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Brief communication (Original)

Evaluation of graft flow between on-pump and off-pump coronary artery bypass grafting

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Background: Coronary artery bypass grafting (CABG) is an effective method to afford sufficient blood flow for that ischemic myocardium. Off-pump coronary bypass surgery (OPCAB) has been rediscovered and refined to avoid cardiopulmonary bypass. However, it's a high technique demanding skill. And evaluation of the blood flow should be reliable. Transit time flow measurement (TTFM) is introduced to evaluate graft flow and anastomosis patency intraoperatively. The accuracy of graft flow depends on how to explain the parameters of TTFM. Here, we introduce our experiences on the explanation of TTFM parameters.
Objective: We compared the graft patency of off-pump coronary artery bypass grafting with those of on-pump coronary artery bypass grafting by intraoperative transit time flow measurement (TTFM).
Methods: Three hundred patients were divided into off-pump group and on-pump group. TTFM was routinely performed for assessment of graft patency during operation. Revision of the grafts depends on the TTFM findings.
Results: One patient in OPCAB group was converted to conventional CABG group due to ventricular fibrillation. One patient died of multiple organ failure 21 days post-operation. Seven grafts were revised based on unsatisfactory TTFM findings. There was no statistical difference in the variables between the two groups except for anastmosis to right coronary artery.
Conclusions: Off-pump surgery can provide the same flow of grafts as that of on-pump surgery. TTFM is an effective tool to decide if a well-function graft is or not, and it allows for revision of failure graft during operation.

Keywords: Backward flow percentage, coronary artery bypass grafting, pulsatile index, revascularization, transit time flow measurement

Coronary artery bypass grafting (CABG) is an effective method to management of ischemia heart disease. In order to avoid the deleterious effects of cardiopulmonary bypass (CPB), off-pump coronary bypass surgery (OPCAB) has been rediscovered and refined. The patency of the ananstomosis and the completeness of revascularization are the most important aspects being discussed about OPCAB. Consequently, transit time flow measurement (TTFM) has been introduced as an effective method to evaluate graft flow and anastomosis patency intraoperatively. It is suitable for intraoperative assessment of graft function, independent of graft size, though exact interpretation of the transit time flow pattern is essential.

The purpose of this study is to compare the patency of anastomosis of OPCAB with conventional on-pump coronary artery bypass grafting (CCABG).

Material and methods

Patient population

Three hundred patients with triple vessel disease were divided into two groups, one hundred and fifty in each group respectively. Patients with single or double vessel disease, combined valve surgery, cardiac aneurysms, ejection fraction (EF) <35%, EuroScore >6, trans-myocardial laser revascularization (TMR) or undergoing re-do CABG surgery were excluded. All the surgical procedures were completed by the same group of surgeons. Patients received OPCAB or CCABG randomly, with no regard to medical

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criteria, such as coronary artery anatomical structure, size of heart, or left ventricular ejection fraction (LVEF). Preoperative characteristics of the patients are shown in **Table 1**.There was no significant differences of the preoperative characteristics between the two groups, such as the degree of angina, presence of chronic obstructive pulmonary disease (COPD), history of myocardial infarction (MI), diabetes mellitus (DM), emergency surgery, presence of left main trunk lesions.

Surgical technique

Left internal mammary artery (LIMA) was used to bypass left anterios descending artery (LAD) in all the patients studied routinely except for one patient in CCABG group due to small LIMA. The surgical procedure was same as that was previously performed [1]. A median sternotomy was performed in every case. The left internal mammary artery (LIMA) was regularly harvested and the great saphenous vein was prepared simultaneously. Other grafts were great saphenous veins. Heparin was given at 3750 iu/kg and activated clotting time (ACT) was kept above 480s in the cases of the CCABG group. After cross-clamping the aorta, cold crystal cardioplegia was given through the root of the aorta. Size 7-0 prolene was used for distal anastomosis. A side-biting clamp was applied to the aorta and 5-0 prolene was used to finish the proximal anastomosis after the cross-clamp had been released. In the OPCAB group, a single deep pericardial stay suture between the left inferior pulmonary vein and the inferior vena cava was used with a sling snared down. By adjusting the two ends of the sling and the operating table, all target coronary vessels could be exposed. After systematic heparinization (1250 iu/ kg), ACT was maintained above 300s, and a mechanical heart stabilizer (Octopus Ⅱ- Ⅲ, Medtronic, MN, USA) was used to facilitate distal anastomosis. Endovascular shunts (Medtronic, MN, USA) were placed into the vessels and the anastomosis was completed using a continuous 7-0 prolene suture. A side-biting clamp was applied to the aorta and 5-0 prolene was used to finish the proximal anastomosis. Generally, LIMA to left anterior descending artery (LAD) was completed first, followed by grafting to right coronary artery (RCA), posterior descending artery (PDA), diagnal branch (DIAG) and, finally, the obtuse marginal branch (OM). While exposing OM and PDA, the Trendelenburg position was adopted to improve exposure and reduce hemodynamic compromise brought on by heart manipulation. Proximal anastomosis was completed with the help of a side-biting clamp in the ascending aorta. No sequential or "T", "Y" grafts were performed.

