Evaluation of Graft Flow between On-Pump and Off-Pump in Coronary Artery Bypass Graft Surgery

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Received **: 12- 04 -2025 ,** ***Accepted*** **: 26 - 04 -2025 ,** ***Published*** **: 27 - 05 -2025**

ABSTRACT

Background: Coronary Artery Bypass Grafting (CABG) has contributed to treatment of patients with ischemic heart disease to increase their survival and reduce ischemic complications. **Objective:** to compare intra-operative graft flow between On-pump versus Off-pump CABG by using transient time flow meter (TTFM). **Patients and methods:** This was a prospective study was done on 60 patients underwent CABG and were divided equally into two groups: on-pump (ONCABG) and off- pump (OPCABG) according to center surgeon preference and patient selection criteria for off pump surgery. TTFM was routinely used to assess graft patency and flow during surgery. **Results:** Number of grafts, mean flow in grafts in ml/min was significantly higher in on-pump group, while pulsatility index was significantly higher in off-pump group. There was statistically significant difference regarding weaning from ventilator. There was no significant difference between the studied groups in terms of post-operative complications. **Conclusion:** Transit time flow measurement could be of great use during clinical practice, reminding the surgeon to investigate the cause of poor graft flow, and that off-pump coronary bypass surgery could achieve the same anastomosis as on-pump coronary bypass surgery with accepted TTFM measurements.

Keywords: Coronary Artery Bypass Graft Surgery; On-Pump; Off-Pump; Graft Flow

Introduction

Outcomes of coronary Artery Bypass Grafting (CABG) have significantly improved since the introduction of the modern CABG procedure (1). Despite increasing use of percutaneous coronary intervention (PCI), CABG remains the treatment of choice for patients with complex multi vessel disease (2).

PCI outcomes are continuously improving with new advancements, many new techniques to optimize short- and long-term outcomes of CABG have not been adopted widely. One of such techniques to improve CABG outcomes and graft patency is intraoperative graft flow assessment. Early graft failure can occur due to limited outflow, graft kinking upon chest closure, thrombosis, yet also due to anastomotic problem (3).

Many patients who underwent CABG had severely compromised haemodynamics due to postoperative myocardial infarction (MI); the cause of this adverse event was probably found to be an incorrect anastomosis. Intraoperative graft assessment has therefore been introduced to identify anastomotic problems and limited outflow before chest closure (4).

Early graft occlusion after conventional CABG or OPCAB may have deleterious consequences as it is associated with a high risk of post-operative myocardial infarction, postoperative hemodynamic instability, and even sudden death (5). Thus, anastomotic quality of CABG is directly associated with both perioperative and long-term clinical results. It has recently been demonstrated that off-pump surgery is associated with a lower graft patency at short term follow-up when compared with on-pump CABG, suggesting that there is a risk of less anastomotic accuracy, secondary to a more technically demanding procedure and to the learning curve of surgeons performing myocardial revascularization without cardiopulmonary bypass [(6)].

It is critical for surgeons to evaluate the quality of the anastomoses of CABG in the operating room. Multiple techniques for intraoperative graft assessment have been proposed: coronary angiography (CAG), transit-time flow measurement (TTFM), high-resolution-epicardial ultrasonography (HR-ECUS) and intraoperative fluorescence imaging (IFI) [(1)].

Transit-time flow measurement is considered to be more convenient, less invasive, more reproducible, and less time consuming. Although angiography is thought to be the best and most reliable method for assessing flow, the infrastructure required for CAG is rarely available in standard operating theatres [(3)]. Thus, the aim of this study is to compare intra-operative graft flow between On-pump versus Off-pump CABG by using TTFM.

Patients and Methods

This was a prospective study done on 60 patients underwent coronary artery bypass grafting (CABG) in the Cardiothoracic Surgery Department ,Tanta University Hospitals, and other cardiac surgery centers were added from January 2021 to January 2024 and were assigned to two groups:

- Group A: 30 patients underwent on pump Coronary artery bypass grafting (ONCABG).
- Group B: 30 patients underwent off pump Coronary artery bypass grafting (OPCABG).

Inclusion criteria:

All patients undergoing coronary artery bypass graft surgery by conventional simple arterial & venous grafts with EF over 40%.

Exclusion criteria:

Patients with ejection fraction below 40%, concomitant valve disease, emergency CABG, redo CABG, sequential, T and Y graft anastomosis. Patients with left ventricular cardiac aneurysm, significant symptomatic carotid lesion, bleeding tendency, concomitant respiratory disease, and central nervous system disease. The study compared both fixed and variable data from patients before, during, and after surgery.

Ethical Consideration:

An approval of the study was obtained from Tanta University Academic and Ethical Committee (**IRB #34407/1/21**). Written informed consent of all the participants was obtained. This work has been carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for studies involving humans.

Preoperative evaluations:

a) A thorough and detailed history was taken, as regards the age, sex, hypertension, diabetes mellitus and other medical and surgical condition.

b) A complete clinical general and local cardiological examination was performed.

c) Investigations:

Complete blood count, liver function tests (total & direct bilirubin, AST, ALT, serum albumin, serum proteins, prothrombin time and concentration, kidney function tests (serum urea &creatinine), fasting blood sugar, serum electrolytes, electrocardiogram (ECG): 12 leads ECG obtained for every patient to detect any ischemic changes or arrythmias.

Radiological examination as plain chest X-ray postero-anterior and lateral view in the erect position CT chest was done. Echocardiography including M mode, two dimension and Doppler echocardiography were done for each patient. Coronary angiography was done.

The morning dose of cardiac medications such as, B blockers were administered to all patients with sips of water. After entering the preparation room, a 14-gauge peripheral intravenous cannula was inserted under local anesthesia. Sedation with midazolam was optimized at 0.03-0.07 mg/kg. A 20-gauge non-dominant radial artery cannula was inserted under local anesthesia. The arterial line was used to draw two blood samples, the first for preoperative baseline activated clotting time (ACT) analysis and the second for preoperative baseline arterial blood gas (ABG) analysis.

