Original Article

# Transit time flow measurement and outcome in coronary artery bypass grafting for surgeon and trainee

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**Background:** Trainees need to operate under appropriate supervision to become competent. Transit time flow measurement (TTFM) is useful in detecting intraoperative graft failures during coronary artery bypass grafting (CABG). This study aims to compare the intra- and postoperative outcomes, including TTFM, of isolated CABG performed by a single consultant versus trainees and to determine the relationship between the pulsatility index (PI) and postoperative outcomes.

**Methods:** This retrospective study included 155 isolated CABG cases. Intraoperative outcomes included duration of cardiopulmonary bypass (CPB) and aortic cross-clamp and TTFM for arterial and venous grafts. Postoperative outcomes included common postoperative complications and mortality. The odds ratios of postoperative complications and mortality for arterial and venous grafts with PI ≤3 relative to grafts with PI >3 were determined with multiple logistic regression.

**Results:** The duration of CPB and aortic cross-clamp was significantly shorter in the consultant's group. TTFM for both arterial and venous grafts were similar and no significant differences in postoperative complications and mortality were detected between the two groups. Patients with arterial grafts with PI ≤3 were less likely to require an intra-aortic balloon pump (IABP) or be ventilated for a prolonged period. No significant differences in postoperative outcomes and mortality were detected between venous grafts with PI ≤3 and PI >3.

**Conclusions:** Trainees can achieve good results in isolated CABG with appropriate case selection. Patients with arterial grafts with PI ≤3 have better postoperative outcomes.

**Keywords:** Coronary artery bypass grafting (CABG); transit time flow measurement (TTFM); trainee

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## Introduction

Allowing trainees to perform isolated coronary artery bypass grafting (CABG) without compromising patient safety has been a challenge to cardiothoracic consultants. The duration of cardiopulmonary bypass (CPB) and surgery tend to be longer when performed by trainees, which may lead to worse patient outcomes. However, trainees need to operate under appropriate supervision to acquire surgical competency. Most studies showed no significant differences in postoperative morbidity and mortality for CABG cases

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performed by consultants versus trainees (1-3). However, several studies showed that CABG performed by trainees resulted in longer ventilatory support and a higher risk of postoperative myocardial infarction (MI) (3,4). Recently, intraoperative graft assessment by transit time flow measurement (TTFM) was shown to improve postoperative outcomes by detecting intraoperative graft failure (5-9). TTFM is recommended by the European Society of Cardiology and the European Association for Cardio-Thoracic Surgery for intraoperative graft assessment (10). Intraoperative TTFM have not been used to compare surgeries performed by consultants versus trainees. This study aims to compare intra- and postoperative patient outcomes of isolated CABG, including TTFM, performed by a consultant and trainees and to study the relationship between pulsatility index (PI) and postoperative patient outcomes. We present the following article in accordance with the STROBE reporting checklist (available at https://jtd.amegroups.com/article/view/10.21037/jtd-21-1550/rc).

## Methods

This is a retrospective study conducted at the University of Malaya Medical Center (UMMC), a tertiary medical center in Kuala Lumpur, Malaysia. All patients who had elective isolated CABG, from January 1, 2017 to September 30, 2020, were recruited. Of the 155 patients included in the study, 84 patients were operated on by a single consultant and 71 patients were operated on under the supervision of the consultant by cardiothoracic trainees who were in the 3rd year of cardiothoracic training. The CABG surgeries were performed by a single consultant with more than 10 years of experience in cardiac surgery. The coronary angiogram of the patients that were operated by trainees were assessed by consultants before surgery to ensure the presence of good anastomotic target.

