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Original Article

Intraoperative Graft Flow Measurement in Off-Pump Coronary Artery Bypass Grafting Indicating Graft Revision: Our Experience of 1203 Grafts

Seetharama Bhat PS[1], Girish Gowda SL[1,*], Chandana NC[1], Manjunath N[2], Cholenahally Nanjappa Manjunath[3]

[1]Department of Cardiothoracic and Vascular Surgery, Sri Jayadeva Institute of Cardiovascular Sciences and Research, Bangalore, Karnataka, INDIA.
[2]Department of Cardiac Anesthesia, Sri Jayadeva institute of Cardiovascular Sciences and Research, Bangalore, Karnataka, INDIA.
[3]Department of Cardiology, Sri Jayadeva Institute of Cardiovascular Sciences and Research, Bangalore, Karnataka, INDIA.

ABSTRACT

Background: This study was undertaken to evaluate the use of Transit time flowmetry (TTFM) to identify the malfunctioning graft for the need of graft revision or intervention while performing Off-pump coronary artery bypass grafting (OPCAB). **Methods:** From July 2014-July 2018 transit time flowmetry was performed on 1206 grafts in 424 patients who underwent OPCAB. The grafts were taken as patent and acceptable if the mean graft flow was more than 20 ml/minute, Pulsatility index (PI) of < 5 and Diastolic flow (DF) more than 50% with a minimal systolic spike. The grafts which did not fulfill the above criteria were revised/appropriate intervention done after identifying the cause for graft malfunction. **Results:** A total of 1203 grafts were measured in 424 patients who underwent OPCAB. Out of 1203 grafts measured, 51 grafts in fours nine patients showed abnormal flowmetry reading requiring graft revision or intervention. The cause for graft malfunction was graft twisting, anastomosis stenosis, graft kinking, Lima spasm, coronary dissection, reversed vein, graft anastomosis thrombosis and retained coronary shunt. All fifty-one grafts flow returned to normal after graft revision or intervention. We had one-mortality out of forty-nine patients who had grafts revised and the mortality was not attributed to graft malfunction. **Conclusion:** Intraoperative evaluation of the graft flow with TTFM promptly helps in identifying the abnormal grafts before the patient becomes hemodynamically unstable. Correcting the abnormal grafts prior to chest closure leads to a reduction in mortality and morbidity which will help in improving the patient's outcome.
Key words: Transit time flowmetery, Graft revision, OPCAB.

Correspondence
Dr. Girish Gowda S L
Associate Professor,
Department of Cardiothoracic and Vascular Surgery,
Sri Jayadeva Institute of Cardiovascular Sciences and Research, Bangalore,
Karnataka-560069, INDIA.
Ph.no: +91-9449046932
E-mail address: gowda1212@yahoo.co.in

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INTRODUCTION

The Off-pump coronary artery bypass grafting (OPCAB) is the commonly performed surgery for coronary revascularization in developing countries when compared to western countries. Intraoperative evaluation of graft flow is very important to have a good patient outcome. TTFM is an effective method for evaluation of graft patency during the intraoperative period. The intraoperative monitoring of graft flow by TTFM is the most commonly applied technique and is suggested by the European Association for Cardio-Thoracic Surgery (EACTS) 2018 guidelines.[1] Specific cut-off values for TTFM have been recommended to avoid graft occlusion postoperatively by few studies as, mean graft flow of more than 20 ml/min and PI of < 5.[2,3] Few studies have shown that PI of < 3 is a desirable value.[4,5] The objective of this study is to assess the intraoperative graft flow to identify the graft patency and quality, to rule out surgical technical problems requiring immediate graft revision.

MATERIALS AND METHODS

All 424 patients who underwent OPCAB in a single surgical unit from July 2014 to July 2018, had graft flow measured intraoperative using VeriQTM Transit time flow measurement (TTFM) device. A total of 1203 grafts were measured in these patients. The grafts were taken as patent and acceptable if pulsatility index (PI) of was less than 5 with mean graft flow of more than 20 ml/min and Diastolic flow (DF) more than 50%. The grafts which did not fulfill the above criteria were revised after identifying the cause for graft dysfunction. Ethical committee clearance was taken from our institute before staring the study.

Surgical techniques

All patients had median sternotomy and Left internal mammary artery (LIMA), Left or right greater saphenous vein was harvested. Coronary stabilization was done using Medtronic stabilizers during grafting. LIMA was always anastomosed to LAD and SVG used for another coronary grafting. Once the anastomosis was completed, the graft flows were measured and again after completing protamine infusion. If TTFM results are not satisfactory, then the cause is identified and graft anastomotic revision or the reason causing graft dysfunction if rectified. The systolic BP of more than 100 mmHg was maintained during TTFM measurement.