Intra-operative procedure:

- **Anesthetic technique:**

Fentanyl 5-10 mic/kg was used as an intraoperative anesthetic technique for all patients, with endotracheal intubation aided by pancuronium0.02 mg/kg and 0.5-1 mg/kg of propofol as a hypnotic supplement. An additional dose of Fentanyl 100-200 micogram was administered. The trachea was intubated orally with an appropriately sized endotracheal tube after complete muscle relaxation. Isoflurane 0.5-1% inhalation was used to maintain anesthesia in all patients. Following induction, a triple lumen central venous catheter (Angio 16 gauge) was inserted into the right internal jugular vein. Urinary catheter, nasogastric tube, and nasopharyngeal temperature probe were also placed. A probe for transesophageal echocardiography was introduced (personal communication with anesthetic).

- **Surgical Considerations:**

The patient was placed supine, and the lower neck, chest, and abdomen are draped circumferentially between the anterior axillary lines, along with the lower neck, chest, and abdomen. Preoperative hygienic anti-infection measures were included: hair removal at night before the operation, skin preparation shower with povidone-iodine and the routine antibiotic prophylaxis regimens. After a skin incision and a median sternotomy, the saphenous vein was harvested in some cases concurrently with the sternotomy. The internal thoracic artery (ITA) was harvested after the sternum has been divided. Thymic and pericardial fat vestiges were split in the center line to the inferior surface of the left innominate vein. Sutures used to improve exposure of the ascending aorta and right atrium. To allow the completed ITA graft to fall laterally into the pleural space away from the sternum, the left pericardium was divided at the level of the great vessels towards the phrenic nerve. Palpation of the distal ascending aorta was performed to look for delicate, non-atherosclerotic areas suitable for arterial cannulation, root ventilation, proximal graft anastomosis, and aortic cross-clamp placement.

The pericardium was split directly down to the diaphragm, and the pericardium's inferior connection to the diaphragm was split transversely. Systemic anticoagulation was achieved by administering 300 U/kg of heparin intravenously, and anticoagulation adequacy was demonstrated by an activated clotting time of more than 450 seconds. To reduce the risk of aortic dissection, systolic blood pressure should be reduced to around 100 mm Hg prior to aortic cannulation.

Two partial-thickness concentric diamond-shaped purse-string sutures were placed in the distal ascending aorta using 2-0 braided or monofilament nonabsorbable suture (ProleneTM), The aortic cannula was placed and correctly positioned, and the purse strings were tightened. A 2-0 Prolene purse-string suture was wrapped around the tip of the right atrial appendage, A two-stage venous cannula was implanted into the right atrial appendage, and the venous line was attached to the pump tubing.

I- Surgical technique in on-pump CABG group

Antegrade cardioplegia was achieved by inserting an aortic root cannula into the ascending aorta. The patient was placed on 2.4 L/min/m2 cardiopulmonary bypass and cooled to 34°C. Flow ventilation was turned off once the patient was on full bypass. Because the target vessels are fully distended prior to cardioplegic arrest, they were simpler to identify. The locations of planned distal anastomoses were marked with a scalpel. The pump flow was temporarily reduced, and the aortic cross-clamp was applied just proximal to the arterial cannula, with bypass flow restored to normal. Custadiol cardioplegia (10 mL/kg) was administered via the antegrade catheters. The redosing of cardioplegia should be timed so that it did not disrupt the 'flow' of the operation.

During proximal anastomoses were performed using an aortic partial-occluding clamp. Lower the systolic blood pressure (for example, to 95 mm Hg), apply the clamp, and perform aortotomies with a 4.0- 4.5 mm aortic punch to perform an aortic clamp. After that, proximal anastomoses were performed with 6-0 polypropylene suture. Before tying down the most anterior proximal anastomosis, the clamp was released, and the air was removed from the aorta through the proximal anastomosis with clamps on vein grafts. After tying down the suture, the air was removed from the vein grafts with a 25-gauge needle and remove the clamps. Arteriovenous grafts were not punctured prior to clamp removal, but were allowed to bleed backward.

To define the desired target site, sharp dissection of overlying tissue was required, the left ITA-to-LAD artery anastomosis was grafted last to prevent strain and potential anastomosis disturbance. The venous conduit were transplanted to the specific target vessels first. The aortic cross-clamp was removed once all anastomoses have been finished, and a stable heart rhythm was created. Allow the heart to recover for 10 minutes on full bypass for every 60 minutes of aortic cross- clamp time. During this period of recovery, the patient was getting ready to transition from supported to native circulation. The aortic root vent and retrograde catheters were removed. The bypass grafts were examined for kinks, twists, and tension, as well as the presence of hemostasis. The patient's temperature was returned to normal, and the acid-base status and electrolyte imbalances were corrected.

- **Surgical technique in off-pump CABG group:**

To aid in heart visibility and lateral displacement, several pericardial traction sutures were used. An important pericardial traction suture was the "deep stitch," which was located about half way between the inferior vena cava and the left pulmonary vein, at the spot where the pericardium reflects over the posterior left atrium. To prevent laceration of the epicardium during retraction, this suture was coated with a rubberized catheter.

Cardiac positioning devices were used to ensure adequate exposure of the target vessels. The coronary stabilizer devices were placed on the epicardium with minimal tension to allow for mechanical stabilization. Manipulation of the traction sutures, in addition to positioners, stabilizers and orientation operating table were greatly improve exposure. To help elevate the heart out of the pericardium on occasion, a wet and warm laparotomy pad was positioned between the heart and the posterolateral pericardium.

A soft silastic retractor tape was constructed on a blunt needle in preparation for distal anastomosis was wrapped widely around the proximal vessel for transient atraumatic occlusion and intra coronary shunts were used. A humidified CO2 blower, controlled by the scrub nurse or second assistant, keeps the field free of blood. To avoid injury to the coronary endothelium, the blower was set to the lowest setting required for exposure (5 L CO_2) and was used only when passing the needle through the vessel. In patients with a lot of epicardial fat, an epicardial fat retractor was used to expose the coronary target.

