Clinical validation of coronary artery flow through an intracoronary shunt during off-pump coronary artery bypass grafting

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Objectives: Intracoronary shunts have been developed for a bloodless field and preserved forward flow preventing ischemia during off-pump coronary artery bypass (OPCAB) surgery. However, reports directly measuring the forward flow through the shunt in clinical settings are lacking.

Methods: Using a 7.5-MHz Doppler probe, we investigated the coronary flow through a 1.5-mm shunt inserted into the left anterior descending artery (LAD) for anastomosis with the internal thoracic artery during OPCAB in 30 consecutive patients. The following Doppler flow parameters were obtained before and after shunting: peak velocity, mean velocity, time-velocity integral, and flow.

Results: No patients developed significant electrocardiographic changes and the peak value of postoperative myocardial band of creatine kinase was 17 ± 16 IU/L. All Doppler flow parameters of the LAD decreased significantly after shunting; peak velocity: 71.3 ± 34.6 cm/second to 54.5 ± 25.3 cm/second ($-24\% \pm 27\%$), mean velocity: 33.3 ± 18.3 cm/second to 26.3 ± 14.0 cm/second ($-21\% \pm 23\%$), and time-velocity integral: 28.7 ± 12.1 cm to 19.0 ± 7.1 cm ($-28\% \pm 14\%$), and flow: 38.7 ± 16.8 mL/minute to 25.0 ± 9.5 mL/minute ($-31\% \pm 13\%$) ($P < .01$).

Conclusions: The LAD flow is preserved at least 50% through a 1.5-mm intracoronary shunt, although the flow pattern was attenuated, during OPCAB anastomosis. The Doppler evaluation of the coronary artery flow before and after shunting is useful to justify the protective use of the shunt on myocardial perfusion during OPCAB. (J Thorac Cardiovasc Surg 2014;147:259-63)

Intracoronary shunts were developed for vascular control during off-pump coronary artery bypass (OPCAB) surgery. Surgeons who use the shunts claim the following advantages enabling precise and safe anastomosis: a relatively bloodless field, forward flow through the shunt preventing ischemia, protection of the back wall of the coronary artery during the anastomosis, and easy exposures of the edges of the arteriotomy.¹ Regarding the forward flow through the shunt, it is common for ischemic changes that appear on electrocardiogram to resolve when a shunt has been inserted. Some clinical studies revealed that the use of shunts preserved left ventricular wall motion when compared with snaring by extraluminal occlusion with vessel loops.²⁻⁴ In addition, prospective randomized studies showed protective effects on myocardium associated with significant reduction in postoperative release of cardiac enzymes.^{5,6}

Although most surgeons who use intracoronary shunts have observed good flow of blood out of the distal limb

when the proximal limb is inserted, there are scant data regarding forward flow through the shunt during OPCAB in clinical settings. We directly investigated the coronary flow through shunts inserted into the (LAD) artery for anastomosis with the internal thoracic artery (ITA) during OPCAB, using Doppler flow measurement.

MATERIALS AND METHODS

Study Patients and Surgical Techniques

The study group comprised 30 consecutive patients (24 men and 6 women aged 69 ± 9 years) with severe coronary artery disease who underwent OPCAB, including grafting to the LAD with the use of an intracoronary shunt, at our institute. We excluded patients for whom the intracoronary shunt was not applied during OPCAB because the LAD lesion was totally occluded and received flow from the collaterals. The study protocol was approved by the institutional review board of our hospital. Written informed consent for the study was obtained from each patient before surgery. Preoperative patient profiles of the patients are summarized in Table 1.

OPCAB surgery was performed using median sternotomy. After the left and right ITAs and right gastroepiploic artery or saphenous vein were harvested, and partial anticoagulation was accomplished with 1 to 2 mg/kg body weight heparin until a target activated clotting time of 250 to 300 seconds was achieved. The heart was positioned by pericardial sutures and a suction cup device (Starfish; Medtronic, Minneapolis, Minn). A stabilizer (Acrobat; MAQUET Cardiovascular LLC, Wayne, NJ) was applied for regional stabilization of the target coronary artery on a beating heart in the condition of systolic blood pressure >100 mm Hg and cardiac index >1.8 L/minute/m² with the use of a small amount of norepinephrine. To facilitate visualization of the surgical field, a mist carbon dioxide blower (VisuFlo II; Edwards Lifesciences LLC, Irvine, Calif) and irrigation with