Data on patient characteristics were collected, including age, gender, functional status, left ventricular ejection fraction, and comorbidities, such as a history of previous cardiac surgery, recent MI, extracardiac arteriopathy, stroke, diabetes mellitus, chronic lung disease, and advanced chronic kidney disease (CKD). Left ventricular dysfunction was defined as ejection fraction ≤40% within 3 months before surgery, recent MI was defined as documented MI within 1 month before surgery, and advanced CKD was defined as CKD stage 4 and higher. Intraoperative outcomes included the duration of CPB and aortic cross-clamp and TTFM, which included PI, mean graft flow (MGF), and diastolic fraction. TTFM was directly measured using a Medistim VeriQ System (Medistim ASA, Oslo, Norway) for all grafts after protamine administration. Arterial graft was assessed using 2 mm Medistim probe whereas venous graft was assessed using 4 mm Medistim probe. Graft revision was performed if PI >5 and MGF <15 mL/min. If PI and MGF were inconsistent, the decision to revise is made on case-by-case basis by the consultant, factoring in the extent of the disease of the target coronary vessels. Postoperative outcomes included the need for chest reopen, low cardiac output syndrome (LCOS), perioperative MI, atrial fibrillation, stroke, renal failure, prolonged ventilation, surgical site infection, and in-hospital mortality. We defined LCOS as a postoperative cardiac index <2 L/min/$m^2$ accompanied by signs of poor peripheral perfusion, poor oxygenation, oliguria, and metabolic acidosis. Perioperative MI was defined as persistent ST segment changes in the perioperative period. Postoperative renal failure was defined as renal dysfunction requiring the administration of postoperative renal replacement therapy for patients who did not require renal replacement therapy preoperatively. Prolonged ventilation was defined as invasive ventilation for ≥5 days.

The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The need for ethical approval was waived by the UMMC surgical department and ethics committee as it is a retrospective observational study. Written permission was given by the UMMC Department of Medical Records for the retrospective analysis of the medical records. All data were analyzed using SPSS software version 22 (Chicago, Illinois, USA). Chi-square tests and independent *t*-tests were used to compare qualitative and quantitative data, respectively. A univariate logistic regression analysis was used to compare postoperative outcome odds between PI ≤3 and PI >3 for both arterial and venous grafts. A PI of 3 was used as the cut-off because a PI >3 is predictive of early graft failure (11). Statistical significance was set at $P<0.05$.

## Results

The patient characteristics are shown in *Table 1*. The mean ages of patients in the consultant and trainee groups were 58.6±9.9 and 59.0±9.1, respectively. No significant differences in age and gender were detected between the two groups. No patients underwent previous cardiac surgeries in either group. Left ventricular systolic

**Table 1** Comparison of patient characteristics between consultant and trainees

| Patient characteristics | Consultant (N=84) | Trainees (N=71) | P value |
|---|---|---|---|
| Age, years | 58.6±9.9 | 59.0±9.1 | 0.805 |
| Males, n (%) | 71 (84.5) | 64 (90.1) | 0.299 |
| Comorbidity, n (%) | | | |
| Previous cardiac surgery | 0 | 0 | – |
| Recent myocardial infarction | 17 (20.2) | 17 (23.9) | 0.579 |
| Extracardiac arteriopathy | 9 (10.7) | 3 (4.2) | 0.132 |
| Stroke | 3 (3.6) | 2 (2.8) | 0.791 |
| Diabetes mellitus | 21 (25.0) | 9 (12.7) | 0.053 |
| Chronic lung disease | 2 (2.4) | 3 (4.2) | 0.517 |
| Advanced chronic kidney disease | 2 (2.4) | 1 (1.4) | 0.661 |
| Left ventricular systolic dysfunction, n (%) | 15 (17.9) | 5 (7.0) | 0.045 |
| CCS class 2 and above, n (%) | 38 (45.2) | 40 (56.3) | 0.168 |
| NYHA class 2 and above, n (%) | 60 (71.4) | 49 (69.0) | 0.743 |

CCS, Canadian Cardiovascular Society; NYHA, New York Heart Association.

**Table 2** Comparison of intraoperative outcomes between consultant and trainees

| Intraoperative outcome | Consultant (N=84) | Trainees (N=71) | P value |
|---|---|---|---|
| Duration of cardiopulmonary bypass, min | 91.7±31.2 | 130.3±44.9 | <0.001* |
| Duration of aortic cross-clamp, min | 61.4±34.2 | 80.4±35.0 | 0.001* |
| Transit time flow measurement, n (%) | | | |
| Arterial graft | | | |
| Pulsatility index ≤3 | 74 (88.1) | 57 (80.3) | 0.116 |
| Flow >15 mL/min | 74 (90.2) | 61 (88.4) | 0.715 |
| Diastolic filling >50% | 79 (96.3) | 63 (91.3) | 0.193 |
| Venous graft | | | |
| Pulsatility index ≤3 | 40 (47.6) | 38 (53.5) | 0.675 |
| Flow >15 mL/min | 74 (100.0) | 66 (100.0) | – |
| Diastolic filling >50% | 52 (70.3) | 46 (70.8) | 0.949 |

*, P value <0.05.

dysfunction occurred in significantly more patients in the consultant group (17.9%) compared with the trainee group (7.0%). No significant differences in comorbidities or functional status were detected between the two groups.

