

# Comparison between OPCABG and CABG Surgical Revascularization Using Transit Time Flow Measurement (TTFM)

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## ABSTRACT

**Objective:** To compare the intraoperative quality of coronary anastomoses performed with or without cardiopulmonary bypass using transit time flow measurement (TTFM) parameters.

**Methods:** We collected data from 588 consecutive patients who underwent surgical revascularization. We retrospectively reviewed data from two groups: 411 with cardiopulmonary bypass (CABG group) and 177 off-pump (OPCABG group). Transit time flow measurement parameters: mean graft flow (MGF), pulsatile index (PI), and diastolic filing (DF) were measured for each graft and patient.

**Results:** Patients in the OPCABG group had higher EuroSCORE compared with the CABG group ( $3.53 \pm 2.32$  versus  $2.84 \pm 2.15$ ,  $P = .002$ ). Overall comparison of TTFM parameters showed no statistical difference between the two surgical techniques except for PI in circumflex artery territory, which was higher in the OPCABG group for all types of grafts  $3.0 \pm 4.9$  versus  $2.4 \pm 2.0$  in,  $P = .026$ .

**Conclusion:** The comparison between OPCABG and CABG in this study showed comparable results with both surgical techniques. PI was higher in the OPCABG group in harder-to-reach vessel territories. Measurement of transit time may improve the quality, safety, and efficacy of coronary artery bypass grafting and should be considered as a routine procedure.

## INTRODUCTION

Surgical myocardial revascularization can be performed with the assistance of extracorporeal circulation or without the use of an extracorporeal circulation machine, and there are ongoing debates about the advantages and limitations of off-pump surgical revascularization [Sellke 2005]. Several randomised trials and observational studies have demonstrated the advantages of off-pump coronary artery bypass grafting (OPCABG) over on-pump coronary artery bypass grafting (CABG), particularly in terms of postoperative neurologic

events, atrial fibrillation, blood transfusion requirements, and perioperative mortality [Panesar 2006; Sedrakyan 2006; van Dijk 2001; van Dijk 2002]. The main reported disadvantages of OPCABG are incompleteness of revascularization and graft patency.

The literature indicates that up to 11% of bypass grafts, affecting approximately 10% of all patients, become occluded early after surgery [Hattler 2012; Kolh 2010; Becit 2007; di Giammarco 2006; D'Ancona 2000; Kieser 2010]. In an attempt to address this problem, there is increasing emphasis on the importance of intraoperative review of the bypass grafts created, in an attempt to detect perioperative and early postoperative complications due to graft failure. The introduction of transit time flow measurement (TTFM) in 2007 [Balacumaraswami 2007] has greatly improved intraoperative assessment of graft quality. The TTFM itself assesses graft flow and thus the quality of the anastomosis and/or conduit and allows for immediate revision of the graft in situations where the surgical outcome is less than optimal. Transit-time flow measurement is the most used technique for graft assessment, which can detect up to 2-4% graft that require revision [Kieser 2010; Mujanovi 2007]. The use of TTFM to assess graft quality results in a significant reduction in perioperative adverse events and an improvement in graft patency by identifying surgically inadequate grafts and reducing the proportion of unnecessary graft revisions.

The 2018 European Society of Cardiology/European Association for Cardio-Thoracic Surgery Guidelines on myocardial revascularization provide a IIa recommendation, Evidence Level B, for intraoperative graft flow assessment, with important notice that interpretation can be challenging in sequential and T-graft configurations [Kieser 2010; Neumann 2019; Jokinen 2011; Lehnert 2015; Niclauss 2017].

Several TTFM parameters are measured or calculated intraoperatively. Mean graft flow (MGF =  $Q_{\text{mean}}$ ; ml/min) depends on the quality and diameter of the graft, the quality of the target vessel, and the distal outflow of the bypass graft. Pulsatility index (PI) estimates the resistance in the graft or the distal target vessel outflow. Its value is calculated as the difference between the peak systolic flow minus the peak diastolic flow divided by the median flow ( $PI = [Q_{\text{max}} - Q_{\text{min}}] / Q_{\text{mean}}$ ). The diastolic flow fraction (DF) can be determined by connecting the TTFM console to an ECG to calculate the percentage of total flow during diastole ( $DF = Q_{\text{diastole}} / [Q_{\text{systole}} + Q_{\text{diastole}}]$ ), which should be higher than the systolic flow, especially for the left coronary system because of

