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Perfusion Flow Assessment of Coronary Shunt during Off-Pump Coronary Artery Bypass Grafting

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ABSTRACT

Background: Coronary shunts are widely used to prevent myocardial ischemia during off-pump coronary artery bypass graft (OPCAB) procedures. Although clinical effectiveness has been reported, actual perfusion flow has not been well assessed. The purpose of this study was to evaluate actual shunt flow and its pattern during passive coronary perfusion in clinical OPCAB.

Methods: In 15 OPCAB cases, the coronary perfusion flow of the external shunt (1.7 or 2.0 mm) during anastomosis and the free flow of the shunt were measured with an in-line electromagnetic or ultrasonic flow probe. The perfused coronary blood vessel was either the left anterior descending coronary artery or the right coronary artery. The inflow vessel of the external shunt was either the femoral artery (FA) or the ascending aorta (AA).

Results: Free flow values of a 1.7-mm FA shunt, 1.7-mm AA shunt, and 2.0-mm FA shunt were 34 ± 7, 39 ± 3, and 44 ± 7 mL/min. Perfusion flows were 13 ± 4, 14 ± 3, and 22 ± 4 mL/min, respectively. Perfusion flow was significantly lower than free flow and correlated well with coronary resistance. Although inflow site did not influence net perfusion flow, diastolic/systolic flow fraction ratio was significantly greater when the shunt was perfused from the FA.

Conclusions: External shunt from FA would provide limited but effective perfusion flow with a physiological pattern, which is passively regulated by coronary resistance.

INTRODUCTION

Because the feasibility of off-pump coronary artery bypass graft (OPCAB) procedures has been well demonstrated, the operation is becoming increasingly popular worldwide. There is general agreement that OPCAB is more advantageous than conventional coronary artery bypass grafting with cardiopulmonary bypass in terms of reduced transfusion requirement, reduced myocardial injury, shorter hospital stay, and reduced morbidity and mortality in high-risk patients (Ascione 2001, Dijk 2001, Güler 2001, Bittner 2002, Lee 2003). Various types of devices make it possible to perform OPCAB procedures with nearly complete revascularization. However, OPCAB procedures sometimes have resulted in significant hemodynamic deterioration caused by the myocardial ischemic insult due to snaring of the coronary arteries during construction of distal anastomoses. To prevent regional myocardial ischemia during temporary occlusion, some surgeons use intraluminal shunts. We previously developed an external shunt system for distal coronary perfusion and used it in clinical cases (Arai 2000). Whether the shunt is intraluminal or external, blood is passively perfused through it depending on inflow blood pressure and distal coronary resistance. Although clinical and experimental effectiveness of shunts has been reported (Levinson 1995, Borges 1997, Rivetti 1997, Malkowski 1998, Rivetti 1998, Aarnheim 1999, Dapunt 1999, Lucchetti 1999, Arai 2000, Menon 2002, Ohtuka 2002, Yeatman 2002), quantitative assessment of actual perfusion flow rate during anastomosis has not been well demonstrated.

The purpose of the present study was to evaluate shunt flow both quantitatively and qualitatively during passive coronary perfusion in clinical OPCAB procedures.

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MATERIALS AND METHODS

Patients

The subjects were 15 patients ranging in age from 43 to 78 years (mean age, 67 ± 10 years) who underwent OPCAB in which an external shunt was used for left anterior descending artery (LAD) and/or right coronary artery (RCA) with quantitative flow rate measurement during perfusion. An average of 3.3 ± 1 (range, 1-5) distal coronary grafts per patient were constructed.

External Shunt System

An external shunt tube was used as the coronary perfusion catheter (Sumitomo Bakelite, Tokyo, Japan) (Figure 1). This perfusion catheter is made of polyurethane. The length is 30 cm, and the outer diameter is 2.5 mm. The distal end of

