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Validation of Intracoronary Shunt Flow Measurements for Off-Pump Coronary Artery Bypass Operations

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ABSTRACT

Introduction: Intracoronary shunting is a useful, easy and inexpensive technique to maintain blood flow during off-pump surgery to lessen myocardial ischemia. Intracoronary shunts should provide a minimal flow for adequate myocardial protection.

Material and Methods: Two commercially available shunts were used to measure flow from a bulb-size diameter of 1.00 mm to 3.00 mm (n = 10) in an in vitro setup. Shunts were perfused with Glycerin 47% solution at 37°C. Inlet pressure was raised continuously from 0 to 160 mmHg in all intracoronary shunts.

Results: In both groups (recipients of either type A shunt or type B shunt), mean pressure of 40 mmHg was necessary in shunts with diameter of 3.0 mm to provide a flow of approximately 50 mL/min. At mean pressure of 100 mmHg, a maximum flow of 126 mL/min was measured. Shunt B of 2.5-mm and 3.0-mm diameter showed similar flow patterns: 50 versus 52 mL/min at 40 mmHg and 98 versus 108 mL/min at 100 mmHg. Shunt A at 2.5-mm diameter showed 37 mL/min at 40 mmHg and 80 mL/min at 100 mmHg (P = .01). Shunt B at 1.5-mm diameter required 75 mmHg for approximately 40mL/min and showed maximum flow of 51 mL/min at 100 mmHg (P < .001). Only minimal flow was measured in 1.0-mm shunts of both groups.

Conclusions: There is a clear pressure/flow correlation in 2.0-mm to 3.0-mm shunts with maximum flow of 126 mL/min. Type B shunt of 1.5-mm and 2.5-mm diameter showed significant better flow rates. The possible value of 1.0-mm shunts is only in stenting and facilitating anastomosis and to obtain better visibility during anastomosis.

INTRODUCTION

Although the majority of coronary artery bypass grafting (CABG) procedures are performed with the use of cardiopulmonary bypass (CPB) and cardioplegia, systemic and hematologic effects of extracorporeal circulation (ECC) are complications in postoperative patients. Neurologic events, coagulopathy, inflammatory reactions, vascular complications, aortic trauma, atheroemboli, vasomotor changes, and other side effects are at least partially caused by ECC. Even though this technology has been well established within cardiothoracic surgery, the necessity of this technique for every revascularization procedure is questioned due to the possible complications. The technique of off-pump coronary artery bypass grafting (OPCAB) as an alternative to CABG with ECC is not a new method and was described as early as the late 1960s [Kolessov 1967].

In 1975, Trapp and Bisarya were the first to describe the use of a temporary intraluminal shunt to facilitate the construction of coronary grafts without ECC [Trapp 1975], but their technique did not become widely accepted.

In the past few years the off-pump CABG technique has been revitalized. Pfister et al described a reduction in hospital morbidity and mortality in elderly patients when OPCAB was performed compared to historical controls operated on with ECC [Pfister 1992]. Further, a reduced number of blood transfusions and less incidence of low output syndrome were described in the group of patients receiving OPCAB compared to operations performed with ECC [Pfister 1992]. Rivetti and Gandra reported on the use of an intraluminal shunt during revascularization of the beating heart, showing that the complication rate did not differ from those reported by others using CPB [Rivette 1997], emphasizing the advantages of intraluminal shunting such as reducing the degree of myocardial ischemia [Franzone 1977, Rivetti 1997], maintaining the operating field blood-free, improving the visualization of the anastomotic site and preventing suture mishaps, compared to OPCAP procedures without use of intraluminal shunting [Rivetti 1997].

Intracoronary shunting seems to be a useful, easy, and inexpensive technique for maintaining blood flow during off-pump bypass surgery. According to several studies, the shunt should provide a minimal required flow of 40 to 60 mL/min, depending on the mass of supplied myocardium for adequate myocardial protection [de Muinck 1994, Gorge 1994].

The purpose of this experimental study is to measure the flow from 2 commercially available intracoronary shunts with different diameters at different pressures.

