Measurement of coronary sinus blood flow using transesophageal echocardiography to estimate the adequacy of revascularization in patients undergoing off-pump coronary artery bypass grafting

Mrugesh Prajapati, Nikhil Yadav, Hemang Gandhi, Varun Arora, Srikanth Gujja, Prahya Sachan, Sanjay Patel

U. N. Mehta Institute of Cardiology and Research Center (Affiliated to B. J. Medical College), Civil Hospital Campus, Asarwa, Ahmedabad, Gujarat, India

Correspondence to Dr. Hemang Gandhi, MD, PDCC, Department of Cardiac Anesthesia, U. N. Mehta Institute of Cardiology and Research Centre, Civil Hospital Campus, Asarva, Ahmedabad 380016, Gujarat, India.
fax: 22682092;
e-mail: drhemang77@yahoo.co.in

Received: 9 February 2021
Revised: 1 June 2021
Accepted: 18 June 2021
Published: 25 August 2021

The Egyptian Journal of Cardiothoracic Anesthesia 2021, 15:48–54

Introduction
Revascularization of coronary artery increases the blood flow in the coronary sinus (CS) too. The study aimed to measure the CS blood flow using transesophageal echocardiography (TEE) to estimate the adequacy of revascularization in patients undergoing off-pump coronary artery bypass grafting.

Patients and methods
After ethical committee approval, 100 patients scheduled for elective coronary artery bypass grafting were included in this study. After induction of balanced anesthesia according to institutional protocol, a 5-Hz multiplane phased-array TEE probe was inserted into patients' esophagus, and the following parameters were calculated at pre-revascularization and post-revascularization periods: velocity time integral of CS, coronary sinus diameter, coronary sinus cross-section area, and coronary sinus blood flow (CSBF) per beat and per minute.

Results
Our study showed a statistically significant increase in velocity time integral in the post-revascularization period as compared with the pre-revascularization period ($P<0.001$). There was significant increment in mean CS diameter in the post-revascularization period as compared with the pre-revascularization period (0.79 vs.0.68 cm) ($P<0.001$). There was a significant increase in CSBF per minute in the post-revascularization period (363.8±80.55 ml) as compared with the pre-revascularization period (218.9±46.61 ml) ($P<0.001$).

Conclusion
TEE is a superior modality to evaluate CSBF before and after coronary artery bypass revascularization to determine the adequacy of surgical revascularization in real time during off-pump coronary artery bypass revascularization.

Keywords:
coronary artery bypass grafting, coronary sinus blood flow, transesophageal echocardiography

Egypt J Cardiothorac Anesth 15:48–54

1687-9090

Introduction

The supply of oxygen to the myocardium is determined mainly by the volume of the coronary blood flow. Therefore, measurement of coronary blood flow is a useful way of evaluating coronary lesions and myocardial ischemia. Measurement of coronary blood flow can be assessed by coronary sinus blood flow (CSBF) [1]. In patients with coronary artery disease, there is reduced CSBF. Any intervention that increases coronary perfusion may also increase CSBF [2,3].

Measurement of CSBF is done by various invasive techniques that require cardiac catheterization using intracoronary Doppler flow wire, thermodilution catheter [4], or digital coronary angiography. It can also be measured using radioisotope dyes such as argon technique or xenon scintigraphy [1].

Transesophageal echocardiography (TEE) has been used during cardiac surgery worldwide.Because the echocardiographic probe is located in the esophagus in proximity to the left atrioventricular junction, the TEE can demonstrate the coronary sinus (CS) with high resolution [5]. TEE is also superior to transthoracic echocardiography in the anatomic demonstration of the CS [5]. Besides this, it can evaluate CSBF in real time with good reproducibility and allows the monitoring of flow before and after the administration of a vasodilator drug [6].

There has been limited literature available on CSBF for assessment of coronary artery perfusion after surgical revascularization using TEE. Hence, this study was undertaken to compare CSBF before and after OP-coronary artery bypass grafting (CABG) to determine the adequacy of surgical revascularization using TEE.

Patients and methods

After ethical committee approval and preoperative written and informed consent, 100 patients scheduled for elective CABG surgery were included in the study during November 2016 to January 2019.

