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Original Article

Doppler Flowmeter Is a Valuable Tool for Prevention of Early Postoperative Myocardial Infarction

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Abstract

Background: Early postoperative myocardial infarction (MI) remains a critical complication following coronary artery bypass grafting (CABG). The intraoperative use of Doppler flowmetry could improve outcomes by ensuring optimal graft patency and flow. This study evaluated the effect of Doppler flowmetry on early postoperative MI in patients undergoing CABG.

Methods: This double-blinded, randomized controlled study included 120 patients who underwent elective CABG. Patients were divided into two equal groups: Group A underwent CABG with Doppler flowmetry, and Group B underwent CABG without Doppler flowmetry. The patients' ages ranged between 45 and 60 years old, with no difference in gender distribution between groups. The primary outcomes were early postoperative arrhythmias and echocardiographic parameters. Secondary outcomes included mechanical ventilation duration, ICU stay, and complication rates.

Results: There was no difference in postoperative arrhythmias between groups (P= 0.142). Postoperative regional wall motion abnormalities occurred in 90% of Group B versus 5% of Group A (P < 0.001). Difficult weaning (10 (16.7%) vs. 25 (41.7%); P= 0.003), longer ventilation time (8 ±3 vs. 17 ±7 h; P<0.001), and prolonged ICU stay (3 (3 – 10) vs. 5 (2 – 9) days; P<0.001) were all significantly higher in Group B than that of group A. Infection and re-exploration rates were significantly higher in Group B (13.3% and 25%) than in Group A (1.7% and 6.7%) (P = 0.032 and P = 0.006, respectively). The cross-clamp time and total circulatory time were shorter in Group A (55 ± 6 minutes and 87 ± 12 minutes) than in Group B (89 ± 12 minutes and 110 ± 17 minutes) (P < 0.001). Multivariable logistic regression indicated that using Doppler flowmetry reduced the risk of reexploration by 81% (OR: 0.189, 95% CI:0.054 – 0.663, P= 0.009). There was no early mortality in both groups

Conclusion: Using Doppler flowmetry during CABG could improve intraoperative and postoperative outcomes, reducing perioperative myocardial infarction and related complications. This technique could be valuable to standard CABG procedures, enhancing patient recovery and reducing hospital stay duration.

KEYWORDS

Doppler flowmetry, Coronary artery bypass grafting, Perioperative myocardial infarction, Clinical trials

Article History

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Introduction

Coronary artery bypass grafting (CABG) is the most common worldwide cardiac surgery procedure [1,2]. Even with improvements in surgical techniques and postoperative care, early postoperative myocardial infarction continues to be a major complication, leading to higher morbidity and mortality rates. Ensuring optimal graft patency and function during the immediate postoperative period is crucial to improving patient outcomes. While effective to some extent, traditional intraoperative assessment methods may not provide real-time, dynamic evaluation of blood flow and vascular resistance through the grafts [3-6].

Doppler flowmetry, a non-invasive ultrasound technique, has emerged as a valuable tool in various surgical fields for assessing blood flow in real time [7]. Its application in CABG could enhance intraoperative decision-making and graft quality assessment. By providing continuous feedback on the hemodynamic status of the grafts, Doppler flowmetry allows for immediate correction of any detected abnormalities, thereby improving overall graft patency and reducing the risk of early postoperative myocardial infarction [4,8].

Several studies have highlighted the benefits of intraoperative Doppler flowmetry in vascular surgeries [9,10]; however, its application in cardiac surgery, particularly in CABG, is still under investigation. Previous research suggests that Doppler flowmetry can detect subtle changes in blood flow and resistance that may not be apparent through conventional methods [11]. These findings underscore the potential of Doppler flowmetry to optimize graft outcomes and enhance patient recovery following CABG. We hypothesized that the intraoperative use of Doppler flowmetry in CABG improves graft patency and reduces the incidence of early postoperative myocardial infarction compared to CABG performed without Doppler flowmetry. Therefore, this study aimed to evaluate the efficacy of Doppler flowmetry in preventing early postoperative myocardial infarction and improving postoperative outcomes in patients undergoing CABG.