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Table 1. Preoperative patient characteristics

Variable	OPCAB	CABG	P
N	177	411	
Age	64.4 ± 10.4	64.0 ± 8.3	NS
N women (%)	19.2	18.3	NS
EuroSCORE	3.53 ± 2.32	2.84 ± 2.15	.002
EuroSCORE logistic (%)	3.26 ± 1.22	2.57 ± 2.26	.009

the higher left ventricular transmural pressure gradients. The EACTS/ESC guidelines do not specify definite values but in some observational studies find an MGF of  $\geq 20$  ml/min and an PI of  $\leq 5$  as acceptable perioperative outcomes for TTFM [Mujanović 2007]. Some authors accept lower thresholds with an MGF of 15 ml/min or 10 ml/min before calling TTFM "abnormal" [Neumann 2019; Handa 2015; Walker 2013; Gao 2010; Singh 2010].

We investigated the correlation of anastomotic quality parameters measured by the TTFM with surgical technique in relation to the use of CPB.

## PATIENTS AND METHODS

This study was a single center, retrospective observational study of 588 consecutive isolated myocardial revascularizations. Patients were divided into two groups, according to the use of cardiopulmonary bypass. Preoperative risk was assessed using the logistic EuroSCORE. The left internal thoracic artery (LIMA), radial artery (RA), and great saphenous vein (VSM) were used for myocardial revascularization.

VeriQ C device (Medistim ASA, Oslo, Norway) was equipped with an ultrasound probe and the measurement data displayed in real time. Data collected simultaneously at each measurement included flow, diastolic filling, and pulsatile index. Mean flow rate is measured in milliliters per minute.

### Statistical analysis

Continuous data were expressed as mean SD. Categorical variables were expressed as number (percent of total) and compared using the chi-square test. Continuous variables were expressed as median ± SD. Nonparametric samples were compared using the Mann-Whitney U test. Continuous variables were compared using the Student t test or the Kolmogorov-Smirnov test. A two-sided P-value of .05 was considered significant. Results were analyzed using MS Office Excel (2010).

## RESULTS

EuroSCORE was higher in the OPCABG group 3.53 ± 2.32 versus 2.84 ± 2.15 in the CABG group;  $P = .009$  (Table 1). The total number of distal anastomoses analyzed was 1333. Patients in the OPCABG group received 320 bypass

Table 2. Flow parameters in LAD territory

LAD	CABG	OPCAB	P
IMA			
N	392	150	
Flow	37.7 ± 20.3	37.5 ± 21.5	0.667
PI	2.3 ± 1.3	2.2 ± 0.9	0.114
DF	72.3 ± 7.4	72.6 ± 9.6	0.412
RA			
N	1	2	
Flow	74.0	94.0 ± 114.6	*
PI	1.0	2.2 ± 0.7	*
DF	73.0	64.0 ± 14.1	*
VSM			
N	13	17	
Flow	64.7 ± 46.0	65.2 ± 33.2	0.973
PI	1.7 ± 0.5	1.9 ± 0.7	0.309
DF	68.9 ± 5.7	73.8 ± 8.4	0.094
Total			
N	406	169	
Flow	38.7 ± 22.0	41.0 ± 26.4	0.711
PI	2.3 ± 1.2	2.2 ± 0.9	0.989
DF	72.2 ± 7.4	72.6 ± 9.5	0.646

grafts (1.9 ± 0.81 per patient), compared with a total of 1013 bypass grafts (2.5 ± 0.58) in the CABG group. Detailed analysis revealed that in the OPCABG group, 4 (4%) patients had one-vessel disease, 71 (64%) had two-vessel disease, 36 (32%) had three-vessel disease, and 4 (4%) had four-vessel disease, while in the CABG group, 8 (2%) patients were treated with one-vessel disease, 196 (49%) with two-vessel disease, 197 (49%) with three-vessel disease, and 10 (3%) with four-vessel disease. There was no significant difference in the grafts used in both groups. The types of grafts used in both groups are shown in Figure 1.