*Tables 2,3* show intra- and postoperative outcomes in the consultant and trainee groups. The mean duration of CPB was significantly shorter in the consultant group compared with the duration in the trainee group (91.7±31.2 *vs.* 130.3±44.9 minutes, P<0.001). The mean duration of aortic cross-clamp was also significantly shorter in the consultant group compared with the duration in the trainee group (61.4±34.2 *vs.* 80.4±35.0 minutes, P=0.001). TTFM for both arterial and venous grafts were similar in the two groups. No significant differences in achieving a PI ≤3, flow

**Table 3** Comparison of postoperative outcomes between consultant and trainees

| Postoperative outcome | Consultant (N=84), n (%) | Trainees (N=71), n (%) | P value |
|---|---|---|---|
| Chest reopen | 6 (7.1) | 5 (7.0) | 0.981 |
| Low cardiac output syndrome | 4 (4.8) | 0 | 0.062 |
| Perioperative myocardial infarction | 1 (1.2) | 0 | 0.356 |
| Atrial fibrillation | 3 (3.6) | 1 (1.4) | 0.397 |
| Stroke | 2 (2.4) | 0 | 0.191 |
| Renal failure | 2 (2.4) | 0 | 0.191 |
| Prolonged ventilation | 4 (4.8) | 1 (1.4) | 0.239 |
| Sternotomy site infection | 0 | 0 | – |
| Drain site infection | 0 | 0 | – |
| Lower limb wound infection | 0 | 0 | – |
| Mortality | 1 (1.2) | 1 (1.4) | 0.905 |

**Table 4** Odds ratios of postoperative outcomes and mortalities for arterial grafts with PI ≤3, relative to arterial grafts with PI >3

| Postoperative outcome | PI ≤3, n (%) | PI >3, n (%) | β | SE | Wald | P value | OR | 95% CI |
|---|---|---|---|---|---|---|---|---|
| Require IABP | 15 (11.5) | 7 (33.3) | –1.352 | 0.538 | 6.316 | 0.012* | 0.259 | 0.090, 0.743 |
| Require chest reopen | 9 (6.9) | 2 (9.5) | –0.356 | 0.820 | 0.188 | 0.665 | 0.701 | 0.141, 3.494 |
| Low cardiac output syndrome | 3 (2.3) | 1 (4.8) | –0.758 | 1.179 | 0.413 | 0.521 | 0.469 | 0.046, 4.730 |
| Myocardial infarction | 1 (0.8) | 0 | 16.335 | 8.77E+03 | <0.001 | >0.999 | 1.24E+07 | <0.001, – |
| Atrial fibrillation | 3 (2.3) | 1 (4.8) | –0.758 | 1.179 | 0.413 | 0.521 | 0.469 | 0.046, 4.730 |
| Stroke | 1 (0.8) | 1 (4.8) | 1.872 | 1.434 | 1.703 | 0.192 | 0.154 | 0.009, 2.559 |
| Renal failure | 2 (1.5) | 0 | 17.036 | 8.77E+03 | <0.001 | 0.998 | 2.50E+07 | <0.001, – |
| Prolonged ventilation | 2 (1.5) | 3 (14.3) | –2.375 | 0.947 | 6.290 | 0.012* | 0.093 | 0.015, 0.595 |
| Mortality | 2 (1.5) | 0 | 17.036 | 8.77E+03 | <0.001 | 0.998 | 2.50E+07 | <0.001, – |

*, P value <0.05. CI, confidence interval; IABP, intra-aortic balloon pump; OR, odds ratio; PI, pulsatility index; SE, standard error.

>15 mL/minute, and diastolic filling >50% were detected between the two groups. No postoperative infections at the sternotomy site, chest drain site, and lower limb occurred in either group. No significant differences in other postoperative complications or mortality were detected between the two groups.