Patients and Methods

Study settings

Between December 2023 and June 2024, a double-blinded, randomized controlled study was conducted on 120 patients undergoing CABG, with or without the Doppler technique. The study received approval from the Institutional Review Board (IRB), and informed consent was obtained from all participants. Eligible participants included both male and female patients with an ejection fraction (EF) > 50% and a New York Heart Association (NYHA) classification up to grade III, who required elective CABG for coronary artery lesions. All surgeries were performed using cardiopulmonary bypass (CPB). Exclusion criteria included patients undergoing redo or emergency CABG and those with end-organ failure.

Randomization and groups

The patients were randomly assigned into two equal groups using blocked randomization. The age of patients ranged between 45-60 years old, with no difference in sex distribution between both groups. Group A (n= 60) included patients who underwent CABG with the Doppler technique, and Group B (n= 60) included patients who underwent CABG without the Doppler technique. Comorbidities of all patients, such as hypertension, diabetes mellitus, smoking, and arrhythmias, were nearly equally distributed in both groups. Randomization was achieved using a computer-generated random sequence, and allocation was concealed using sealed opaque envelopes. Blinding was maintained by ensuring the postoperative care team was unaware of the group assignments.

Management, data and outcomes

The preoperative assessment involved a thorough medical history and a series of investigations. Laboratory tests included a complete blood count (CBC), liver function tests (LFT), renal function tests (RFT), and the international normalized ratio (INR). Additional tests included a plain chest X-ray, an electrocardiogram (ECG), and echocardiography.