TTFM measurement

The measurements of the graft flow were made with TTFM device VeriQTM (Medistim, Norway). The data collected during the graft flow measurement were mean flow, DF and PI. The shape of the waveform was analyzed in correlation with ECG to look for systolic spike if any. Different size TTFM probes were used for measurement of the graft flow depending on the diameter of the conduct. Partial skeletonization of LIMA was done to facilitate the probe placement for measurement. 2mm probe was used for LIMA and 4 mm or 3 mm probe was used for venous grafts. The flow flows were always compared with ECG to identify the systolic and diastolic flow. Physiologically diastolic flow is more with minimal systolic peak flow. The DF of more than 50%, mean graft flow of more than 20 ml/min and PI of less than 5 was taken as an acceptable value. The TTFM values were correlated with hemodynamics and ECG. TTFM measurement was done immediately after completing the anastomosis and again after completing protamine infusion. If in case grafts did not fulfill the above criteria, then grafts were revised after identifying the cause for graft dysfunction and again TTFM measurement was done.

Statistics

Continuous variables are reported as mean ± standard deviation and were compared using the *t*-test for normal distributions. The *t*-test for testing of one mean and comparison of mean, of TTFM grafts reading before and after graft intervention was done. Reported *p*-values of $p<0.05$ was considered statistically significant. Statistical analysis was performed in MedCalc statistical software.

RESULTS

The data was collected from 424 numbers of patients and total grafts measured in these patients were 1203 number of graft measurements. Demographically there was no difference between the intervention group and nonintervention group (Table 1). A total of 51 grafts (51 /1203) were revised in forty-nine patients. In these forty-nine patients, two patients had two grafts revised and rest forty-seven patients had one graft revised. Of the total grafts revised, 5 where to LAD, 13 to OM, 8 to diagonal, 3 to RAMUS, 9 to RCA and 13 to PDA. Forty-seven grafts were revised off-pump and four grafts were revised on Cardiopulmonary bypass (CPB). The decision to revise the graft was taken when the TTFM measurement showed low flow, high PI and predominantly systolic flow. The causes for which revision of the grafts was done were, 6 grafts had twisted, 6 grafts had kinking, 3 grafts had Lima spasm of which did not respond to papaverine hence it was replaced with SVG to LAD, 1 graft had reversed vein, 8 grafts had coronary dissection, 16 grafts had anastomotic stenosis, 9 grafts had thrombus, 1 graft had a retained coronary shunt and in 1 graft, proximal anastomosis block was the cause. Twenty-four patients had intraoperative ST elevation with hemodynamic instability. All Twenty-four patient's ECG settled to a normal range once the dysfunctional grafts were revised. ECG Graft revision/intervention was according to the cause for graft malfunction (Table 2). Post revision grafts were accepted as good, once our criteria were fulfilled. Pre and post revision or intervention TTFM readings of all grafts are tabulated (Table 3) and t-test for mean and comparison of the mean was significant with $p<0.001$. The TTFM, graft flow values before and after graft revision/intervention (Table 4) and TTFM, PI values before and after graft revision/intervention (Table 5) were tested statistically and found to be statistically significant with $p<0.001$. The OM and PDA were the grafts which were more revised when compared to other grafts. We had mortality of one patient out of forty-nine patients who had grafts revised and this mortality was due to pneumonia leading to sepsis.

Table 1: Patients Demographics.

	Graft not revised (*n*=375)	Graft revised (*n*=49)
Average age	41-78(51) years	39-81 (52) years
Male	293(78%)	40 (80%)
Hypertension	225(60%)	30(62%)
Diabetes mellitus	210(56%)	29(58%)
Elective	367(98%)	47(97%)
Emergency	15(4%)	2(5%)
Previous PCI	45(12%)	7(15%)
Renal dysfunction	45(12%)	6(14%)
Smoking	142(38%)	18(36%)

Table 2: Cause for Graft Dysfunction and Intervention Done to Rectify the Cause.

Cause for graft dysfunction (*n*-51)	Intervention done to rectify the cause
Graft twisting (*n*-6)	Graft anastomosis revision (Proximal),
Graft kinking (*n*-6)	Fixing graft to prevent link
Lima spasm (*n*-3)	SVG-LAD
Reversed vein (*n*-1)	Graft anastomosis revision both proximal and distal
Coronary dissection (*n*-8)	Graft anastomosis revision (Distal)
Anastomotic stenosis (*n*-16)	Graft anastomosis revision (Distal)
Graft anastomosis thrombosis (*n*-9)	Graft anastomosis revision (Distal)
Retained intracoronary shunt (*n*-1)	Remove the intracoronary shunt and Graft anastomosis revision (Distal)
Proximal anastomosis block (*n*-1)	Graft anastomosis revision (Proximal).