The current study included adult patients (age, 18–75 years) with American Society of Anesthesiologists grade III or less who were scheduled for elective off-pump CABG. We have excluded patients who refused to give consent for study, have accompanying valvular or other cardiovascular surgery, severe left ventricular dysfunction (left ventricular systolic function ≤30%), history of stroke, associated renal or liver diseases, re-do surgeries, on-pump CABG, or any contraindications for insertion of TEE probe.

In this prospective observational study, we measured the CS cross-section area and velocity time integral (VTI) at three different intervals correspondingly at before coronary artery bypass revascularization and after revascularization and calculated CS cross-section area and CSBF per beat and per minute.

The patients were managed intraoperatively based on the standard operating procedures within the department. A radial artery was cannulated with a 20-G cannula, and a large-bore peripheral venous cannula was inserted before induction of anesthesia in all patients.

Anesthesia was induced with midazolam 0.1 mg/kg, fentanyl 5–10 μg/kg, and vecuronium 0.2 mg/kg, and patients were intubated with an appropriate-size endotracheal tube. Patients were ventilated with a tidal volume of 8 ml/kg, O_2-air mixture (FiO_2 of 50%), respiratory rate of 10–14/min, with $PaCo_2$ goal of between 35 and 40 mmHg. Maintenance of anesthesia was done with sevoflurane 0.7–1.5 MAC according to hemodynamics, vecuronium 0.04 mg/kg, and fentanyl 2 μg/kg every 40 min. The right internal jugular vein was cannulated with 7-Fr triple-lumen catheter using Seldinger's technique under all aseptic precautions. After central venous cannulation, a 5-MHz multiplane phased-array TEE probe (GE Healthcare Vivid-I 6T-TS probe; GE Healthcare, 3920 Howard Ave, New Orleans, LA, USA) was inserted into the patient's esophagus for intraoperative monitoring. By using B-mode echocardiography, we obtained a view of the CS in the modified four-chamber view. The pulse-Doppler sample volume was placed in the CS 1 cm before its inflow in the right atrium. The transducer position was optimized to obtain an angle of less than 40° between the Doppler beam and direction of CSBF.

The following data were recorded before revascularization (5 min before starting coronary revascularization) and following revascularization 5 min after protamine administration. We measured the angle of the Doppler beam, peak velocity, and VTI. An average of 3 VTI of CS was noted. Diameter of CS (Fig. 1) was measured in M-mode at three different cardiac cycles, and its average is taken as the diameter of the CS. Assuming that the cross-section of CS is elliptical and that the major diameter is double the length of the minor diameter, the cross-section area of CS was calculated as 0.39×(average diameter) [4]. CSBF per beat was then calculated as CS VTI×cross-sectional area of CS [7].

Hemodynamic measurements consisted of heart rate, systolic blood pressure, diastolic blood pressure, mean arterial pressure, and central venous pressure (CVP).

The sample size was calculated through Rao Software (http://www.raosoft.com/samplesize.html).

Results

This study included 100 patients with American Society of Anesthesiologists III, posted for elective off-pump coronary artery bypass revascularization. A total of 80 males and 20 females were included in the study. The average age, height, and weight were 58.66 ±8.10 years, 166.52±7.42 cm, and 73.26±10.69 kg, respectively. The minimum and maximum age was 37 and 79 years, minimum height was 151 cm and maximum was 182 cm, and minimum and maximum weight was 51 and 98 kg, respectively. The majority of the patients (n=53) had triple-vessel disease followed by double-vessel disease (n=45) and two patients were diagnosed with single-vessel disease.

The difference in heart rate and CVP is comparable. The differences in systolic blood pressure, diastolic blood pressure, and mean arterial pressure were statistically significant ($P<0.05$) in pre-revascularization and post-revascularization periods (Table 1). However, these differences were clinically not significant, as the pre-revascularization and post-revascularization parameters were within clinically acceptable range (±10% of baseline value).

The VTI was observed at three different cardiac cycles in both pre-revascularization and post-revascularization periods. Data showed an increase in VTI in the post-revascularization period (Fig. 2) as compared with the pre-revascularization period (Fig. 3). The difference was statistically highly significant ($P<0.001$) (Table 2).