Table 1. Preoperative characteristics of the patients in OPCAB and CCABG.

Characteristics	OPCAB (n = 149)	CCABG (n = 151)	*p value*
Age (years)	65.5±8.8	67.3±7.3	0.0546
Gender(male/ female)	113/36 (75.84%/24.16%)	121/30 (80.13%/19.87%)	0.3698
Chronic obstructive pulmonary disease	28 (18.79%)	23 (15.23%)	0.4118
History of myocardial infarction	41 (27.52%)	35 (23.18%)	0.3875
History of stroke	38 (25.50%)	27 (17.88%)	0.1092
Diabetes mellitus	43 (28.86%)	38 (25.17%)	0.4717
Renal insufficiency	33 (22.15%)	26 (17.22%)	0.2828
LM lesion	32 (21.48%)	29 (19.21%)	0.6253
Ejection fraction	52□7.2%	53±8.1%	0.2595
Urgent operation	18 (12.08%)	15 (9.93%)	0.5518
European system for cardiac operative risk evaluation	4.73±1.26	4.56±1.05	0.2050

One thousand one hundred forty two anastomosis were performed in the 300 patients. The numbers of distal anastomoses varied from three to six per patient, with the average number similar in both groups (OPCAB group: 3.83±0.93, CCABG group: 3.78±1.11) as shown in **Table 2**. There were no significant differences about the anatomy site of target vessels between the two groups. As to bypassing the RCA system, more PDAs were bypassed in the OPCAB group than in the CCABG group, while more main distal RCAs were bypassed in the CCABG group than in the OPCAB group. Temporary right ventricular pacing probe was placed routinely during the operation. Heart was paced when heart rate <60 per minute, malignant arrhythmia, morbiz II or III-degree AV block. The pacing rate was 80 per minute. There was no difference about pacing rate in the two groups.

Intraoperative flow measurement

After completion of the bypass, flow values and flow curves were obtained using the TTFM device (Medi-stim butterfly flowmeter, Medi-stim, Oslo, Norway). The TTFM probe was fitted snugly around the graft. Probes of different size were used to avoid distortion or compression of the graft. Skeletonization of a small segment of the mammary artery was necessary to reduce the quantity of tissue interposed between the vessel and the probe. Before making any measurement, adequate de-airing of the grafts was performed, and then systolic blood pressure was maintained at 100 to 120mmHg, traction on the pericardium was released and the stabilizer was removed from the epicardial surface to allow the heart to return to its anatomical position. TTFM was repeated before sternum closure to confirm graft patency and to detect any possible graft kinking or compression. The device displays a flow curve and calculates the mean flow (ml/min). The curves were coupled with the ECG tracing to correctly differentiate the systolic flow from the diastolic flow. In patent grafts, the hemodynamics is similar to those physiologically observed in normal coronary circulation: positive blood flows mainly during diastole with minimal negative systolic peaks occurring during the isovolumetric ventricular contraction. From the flow curves, pulsatile index (PI) and percentage of backward flow (%BF) could be obtained. The PI is obtained by dividing the difference between the maximum and the minimum flow by the value of the mean flow. The %BF is obtained as the ratio of the backward flow value to the total flow value. In case of the %BF >3% and/or PI >5, it was confirmed as an indicator of poor flow. The mean flow was not solely used as an indicator of poor flow, and it was evaluated together with the other two parameters. Interpretation of the values obtained has allowed us to decide whether to check and revise a graft.

Statistical analysis

The data were expressed as mean□standard deviation. SPSS 13.0 was adopted for statistical analysis. Comparison of data between the two groups was performed using unpaired 2-tailed t-test for continuous variables and □2 test for categorical variables. A p value of less than p <0.05 was considered to be statistically significant.

Results

All the 300 patients underwent surgery without difficulties, but one patient in OPCAB group was converted to CCABG because of unstable hemodynemics and ventricular fibrillation. One overweight (body mass index>30) patient with renal insufficiency pre-operation in OPCAB group had renal failure which was not cured by continuous renal

Table 2. Main postoperative complications after OPCAB and CCABG surgery.