The anastomosis was otherwise performed in the same manner as with on-pump grafting. It was critical to maintain communication with the anesthesia team so that appropriate steps were taken as soon as hemodynamic conditions deteriorated. At this point, decision was made as to whether the procedure was converted "electively" to an on-pump procedure or completed off-pump with better preparation (eg, fluids, inotropes, vasopressors, pacing, and shunt). The use of intra-aortic balloon counter-pulsation for mechanical support during cardiac displacement and positioning was another option for patients at high risk. The grafting pattern was crucial because regional myocardial perfusion was disrupted during anastomosis on the beating heart.

In general, the collateralized vessel(s) were grafted first, followed by the non-collateralizing vessel. In patients with an occluded RCA and a PDA supplied by collaterals from the LAD, for example. Not only the anterior wall was ischemic during the anastomosis if the LAD was grafted first, but flow to the septum, inferior wall, and right ventricle were disrupted as well. To ensure adequate flow to the inferior wall while the proximal LAD was occluded during IMA-LAD anastomosis construction, a more conservative approach was to graft the PDA first, followed by a proximal anastomosis.

First, anastomose a completely occluded or collateralized vessel. If the LAD was not a collateralizing vessel, anastomose the LAD-LIMA first was done to allow anterior wall perfusion while placing the lateral and inferior walls. When cardiac positioning was not accommodated well, proximal anastomoses were executed after each distal anastomosis to enable target vessel perfusion.

- **Intraoperative flow measurement**

Flow values and flow curves were obtained using the transit time flowmetry device (Sono TT Flowlab flowmeter, em-Tec, Munich). The TTFM probe was snugly wrapped around the graft. To avoid graft distortion or compression, different-sized probes (3mm , 4mm & 5mm) were used.

The TTFM values of all grafts were recorded intra-operatively in a standardized fashion 5 min after the patient weaning from cardiopulmonary bypass and the hemodynamic condition is stable, in Group A (On pump cases) and after finishing the proximal anastomosis in Group B (Off pump cases).

A small section of the mammary artery had to be skeletonized to minimize the amount of tissue between the vessel and the probe. Before taking any measurements, the grafts were adequately de-aired, and then systolic blood pressure was kept between 100 and 120mmHg.Pericardium traction was released, and the stabilizer from the epicardial surface was removed, allowing the heart to return to its normal anatomical position.

The flow curve was displayed on the device and the pulsatile index (PI) and percentage of backward flow (%BF) were calculated from the flow curve.

The mean flow (ml/min) was calculated. To correctly distinguish systolic flow from diastolic flow, the curves were combined with ECG tracing. Patent graft hemodynamics was comparable to those seen in normal coronary circulation: favorable blood flows mainly during diastole, with only a few negative systolic peaks happening throughout isovolumetric ventricular contraction.

The PI was determined by dividing the highest and minimum flow values by the mean flow value. The %BF was calculated by dividing the backward flow value by the total flow value and was defined as the amount of flow directed backward across the anastomotic site through the graft. It was confirmed that %BF >3% and/or PI >3 were indicators of poor flow [(7)]. The mean flow was evaluated alongside the other two parameters and was not used solely as an indicator of poor flow which is considered when MGF below 15 ml/min [(8)]. We were able to decide whether to check and revise a graft after interpreting the values obtained based om MGF and PI.

Post-operative evaluation:

The patients received the standard postoperative care and were followed up at outpatient clinics s after surgery (as a secondary endpoints).The evaluation during follow up included mechanical support (IABP), inotropic support, weaning from mechanical ventilator, cardiac biomarkers (CK-MB), post-operative ischemic ECG changes, and arrhythmias.

Post-operative bleeding, blood transfusion and reopening for hematoma evacuation were evaluated. Neurological, hepatic, renal complications, fever, Infection, ICU stay, hospital stay, and mortality were recorded.

Statistical analysis:

Data was performed using IBM SPSS Statistics® version 26.0 [Chicago, IL, USA]. Shapiro-Wilk test was used as one of the normality tests. The independent T-test was used to compare two means of normally distributed quantitative variables, while the Man-Whitney test was used for variables that were not normally distributed. The chi-squared and Fisher's exact tests were used for qualitative variables. P-value considered a significant when p <0.05.

RESULTS

In group A (on-pump CABG), age ranged from 53-68 years with mean of 61.1±4.6 and there were 18 males (60%) and 12 female (40%), while in group B (off-pump CABG) age ranged from 50-68 years with mean of 60.5±4.6 and there were 21 males (70%) and 9 females (30%), and there was no statistical significance (P>0.05). In on-pump CABG group, there were 21 hypertensive patients (70%) and 9 non hypertensive patients (30%); and there were11 diabetic patients (36%) and 19 non diabetic patients (64%), while off-pump CABG group there were 21 hypertensive patients (70%) and 9 non hypertensive patients (30%); and there were 12 diabetic patients (40%) and 18 non diabetic patients (60%) with no statistical significance(P>0.05). In on-pump CABG group, there were 13 smoker patients (44%) and there were 16 patients (53%) with positive family history of cardiac diseases, while in off-pump CABG) group, there were 16 smoker patients (53%) and there were 16 patients (53%) with positive family history of cardiac diseases with no statistical significance **(Table 1)**. In on-pump CABG group, there were 5 patients (17%) with NYHA class1, 25 patients (83%) with NYHA class 2, while in off-pump CABG group there were 4 patients (12%) with NYHA class1, 26 patients (88%) with NYHA class 2 with no statistical significance(P>0.05). Preoperatively assessed ejection fraction (EF %), in group A was 55.8±6.3, while in off-pump CABG group was 54.8±6.1 with no statistical significance (P>0.05) **(Table 1)**.