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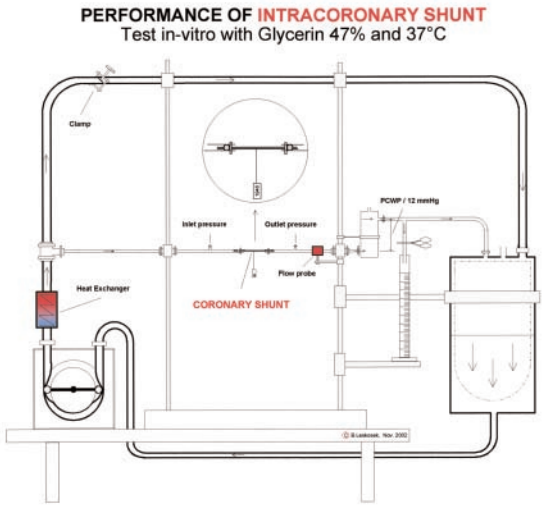

Figure 1. In-vitro setup of flow measurement.

MATERIAL AND METHODS

In Vitro Setting

Two commercially available intracoronary shunt types (type A, Clearview, Medtronic, MN, USA; type B, Axius, Guidant, Santa Clara, CA, USA) were used to measure flow from different bulb-size diameters in an in vitro setting. Type A shunt (n = 5) and type B shunt (n = 5) were used, each with diameters of 1.0 mm, 1.5 mm, 2.0 mm, 2.5 mm, and 3.0 mm. The in vitro setting is shown in Figure 1.

Shunts were perfused with Glycerin 47% solution at 37°C. The inlet pressure was raised continuously from 0 to 160 mmHg in all intracoronary shunts, and the wedge pressure was set at 12 mmHg. A roller pump with a heat exchanger guaranteed the inlet pressure and a stable fluid temperature of 37°C. The flow through the shunts was measured by a transit-time Doppler flow probe (Medi-Stim; AS, Oslo, Norway).

Statistics

The definition of mean value and standard deviation conform to standard use. A *P* value less than .05 indicated statistical significance.

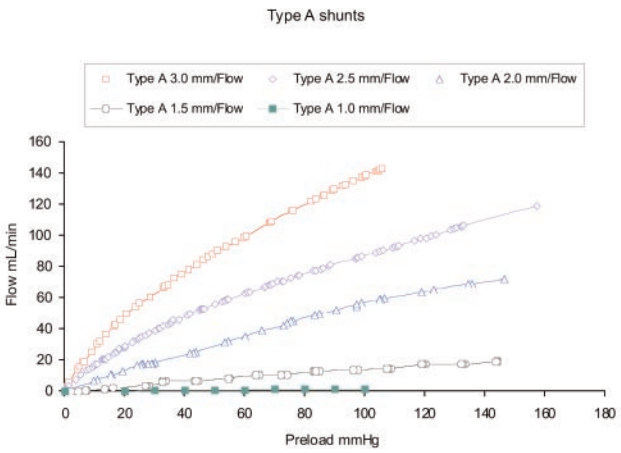

Figure 2. Type A shunt: flow measurements.

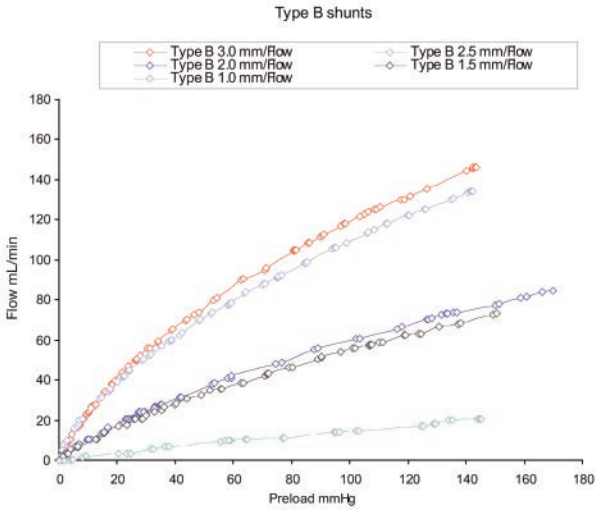

Figure 3. Type B shunt: flow measurements.