In general, intraoperative measurement of bypass graft flow by TTFM showed that the CABG group had slightly lower values of flow and diastolic filling and a slightly higher pulsatility index. Mean graft flow was 44.4 ± 28.6 ml/min in the CABG group, compared with OPCAB 45.8 ± 28.5 ( $P = .492$ ); the mean value of PI was 2.4 ± 2.5 in CABG and 2.3 ± 1.6 in OPCAB ( $P = .829$ ). The mean value of diastolic filling was 67.7 ± 13.3% in the CABG group and 68.8 ± 13.6% in the OPCABG group ( $P = .270$ ).

### Left anterior descending (LAD)

Mean graft flow compared between CABG and OPCABG showed higher total values in the OPCAB group (41.0 ± 26.4 ml/min) compared with the CABG group (38.7 ± 22.0 ml/min) ( $P = .771$ ), but with no statistical difference. There was no statistical difference in PI (2.3 ± 1.2 versus 2.2 ± 0.9)

Table 3. Flow parameters in ACx territory

ACx	CABG	OPCAB	P
<b>IMA</b>			
N	8	5	
Flow	26.6 ± 20.6	46.8 ± 35.1	*
PI	3.1 ± 1.9	7.1 ± 11.3	*
DF	65.9 ± 11.8	58.2 ± 13.9	*
<b>RA</b>			
N	90	4	
Flow	53.1 ± 31.2	32.5 ± 10.8	*
PI	1.9 ± 0.7	1.7 ± 0.4	*
DF	66.4 ± 7.3	68.5 ± 3.0	*
<b>VSM</b>			
N	193	49	
Flow	55.3 ± 34.8	55.4 ± 31.7	0.703
PI	2.7 ± 2.4	2.7 ± 4.0	0.003
DF	63.9 ± 10.9	63.1 ± 12.3	0.638
<b>Total</b>			
N	291	58	
Flow	53.8 ± 33.7	53.1 ± 31.2	0.889
PI	2.4 ± 2.0	3.0 ± 4.9	0.026
DF	64.8 ± 10.0	63.0 ± 12.1	0.347

(*P* = .989) and DF (72.2 ± 7.4% versus 72.6 versus ± 9.5%) (*P* = .646) in CABG versus OPCABG. No statistical difference was found in the use of LIMA versus VSM in LAD area (Table 2).

**Circumflex artery (ACx)**

MGF showed no statistical difference, when comparing the graft used to the total MGF in OPCABG versus CABG, (53.1 ± 31.2 ml/min versus 53.8 ± 33.7 ml/min) (*P* = .889). The use of VSM in this area showed a higher PI in the OPCABG group versus the CABG group, (2.7 ± 4.0 versus 2.7 ± 2.4) (*P* = .003), and also with respect to all three available grafts, the total PI was higher in the OPCABG group (3.0 ± 4.9 versus 2.4 ± 2.0) in the CABG group (*P* = .026). DF showed no statistical difference between the groups, with an overall DF in the OPCABG versus CABG group, (63.0 ± 12.1% versus 64.8 ± 10.0%), respectively, (*P* = .347) (Table 3).

**Right coronary artery (RCA)**

No differences were observed with respect to the type of graft used, MGF was similar in the CABG group (50.5 ± 27.1 ml/min) compared with the OPCABG group (50.2 ± 29.5 ml/min) (*P* = .94). The PI values showed statistical difference between the procedures when VSM was used, CABG group (2.9 ± 4.9) versus OPCABG group (2.1 ± 1.2) (*P* = .046), and for RA the results were not significant (*P* =

Table 4. Flow parameters in RCA territory

RCA	CABG	OPCAB	P
<b>IMA</b>			
N	7	4	
Flow	27.4 ± 12.6	14 ± 10.1	*
PI	3.2 ± 4	6.7 ± 5.9	*
DF	56 ± 16.8	52.6 ± 17.9	*
<b>RA</b>			
N	63	15	
Flow	50.5 ± 21.1	57.8 ± 25.1	0.31
PI	1.9 ± 0.8	1.74 ± 0.6	0.394
DF	59.7 ± 11.1	64.5 ± 10.1	0.119
<b>VSM</b>			
N	185	49	
Flow	51.3 ± 28.9	50.9 ± 29.9	0.933
PI	2.9 ± 4.9	2.1 ± 1.2	0.046
DF	57.1 ± 13.6	60.2 ± 14.9	0.192
<b>Total</b>			
N	255	68	
Flow	50.5 ± 27.1	50.2 ± 29.5	0.94
PI	2.6 ± 4.3	2.3 ± 1.9	0.573
DF	57.7 ± 13.1	60.8 ± 14.1	0.105

.394). Since too few IMA grafts were used, no meaningful statistical analysis could be performed. The summary PI for all three available grafts was (2.6 ± 4.3) and (2.3 ± 1.9) for CABG versus OPCABG, respectively. DF showed no statistical difference between the groups, with an overall DF in the CABG (57.7 ± 13.1) and (60.8 ± 14.1) in OPCABG, (*P* = .105). (Table 4).