Intra operative assessment for operative time showed that the mean was 184.7±9.2 in on-pump CABG group, while off-pump CABG group, the mean was 164.3±7.8 with no statistical significance (P>0.05). Mean of total number of grafts was 3.5±0.7 in group A, while in off-pump CABG group the mean of total number of grafts was 3.8±0.4 with no statistical significance (P>0.05). In on-pump CABG group the percentage of two grafts was 6.0%, while in off-pump CABG group the percentage of two grafts was 0.0 %, with no statistical significance (P>0.05). The percentage of three grafts was 44.0% in group A, while in group B the percentage of three grafts was 80.0%, with significant statistical difference (P=0.018). In group A (on-pump CABG) the percentage of four grafts was 46.0%, while in group B (off-pump CABG) the percentage of four grafts was 20.0%, with significant statistical difference (p<0.001). In group A, the percentage of five grafts was 3.0%, while in off-pump CABG group, the percentage of five grafts was 0.0 % with no significance **(Table 2)**.

In group A the mean flow in grafts was 47.7±3.5 ml/min while in off-pump CABG the mean flow in grafts was 45.7±3.1 ml/min, mean flow in grafts was significantly higher in on-pump CABG (P=0.002).The pulsatility index, in group A (on-pump CABG) the Mean was 1.7±0.17, while off-pump CABG group the mean was 1.9±0.18, pulsatility index was significantly higher in off-pump CABG. The percentage of backward flow (% BF), the mean was 2.0±0.19 in group A, while the mean was 2.1±0.21 in group B, with no statistical significance (P>0.05) **(Table 2)**.

In this study all arterial graft was pedicle LIMA to LAD which numbers were equal in both groups 30 in each one .In group A; mean flow was 34.1±2.2, pulsatile index was 2.3±1.4, BF % was 2.1±0.7. In group B; mean flow was 31.5±19.8, pulsatile index was 2.4±4.2, BF % was 1.7±0.8. SVG-Diag represents 12.6% in group A and 14.1% in group B .While in group A; mean flow was 27.1±1.6, pulsatile index was 2.2±0.9, BF % was 1.8±0.6. In group B; mean flow was 22.4±1.8, pulsatile index was 1.7±0.8, BF % was 1.7±0.8. SVG-OM represents 28.8% in group A and 26.3% in group B .While in group A; mean flow was 36.5±22.3, pulsatile index was 2.2±4.9, BF% was 2.3±0.6. In group B; mean flow was 39.4±26.1, pulsatile index was 2.0±3.9, BF % was 2.1±0.5. SVG-RCA represents 15.3% in group A and 15.7% in group B .While in group A; mean flow was 45.5±1.3, pulsatile index was 1.9±0.7, BF % was 1.9±0.7. In group B; mean flow was 43.1±2.8, pulsatile index was 1.8±0.8, BF % was 1.9±0.8. SVG-PDA/PL represents 14.5% in group A and 17.6% in group B .While in group A; mean flow was 38.0±1.2, pulsatile index was 2.0±0.8, BF % was 1.8±0.9. In group B; mean flow was 35.7±21.0, pulsatile index was 2.2±4.0, BF% was 2.0±0.7 **(Table 3)**.

In group A (on-pump CABG) we revised 1graft in 1 patient 4%, one SV graft were re-anastomosed due to graft twist, while in group B (off-pump CABG) we revised 1 graft in 3 patients 10% cause of unsatisfactory TTFM findings, two LIMA-LAD graft was re anastomosed due to stenosis at the anastomosis site, one SV grafts were re-anastomosed due to graft twist. The mean flow in the non-functioning grafts before correction was 8 ml/min in Group A patients, and 17.1±15.6 ml/min for group B patients, while it show significant rise after correction to 48 ml/min for group A and 36.5±17.3 ml/min for group B. The mean pulsatility index in the non-functioning grafts before correction for Group A patients was 3.9, and 4.1±0.7 for Group B patients; while it show significant decline after correction to 1.6 for group A and 2.0±0.9 for group B with significant statistical difference between two groups (P=0.001) **(Table 4)**. The mean BF in the non-functioning grafts before correction for Group A patients was 2.08, and 2.1±0.4 for Group B patients (p=0.176).; while after correction to 2.1 for group A and 2.0±0.8 for group B without significant statistical difference between two groups (P=0.165) **(Table 4, Fig. 1)**.

In group A, the mean of weaning from ventilator was 8.3±12.8, while in group B (off-pump CABG) the Mean of weaning from ventilator was 6.7±10.2, weaning from ventilator was significantly higher in (on-pump CABG) (P<0.001). In group A (on-pump CABG) the percentage of intraoperative blood transfusion was 18.0% And the percentage of post-operative blood transfusion was 20%, while in group B the percentage of intraoperative blood transfusion was 26.0 % And the percentage of post-operative blood transfusion was 34.0%, with no statistical significance(P>0.05). In group A the percentage of intraoperative inotropic support was 42.0% and the percentage of post-operative inotropic support was 42.0 %, while in group B the percentage of intraoperative inotropic support was 50.0 % and the percentage of post-operative inotropic support was 50.0%, with no statistical significance(P>0.05). In group A (on-pump CABG) the percentage of (IABP) was 3.0%, while in group B was 6.0 %, with no statistical significance (P>0.05) **(Table 5)**.

The mean of ICU stay was 2.3±0.9 in on-pump CABG group, while off-pump CABG group was 2.4±0.9, with no statistical significance. The mean of hospital stays was 7.1±1.0 in on-pump CABG group, while off-pump CABG group was 6.7±1.8, with no statistical significance (P>0.05) **(Table 6)**.

In on-pump CABG group, the percentage of Elevated cardiac biomarkers was 6.0%, while in group B was 10.0%, with no statistical significance (P>0.05). In group A, the percentage of ECG ischemic changes was 6.0%, while in off-pump CABG group was 10.0%, with no statistical significance. In on-pump CABG group, the percentage of post-operative arrythmia was 20.0%, while in group B was 26.0%, with no statistical significance (P>0.05). In group A, the percentage of reopening for bleeding control was 6.0%, while in off-pump CABG group was 10.0%, with no statistical significance. In on-pump CABG group the percentage of CNS complications was 3.0%, while in off-pump CABG group was 3.0%, with no statistical significance. In group A, the percentage of liver complications was 6.0%, while in group B (off-pump CABG) was 10.0%, with no statistical significance. In group A (on-pump CABG) the percentage of renal complications was 6.0%, while in group B was 10.0%, with no statistical significance (P>0.05). In on-pump CABG group the percentage of fever was 6.0%, while in group B was 6.0%, with no statistical significance (P>0.05). In group A, the percentage of wound infection was 6.0%, while in group B was 10.0%, with no statistical significance (P>0.05). There was one mortality case in each group with no statistical significance(P>0.05); Both patients were very difficult to come off-bypass and required high inotropic support and IAB counter pulsation and both died due to intractable low cardiac output syndrome in second and fourth postoperative days. The two mortalities had a very poor distal run-off in their LAD territory with accepted TTFM measurements ; MGF: 32 ml/min , PI: 2.7 in on-pump case ;while , MGF: 26 ml/min , PI: 2.8 in off-pum case **(Table 7)**.