Postoperative complications	OPCAB (n = 149)	CCABG (n = 151)	*p value*
Pacing rate	6 (4.03%)	5 (3.31%)	0.332
Grafts need revision	3 (2.01%)	4 (2.67%)	0.7055
Perioperative myocardial infarction	1 (0.67%)	3 (2%)	0.3164
Reexploring due to bleeding	2 (1.3%)	3 (2%)	0.6344
Respiratory dysfunction	1 (0.67%)	4 (2.67%)	0.1773
Renal insufficiency	2 (1.3%)	3 (2%)	0.6344
Postoperative death	1 (0.67%)	0(0%)	0.3137

replacement therapy after surgery, succeeding with respiratory failure, infection and multiple organ failure, then died 21 days post-operation. There was no difference about post-operative intubation time, renal dysfunction, peri-operative MI, peri-operative death and re-exploring due to bleeding between the two groups (**Table 2**).

Most of the grafts were detected with satisfactory TTFM findings (**Figure 1**). Eleven grafts were detected with unsatisfactory TTFM findings in OPCAB group. No special management was performed in eight grafts because of poor run-off (**Figure 2**). One LIMA-LAD graft was re-anastmosed due to small anastmosis. Two SV grafts were re-anastmosed due to graft twist. Nine grafts were detected with unsatisfactory TTFM findings in CCABG group. No special management was performed in five grafts because of poor run-off. Two LIMA-LAD grafts were with unsatisfactory TTFM findings. One was re-anastmosed for anastmosis stenosis, the other one was substituted by SV due to small LIMA. One Two SV graft was re-anastmosed, one because of graft twist, and the other one was stenosis of the anastmosis. After revision, mean flow increased from 5-8 ml/minute to 20 to 26ml/min, PI decreased from 9 to 14 to 2 to 4, and %BF values from 6 to 9% to 1 to 3%. No electrocardiographic changes were noted in those patients in whom unsatisfactory TTFM findings were noticed and the anastomoses were revised.

TTFM parameters are given in **Table 3**. The PI values were less than five, and the %BF values were less than 3%. There was no significant difference about the mean flow, PI and %BF between the two groups.

Discussion

Coronary artery bypass surgery has been performed for almost half a century. Despite substantial improvement in surgical technique, the operative treatment of the ischemic heart disease is still only palliative. Closure of 10 to 15% of saphenous vein grafts in the first month, followed by another 5 to 10% in the next 11 months is mostly secondary to a failure in surgical technique. This could be caused by a twist of the graft, linear tension in consequence of insufficient graft length but most frequently because of failure in the construction of the anastomosis itself [2]. The quality of anastomosis in CABG is directly associated with both early and long-term clinical results. It is a complication that may lead to refractory angina, myocardial infarction, arrhythmias, and even mortality [3-5]. Sometimes, these conditions need emergent CABG again [6].

Several techniques have been adopted in the past to evaluate graft patency intra-operatively, and they were replaced by TTFM eventually. Several authors have reported excellent results in diagnosing technical failures during CABG and resolving the problem during the same operation by using TTFM technique [7-9]. Many authors have compared TTFM with intra-operative [10] or post-operative [7, 11, 12] angiography and got satisfying results. Beldi et al [13] compared the flow measured by TTFM with that of volume sampling (true flow) in arteries and veins. They found a high correlation (r = 0.93-0.95) between the two measurements. In addition, TTFM is confirmed as a reliable method to verify intraoperative graft patency [14]. Therefore, TTFM findings may substitute intra-operative angiography in some extent.