**DISCUSSION**

Off-pump CABG requires technical skill and experience of the surgeon. In the early 1990s, OPCABG was getting more widely accepted facilitated by development of mechanical and pharmacological organ stabilizers and intracoronary shunts [Cooley 2000; Hirose 2001]. Widespread use of the technically more complex method led to concerns about the quality of the anastomoses. One of quality control tools was the development of the TTFM (Transit Time Flow Measurement) as a method to quantify anastomotic quality.

Since there still is a lack of standardization in the application of the method and interpretation of the results, it is necessary to agree on the values to be expected, when assessing individual grafts. The advantage of this method is that it immediately can detect dysfunctional grafts. Qualities of anastomoses performed without the use of CPBs had similar flow results, PI and DF, in most supply areas. In the obtuse

branch area, the results showed slightly higher PI values in the OPCABG group, which could be attributed to more difficult exposure and loss of quality in the graft anastomosis. The mean values of flow in the right coronary artery territory were higher in the CABG group.

TTFM is an established non-invasive method to evaluate the quality of anastomoses intraoperatively. Previous studies have identified PI >5 as a predictor of short-term adverse effects, i.e longer duration of ventilation, higher incidence of MI, and early mortality [Herman 2008]. Balacumaraswami et al compared intraoperative flow measurement and flow to pressure ratio, according to revascularization technique (OPCABG versus CABG), and reported significantly higher mean flow rates and flow to pressure ratio in the CABG group [Balacumaraswami 2008]. They hypothesized that ischemic arrest during CPB induced the state of reactive hyperemia and coronary vasodilatation responsible for the differences noted. Flow parameters in our study were comparable between groups. Statistically significant difference, comparing supply areas, was noted for the right coronary artery, with MGF values higher in the CABG group. Studies that have specifically looked at flow in left-sided versus right-sided grafts are scarce and have included cohorts of arterial and venous conduits. Therefore, the current evidence for a potentially clinically relevant difference is insufficient and conflicting [Amin 2018; Tokuda 2007; Kim 2005; Nordgaard 2009]. Since this study only describes perioperative flow profiles, these results do not reflect the long-term flow profile in either group. PI values, which are to some extent independent of blood vessel size, were significantly higher in the OPCABG group in the supply of ACx. This probably reflects technical challenges of revascularizing ACx territory with the heart beating. It is not uncommon that OM branches are revascularized more distally as the vessel is better exposed with less hemodynamic instability. That might explain worse OPCABG outcomes in the repeatedly emphasized critical role of surgeons' experience [Benedetto 2018]. Previous studies comparing differences in intraoperative flow profiles between OPCABG and CABG showed lower flow values in the OPCABG group [Amin 2018; Hassanein 2005]. Recent studies comparing flow profiles between arterial and venous grafts in the left coronary supply territory and between OPCABG and CABG correlate with our flow analyses [Amin 2019]. Our study showed higher flow values in the OPCABG group for arterial grafts, except for the right coronary artery territory. At this moment, it's impossible to comment on the clinical relevance of this data since there are no guidelines that determine flow parameters' thresholds for individual territories. This was a non-randomized retrospective observational study. Thus, the groups were unequally distributed with the possibility of choice bias based on operators' experience with OPCABG. Of note, the majority of patients in the OPCABG group were operated on by a single surgeon, who was highly experienced in this procedure. Lack of post-discharge follow up is another limitation of this study. This prevents us from making conclusions on clinical relevance of flow parameters on long-term graft function and potential failure with clinical consequences beyond the

intraoperative period.

## CONCLUSION

Our study showed predominantly similar results of coronary flow in the CABG and OPCABG groups quantified by the intraoperative TTFM method of measuring graft flow. TTFM has the potential to improve the quality of coronary surgery and possibly the clinical outcome of patients. Further studies are needed to clarify whether TTFM parameters have an impact on long-term graft patency.

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