Table 3: TTFM Values of Grafts Revised.

TTFM result (*n*-51)	Pre graft revision/ intervention	Post graft revision/ intervention	*t* -test
Flow ml/min	4.41 ± 2.06 (1-9) p<0.001	37.52 ± 15.27 (17-83) p<0.001	$p<0.001$
PI	20.29 ± 9.09 (7.9-39) $p<0.001$	2.19 ± 0.730 (1-1.4) p<0.001	$p<0.001$

The values are expressed as Mean ± Standard deviation SD (Range). PI- Pulsatility index.

DISCUSSION

TTFM is advised by European Association for Cardio-Thoracic Surgery EACTS-2018 guidelines for myocardial revascularization for evaluation of graft patency intraoperatively during CABG.[1] Patency of graft is measured and accepted as fine when DF is >50% and PI is 5 or < 5 with good MGF.[2,3] TTFM is the most commonly used method for intraoperative evaluation of grafts.[2] Different techniques have been used before like electromagnetic flowmeters, but now they are all replaced by TTFM. Intraoperative measurement of graft flow for its patency is more important in OPCAB. The sensitivity of detecting less than critical stenosis remains to a major concern. It is evident that less than critical stenosis cannot be detected by TTFM due to the fact that no modifications in the hemodynamic performances of the grafts happen at this level. The surgeon usually acquires the experience to interpret the TTFM readings in these types of situations.[6] In these authors experience, in 10–15% of TTFM measurements, the readings are difficult to interpret or ambiguous as to whether the graft is functioning properly or not.[7-9] With our experience of more than 1200 graft measurements we are now capable of identifying the graft which requires revision. The TTFM readings have to be correlated and supported by hemodynamics and ECG changes before taking a decision to revise the graft. The predominant forward flow through the graft occurs during the diastolic phase, whereas systolic flow through the graft is due to backward flow due to stenosis anastomosis or because of competitive flow in the native coronary vessel. This is true for all coronary arteries except right coronary artery as it will have minimal epicardial coronary compression.[10] This has to be kept in mind while interpreting

Table 4: TTFM Flow values Measurements before and after Graft Revision/Intervention.

GRAFTS	Number of grafts (*n*=51)	Pre graft revision/ intervention Flow ml/min- mean ± SD (Range)	Post graft revision/ intervention Flow ml/min- mean ± SD (Range)	*t*-test
LIMA-LAD	5	4.2 ± 1.78 (2-6) *p*<0.001	24 ± 5.78 (18-32) *p*<0.001	*p*<0.001
SVG-D	8	5 ± 2.67 (2-9) *p*<0.001	25± 7.07 (17-37) *p*<0.001	*p*<0.001
SVG-OM	13	4.38 ± 1.89 (1-7) *p*<0.001	38.23 ± 10.15 (23-52) *p*<0.001	*p*<0.001
SVG-RAMUS	3	4.33 ± 1.52 (3-6) *p*<0.001	32.33 ± 8.50 (24-41) *p*<0.001	*p*<0.001
SVG-RCA	9	5.11 ± 2.02 (2-8) *p*<0.001	56.11 ± 18.69 (33-83) p<0.001	*p*<0.001
SVG-PDA	13	3.69 ± 2.13 (1-8) *p*<0.001	38.07 ± 11.65 (21-61) p<0.001	*p*<0.001

The values are expressed as Mean ± Standard deviation SD (Range). LIMA-Left internal mammary artery; D- Diagonal, OM- Obtuse marginal, RCA- Right coronary artery, PDA- Posterior descending artery, PI- Pulsatility index, SVG- Saphenous vein.

Table 5: TTFM *PI* values Measurements before and after Graft Revision/Intervention.