It showed a statistically significant increment in mean CS diameter in the post-revascularization phase (0.79 cm) (Fig. 4) as compared with the pre-revascularization phase (0.68 cm) ($P<0.001$) (Table 3).

The pre-revascularization and post-revascularization cross-section areas were compared and a statistically significant increase in cross-section area in the post-revascularization phase was noted ($P<0.001$) (Table 4).

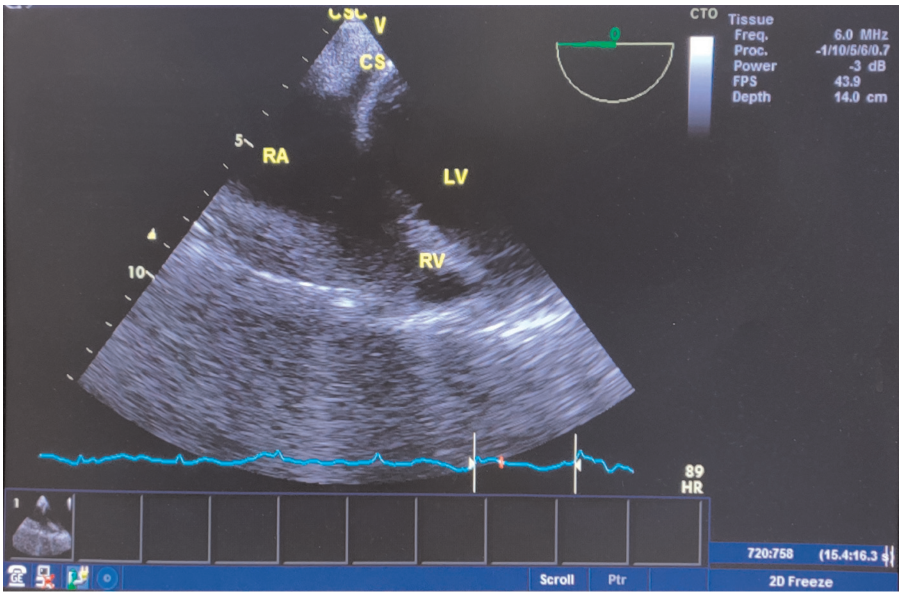
There is a statistically significant increase in CSBF per beat in the post-revascularization period as compared with the pre-revascularization period ($P<0.001$).

There is statistically significant increase in CSBF per beat per minute in the post-revascularization period as compared with the pre-revascularization period ($P<0.001$) (Table 5).

Discussion

In CABG, graft patency is a major factor contributing to cardiac morbidity and mortality, especially in the early follow-up period. At 1-year follow-up, graft occlusion rates of 20.0% for venous and 8.0% for arterial grafts have been reported. Although the cause of late graft failure is attributed to intimal hyperplasia and atherosclerosis, failure within the first year is, thought in part, to be related to technical error that could be corrected at the time of surgery. However, after percutaneous transluminal coronary angioplasty (PTCA), the adequacy of the revascularization could be assessed by fluoroscopic evaluation using intracoronary dye injection; the immediate assessment of grafts following anastomosis is often neglected or performed with