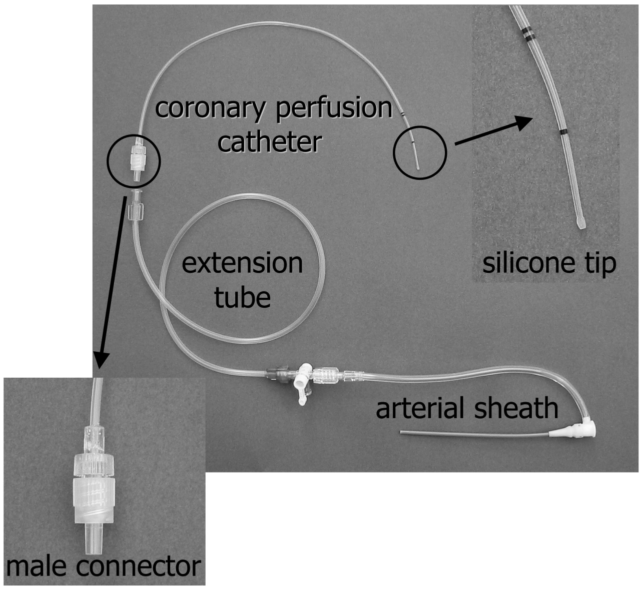

Figure 1. The external shunt system consists of a coronary perfusion catheter (Sumitomo Bakelite, Tokyo, Japan), extension tube (50 cm long), and 6F femoral arterial sheath (Clinical Supply, Gifu, Japan). A small silicone tip (1.4, 1.7, or 2.0 mm) is attached to the distal end of the catheter. The proximal end of the catheter is designed as a male connector. The diameter of the side arm of the arterial sheath is designed to be 5 mm to obtain sufficient flow.

the perfusion catheter is tapered to 1.0, 1.2, or 1.6 mm outer diameter. A small silicone tip is attached to the distal end of the catheter. The outer diameter of the tip is 1.4, 1.7, or 2.0 mm. The proximal end of the catheter is designed as a male connector. To obtain arterial blood from the femoral artery (FA), the catheter is connected to an extension tube (50 cm long) and to the 3-way stopcock of the side branch of the 6F FA sheath (Clinical Supply, Gifu, Japan). The diameter of the side arm of the arterial sheath is designed to be 5 mm to obtain sufficient flow.

Flow Measurement and Analysis

In this study, either FA or ascending aorta (AA) was used for the inflow of the perfusion catheter, and shunt flow was assessed (Figure 2).

In the FA inflow group, the shunt was connected to the FA sheath interposed with the extension tube. The in-line electromagnetic flow probe (Nihon-Kohden, Tokyo, Japan) was connected to the extension tube. Eleven LADs were revascularized with left internal thoracic artery (LITA) during distal perfusion with a 1.7-mm shunt. Five midportions of the right coronary artery (RCA) were revascularized with either right internal thoracic artery or saphenous vein graft (SVG) with a 2.0-mm shunt. In the AA inflow group, the shunt was connected to the SVG, which was anastomosed in advance to the AA with a bypass system aortic connector (Symmetry; St. Jude Medical, St. Paul, MN, USA). An ultrasonic flow probe (Transonic Systems, Ithaca, NY, USA) was externally applied to the SVG. Three LADs were revascularized with LITA, and the SVG was anastomosed to another coronary lesion (ie, left circumflex artery or distal RCA).

The free flow and perfusion flow rates were measured every 5 minutes during anastomosis, up to 15 minutes. The ratio between diastolic and systolic flow fraction (diastolic flow/systolic flow) was calculated by measuring the area of each flow fraction of actual flow waveform with Image software (Scion, Frederick, MD, USA) (Figure 3). The inflow pressure (mm Hg) also was measured. Coronary resistance was defined as the value of mean inflow pressure divided by perfusion flow rate. The measured flow data were divided into 3 groups according to inflow site and shunt size (FA 1.7 mm, AA 1.7 mm, and FA 2.0 mm) and compared.