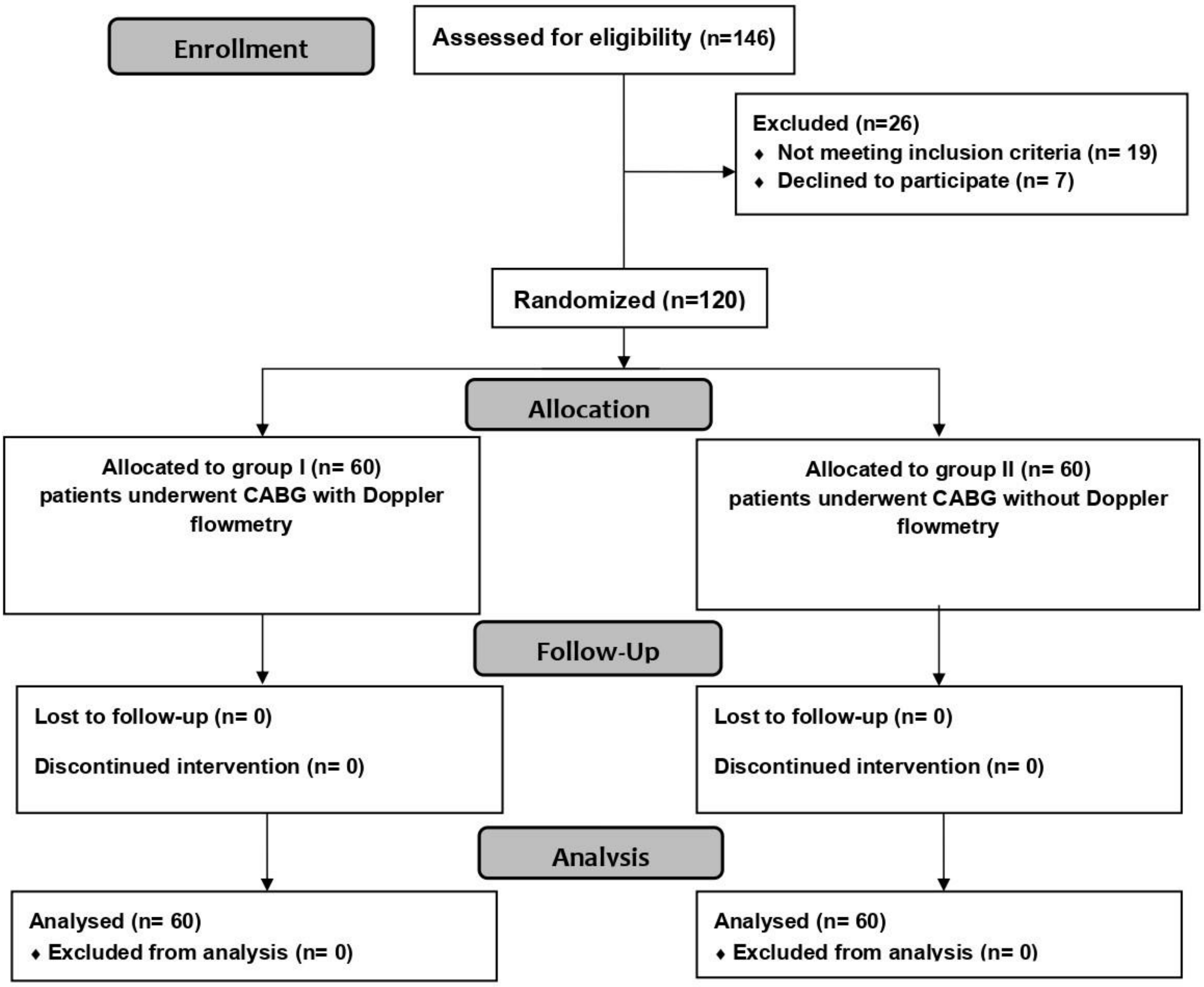

Figure 1: Consort flow diagram of patients enrolled in the study

The echocardiography provided detailed information on the ejection fraction, fractional shortening, resting wall motion, left ventricular function, and geometry. All patients scheduled for CABG also underwent cardiac catheterization.

General anesthesia was administered, and a median sternotomy incision was performed. The left internal mammary artery (LIMA) and saphenous vein graft (SVG) harvesting were conducted. An arterial cannula was placed in the femoral artery or ascending aorta, and a common atrial venous cannula was used for venous drainage. A cardioplegic arrest was induced during CPB with an aortic cross-clamp using Custodiol (HTK) solution for 5-7 minutes at 50-70 mmHg pressure. In Group A, patients underwent CABG with the intraoperative use of the Doppler technique for assessment of blood flow and vascular resistance measured through the graft during CBP and after coming off bypass. The accepted values were a mean flow of 15 mL/min or more and a pulsatility index of 3.0 or less. While in Group B, patients underwent CABG without the intraoperative use of the Doppler technique.

The primary outcomes were early postoperative arrhythmias and detailed echocardiographic assessments, including ejection fraction, fractional shortening, left ventricular function and geometry, and the dimensions of the left ventricular and atrial chambers. Secondary outcomes encompassed the duration of mechanical ventilation, mean arterial blood pressure, central venous pressure, ECG changes, cardiac enzyme levels, ICU and hospital stay duration, and complications such as renal, hepatic, or neurological, bleeding, and wound infections.

All patients were monitored at three and six months postoperatively to evaluate dyspnea using

Table 1: Comparison of demographic data and comorbidities between patients who had coronary artery bypass grafting with (Group A) and without (Group B) Doppler flowmeter. Data were presented as mean and SD or numbers and percentages

	Group A (n = 60)	Group B (n = 60)	P-value
Age (years)	61 ±7	60 ±7	0.232
Sex			
Males	53 (88.3)	49 (81.7)	0.306
Females	7 (11.7)	11 (18.3)	
Weight (kg)	84 ±25	88 ±32	0.381
Height (cm)	166 ±9	160 ±36	0.242
DM	39 (65)	35 (58.3)	0.453
HTN	38 (63.3)	35 (58.3)	0.575
Smoking	41 (68.3)	41 (68.3)	>0.99
Rhythm			
AF	13 (21.7)	7 (11.7)	0.142
Sinus	47 (78.3)	53 (88.3)	
ACS			
NSTEMI	31 (51.7)	35 (58.3)	0.715
STEMI	7 (11.7)	5 (8.3)	
Unstable angina	22 (36.7)	20 (33.3)	
OM	58 (96.7)	54 (90)	0.272
LAD	60 (100)	60 (100)	-
RCA	23 (38.3)	27 (45)	0.459
PDA	14 (23.3)	10 (16.7)	0.361
Diagonal	11 (18.3)	9 (15)	0.624
Syntax score	30 ±3	31 ±3	0.1
RWMA	53 (88.3)	55 (91.7)	0.543
EF (%)	53 ±7	55 ±4	0.086

DM: Diabetes mellitus; HTN: Hypertension; AF: Atrial fibrillation; ACS: Acute coronary syndrome; NSTEMI: Non-ST elevation myocardial infarction; STEMI: ST-elevation myocardial infarction; OM: Obtuse marginal; LAD: Left anterior descending; RCA: Right coronary artery; PDA: Posterior descending artery; RWMA: Regional wall motion abnormalities; EF: Ejection fraction

NYHA classification and orthopnea. Additionally, Follow-up included cardiac catheterization within one year, a plain chest X-ray, and echocardiography.