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Abbreviations and Acronyms

CK	= creatine kinase
CK-MB	= creatine kinase myocardial band
ITA	= internal thoracic artery
LAD	= left anterior descending
OPCAB	= off-pump coronary artery bypass
RCA	= right coronary artery
TVI	= time-velocity integral

warm saline were used. Routinely, we use an intracoronary shunt (Anastomosis, Edwards Lifesciences LLC) with a diameter of the bulb of 1.5 mm for anastomosis of the LAD and proximal right coronary artery (RCA) with 7-0 polypropylene suture. We performed off-pump grafting of the other coronary arteries without the use of an intracoronary shunt.

Doppler Measurement of Coronary Flow

Once the anastomosis site of the LAD was stabilized, both proximal and distal sites were encircled with 2 polyurethane sutures (Elastic; Matsuda Ika Kogyo Co Ltd, Tokyo, Japan). The preshunting flow of LAD was measured by applying a 7.5-MHz Doppler probe (X-Plore; Medistim AS, Oslo, Norway) on the LAD just distal to the anastomosis site. After the LAD was occluded by the proximal and distal snares, a coronary arteriotomy was made with a no. 15 blade until blood leakage was seen. Consequently, extension of the arteriotomy was performed using a microscissor. The arm of the shunt was introduced into the proximal LAD while loosening the proximal snare. Blood flow was observed through the shunt to confirm adequate insertion of the shunt into the proximal LAD. Then the other arm of the shunt was introduced into the distal LAD by holding the arm with a forceps to block the blood flow through the shunt. Once both arms were placed in the LAD, the snares were completely loosed and the position of the shunt was adjusted for anastomosis. At this moment, the postshunting flow of LAD was measured using the X-Plore probe again on the same site as the measurement of the preshunting flow. The shunt was removed just before we began to tie the anastomosis suture.

TABLE 1. Demographics for 30 study patients

Demographic	Number (%) or mean $\pm$ SD
Age (y)	69 $\pm$ 9
Male/female	24/6
Hypertension	18 (60)
Smoking	18 (60)
Diabetes mellitus	19 (63)
Hyperlipidemia	18 (60)
History of heart failure	8 (27)
History of MI	12 (40)
Serum creatinine (mg/dL)	2.35 $\pm$ 2.87
Hemodialysis-dependent	5 (17)
Left ventricular ejection fraction	0.62 $\pm$ 0.08
Coronary lesions	
1 vessel disease	0
2 vessel disease	7 (23)
3 vessel disease	12 (40)
3 vessel disease + LMT	3 (10)
LMT	8 (27)

SD, Standard deviation; MI, myocardial infarction; LMT, left main trunk disease.

From the Doppler spectrum of the LAD flow, which was recorded using a transit-time flowmeter (Veri-Q, Medi-Stim AS) with a 10-Hz filter, the following measures were obtained before and after shunting: peak velocity (in centimeters/second), mean velocity (in centimeters/second), and time-velocity integral (TVI) (in centimeters). Because the measurement sites for Doppler flow were the same, we can compare the TVI values before and after the shunt insertion in each patient to evaluate the flow changes. In addition, the diameter (r) (in millimeters) of the Doppler measurement site of the LAD distal to the anastomosis was obtained quantitatively from the preoperative coronary angiogram⁷ to calculate the coronary flow (in milliliters/minute): coronary flow = TVI πr^2 heart rate/400. The change of each variable after shunting was also calculated as percentage of baseline value before shunting.

Postoperative Evaluation of Myocardial Damage

All study patients underwent electrocardiographic assessments regarding new ST elevation, loss of R wave progression, and development of new Q waves on each day after OPCAB. In addition, we collected postoperative data on cardiac enzymes, creatine kinase (CK) and its myocardial band (CK-MB).

Statistical Analysis

Continuous variables are presented as means $\pm$ standard deviations and categorical variables are presented as frequencies and percentages. The paired data before and after shunting were assessed using Wilcoxon's signed rank test. All statistical analyses were performed with StatView 5.0 (Abacus Concepts Inc, Berkeley, Calif).