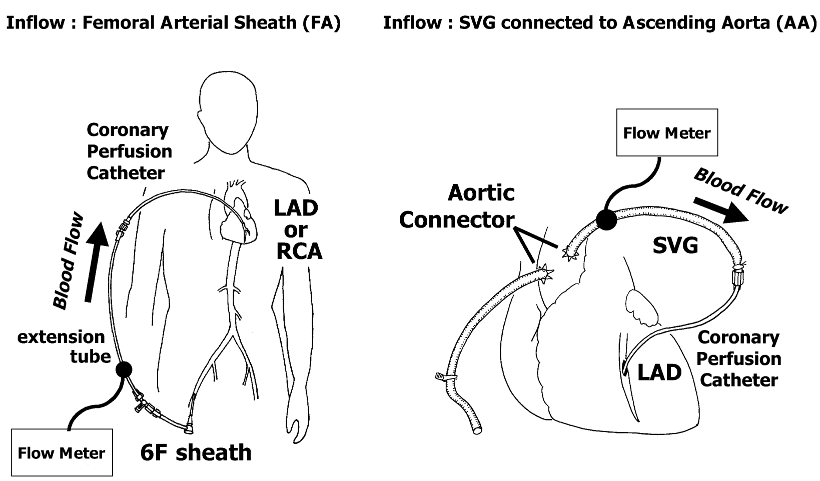

Figure 2. In the femoral arterial (FA) inflow group, the shunt was connected to the FA sheath interposed with the extension tube. The in-line electromagnetic flow probe (Nihon-Kohden, Tokyo, Japan) was connected to the extension tube. In the ascending aortic (AA) inflow group, the shunt was connected to the saphenous vein graft (SVG), which was anastomosed in advance to the AA with a bypass system aortic connector (Symmetry; St. Jude Medical, St. Paul, MN, USA). The ultrasonic flow probe (Transonic Systems, Ithaca, NY, USA) was externally applied to the SVG. LAD indicates left anterior descending coronary artery; RCA, right coronary artery.

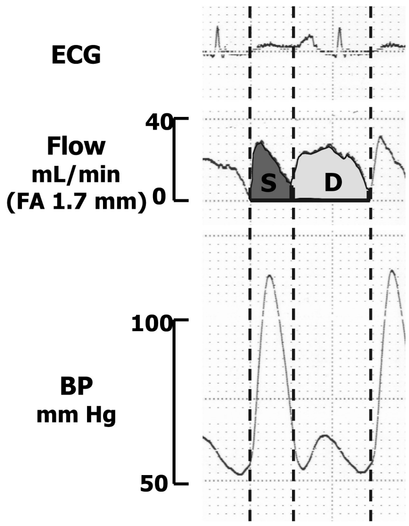

Figure 3. Typical flow waveform during perfusion. Diastolic (D)/systolic (S) flow fraction ratio was calculated by measuring the area of each flow fraction of actual flow waveform. ECG indicates electrocardiogram; FA, femoral artery; BP, blood pressure.

Statistical Analysis

All values are expressed as mean ± SD. Comparison of data was performed by analysis of variance with the Scheffé test. Statistical correlation of variables was assessed by linear regression analysis. A *P* value less than .05 was considered statistically significant.

RESULTS

Shunt Flow

The flow data recorded in each of the study groups are summarized in the Table. Both free flow and perfusion flow of 2.0-mm shunts were higher than those of 1.7-mm shunts. In 1.7-mm shunts, both free flow and perfusion flow showed no significant difference between FA and AA inflow. However, in 1.7-mm shunts, diastolic/systolic flow fraction ratio was significantly higher in FA inflow.

Perfusion flow was significantly lower than free flow in each group. Shunt flow did not show any significant change during the course of distal perfusion in each group (Figure 4). Although it did not correlate with inflow pressure, perfusion flow did correlate significantly with coronary resistance (Figures 5 and 6).

Shunt Efficacy

Prior to shunt insertion, all coronary arteries were test clamped for a few minutes for evaluation of ischemic change due to coronary occlusion. In 6 of 14 LADs and all RCAs test clamped, ischemic change (ie, ST alteration and/or T inversion in electrocardiogram [ECG]) was observed. After establishment of coronary perfusion, ischemic change was improved in all cases except 1 RCA case. In that case, although coronary perfusion (23-26 mL/min) did not relieve ST-T alteration, further ischemic change was not observed, and hemodynamics were maintained stable during perfusion lasting 18 minutes.

DISCUSSION

In most OPCAB procedures, because of the presence of sufficient collateral circulation, temporary coronary occlusion during anastomosis is tolerable without signs of major ischemia and without affecting hemodynamics. However, both subclinical ECG alterations (ST-segment elevation, arrhythmias) and reduction of myocardial contractility documented with transesophageal echocardiography following temporary occlusion in OPCAB have been reported to occur in as many as 40% of cases (Malkowski 1998, Dapunt 1999). Sometimes such myocardial ischemia can lead to hemodynamic deterioration, mostly in cases of occlusion of the midportion of the RCA or large LAD with moderate stenosis. The shunt has been reported to be most effective for prompt restoration of regional myocardial ischemia; thus conversion to cardiopulmonary bypass can be avoided.

The benefits of shunt insertion have been demonstrated clinically and experimentally as better prevention of regional left ventricular dysfunction and preservation of myocardial energy sources (Dapunt 1999, Lucchetti 1999, Menon 2002, Yeatman 2002). Other technical advantages of shunt insertion are that the shunt allows unhurried anastomosis, reduces bleeding in the surgical field, and protects the posterior wall of the coronary artery from errors in suturing (Rivetti 1998).