Table (1): General and Medical Characteristics of the studied groups:

	Coronary artery bypass grafting				Test of sig	P value
	On-Pump (No.=30)		Off-Pump (No.=30)			
	No	%	No	%		
Age (Y): Mean ±SD	61.1±4.6		60.5±4.6		t=0.67	0.504
Sex						
Male	18	60.0	21	70.0	-	-
Female	12	40.0	9	30.0		
Hypertension	21	70.0	21	70.0	-	-
Diabetes Mellitus	11	36.0	12	40.0	χ^2=0.17	0.680
Smoking	13	44.0	16	53.0	χ2=0.64	0.423
Positive Family history	16	53.0	15	50.0	-	-
NYHA classification					χ^2=0.70	0.401
1	5	17.0 %	4	12.0 %		
2	25	83.0 %	26	88.0 %		
Preoperative (EF %)	55.8±6.3		54.8±6.1		t=0.67	0.504

**: significant, P-value ≤0.05 considered significant, P value>0.05 considered insignificant, (T test), χ^2 (chi-squared).*

Table (2): Operative time, number of grafts and TTFM measurements between the studied groups

	Coronary artery bypass grafting				Test of sig	P value
	On-Pump (No.=30)		Off-Pump (No.=30)			
	Mean ±SD		Mean ±SD			
Operative time(min)	184.7±9.2		164.3±7.8		t=0.67	0.504
Number of grafts:	3.5±0.7		3.8±0.4		t=0.67	0.504
No, %						
2	2	6.0 %	0	0.0 %	Z=1.17	0.241
3	13	44.0%	24	80.0%	Z=2.36	**0.018***
4	14	46.0%	6	20.0%	Z=3.31	**<0.001***
5	1	3.0%	0	0.0%	Z=0.71	0.475
Mean flow in grafts (ml/min)	47.7±3.5		45.7±3.1		t=3.12	**0.002***
Pulsatility index	1.7±0.17		1.9±0.18		t=4.83	<0.001*
BF%	2.0±0.19		2.1±0.21		t=2.71	0.184

**: significant, P-value ≤0.05 considered significant, P value>0.05 considered insignificant, (T test), (Z test), No (number).*

Table (3): TTFM measurements for different target vessels

	Coronary artery bypass grafting							
	On-Pump (No.=30)				Off-Pump (No.=30)			
	Mean flow (ml/ min)	**PI**	**BF%**	**No, %**	**Mean flow (ml/ min)**	**PI**	**BF%**	**No, %**
LIMA - LAD	34.1±2.2	2.3±1.4	2.1±0.7	30 , 28.8%	31.5±19.8	2.4±4.2	1.9±0.9	30 , 26.3%
SVG -Diag	27.1±1.6	2.2±0.9	1.8±0.6	13 , 12.6%	22.4±1.8	2.1±0.8	1.7±0.8	13 , 13.5%
SVG -OM	36.5±22.3	2.2±4.9	2.3±0.6	30 , 28.8%	39.4±26.1	2.0±3.9	2.1±0.5	24 , 21.9%
SVG -RCA	45.5±1.3	1.9±0.7	1.9±0.7	16 , 15.3%	43.1±2.8	1.8±0.8	1.9±0.8	14 , 14.6%
SVG -PDA/PL	38.0±1.2	2.0±0.8	1.8±0.9	15 , 14.5%	35.7±21.0	2.2±4.0	2.0±0.7	15 , 16.1%

**: significant, P-value ≤0.05 is considered significant, P value>0.05 is considered insignificant, (T test), (Z test), No (number).*

Table (4): Data of revised grafts between the studied groups

	Coronary artery bypass grafting		Test of sig	P value
	On-Pump (No.=30)	Off-Pump (No.=30)		
	Mean ±SD	Mea±SD		
Number of revised grafts: No, %	1	3	χ^2=1.38	0.436
MGF in ml/Min (before correction)	8	17.1±15.6	t=2.92	**0.002***
MGF in ml/Min (after correction)	48	36.5±17.3	t=3.12	**0.002***
Pulsatility index (before correction)	3.9	4.1±0.7	t=4.83	**<0.001***
Pulsatility index (after correction)	1.6	2.0±0.9	t=4.23	**<0.001***
BF% (before correction)	2.08	2.1±0.4	t=2.68	0.176
BF% (after correction)	2.1	2.0±0.8	t=2.73	0.165

**: significant, P-value ≤0.05 is considered significant, P value>0.05 is considered insignificant, (T test), (Z test), No (number).*