RESULTS

The study patients underwent OPCAB with mean anastomoses per patient of 2.9 ± 0.8 . The LAD was grafted with the in situ left ITA in 11 patients (37%) and with the in situ right ITA in 19 patients (63%). With the ITA grafts, the right gastroepiploic artery and saphenous vein were used in 17 (57%) and 2 (7%) patients, respectively. All patients survived and no patients developed significant electrocardiographic changes after OPCAB. The peak values of postoperative CK and CK-MB were 670 ± 290 IU/L and 17 ± 16 IU/L, respectively. The resultant peak ratio of CK:CK-MB was $2.9\% \pm 2.2\%$.

Figure 1 shows representative Doppler flow profiles before and after inserting a shunt in a 69-year-old woman who underwent off-pump grafting of the right ITA to the LAD using a coronary shunt as well as anastomoses of the left circumflex artery with the left ITA and posterior descending artery with the gastroepiploic artery. In all study patients, all Doppler flow parameters of the LAD decreased significantly after shunting, as shown in Table 2 (peak velocity from 71.3 ± 34.6 to 54.5 ± 25.3 cm/second [$P = .004$], mean velocity from 33.3 ± 18.3 to 26.3 ± 14.0 cm/second [$P = .006$], and TVI from 28.7 ± 12.1 cm to 19.0 ± 7.1 cm [$P = .005$]). The changes of these parameters were peak velocity $-24\% \pm 27\%$, mean velocity $-21\% \pm 23\%$, and TVI $-28\% \pm 14\%$, respectively. Based on the measured diameter (1.84 ± 0.12 mm) of the LAD on the preoperative coronary angiogram, the estimated LAD flow decreased significantly from 38.7 ± 16.8

FIGURE 1. Intraoperative recordings of Doppler flow measurement of the left anterior descending (LAD) artery before and after shunting with a 1.5-mm Anastasflow shunt (Edwards Lifesciences LLC, Irvine, Calif) in a 69-year-old woman who underwent off-pump grafting of the right internal thoracic artery to the LAD artery. The Doppler flow parameters changed significantly after shunting: peak velocity 62 cm/second to 57 cm/second, mean velocity 28 cm/second to 24 cm/second, and time-velocity integral (shown by the dotted area) 33 cm to 19 cm. HR, Heart rate; BPM, beats per minute; ECG, electrocardiogram.

mL/minute to 25.0 ± 9.5 mL/minute after shunting ($P = .003$), a change of $-31\% \pm 13\%$.

DISCUSSION

The principal finding of our observational study was that the LAD flow was preserved at least 50% through a 1.5-mm intracoronary shunt, although the flow pattern was

attenuated, during OPCAB anastomosis. This is the first report of the direct measurement of the LAD flow through the shunt in a clinical setting.

We routinely use the shunt for revascularization of the LAD and proximal RCA for the following reasons. First, the LAD is the key coronary artery affecting a patient's long-term prognosis; second, the LAD is the first vessel to

TABLE 2. Changes of determinants of intraoperative Doppler flow measurement before and after shunting of the left anterior descending artery during off-pump coronary artery bypass

	Before shunting	After shunting	Change (%)	P value
Vmean (cm/s)	33.3 ± 18.3	26.3 ± 14.0	-21 ± 23	.006
Vmax (cm/s)	71.3 ± 34.6	54.5 ± 25.3	-24 ± 27	.004
TVI (cm)	28.7 ± 12.1	19.0 ± 7.1	-28 ± 14	.005
Q (mL/min)	38.7 ± 16.8	25.0 ± 9.5	-31 ± 13	.003

Vmean, Mean velocity; Vmax, peak velocity; TVI, time-velocity integral; Q, estimated left anterior descending artery flow calculated as $TVI \pi r^2 \text{ heart rate}/400$ using the diameter on the preoperative coronary angiogram.

revascularize during OPCAB in our institute; third, ischemia of the proximal RCA is empirically known to induce arrhythmia, including atrioventricular block; and fourth, the left circumflex artery and distal RCA are technically more difficult for the insertion of the shunt with higher risk of endothelial denudation.