Statistical analysis

Data handling and statistical evaluation were performed utilizing SPSS software, version 28 (IBM, Chicago, IL, USA). The normality of quantitative data was examined using the Shapiro-Wilk test alongside visual inspection methods. Based on the normality assessment, quantitative data were expressed as means with standard deviations, while categorical data were presented as frequencies and percentages. For the comparison of quantitative data between groups, the independent t-test was employed. Comparisons of categorical variables were conducted using the chi-squared test or Fisher's exact test as appropriate. The Doppler pulsatility index (PI) parameters were analyzed pre- and post-procedure using the paired t-test. Multivariable logistic regression analysis was performed to predict the likelihood of re-exploration, and odds ratios with 95% confidence intervals were reported. All statistical tests were conducted as two-sided, with P values below 0.05 deemed statistically significant.

Results

In this trial, 146 cases were assessed for eligibility; 19 did not meet the inclusion criteria, and seven patients declined to participate. The remaining 120 cases were randomly allocated into two groups of equal size (Figure 1).

Baseline and operative characteristics

The studied groups were comparable regarding age (P = 0.232), sex (P = 0.306), weight (P = 0.381), height (P = 0.242), diabetes mellitus (P = 0.453), hypertension (P = 0.575), smoking status (P> 0.99), rhythm (P = 0.142), acute coronary syndrome (ACS) (P = 0.715), type of graft, including obtuse marginal (OM) (P = 0.272), right coronary artery (RCA) (P = 0.459), posterior descending artery (PDA) (P = 0.361), and diagonal (P = 0.624), SYNTAX score (P = 0.1), regional wall motion abnormalities (RWMA) (P = 0.543) and EF (P = 0.086) (Table 1).

Table 2: Pulsatility index during and after coming off the bypass in patients who had Doppler flowmeter

PI	Mean ±SD (n= 60)	P-value
SVG-OM1		
During	37 ±15	< 0.001
After	2.2 ±0.9	
LIMA-LAD		
During	83 ±15	< 0.001
After	2.3 ±1.4	
SVG-D		
During	36 ±5	< 0.001
After	2.1 ±0.7	
SVG-RCA		
During	48 ±21	< 0.001
After	1.6 ±0.6	
SVG-PDA		
During	45 ±10	< 0.001
After	1.9 ±0.8	

PI: Pulsatility index; **SVG-OM1**: Saphenous vein graft to the obtuse marginal artery; **LIMA-LAD**: Left internal mammary artery to left anterior descending artery; **SVG-D**: Saphenous vein graft to the diagonal artery; **SVG-RCA**: Saphenous vein graft to the right coronary artery; **SVG-PDA**: Saphenous vein graft to the posterior descending artery

Doppler PI in different grafts

Significant changes were observed in the hemodynamic parameters of the grafts. The PI of the SVG-OM1 significantly decreased from 37 ± 15 during CPB to 2.2 ± 0.9 after the coming-off bypass (P < 0.001). Similarly, the PI of the LIMA-LAD showed a marked reduction from 83 ± 15 during bypass to 2.3 ± 1.4 after coming off bypass (P < 0.001). The SVG-D experienced a significant decline in PI from 36 ± 5 during bypass to 2.1 ± 0.7 after coming off bypass (P < 0.001). The SVG-RCA also demonstrated a substantial decrease in PI from 48 ± 21 during bypass to 1.6 ± 0.6 after coming off bypass (P < 0.001). Lastly, the PI of the SVG-PDA significantly dropped from 45 ± 10 during the bypass to 1.9 ± 0.8 after coming off the bypass (P < 0.001) (Table 2 and Figure 2).