*Tables 4,5* show the postoperative outcomes and mortality in arterial and venous grafts with PI ≤3 and PI >3. Patients with arterial grafts with PI ≤3 were less likely to require an intra-aortic balloon pump (IABP) or be ventilated for prolonged periods. The odds ratios of requiring IABP and prolonged ventilation were 0.259, CI (0.090, 0.743) and 0.093, CI (0.015, 0.595) respectively, for arterial grafts with PI ≤3 compared with arterial grafts with PI >3. No significant differences in postoperative outcomes and mortality were detected between venous grafts with PI ≤3 and PI >3.

## Discussion

Numerous studies have shown that postoperative morbidity and mortality are not different in CABG performed by consultants versus trainees. Oo *et al.* (1) studied 5,678 isolated CABG and found that the cases operated by trainees were less likely to be hypertensive, obese, or have a history of MI, stroke, renal dysfunction, and poor

**Table 5** Odds ratios of postoperative outcomes and mortalities for venous grafts with PI ≤3, relative to venous grafts with PI >3

| Postoperative outcome | PI ≤3, n (%) | PI >3, n (%) | β | SE | Wald | P value | OR | 95% CI |
|---|---|---|---|---|---|---|---|---|
| Require IABP | 13 (16.7) | 6 (9.7) | 0.624 | 0.526 | 1.407 | 0.236 | 1.867 | 0.666, 5.235 |
| Require chest reopen | 5 (6.4) | 5 (8.1) | −0.247 | 0.657 | 0.142 | 0.706 | 0.781 | 0.216, 2.828 |
| Low cardiac output syndrome | 3 (3.8) | 0 | 17.984 | 5.10E+03 | < 0.001 | 0.997 | 6.46E+07 | <0.001, – |
| Myocardial infarction | 0 | 1 (1.6) | −17.092 | 4.55E+03 | <0.001 | 0.997 | <0.001 | <0.001, – |
| Atrial fibrillation | 2 (2.6) | 2 (3.2) | −0.236 | 1.015 | 0.054 | 0.816 | 0.789 | 0.108, 5.770 |
| Stroke | 0 | 2 (3.2) | −17.802 | 4.55E+03 | <0.001 | 0.997 | <0.001 | <0.001, – |
| Renal failure | 1 (1.3) | 1 (1.6) | −0.233 | 1.425 | 0.027 | 0.870 | 0.792 | 0.049, 12.925 |
| Prolonged ventilation | 3 (3.8) | 2 (3.2) | 0.182 | 0.929 | 0.039 | 0.844 | 1.200 | 0.194, 7.414 |
| Mortality | 0 | 2 (3.2) | −17.802 | 4.55E+03 | <0.001 | 0.997 | <0.001 | <0.001, – |

CI, confidence interval; IABP, intra-aortic balloon pump; OR, odds ratio; PI, pulsatility index; SE, standard error.

ejection fraction. Trainees produced better outcomes due to selection bias but no significant differences in morbidity or short- and mid-term survivals were detected after adjusting for propensity scores. Jenkins *et al.* (2) studied 4,243 isolated CABG and found that the cases operated by trainees were lower risk; morbidities were 10% and 21%, respectively, and the 30-day mortalities were 3% and 8%, respectively, for CABG performed by trainees and consultants. These studies demonstrated that trainees could achieve good results with appropriate case selection. In contrast, Baskett *et al.* (3) studied 366 isolated CABG and found that patients were at higher risk if operated on by trainees and a significantly higher proportion of cases operated by trainees required ventilation >24 hours. However, no significant differences in morbidity and mortality were detected in a multivariate analysis. Yap *et al.* (4) studied 983 isolated CABG and demonstrated a significantly higher incidence of postoperative MI in cases operated by trainees but the 1-, 3- and 5-year survival rates were similar to cases operated by consultants.

Our study yielded similar results to the studies described above. A significantly higher proportion of patients with left ventricular dysfunction occurred in cases operated by the consultant. Although CPB and aortic cross-clamp times were significantly longer in cases operated by trainees, no significant differences in TTFM were detected in cases operated by trainees compared to the consultant. No significant differences in postoperative outcomes and mortality were detected between cases performed by the consultant versus trainees. This shows that trainees achieve good results in isolated CABG with appropriate case selection.