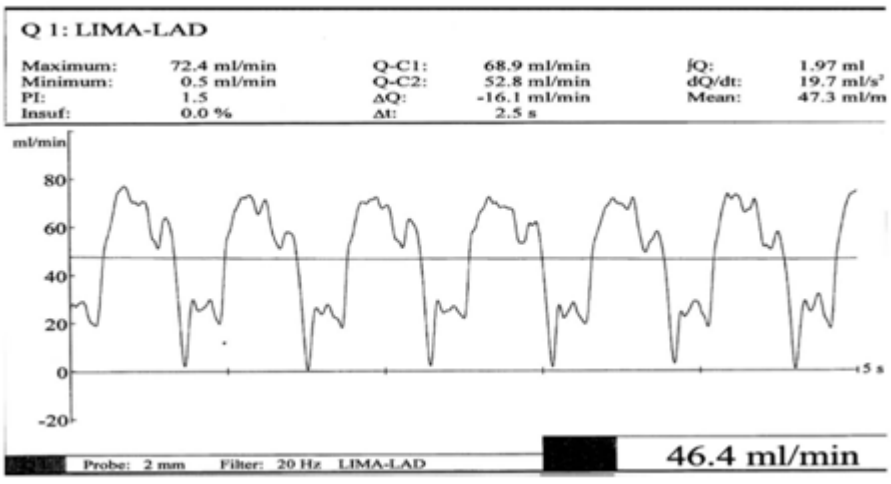

Figure 1. TTFM shows satisfied flow curve with high mean flow, low PI, and %BF (Insuf).

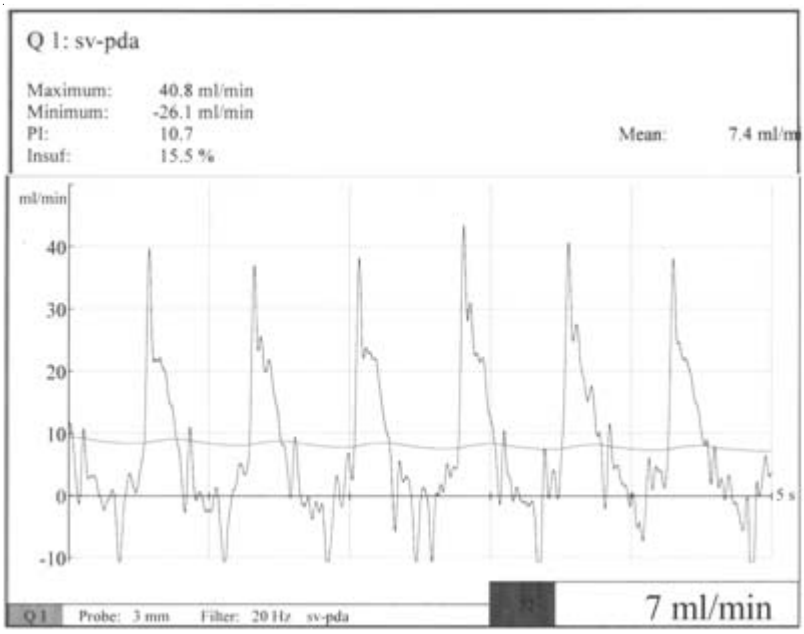

Figure 2. TTFM shows poor flow curve with low mean flow, high PI, and %BF (Insuf) in poor run-off graft.

Table 3. Before sternal closure intraoperative TTFM findings.

	OPCAB			CCABG		
	Mean flow (ml/min)	**PI**	**%BF**	**Mean flow (ml/min)**	**PI**	**%BF**
LIMA-LAD	31.5±29.8	2.3±1.4	2.1±0.7	34.1±27.2	2.4±1.1	1.6±0.9
AO-DIAG	22.4±12.8	2.2±0.9	1.8±0.6	27.1±15.6	2.1±0.8	1.7±0.8
AO-OM	39.4±22.1	2.2±0.9	2.3±0.6	36.5±17.3	2.0±0.9	1.9±0.5
AO-RCA	43.1±21.8	1.9±0.7	1.9±0.7	45.5±19.3	1.7±0.8	1.9±0.8
AO-PDA/ PL	35.7±17.0	2.0±0.8	1.8±0.9	38.0±15.2	2.2±1.0	2.0±0.7

Walpoth et al [15] and D'Ancona et al [16] have reported that a technical failure can be diagnosed with TTFM and resolved during the same operation in 6 to 8% of all patients. This is of great benefit for the patient avoiding unnecessary peri-operative complications. The basic parameter in TTFM is flow. Flow is expressed as a flow curve that displays the systolic and diastolic filling of the graft, and a mean flow value (ml/min). The curve should always be coupled with the electrocardiography (ECG) tracing to correctly differentiate the systolic from the diastolic flow. Mean flow is dependent on many variables including blood viscosity, the size of the graft, resistance in the graft, the area of the outflow bed, the size of the native coronary artery and spasms in arterial grafts. Absolute mean blood flow value is not a good indicator of the quality of the anastomosis. It should be considered together with other indicators and clinical outcomes (ECG, hemodynamic values). Recent studies suggest that diastolic flow (DF) is the most important indicator for intra-operative graft patency verification, especially in low flow situations where the mean flow value is <10 ml/min. The reason is that DF is the metabolic part of the flow, which brings nutrients and oxygen to the heart. The systolic flow is useful for the compliance [8, 9]. Therefore, Medi-stim takes DF as a standard parameter in its new flowmeter. However, we hold the opinion that systolic positive flow may also be nutritive and %BF maybe more accurate. %BF shows the insufficient flow in the flow pattern. The rest in total flow shows effective flow in the heart cycle, which is more accurate than DF. Takami [11] analyzed 82 grafts intraoperative TTFM and angiography 2 weeks post-