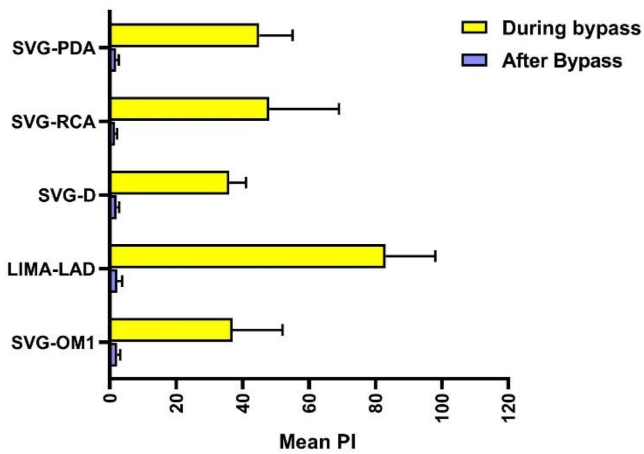

Figure 2: Pulsatility index during and after coming off the cardiopulmonary bypass in patients who had coronary artery bypass grafting and Doppler flowmeter

Procedural and post-procedural characteristics

Cross-clamp time was significantly longer in Group B (89 ± 12 minutes) compared to Group A (55 ± 6 minutes) (P < 0.001). Total bypass time was also significantly longer in Group B (110 ± 17 minutes) versus Group A (87 ± 12 minutes) (P < 0.001). Group B had a higher incidence of difficult weaning (41.7%) than Group A (16.7%) (P= 0.01). Ventilation time was significantly longer in Group B (17 ± 7 minutes) compared to Group A (8 ± 3 minutes) (P < 0.001). The ICU stay was also longer in Group B (median = 5) compared to Group A (median = 3) (P < 0.001). Post-procedural RWMA was significantly higher in Group B (90%) compared to Group A (5%) (P < 0.001). Group B had a higher rate of infection (13.3%) compared to

Table 3: Comparison of the primary and secondary outcomes between patients who had coronary artery bypass grafting with (Group A) or without (Group B) Doppler flowmeter. Continuous data were presented as mean, SD, or median (25th- 75th percentiles). Categorical data were presented as numbers and percentages

	Group A (n = 60)	Group B (n = 60)	P-value
Number of grafts	3 (2 – 5)	3 (2 – 5)	0.477
Cross clamp time (min)	55 ±6	89 ±12	<0.001
TC time (min)	87 ±12	110 ±17	<0.001
IABP	11 (18.3)	20 (33.3)	0.061
Difficult Weaning	10 (16.7%)	25 (41.7%)	0.003
Ventilation time (min)	8 ±3	17 ±7	<0.001
ICU stay (days)	3 (3 – 10)	5 (2 – 9)	<0.001
Post-procedural RWMA	3 (5)	54 (90)	<0.001
Post-procedural EF (%)	53 ±6	51 ±4	0.104
Bleeding	9 (15)	12 (20)	0.471
Infection	1 (1.7)	8 (13.3)	0.032
Reopening	4 (6.7)	15 (25)	0.006
Reintubation	2 (3.3)	6 (10)	0.272
Arrhythmia	23 (38.3)	31 (51.7)	0.142
Stroke	0 (0)	0 (0)	-
Limb ischemia	0 (0)	0 (0)	-
Inotropic support	0 (0)	39 (65)	<0.001

*Significant P-value; SD: Standard deviation; TC: Total circulatory time; IABP: Intra-aortic balloon pump; ICU: Intensive care unit; RWMA: Regional wall motion abnormalities; ECHO: Echocardiography.

Group A (1.7%) (P = 0.032), and re-exploration was more frequent in Group B (25%) compared to Group A (6.7%) (P = 0.006). Additionally, Group B required more inotropic support (65%) compared to Group A (P < 0.001) (Table 3 and Figure 3).