GRAFTS	Number of grafts(*n*=51)	Pre-graft revision/ intervention PI	Post graft revision/ intervention PI	*t*-test
LIMA-LAD	5	20.46 ± 9.71 (13-37) *p*<0.001	1.96 ± 0.47 (1.2-2.4) *p*<0.001	*p*<0.001
SVG-D	8	21.3 ± 7.13 (11-36) *p*<0.001	2.33 ± 1.07 (1-4.1) *p*<0.001	*p*<0.001
SVG-OM	13	16.56 ± 9.72 (8-39) *p*<0.001	2.04 ± 0.630 (1.2-3) *p*<0.001	*p*<0.001
SVG-RAMUS	3	27.91 ± 3.52 (23.9-30) *p*<0.001	2.03 ± 0.76 (1.2-2.7) *p*<0.001	*p*<0.001
SVG-RCA	9	25.33 ± 8.56 (10-35) *p*<0.001	3.6 ± 0.63 (1.2-5.2) *p*<0.001	*p*<0.001
SVG-PDA	13	17.86 ± 8.97 (7.9-33) *p*<0.001	2.22 ± 0.82 (1.2-3.1) *p*<0.001	*p*<0.001

The values are expressed as Mean ± Standard deviation SD (Range). LIMA- Left internal mammary artery; D- Diagonal, OM- Obtuse marginal, RCA- Right coronary artery, PDA- Posterior descending artery, PI- Pulsatility index, SVG- Saphenous vein.

TTFM measurements of RCA grafts. Intraoperatively measured graft flow and PI are associated with cardiac anatomical parameters, such as the percentage of stenosis, internal diameter and perfused left ventricle mass volume.[11] Graft flow also depends on many other variables like graft length, size, quality of conduct. It also depends on hematocrit, mean blood pressure, heart rate and quality of distal anastomosis. We can control only a few factors like mean pressure, heart rate and hematocrit while doing TTFM. This was done in few studies.[12-14] The use of TTFM, high-resolution epicardial ultrasound or intraoperative fluorescence imaging allows intraoperative control of the quality of the anastomosis.[15] TTFM and epicardial ultrasound are reliable intraoperative graft patency validation techniques which can verify 1–2 mm coronary vessels.[16,17] The use of epicardial ultrasound in our study could have helped to evaluate the grafts even more efficiently. This is one of the limitations in our study. Studies have shown intraoperative graft dysfunction in 0.6-4.2% of grafts, in our study these values were demonstrated as 4.1%. Using PI for assessing graft function is an important step in deciding about the graft revision. The value of 5 or < 5 is recommended as acceptable but few studies have shown that PI of < 3 is desirable.[4,5] But a large number of studies have recommended PI of 5 or <5 as acceptable. We have taken PI of 5 or < 5 as acceptable value. Out of 51 grafts, 10 grafts were revised based on the TTFM finding found after giving protamine and remaining 41 grafts were revised based on the pre-protamine reading. Hence, it is necessary to do TTFM measurement before giving protamine in all cases. We have to keep in mind that only mean graft flow is not a good indicator of grafts quality but on the

contrary PI values with mean graft, flow is more accurate in knowing the actual status of the graft anastomosis.

Limitation

Radial artery graft conducts were not included in our study. Epicardial ultrasound along with TTFM has to be done to further validate these techniques. These are the limitations in our study.

CONCLUSION

We want to conclude that TTFM is a reliable method in detecting technical errors of the graft conducts during OPCAB. The graft should be revised or the reason causing grafts dysfunction if rectified. Revision of the grafts leads to improvement in graft flow and patency. Hence the operative outcomes can be improved by the use of TTFM in OPCAB. Correcting the abnormal grafts prior to chest closure leads to a reduction in mortality and morbidity. The patient outcome can be improved if TTFM is used as a standard tool during coronary artery bypass graft surgery.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

ABBREVIATIONS

TTFM: Transit Time Flowmetry; **OPCAB:** Off-Pump Coronary Artery Bypass Grafting; **EACTS:** European Association for Cardio-Thoracic Surgery; **PI:** Pulsatility Index; **DF:** Diastolic Flow; **LIMA:** Left Internal Mammary Artery; **CPB:** Cardiopulmonary Bypass; **D:** Diagonal; **OM:** Obtuse Marginal; **RCA:** Right Coronary Artery; **PDA:** Posterior Descending Artery; **SVG:** Saphenous Veininterest.

SUMMARY

We have presented our experience of intraoperative graft flow evaluation in OPCAB using TTFM. Intraoperative graft flow evaluation using TTFM will help in immediate identification of the malfunctioning grafts. This is even more important in OPCAB, as the malfunctioning grafts can cause hemodynamic instability leading to increase in mortality and morbidity. This study has shown the efficacy of TTFM in identifying and re-evaluation of the graft after graft revision. We want to conclude that TTFM is a reliable method in detecting technical errors in the graft conducts during OPCAB. The patient outcome can be improved if TTFM is used as a standard tool during OPCAB.

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