RESULTS

The results of flow measurements with type A shunt is shown in Figure 2 and with type B in Figure 3.

A shunt of type B with a diameter of 1.5 mm required 75 mmHg to achieve a flow of 40 mL/min and showed maximum flow of 51 mL/min at 100 mmHg, whereas the flow in a shunt of type A was insufficient at 1.5 mm diameter (<20 mL/min at 100 mmHg, $P < .001$) (Figure 4). Between shunt type A and shunt type B at 2.0 mm there were no significant differences noted, although shunt type B demonstrated approximately 10 mL/min more flow at a mean pressure of 60 mmHg than shunt type A (Figure 5). Shunt type A at 2.5 mm showed 53 mL/min at a mean pressure of 60 mmHg and 80 mL/min at 100 mmHg; these results were significantly lower than shunt type B (Figure 6), which showed 70 mL/min and 98 mL/min, respectively ($P = .01$). Type B shunt at 2.5 mm and 3.0 mm showed similar flow pattern, and we measured approximately 40 mL/min flow at 18 mmHg and 110 mL/min at a mean pressure of 100 mmHg in either size.

The intracoronary shunts with a diameter 3.0 mm showed no significant differences. At a mean pressure of 60 mmHg,

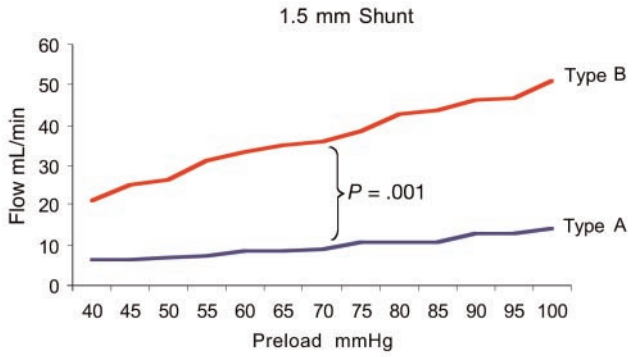

Figure 4. Comparison of type A versus type B shunts with diameter of 1.5 mm.

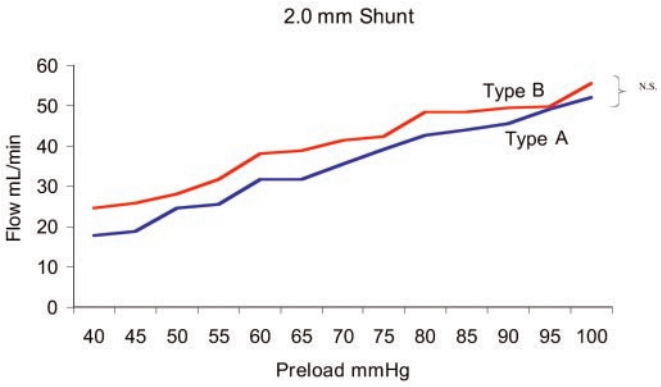

Figure 5. Comparison of type A versus type B shunts with diameter of 2.0 mm.

we measured in type A shunt a flow of 86 mL/min compared to 74 mmHg in type B (Figure 7) under the same conditions. In both groups (types A and B), mean pressure of 18 mmHg was necessary in shunts with diameter of 3.0 mm to provide a flow of 40 mL/min. At mean pressure of 100 mmHg, a maximum flow of 126 mL/min was measured. A diameter of 3.0 mm was the only size in which the type A shunt fared better than type B shunt. Only minimal flow could be measured in shunts of 1.0 mm size of both groups independent of any preload pressure.

Under hypotensive conditions (preload pressure drop from 70 mmHg to 40 mmHg) shunt flow decreased to approximately 50% of baseline flow in shunts of 2.0 mm and smaller and to approximately 70% of baseline flow in shunts of 2.5 mm and bigger. No significant differences were seen between shunt types.