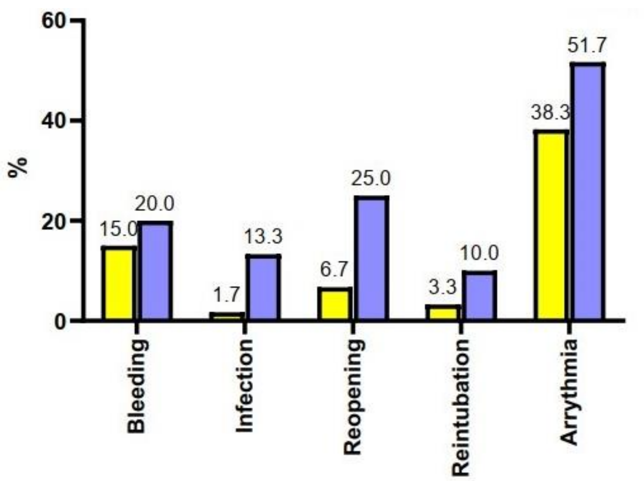

Figure 3: Comparison of the secondary outcomes between patients who had coronary artery bypass grafting with (Group A, yellow) or without (Group B, blue) Doppler flowmeter

There were no significant differences observed in the number of grafts (P = 0.477), IABP (P = 0.061), post-procedural EF (P = 0.104), bleeding (P = 0.471), reintubation (P = 0.272), and arrhythmia (P = 0.142). There were no cases of stroke or limb ischemia in either Group (Table 3).

Prediction of re-exploration

Multivariable logistic regression analysis was done to predict re-exploration. The regression model revealed that using Doppler was associated with about 81% reduced risk of re-exploration (OR = 0.189, 95% CI = 0.054 – 0.663, P= 0.009), controlling for age, sex, weight, height, DM, HTN, and smoking (Table 4).

Discussion

This study is one of the few studies comprehensively evaluating the impact of intraoperative Doppler flowmetry on postoperative outcomes in patients undergoing coronary artery bypass graft (CABG). Our findings indicate that using Doppler flowmetry significantly improves graft patency and reduces the incidence of early postoperative myocardial infarction. Specifically, Group A patients who underwent CABG with Doppler flowmetry exhibited shorter cross-clamp times and total circulatory times compared to Group B. Furthermore, Group A experienced fewer complications, including a significantly lower incidence of difficult weaning, shorter ventilation times, and reduced intensive care unit (ICU) stays. The occurrence of postoperative regional wall motion abnormalities (RWMA) was markedly lower in Group A, and the rates of infection and re-exploration were also significantly reduced. Additionally, no patients in Group A required inotropic support postoperatively, compared to 65% in Group B.

Table 4: Multivariable logistic regression analysis to predict re-exploration

	OR (95% CI)	P-value
Age (years)	0.943 (0.864 – 1.029)	0.187
Sex	0.26 (0.029 – 2.34)	0.230
weight (kg)	0.995 (0.972 – 1.018)	0.649
Height (cm)	0.995 (0.972 – 1.019)	0.698
DM	4.166 (1.083 – 16.031)	0.038
HTN	0.299 (0.097 – 0.919)	0.035
Smoking	0.721 (0.179 – 2.908)	0.645
Doppler flowmeter	0.189 (0.054 – 0.663)	0.009

OR: Odds Ratio; CI: Confidence Interval; DM: Diabetes Mellitus; HTN: Hypertension

The study by Hellmann and associates [12] emphasized the importance of real-time intraoperative monitoring techniques to optimize outcomes in CABG. They demonstrate the utility of flowmetry in detecting intraoperative hemodynamic changes that can influence postoperative outcomes, which is similar to our study. While our study utilized Doppler flowmetry, they employed laser Doppler flowmetry to continuously assess myocardial microvascular perfusion during beating heart surgeries. Parallel to our results, they found significant differences in perfusion signals in a subset of patients who presented with hemodynamic instability and myocardial ischemia. Specifically, their study showed a substantial decrease in perfusion signals from 805.4 ± 200.1 to 577.2 ± 212.8 during artery occlusion and 649.3 ± 220.8 after reperfusion ($p < 0.001$). This finding aligns with our findings, where Doppler flowmetry detected critical intraoperative changes, allowing for immediate intervention and improving postoperative outcomes, such as reduced cross-clamp time, total circulatory time, and incidence of postoperative complications. However, Hellmann and colleagues [12] reported no significant differences in the averaged perfusion signals at baseline, during artery occlusion, or after reperfusion for the majority of their patients (732.4 ± 148.0 vs. 711.4 ± 144.1 vs. 737.0 ± 141.2, $p = 0.110$). This discrepancy may be attributed to differences in the patient population, the specific flowmetry techniques used, and the surgical approaches (beating heart versus traditional CABG with cardiopulmonary bypass) that did not meet this study.