Despite these clinical and experimental demonstrations of intraluminal shunt efficacy, quantitative assessment of perfusion flow has not been done, probably because of difficulty in setting up a flow probe directly into the intraluminal shunt. In the present study, we successfully measured the perfusion flow of external shunts during perfusion in the clinical setting.

The free flow of 34 to 39 mL/min in 1.7-mm shunts and 44 mL/min in 2.0-mm shunts seemed sufficient. However, an extreme difference between free flow and perfusion flow was observed. Perfusion flow was limited to 13 to 14 mL/min in 1.7-mm shunts (LAD position) and 22 mL/min in 2.0-mm

Flow Data*

No. of subjects	11	3	5
Shunt size, mm	1.7	1.7	2.0
Coronary vessel perfused	LAD	LAD	RCA
Inflow	FA	AA	FA
Free flow, mL/min	34 ± 7†	39 ± 3	44 ± 7
Perfusion flow, mL/min	13 ± 4‡	14 ± 3§	22 ± 4
Diastolic/systolic flow ratio	1.67 ± 0.38‖	0.55 ± 0.39	2.02 ± 0.74¶

*Data expressed mean ± SD. LAD indicates left anterior descending coronary artery; RCA, right coronary artery; FA, femoral arterial; AA, ascending aortic.

†*P* = .035 FA 1.7 versus FA 2.0.

‡*P* < .0001 FA 1.7 versus FA 2.0.

§*P* < .0001 AA 1.7 versus FA 2.0.

‖*P* = .01 FA 1.7 versus AA 1.7.

¶*P* = .003 AA 1.7 versus FA 2.0.

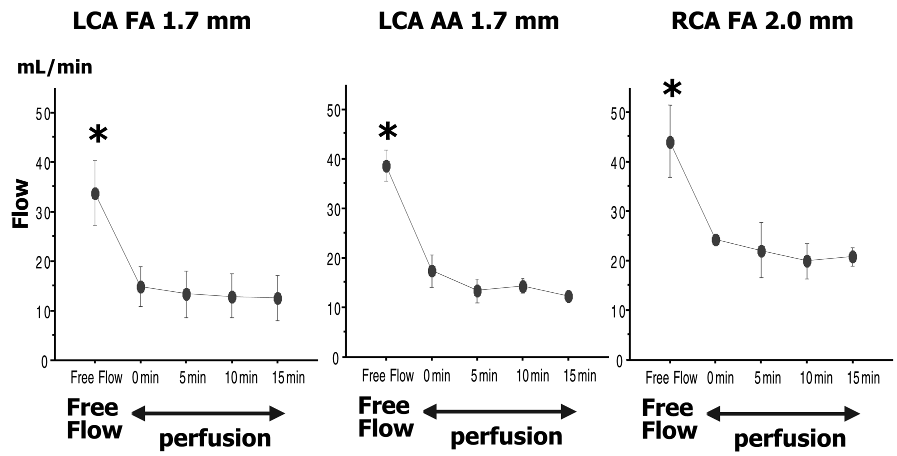

Figure 4. Results of the free flow and change in shunt flow rate during perfusion (*). Free flow was significantly higher than perfusion flow in each group ($P < .0001$). Shunt flow did not show any significant change during distal perfusion in each group. LCA indicates left coronary artery; FA, femoral arterial; AA, ascending aortic; RCA, right coronary artery.

shunts (RCA position). Even with such limited flow, ECG alterations due to temporary coronary occlusion were completely improved in LAD and mostly improved in RCA without leading to critical ischemia. We suspect the cause of this flow difference was distal coronary resistance.

In another in vitro study, we demonstrated linear correlation between the free flow of the shunt and the inflow pressure (unpublished data). However, the present study showed that the perfusion flow of the shunt did not correlate with inflow pressure but correlated well with coronary resistance. This outcome occurred because of the limited flow during systole due to high systolic coronary resistance. Whether the shunt is intraluminal or external, blood flow through the shunt is passively determined by distal coronary resistance, provided the inflow pressure is sufficient.

Various intraluminal shunts recently have become commercially available, and most surgeons probably use intraluminal shunts rather than external shunts. However, intraluminal shunts require insertion of both ends through limited arteriotomy, which is sometimes troublesome. There exists concern about possible endothelial injury related to inadvertent insertion.

Compared with the intraluminal shunt, the external shunt has the following advantages. The insertion and withdrawal technique is extremely simple because proximal insertion is not necessary. The external shunt is easily inserted even in the middle of an anastomosis in case of unexpectedly troublesome suturing, which leads to longer anastomotic time and myocardial ischemia. The external shunt has no threaded tab, which is usually attached to the intraluminal shunt and sometimes becomes entangled in suture material.