Figure 1



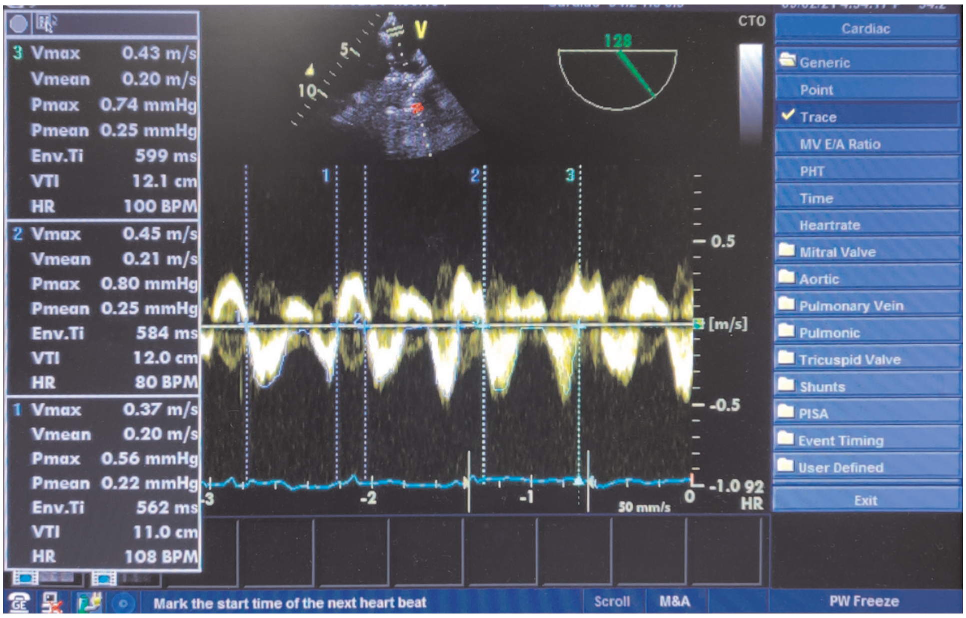
Coronary sinus opening into right atrium.

Table 1 Hemodynamic parameters before and after revascularization

	Before revascularization	After revascularization	*P* value
HR (beats/min)	72.51±6.33	74.73±8.38	0.01603
SBP (mmHg)	120.23±6.97	124.44±7.44	<0.0001
DBP (mmHg)	65.25±5.56	68.3±6.55	<0.0001
MAP (mmHg)	83.44±4.92	87.01±5.46	<0.0001
CVP (mmHg)	5.81±1.63	5.4±1.36	0.0101

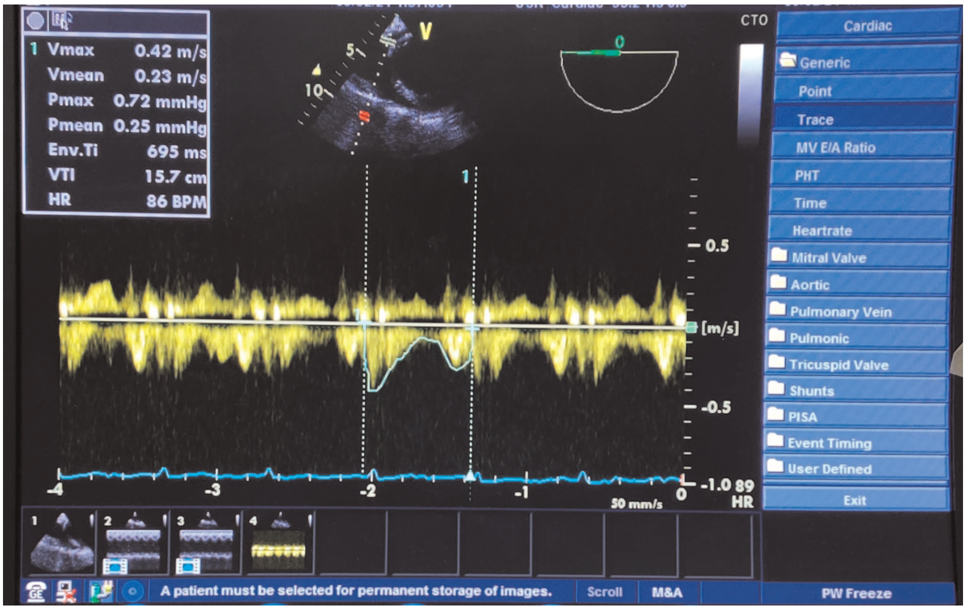
Central venous pressure was observed in pre-revascularization and post-revascularization periods. CVP, central venous pressure; DBP, diastolic blood pressure; HR, heart rate; MAP, mean arterial pressure; SBP, systolic blood pressure.

Figure 2



Pre-revascularization velocity time integral (VTI).

Figure 3



Post-revascularization velocity time integral (VTI).

crude evaluations such as finger palpation. Therefore, further research and examination are required for intraoperative graft assessment modalities that could aid the surgeon in decision making regarding graft revision.