Perioperative MI ranges from 3–10% in CABG (12-14). Fabricius *et al.* (15) reported that 23 out of 2,052 (1.1%) patients who underwent CABG had severely compromised hemodynamics due to postoperative MI and 5 out of 23 (21.7%) had incorrect anastomoses. Hashim *et al.* (16) reported that graft flow abnormalities when the heart is arrested at diastole are purely due to technical problems, such as anastomosis errors; thus, checking the PI and graft flow of the internal mammary artery upon completion of the anastomosis and before tying is recommended. Anastomoses reconstructions are recommended if TTFM are unsatisfactory. A meta-analysis conducted by Thuijs *et al.* (6), which included 8,943 CABG cases, showed that 4.3% of grafts required revisions based on TTFM. Many studies suggest that TTFM predicts graft failure. Jokinen *et al.* (7) reported that TTFM predicts graft failure within 6 months and PI is the best predictor of early graft patency. Oshima *et al.* (8) reported that MGF <11.5 mL/min for arterial graft and PI >5.85 for saphenous vein graft (SVG) are good predictors of graft failure within 1 month. Tokuda *et al.* (9) studied 261 grafts and reported that MGF <15 mL/min or PI >5 for grafts to the left coronary system and MGF <20 mL/min or PI >4.7 for grafts to the right coronary system are predictive of graft failure within 1 year.

Despite the recommendation in a recent study of PI <5, we selected PI ≤3 as our cut-off point (17). In an earlier study by Di Giammarco *et al.* (11), mean flow values ≤15 mL/min, a PI ≥3.0, and a percentage of backward flow ≤3.0% were independent predictors of graft failure.

The views on the correlation between TTFM and postoperative outcomes are conflicting. Kieser *et al.* (18) studied 990 grafts and reported that 15 out of 277 patients (7.4%) with PI <5 and 10 out of 59 patients (17%) with PI >5 had major adverse cardiac events, including recurrent angina, perioperative MI, and the need for postoperative percutaneous coronary intervention (PCI). Mortality rates were significantly lower (2%) for grafts with PI <5 compared with mortality when PI >5 (9%). Bauer *et al.* (19) studied 7,804 isolated CABG and reported that use of TTFM was associated with a significant reduction in ventricular fibrillation from 0.66% to 0.44% and a reduction in mortality from 30% to 12.2%. Furthermore, the rate of insufficient graft flow detected by angiography was reduced by 66%. Similarly, Becit *et al.* (20) reported that IABP insertions were significantly lower when TTFM was used. Taggart *et al.* (17) suggested that intraoperative graft quality assessment with TTFM and high-frequency ultrasound (HFUS) improved the quality, safety, and efficacy of CABG. In contrast, De Leon *et al.* (21) suggested that TTFM of functioning grafts do not predict long-term survival or performance of new PCIs.

Our study showed that patients with arterial grafts with PI ≤3 are less likely to require IABP or prolonged ventilation. No significant differences in postoperative outcomes were detected in venous grafts based on PI. Most arterial grafts are to the left anterior descending artery and left circumflex artery, whereas most venous grafts are to the left circumflex artery and right coronary system; thus, suboptimal PI for arterial grafts leads to graft failure of the left coronary system which frequently leads to LCOS with worse outcomes whereas suboptimal PI for venous grafts does not affect the outcome.

Our study was limited because of the relatively small sample size and single-center. Multi-center studies with larger sample sizes are needed to confirm the findings of our study. However, this is the first study to compare TTFM between surgeries performed by a consultant and trainees. CABG cases were performed by a single consultant with more than 10 years of experience in cardiac surgery. This eliminates the confounding potential of surgical skill and experience differences between consultants.

## Conclusions

Trainees can achieve good results in isolated CABG with appropriate case selection. Patients with arterial grafts with PI ≤3 have better postoperative outcomes

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## Footnote

*Reporting Checklist:* The authors have completed the STROBE reporting checklist. Available at https://jtd.amegroups.com/article/view/10.21037/jtd-21-1550/rc

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*Ethical Statement:* The authors are accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. The study was conducted in accordance with the Declaration of Helsinki (as revised in 2013). The need for ethical approval was waived by the UMMC surgical department and ethics committee as it is a retrospective observational study. Written permission was given by the UMMC Department of Medical Records for the retrospective analysis of the medical records.



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