Similarly, the study by Kaya and coworkers [13] evaluated the effects of graft dysfunction detected by intraoperative transit-time flow measurement (TTFM) in CABG. Their study used TTFM to assess graft patency in 1240 patients undergoing on-pump CABG. They reported that 146 grafts required revision due to insufficient patency detected by TTFM. Notably, they found that the perioperative myocardial infarction rate was low, with only 6 cases detected, and early postoperative mortality was 2.3%. The mean hospital stay was 8.9 ± 3 days, and ICU stay was 2.6 ± 0.8 days, similar to this study, where real-time monitoring with Doppler flowmetry led to fewer postoperative complications and shorter ICU stays and hospital stays. The study by Di Giammarco and colleagues [14] further supports our findings by demonstrating the predictive value of intraoperative TTFM for short-term graft patency in coronary surgery. Their retrospective study of 3567 patients found that 38 out of 304 grafts failed within a mean follow-up of 6.7 ± 4.8 months. The failed grafts had significantly lower mean flow, higher pulsatility index, and a higher percentage of backward flow values. Specifically, mean flow values of 15 mL/min or less, pulsatility index values of 3.0 or greater, and backward flow values of 3.0% or greater were independent predictors of graft failure. These findings align with our results, indicating that real-time intraoperative flow measurements can identify grafts at risk of failure and enable timely interventions to improve outcomes. Additionally, a review by Di Giammarco and Rabozzi [15] concluded that TTFM is a reliable method for verifying intraoperative graft patency, and some evidence suggests that intraoperative graft verification can improve mid-term outcomes similar to this study. They highlighted that mean graft flow values set at 10 or 15 mL/min, a pulsatility index set at three or five, and an insufficiency ratio of 3 or 4% are critical parameters.

Several studies have investigated the use of flowmetry techniques to assess myocardial microvascular perfusion. Bierbach and collaborators [16] demonstrated a significant reduction in myocardial perfusion when the LAD blood flow was reduced in a porcine model. This aligns with our findings that intraoperative monitoring can detect critical changes in perfusion that necessitate immediate intervention. Contrarily, Karlsson and associates [17] found a significantly lower perfusion signal in the arrested heart compared to the beating heart during CABG. However, they did not observe significant differences pre- and post-CABG. In contrast, their study reported no significant difference in perfusion signals pre- and post-CABG, suggesting their findings were against this study. This discrepancy could be attributed to differences in study design, patient populations, or the specific methodologies used for perfusion assessment. Their use of laser Doppler flowmetry and small sample size (n = 13) might have influenced their ability to detect changes in perfusion that were evident in our larger cohort using Doppler flowmetry. Additionally, their observation of perfusion signal influences from mechanical ventilation in 14 out of 17 measurements highlights the complexity of intraoperative monitoring. This contrasts with our findings where Doppler flowmetry allowed for better management of graft patency and reduced postoperative complications

In experimental models, Bierbach and colleagues [16] provided foundational evidence for using laser Doppler flowmetry in assessing myocardial perfusion, supporting the real-time intraoperative monitoring concept that our study further explored. The significant reduction in perfusion observed by Bierbach and associates [16] upon LAD occlusion underscores the importance of monitoring and managing perfusion in preventing myocardial ischemia and infarction, similar to our study.

The current work used multivariate logistic regression analysis to predict re-exploration. The regression model revealed that using Doppler was associated with about an 81% reduced risk of reopening. This significant reduction revealed the effectiveness of Doppler flowmetry in improving surgical outcomes and reducing the need for additional interventions.

Study Limitation:

However, this study has limitations that should be acknowledged. While adequate for detecting significant differences, the sample size could be expanded in future studies to validate these findings further. Additionally, the single-center nature of the study may limit the generalizability of the results. Multi-center trials with larger populations are recommended to confirm the efficacy of Doppler flowmetry in diverse clinical settings.

Conclusion

The intraoperative use of Doppler flowmetry during CABG could improve postoperative outcomes by enhancing graft patency and reducing the incidence of early postoperative myocardial infarction and other complications.

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