Intraoperative assessment tools for measurement of graft patency include transit time flowmetry and intraoperative fluorescence coronary angiography. The predictability for long-term outcomes is variable and inconclusive for both the techniques besides time consumption for performing intraoperative fluorescence coronary angiography, and therefore, both techniques have not gained much popularity.

CS drains the venous blood from its tributaries like great cardiac vein, middle cardiac vein, and small cardiac vein. These veins drain the venous blood from the myocardial that is supplied by coronary arteries. Any intervention that aims at restoring the flow of the stenosed vessel increases coronary artery flow that should consequently increase the CSBF. Measurement of CSBF can be used as an indirect tool for the assessment of adequacy of coronary artery perfusion after surgical revascularization.

There are many techniques available to measure the blood flow through the CS. The existing methods include thermodilution; gas clearance; densitometry; electromagnetic and Doppler flow probes; positron-emission tomography; and newer approaches ultrafast computed tomography, contrast echocardiography, and MRI. All the techniques cannot be used intraoperatively for measurement of CSBF. Hence, we selected this study, because TEE is a standard monitoring technique in cardiac surgery, and measurement of CS parameters in real time is easy, reliable, and reproducible [2,8].

Our primary aim for this study was to evaluate the effectiveness of measuring CSBF using TEE during off-pump CABG, and the secondary aim was to look for limitation of this study.

We found that TEE is a very simple and effective technique for evaluation of adequacy of coronary revascularization in off-pump CABG. Diameter of CS (measured in M-mode), VTI, and derived parameters, which included cross-section area of CS, CSBF per beat, and CSBF per minute using standard formulae, were assessed. All the aforementioned data were collected before commencement of revascularization and after completion of revascularization (before sternal closure). All the data were tabulated, and statistical analysis was carried out using SPSS version 20.0 software (SPSS Inc.). Data were presented as mean±SD or proportion as appropriate. The χ^2 test and paired sample t test

Table 2 Velocity time integral before and after revascularization

	Before	After	*P* value
VTI during first cardiac cycle (cm)	16.33 ±1.55	19.53 ±1.93	<0.001
VTI during second cardiac cycle (cm)	16.72 ±1.55	19.77 ±2.01	<0.001
VTI during third cardiac cycle (cm)	16.54 ±1.42	19.68 ±2.15	<0.001
MEAN VTI (cm)	16.53 ±1.31	19.66 ±1.72	<0.001

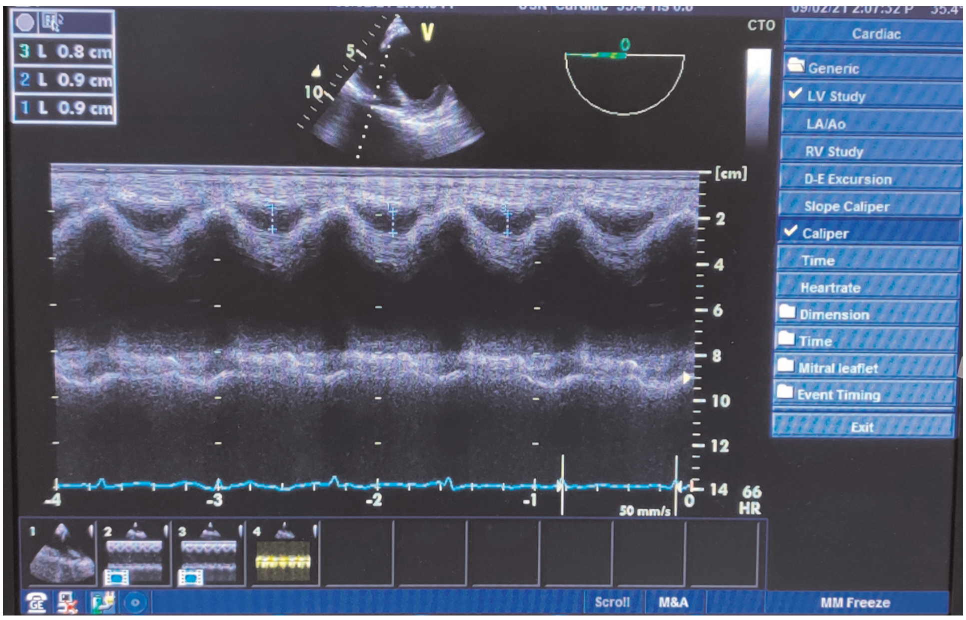
VTI, velocity time integral.