Studies designed to measure the flow through an intracoronary shunt seem to be difficult to perform.¹ In our study, we applied a 7.5-MHz Doppler flow probe as a new modality for measuring regional blood flow distal to the shunt insertion at real time in a clinical setting. A Doppler spectrum of the blood flow through a coronary artery yields a curve that has velocity (in centimeters/second) on the y axis and time (in seconds) on the x axis, as shown in Figure 1. When this curve is integrated, it yields a TVI in centimeters. It indicates the distance the blood travels during a certain cardiac circle. Because the product of TVI (in centimeters) and cross-sectional area of the coronary artery (in centimeters²) will yield volume (in centimeters³), the coronary blood flow is directly proportional to the Doppler TVI. In our study, TVI is the appropriate variable to compare the LAD flow before and after shunting because we placed the Doppler probe on the same surface of the LAD and, therefore, the cross-sectional area was the same before and after shunting.

Kamiya and colleagues⁸ investigated the efficacy of the shunt in a theoretical model. Based on the assumption that blood would be a Newtonian fluid, they found that coronary flow decreases to 2% to 14% after shunting in turbulent flow. They also showed, in a porcine model, that myocardial blood flow decreased to 33% in the endocardium after shunting.⁹ Muraki and colleagues, in a different model, showed a fall in the regional blood flow to 30% of baseline.¹⁰ These data have promoted attempts to provide distal perfusion during OPCAB using a passive external shunt from the femoral artery or the aorta,¹¹ perfusion-assisted direct coronary artery bypass using femoral cannulation,¹²⁻¹⁴ and coronary active perfusion system synchronized with the heartbeat with 15 mL/minute of pulsatile flow.^{15,16} However, there have been no data comparing these perfusion methods and the intracoronary shunt.

In contrast with previous studies, we herein report more preserved flow (approximately 50% to 70% of baseline) through the shunt in a clinical setting. Our finding may

support the minimal biochemical or electrocardiographic evidence of ischemia during OPCAB with the use of a shunt, as shown in our study. Our results coincide with the previous finding by Grünenfelder and colleagues¹⁷ investigating the pressure–flow relationships of shunts in an in vitro model. They showed that at a pressure of 75 mm Hg, the flow through a 1.5-mm shunt was 40 mL/minute. Under hypotensive conditions (ie, blood pressure 40 mm Hg), flows dropped to 50% of baseline in a shunt smaller than 2 mm. They concluded that at a pressure of 75 mm Hg, a 1.5- to 2-mm shunt may provide adequate myocardial protection.

The first limitation of our study is its limited sample size. The second limitation is the varied deviation in the changes of Doppler profiles after shunting. Coronary flow through a shunt is affected by several factors, including cardiac function, myocardial flow demand, and the degree of coronary lesions. We need further investigations regarding these contributing factors to the changes of Doppler profiles after shunting. The third limitation is the lack of angularity correction of Doppler beam. In Doppler examination, cosine theta is applied as a correction for the angle between the ultrasound beam and the direction of blood flow. In our study, the Doppler beam was rather perpendicular to the LAD. Therefore, the cosine theta was approximately 0 and the flow velocity and consequently the TVI and LAD flow would be underestimated. However, such angularity correction of Doppler beam is not important to compare the Doppler profiles before and after shunting at the same angle of beam to the same surface of the LAD. The fourth limitation is a concern of mechanical endothelial denudation leading to endothelial dysfunction when a shunt is used.¹⁸⁻²² Histologic investigation revealed that insertion of shunts led to endothelial denudation with collagen fibers exposed to blood flow and sometimes determined catastrophic endothelial damage in the presence of diffuse calcified atherosclerosis.²⁰ The loss of endothelial cell coverage and regenerated endothelium might accelerate vasospasm and atherosclerosis process. The fifth limitation is that the cardiac enzyme information reflects the cumulative ischemia imposed by a variable number of graft anastomoses performed in the patients, in whom some vessels were not shunted.

CONCLUSIONS

The LAD flow is preserved at least 50% through a 1.5-mm intracoronary shunt, although the flow pattern was attenuated, during OPCAB anastomosis. The Doppler evaluation of the coronary artery flow before and after shunting, as shown in our study, is clinically useful to justify the protective effects of the use of the shunt on myocardial perfusion during OPCAB. It also provides quick objective information of the distal perfusion to the anastomosis before hemodynamic, electrocardiographic, and transesophageal echocardiographic changes may occur.

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