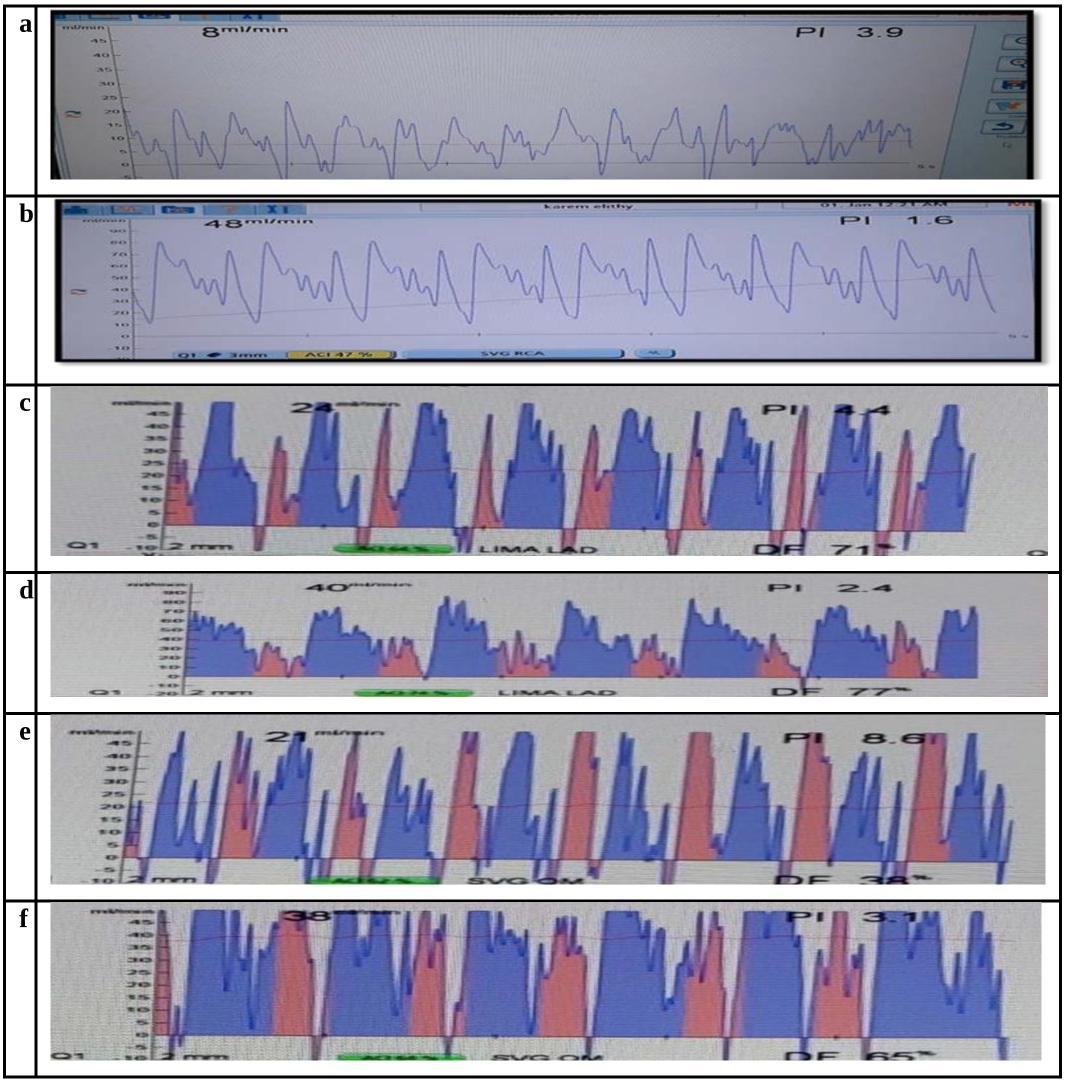

Figure (1): MGF & PI in a graft: (a) before correction, and (b) after correction (On pump group-Venous graft); (c) before correction and (d) after correction (Off pump group-Arterial graft); (e) before correction and (f) after correction (Off pump group-Venous graft).

Table (5): Post-operative data between the studied groups

	Coronary artery bypass grafting				Test of sig	P value
	On-Pump (No.=30)		Off-Pump (No.=30)			
	No	%	No	%		
Weaning from ventilator(h): • Mean ±SD. • Median[range]	8.3±12.8 6[5-96]		6.7±10.2 4.5[3-72]		**MW=5.18**	**<0.001***
Blood transfusion • Intra-operative • Post -operative	5 6	18.0 20.0	8 10	26.0 30.0	χ^2=0.93 χ^2=2.48	0.334 0.115
Inotropes • Intra-operative • Post -operative	13 13	42.0 42.0	15 15	50.0 50.0	χ^2=0.64 χ^2=0.64	0.422 0.422
IABP	1	3.0	2	6.0	χ^2=0.12	1.0^{FE}

**: significant, P-value ≤0.05 is considered significant, P value>0.05 is considered insignificant, (T test), χ2 (chi-squared), No (number), MW (Man-Whitney test).*

Table (6): ICU and Hospital stay between the studied groups

	Coronary artery bypass grafting		Test of sig	P value
	On-Pump (No.=30)	Off-Pump (No.=30)		
ICU (d):				
Mean ±SD.	2.3±0.9	2.4±0.9		
Median[range]	2[2-6]	2[2-6]	MW=0.50	0.611
Hospital stays(d): Mean ±SD	7.1±1.0	6.7±1.8	t=1.20	0.233

Table (7): Post-operative complications between the studied groups

	Coronary artery bypass grafting				Test of sig	P value
	On-Pump (No.=30)		Off-Pump (No.=30)			
	No	%	No	%		
Elevated cardiac Biomarkers	2	6.0	3	10.0	χ^2=0.12	1.0^{FE}
ECG ischemic changes	2	6.0	3	10.0	χ^2=0.12	1.0^{FE}
Arrythmia	6	20.0	8	26.0	χ^2=0.50	0.476
Reopening for bleeding control	2	6.0	3	10.0	χ^2=0.21	1.0^{FE}
CNS complications	1	3.0	1	3.0	-	-
Liver complications	2	6.0	3	10.0	χ^2=0.12	1.0^{FE}
Renal complications	2	6.0	3	10.0	χ^2=0.12	1.0^{FE}
Fever	2	6.0	2	6.0	χ^2=0.21	1.0^{FE}
Wound infection	2	6.0	3	10.0	χ^2=0.21	1.0^{FE}
Mortality	1	3.0	1	3.0	χ^2=0.34	1.0^{FE}

**: significant, P-value ≤0.05 is considered significant, P value>0.05 is considered insignificant, (T test), χ2 (chi-squared), FE (Fisher's exact tests).*

DISCUSSION:

Coronary artery bypass graft surgery (CABG) can be performed in two fundamental ways: on pump CABG and off pump CABG. Compared to on-pump CABG, off-pump CABG is a relatively recent treatment that does not require the use of a cardiopulmonary bypass machine [(6)].