Table 3 Coronary sinus diameter before and after revascularization

	Before	After	*P* value
CS diameter during first cardiac cycle (cm)	0.68 ±0.10	0.78 ±0.09	<0.001
CS diameter during second cardiac cycle (cm)	0.67 ±0.09	0.79 ±0.09	<0.001
CS diameter during third cardiac cycle (cm)	0.69 ±0.09	0.80 ±0.11	<0.001
Mean CS diameter (cm)	0.68 ±0.08	0.79 ±0.08	<0.001

CS, coronary sinus.

Figure 4



M-mode for measurement of coronary sinus diameter.

Table 4 Coronary sinus cross-section area before and after revascularization

	Before	After	*P* value
CS_CROSS_SECTION_AREA (cm^2)	0.18±0.04	0.25±0.053	<0.001

CS, coronary sinus.

Table 5 Coronary sinus blood flow per beat and per minute before and after revascularization

	Before	After	*P* value
CS_BLOOD_FLOW_per_beat (ml)	3.04±0.69	4.90±1.08	<0.001
CS_BLOOD_FLOW_PER_MIN (ml)	218.9±46.61	363.8±80.55	<0.001

CS, coronary sinus.

were used to compare categorical and continuous variables, respectively. The *P* value less than 0.05 was considered to be significant.

Meenakshi *et al.* [9] studied transthoracic echocardiography to assess the improvement in CSBF after successful PTCA. CSBF per beat increased from 3.06±1.12 to 4.2±1.80 ($P<0.038$), and CSBF per minute increased from 231.33±70.68 to 308.20±121.32 ($P<0.042$). These data were comparable to the present study. We also found a significant increase in CS blood flow per minute (218.9±46.61 vs. 363.8±80.55 ml) ($P<0.001$).

Ng *et al.* [1] have studied the usefulness of TTE in demonstrating the CSBF before and after CABG and showed that there was a significant increase in CSVTI from 10.6±1.93 to 13.4±2.3 ($P=0.01$), with no significant change in CS diameter. We also noticed comparable data. There was significant increment in mean CS diameter in post-revascularization phase as compared with pre-revascularization phase (0.79 vs. 0.68 cm; $P<0.001$).

Nagaraja *et al.* [3], in a similar study, also found that mean heart rate increased after left anterior descending (LAD) and obtuse marginal revascularization, which was statistically significant. They proposed that the rise in the heart rate could be owing to increase in inotrope requirement. In our study, we found the average heart rate increased from 72.51±6.33 to 74.73±8.38 bpm ($P=0.016$). Post-revascularization mean blood pressure also increased from 83.44±4 to 87.01±5.46 mmHg ($P<0.0001$). However, CVP showed post-revascularization decrease from 5.81±1.63 to 5.4 ±1.36 cmH_2O ($P=0.01$). The aforementioned data were statistically significant; however, it has little relevance clinically, as the post-revascularization hemodynamic alteration was within±10% of baseline variation.

The aforementioned finding could be explained by the fact that the systemic blood pressure, heart rate, and CVP are dependent on multiple factors such as fluid status, inotropic/vasopressor requirement, depth of anesthesia, and degree of sympathetic stimulation. However, we tried to maintain the hemodynamics within the baseline range as per our institution's protocol using vasopressors.

Our findings were comparable to the results of Nagaraja *et al.* [3] who in a similar study evaluated the CSBF in patients undergoing off-pump CABG. They found that the CSBF per beat increased from 1.28±0.71 to 1.70±0.89 ($P<0001$), CSB per minute increased from 92.59±59.32 to 130.72 ±74.22 ($P<0.0001$), and total VTI increased from 8.93±4.29 to 11.96±5.68 ($P<0.0001$) after LAD revascularization. Similarly, the CSBF per beat increased from 1.67±1.03 to 1.91±1.03 ($P<0.001$), CSBF per minute increased from 131.91±86.59 to 155.20±88.70 ($P<0.0002$), and total VTI increased from 11.00±5.53 to 12.09±5.43 ($P<0.002$) after obtuse marginal revascularization.