The external shunt system that we developed was designed to perfuse arterial blood to coronary arteries from an FA sheath. We chose the FA rather than the aorta for inflow of blood to avoid possible cerebral embolism related to insertion of the arterial sheath into the aorta. Surgeons may not be willing to do the extra procedure of FA sheath insertion. However, this procedure is quite simple. The FA sheath can

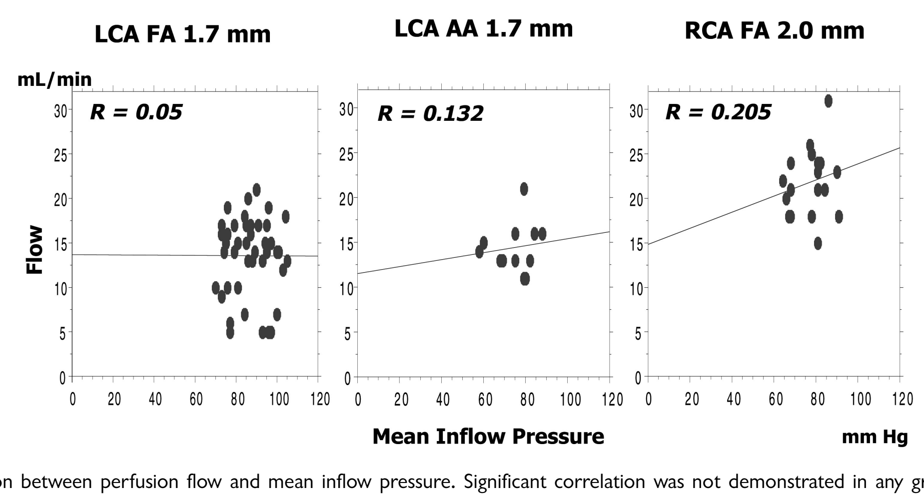

Figure 5. Correlation between perfusion flow and mean inflow pressure. Significant correlation was not demonstrated in any group. LCA indicates left coronary artery; FA, femoral arterial; AA, ascending aortic; RCA, right coronary artery.

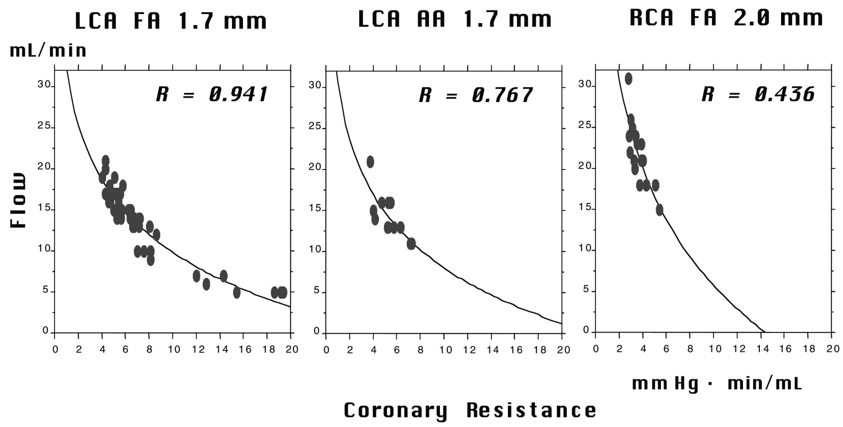

Figure 6. Correlation between perfusion flow and coronary resistance. Significant correlation was demonstrated in each group. LCA indicates left coronary artery; FA, femoral arterial; AA, ascending aortic; RCA, right coronary artery.

be helpful for inserting an arterial cannula in case of emergency conversion to cardiopulmonary bypass; thus the sheath can work as a safety net for OPCAB. However, there remains concern that perfusion flow may be diminished owing to the circuit resistance of a long tract from the FA, so the AA may be better as an inflow site (Ohtuka 2002). The data obtained in our study clearly demonstrated that FA inflow provides not only the same perfusion flow rate as AA inflow but also has a more physiological flow pattern. Although it is not clear why diastolic flow fraction is better preserved in FA inflow, we suspect one reason is that delay of blood transmission through the long tract of the shunt circuit may cause partial transfer of systolic blood during the diastolic phase of low coronary resistance.

In conclusion, this study demonstrated that an external shunt from the FA provides limited but effective perfusion flow with a relatively physiological pattern during distal anastomosis in OPCAB procedures. Perfusion flow was lower than free flow and was passively regulated by distal coronary resistance.

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