In our study; the mean flow in ml/min in group A (on-pump CABG) the mean flow in grafts was 47.7±3.5 ml/min while in group B (off-pump CABG) the mean flow in grafts was 45.7±3.1 ml/min, mean flow in grafts in ml/Min was significantly higher in group A (on-pump CABG). Our results are in agreement with Schmitz and his colleagues who reported that graft flow in on pump CABG patients was higher than that in off pump CABG patients; who conducted his study on 896 patient and reported that the MGF in (on-pump CABG) was 40.25±22.92 ml/min while in (off-pump CABG) the MGF was 27.22±15.55 ml/min [(9)].

Our results are in disagreement with Zhuang et al. [(1)] who found no statistical difference about mean flow between off Pump CABG group and on pump CABG group; who conducted his study on 300 patient and reported that the MGF in (on-pump CABG) was 31.7±27.2 ml/min while in off-pump CABG) the MGF was 31.5±29.8 ml/min.

This interesting and unexpected finding in this study was that the overall performance of grafts in off-pump surgery is about seventy percent the flow, which can be assessed in grafts after operations with CPB. However, this finding did not lead to an increased myocardial damage during the operation. In contrast, postoperative cardiac enzymes (CK-MB and troponin I) were significantly lower in the off-pump group than in the on-pump group. This finding seems to be accepted by [(10)]. This can be explained with that in the beginning of

OPCAB experience the finding of decreased mean flow led to a high graft-revision rate, although flow patterns were very often acceptable. In many cases we were not able to improve the quality of the anastomosis due to the fact that there was no technical error. The decreased mean flow rates compared with the experience from CABG surgery led to a wrong performance rating of the graft, as we did not anticipate such a high impact of the procedure itself [(11)].

An explanation for the decreased flow rates in OPCAB patients might be the procedure itself. It is well documented that CABG surgery on the arrested heart even with cardioplegia leads to global ischemia and subsequent acidosis in the coronary artery system. During myocardial anaerobiosis the amount of energy obtained from glycolysis is not sufficient to cover the demands of myocardial energy turnover, so that a myocardial energy deficit necessarily develops with progressive duration of ischemia. The acidosis in the coronary artery system results in vasodilation of the coronary arteries. In contrast, in OPCAB surgery occlusion of the coronary vessel contributes to a local hypoxia, but generally not to ischemia. Therefore, the vasodilator effect of ischemia is absent. Consequently, flow rates in off-pump coronary artery surgery should be expected to be lower than in on-pump surgery [(12)].

In our study; the pulsatility index, in group A (on-pump CABG) the mean±SD was 1.7±0.17, while in group B (off-pump CABG) was 1.9±0.18, which was significantly higher in (off-pump CABG). Our results are in disagreement with Zhuang et al. [(1)] who revealed no statistical difference about pulsatility index between off Pump CABG group and on pump CABG group and reported that the pulsatility index in (on-pump CABG) was 2.4±1.1 ml/min while in (off-pump CABG) the pulsatility index was 2.3±1.4 ml/min .

The explanation of this point was done by Di Giammarco et al. [(7)] who found that, 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. 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.

In our study; the percentage of backward flow (% BF), in group A (on-pump CABG) the mean ±SD was 2.0±0.19, while in group B (off-pump CABG) was 2.1±0.21, which there was no statistics significant difference between two groups. Our results are in agreement with Zhuang et al. [(1)] who observed that there is a statistical difference about the percentage of backward flow between off Pump CABG group and on pump CABG group and reported that the backward flow (% BF) in (on-pump CABG) was 2.1±0.7 ml/min while in (off-pump CABG) was 1.6±0.9. The explanation of this point was done by Di Giammarco 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.

Our results are in disagreement with Tokuda et al. [(13)] who 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. This can be explained by that 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 [(7)].

In our study, In terms of graft revision, most of the grafts were detected with satisfactory TTFM findings, in group A (on-pump CABG) we revised 1graft in 1 patient 4%, one SV graft were re- anastomosed due to graft twist, while in group B (off-pump CABG) we revised 1 graft in 3 patients 10% cause of unsatisfactory TTFM findings , two LIMA-LAD graft was re anastomosed due to stenosis at the anastomosis site, one SV grafts were re-anastomosed due to graft twist, with no statistical significance.

In study done by Zhuang et al. [1] who reported eleven grafts were detected with unsatisfactory TTFM findings in Off Pump CABG group and Nine grafts were detected with unsatisfactory TTFM findings in on pump CABG group but the number of patients included is larger than our study number of patients.

In study done by D'Ancona et al. [14] who found that PI is a good indicator of the flow pattern and, consequently, of the quality of the anastomosis.This is proportional to the vascular resistance, and 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 et al. [7] who revealed 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.

In our study; in almost all target areas statistically lower mean flow rates were found in patients undergoing OPCAB compared with patients undergoing CABG surgery. The saphenous vein graft to LAD showed markedly higher flow rates than left or right thoracic artery when anastomosed to LAD. All arterial graft was pedicle LIMA to LAD .In on- pump cases; mean flow was 34.1±2.2, pulsatile index was 2.3±1.4, BF% was 2.1±0.7. In Off-pump cases; mean flow was 31.5±19.8, pulsatile index was 2.4±4.2 , BF% was 1.7±0.8.While the average results done by TTFM in venous grafts On-pump cases; mean flow was 36.5±22.3, pulsatile index was 2.2±0.9 , BF% was 2.3±0.6. In Off-pump cases; mean flow was 39.4±26.1, pulsatile index was 2.0±0.9, BF% was 2.1±0.5.

Our results are in agreement with Flemma et al. [15] who showed that blood flow through saphenous vein grafts was 2 to 3 times higher than blood flow through ITA grafts to the same target area (mean arterial and venous graft flow 43 mL/min vs 117 mL/min, respectively). Hamby and coworkers; demonstrated in an angiographic study, performed 2 weeks after bypass surgery, that ITA graft flow was significantly lower than that of saphenous vein grafts. This reveal significant flow difference between arterial and venous grafts in favor of arterial grafts. Although arterial grafts have much better long-term patency than venous grafts, it is important to recognize that arterial grafts sometimes have a limited ability to supply blood flow at peak myocardial demand.