Similar findings were obtained by Hajaghaei *et al.* [10], who also found comparable results in their study, where they found CS diameter increased from 8.6 ±1.06 to 9.4±1.21 ($P<0.01$) 1 month after CABG.

In our study, none of the patient developed ST changes in the immediate postoperative period, and there was no incidence of hemodynamic deterioration requiring conversion to emergency CPB or IABP insertion, which suggest adequate revascularization. All patients in our study had uneventful postoperative course and discharged under satisfactory condition.

Conclusion

We conclude that TEE is a superior modality to evaluate CSBF before and after coronary artery bypass revascularization to determine the adequacy of surgical revascularization in real time during off-pump coronary artery bypass revascularization. We could not compare our findings with coronary angiography or computed tomography angiography to see adequacy of coronary revascularization, and this is a limitation of our study.

Limitation

We found that there are certain limitations of our study. This was a prospective observational pilot study in patients with fair left ventricular functions or moderate dysfunction; therefore, contradictory results to our hypothesis were not observed. There was no comparison with other modalities like flow meters to measure CSBF. Neither we had the postoperative follow up of the patients nor were other investigations like coronary angiography or computed tomography–coronary angiography done to assess the adequacy of CABG in postoperative period for comparison with our findings. Long-term postoperative follow-up, as well as checking with coronary angiography (CAG) or computed tomography–coronary angiography to see the patency of revascularization is required to reinforce our study's overall effectiveness.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

References

1 Ng DW, Vlachonassios K, Nimalasuriya AR, Nguyen VT, Wijesekera C, Khan A, Chandraratna PA. Usefulness of transthoracic echocardiography in demonstrating coronary blood flow after coronary artery bypass grafting. Am J Cardiol 2004; 93:923–925.

2 Toyota S, Amaki Y. Measurement of coronary sinus flow using transesophageal echocardiography in patients undergoing coronary artery bypass grafting. J Clin Anesth 2000; 12:270–272.

3 Nagaraja PS, Singh NG, Patil TA, Manjunath V, Prasad SR, Jagadeesh AM, Kumar KA. Transesophageal echocardiography estimation of coronary sinus blood flow for the adequacy of revascularization in patients undergoing off-pump coronary artery bypass graft. Ann Card Anaesth 2015; 18:381.

4 Ganz W, Tamura K, Marcus HS, Donoso R, Yoshida S, Swan HJ. Measurement of coronary sinus blood flow by continuous thermodilution in man. Circulation 1971; 44:181–195.

5 Kronzon I, Tunick PA, Jortner R, Drenger B, Katz ES, Bernstein N, *et al.* Echocardiographic evaluation of the coronary sinus. J Am Soc Echocardiogr 1995; 8:518–526.

6 Illiceto S, Marangelli V, Memmola C, Rizzon P. Transesophageal Doppler echocardiography evaluation of coronary blood velocity in baseline conditions and during dipyridamole induced coronary vasodilatation. Circulation 1991; 83:61–69.

7 Toufan M, Samadikhah J, Alizadeh-Asl A, Azarfarin R, Hakim SH, Yaghoubi A, Farzam S. Measurement of coronary sinus blood flow after first anterior myocardial infarction with transthoracic echocardiography and its correlation with wall motion scoring index. Saudi Med J 2007; 28:1545–1549.

8 Ramos Filho J, Ramires JA, Turina M, Medeiros CJ, Lachat M, Tsutsui J. Study of coronary sinus flow reserve through transesophageal doppler echocardiography in normal subjects. Arq Bras Cardiol 2002; 79:97–106.

9 Meenakshi K, Swaminathan S, Manickam R. Role of transthoracic echocardiography in the estimation of coronary sinus blood flow in coronary artery disease. Heart Asia 2013; 5:168–171.

10 Hajaghaei M, Maleki M, Salehi HR, Ojaghi Z, Noohi F. Coronary flow reserve measurement in the coronary sinus in pre and post CABG status. Iran Cardiovasc Res J 2007; 1:87–89.