surgery. With univariate analysis, significantly higher %BF and PI were found in non-patent grafts compare to those in patent grafts. Di Giammarco G et al [7] reported that %BF value of 0 or 3.0% or greater can be considered as cutoff values predictive for early graft failure, and they got satisfying outcomes by this cutoff values. Tokuda et al [12] analyzed a series of 261 grafts evaluated by intra-operative TTFM and underwent coronary angiography within three months of surgery. They found the cutoff value of %BF was 4.1% and 4.6% for left coronary arteries and right coronary arteries, respectively. The value of %BF in our study is less than 3.0%, and we consider that the %BF value of 0 may not indicate graft failure if the mean flow is more than 10 ml/min. We choose 3.0% as the cutoff value of %BF. It will be more acceptable to do some meta-analysis to set the ideal cutoff value of %BF in TTFM and angiography compared study. PI is a good indicator of the flow pattern and, consequently, of the quality of the anastomosis. The PI is proportional to the vascular resistance. D'Ancona et al [12] reported 41 revised grafts based on poor TTF findings. After revision, mean flow increased from 6.6 to 36.6ml/min (p <0.0001), and PI decreased from 24.8 to 2.8 (p <0.0001). Di Giammarco G and colleagues [7] reported that failure grafts proved post-operation had high PI (6.4±10.9), which was significantly higher than that (2.8±4.7) of patent grafts (p = 0.001). Grafts with PI ≥3 in functioning group were significantly less than failing group 59 (22.2%) vs. 25 (65.8%), p <0.001]. Therefore, a high PI is an indicator of poor quality of a graft or anastomosis and PI should be between 1 and 5 in the well functioning grafts [7, 9]. Of course, mean flow, PI and %BF should be interpreted together to judge the function of a graft. Isolated interpretation of one or two of these parameters may lead to wrong judgment. We got good PI and %BF values in the study. High PI and %BF values and low mean flow were found in some grafts, PI and %BF values decreased and mean flow increased after revision.

The flow curves were different from each other according to the different anastomosis site. Flow curves in grafts anastomosed to LAD or OM show a mainly diastolic flow pattern, while flow curves in grafts anastomosed to RCA or PDA show double-stage (systolic and diastolic stage positive flow) a flow pattern. High blood flow was also detected in grafts anstomosed to RCA system. These outcomes may be explained as that 1) minor compression of the epicardial vessels during right ventricular contraction, and 2) larger distal territory of RCA system.

The quality of anastmosis is associated with early and long-term clinical outcomes after CABG. It is a high demanding technique and the incidence of peri-operative graft failure has been estimated to be 5 to 11% [7, 17, 18]. TTFM is a recently revived technology technique that allows quick and easy assessment of graft flow, independent of vessel size and shape [7-9, 18]. In this study, unsatisfactory TTFM findings were detected in twenty grafts and seven grafts were revised in the two groups. However, there was no difference of the number of revised grafts in the two groups. It suggests TTFM could be of great use during clinical practice and reminds the surgeon to find out the reason of poor graft flow and OPCAB could obtain the same anastomosis as CCABG. The results of OPCAB depend on the experience and expertise of the surgeon. Therefore, it is worth pointing out that this study was processed based on more than 250 successful OPCAB experience. Some fellows in our institute almost had their anastmoses revised totally in their early training stage on porcine heart based on unsatisfactory TTFM findings. It is recommended that novices in OPCAB field should use TTFM routinely to detect anastomosis dysfunction and revise it timely [1].

Due to the high demanding of OPCAB, some authors pointed out that the quality of anastomosis and graft patency may be compromised in off pump coronary artery bypass grafting [19]. Schmitz et al [20] also reported that graft flow in CCABG patient was higher than that in OPCAB patients. Nevertheless, we found no statistical difference about mean flow, PI, and %BF between OPCAB group and CCABG group. In conclusion, OPCAB can get the same a relatively good graft patency and completeness of revascularization as CCABG, and TTFM can help to detect unsatisfied graft flows, which can help decide whether or not there is a need to revise the anastomosis.

The authors have no conflict of interest to declare.

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