the future of the grafts has not yet been investigated. The intraoperative results for the mean flow rates and for the possible increases of the flow that we obtained in the "off pump" operations are similar or slightly higher than those obtained in the operations with cardiopulmonary bypass [20-22]. In short- and medium-term postoperative examinations with transthoracic echo color Doppler, Prifiti et al. found no differences in mean flow values in the LITA main stem between these two types of coronary operations [17]. However, the influence of extracorporeal circulation on the flow in the grafts during the perioperative period requires further comparative studies applying the same measurement techniques.

Limitations

The basic limitation of this study is the impact of competition flow on the measurement both in basic conditions and after dobutamine administration. The morphological variety of coronary vessels, differences in vessel caliber and diverse advancement of atherosclerosis are also limitations of this study and were not investigated. Due to our limited research material, patients with T grafts were not divided into groups with three, four, and five peripheral anastomoses. We attempted to present general trends connected with the flow rate, the outflow conditions, and the number of anastomoses.

Conclusions

In summary, we have shown that flow measurements at the basic level did not completely illustrate the differences between configurations. Dobutamine administration demonstrated the successful adaptive properties of all configurations. Flow depends upon the baseline flow value and the number of distal anastomoses. Composite arterial grafts manifest very good adaptive properties immediately after implantation but in a limited number of coronary anastomoses. Our results in "off pump" operations are similar to those obtained in operations with cardiopulmonary bypass by others.

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