In our study; morbidity and demographic data; there were no statistically significant difference between the two groups, which was comparable to the findings of Zhuang et al. [1]. Concerning mortality; There was one mortality case in each group with no statistically significant difference between the two groups, which was comparable to the findings of Zhuang et al. [1] and Schmitz et al. [9], respectively. Both patients were very difficult to come off-bypass and required high inotropic support and IAB counter pulsation and both died due to intractable low cardiac output syndrome in second and fourth postoperative days. The two mortalities had a poor distal run-off in their LAD territory with heavily calcified atheromatous plaques with accepted TTFM measurements; MGF: 32 ml/min, PI: 2.7 in on-pump case; while, MGF: 26 ml/min , PI: 2.8 in off-pump case.

Conclusion:

Transit time flow measurement could be of great use during clinical practice, reminding the surgeon to investigate the cause of poor graft flow, and that off-pump coronary bypass surgery could achieve the same anastomosis as on-pump coronary bypass surgery with accepted TTFM measurements.

From the current study, we recommend:

Flow is the most important parameter in TTFM. A flow curve depicts the graft's systolic and diastolic filling as well as the mean flow value (ml/min).To correctly distinguish systolic from diastolic flow, the curve should always be coupled with an electrocardiography (ECG) trace.

Further studies with big sample size should be undertaken regarding different methods of intraoperative graft assessment by TTFM and another devices such as HR-ECUS.

Conflict of interest: The authors declare no conflict of interest.

Sources of funding: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Author contribution: Authors contributed equally in the study.

References:

1- Zhuang, Y., Chen, X., Lu, Z. Q., Xu, M., Jiang, Y. S., & Xiao, L. Q. (2012). Evaluation of graft flow between on-pump and off-pump coronary artery bypass grafting. *Asian Biomedicine*, *6*(2), 265-271.

2- Amin, S., Werner, R. S., Madsen, P. L., Krasopoulos, G., & Taggart, D. P. (2018). Intraoperative bypass graft flow measurement with transit time flowmetry: a clinical assessment. *The Annals of thoracic surgery*, *106*(2), 532-538.

3- Honda, K., Okamura, Y., Nishimura, Y., Uchita, S., Yuzaki, M., Kaneko, M., ... & Akasaka, T. (2015). Graft flow assessment using a transit time flow meter in fractional flow reserve–guided coronary artery bypass surgery. *The Journal of thoracic and cardiovascular surgery*, *149*(6), 1622-1628.

4- Balacumaraswami, L., & Taggart, D. P. (2007). Intraoperative imaging techniques to assess coronary artery bypass graft patency. *The Annals of thoracic surgery*, *83*(6), 2251-2257.

5- Leacche, M., Balaguer, J. M., & Byrne, J. G. (2009, September). Intraoperative grafts assessment. In *Seminars in thoracic and cardiovascular surgery* (Vol. 21, No. 3, pp. 207-212). WB Saunders.

6- Hashim, S. A., Amin, M. A., Nair, A., Mokhtar, R. A. R., Krishnasamy, S., & Cheng, K. (2018). A flowmeter technique to exclude internal mammary artery anastomosis error in an arrested heart. *Heart, Lung and Circulation*, *27*(5), e59-e63.

7- Di Giammarco, G., Pano, M., Cirmeni, S., Pelini, P., Vitolla, G., & Di Mauro, M. (2006). Predictive value of intraoperative transit-time flow measurement for short-term graft patency in coronary surgery. *The Journal of thoracic and cardiovascular surgery*, *132*(3), 468-474.

8- Amin, S., Pinho-Gomes, A. C., & Taggart, D. P. (2016). Relationship of intraoperative transit time flowmetry findings to angiographic graft patency at follow-up. *The Annals of Thoracic Surgery*, *101*(5), 1996-2006.

9- Schmitz, C., Ashraf, O., Schiller, W., Preusse, C. J., Esmailzadeh, B., Likungu, J. A., ... & Welz, A. (2003). Transit time flow measurement in on-pump and off-pump coronary artery surgery. *The Journal of thoracic and cardiovascular surgery*, *126*(3), 645-650.

10- Peivandi, A. A., Dahm, M., Hake, U., Hafner, G., Opfermann, U. T., Loos, A. H., Oelert, H. (2001). Patterns and diagnostic value of cardiac troponin I vs. troponin T and CKMB after OPCAB surgery. *The Thoracic and cardiovascular surgeon*, *49*(03), 137-143.
11- Singh, S. K., Desai, N. D., Chikazawa, G., Tsuneyoshi, H., Vincent, J., Zagorski, B. M., Fremes, S. E. (2010). The graft imaging to improve patency (GRIIP) clinical trial results. *The Journal of thoracic and cardiovascular surgery*, *139*(2), 294-301.
12- Verma, S., Fedak, P. W., Weisel, R. D., Szmitko, P. E., Badiwala, M. V., Bonneau, D., ... & LeClerc, Y. (2004). Off-pump coronary artery bypass surgery: fundamentals for the clinical cardiologist. *Circulation*, *109*(10), 1206-1211.
13- Tokuda, Y., Song, M. H., Oshima, H., Usui, A., & Ueda, Y. (2008). Predicting midterm coronary artery bypass graft failure by intraoperative transit time flow measurement. *The Annals of thoracic surgery*, *86*(2), 532-536.
14- D'Ancona, G., Karamanoukian, H. L., Ricci, M., Schmid, S., Spanu, I., Apfel, L., Salerno, T. A. (2000, June). Intraoperative graft patency verification: Should you trust your fingertips?. In *The Heart surgery forum* (Vol. 3, No. 2, pp. E99-E102).
15- Flemma, R. J., Johnson, W. D., Lepley Jr, D., Tector, A. J., Walker, J., Gale, H., Manley, J. C. (1972). Late results of saphenous vein bypass grafting for myocardial revascularization. *The Annals of Thoracic Surgery*, *14*(3), 232-242.