DISCUSSION

Off-pump coronary artery bypass grafting has been revitalized recently. As a refinement of this technique, temporary insertion of intracoronary shunts has been established to lessen the degree of myocardial ischemia and to avoid technical hazards of OPCAB such as blood in the operative field, to improve the visualization of the anastomotic site. In our study we used 2 types of commercially available shunts with different diameters as described above.

There were significant differences in the flow pattern of type A and type B shunts, possibly due to the different constructions and inner diameters of the two shunt types. At a diameter of 1.5 mm to 2.5 mm, the flow of type B shunt was significantly higher under the same conditions than in type A. In 3.0-mm shunts, the results were similar in both types, showing adequate flow (range from 52 mmHg to 126 mmHg) at a pressure from 40 to 100 mmHg; however, shunt A fared slightly better.

There is a clear pressure/flow correlation in 2.0-mm to 3.0-mm shunts with maximum flow of up to 126 ml/min. However, in shunts of smaller sizes only type B showed adequate flow at physiological pressures. The possible value of shunts with a diameter of 1.0 mm is limited to use for stenting and facilitating the anastomosis and for better visibility during the process of anastomosis.

Whether the use of intracoronary shunts is able to preserve myocardial blood flow during off-pump coronary artery bypass surgery, however, is controversial, because in an animal model or computer simulation the interposition of shunts leads to a substantial reduction of blood flow, up to 68% of the baseline value under normotension [Muraki 2002, Yeatman 2002, Kamiya 2003]. Coronary blood flow decreased even further, to approximately 10% of baseline value, if hypotension (mean arterial pressure approximately 35 mmHg) was present [Muraki 2002]. In our study we found that a under hypotension (40 mm Hg) the flow dropped by approximately 50% in shunts of 2-mm diameter and less compared to normotension (70 mm Hg). In shunts of 2.5 mm and 3 mm, the flow drop from normotension to hypotenison was smaller and measured approximately 30%. However, no differences were seen between shunt types. Therefore, we believe that in off-pump surgery intracoronary shunts have the greatest value under normotension and with the use of the biggest sizes possible.

In conclusion, from our in vitro measurements we can establish the hypothesis that temporary insertion of coronary shunts of either type A or type B is a useful tool to lessen myocardial ischemia, if the shunts are ≥2.5 mm in diameter.

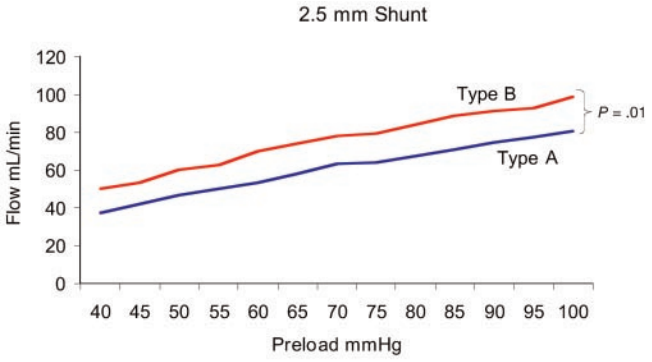

Figure 6. Comparison of type A versus type B shunts with diameter of 2.5 mm.

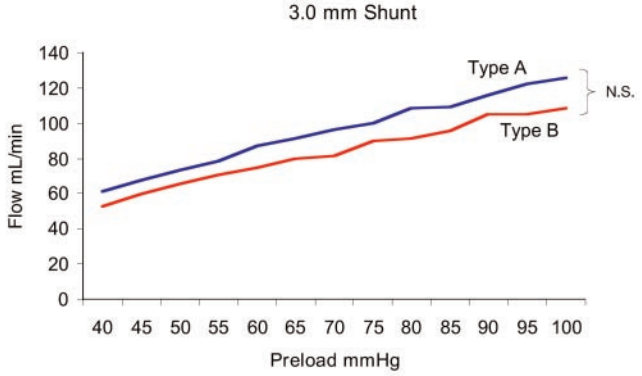

Figure 7. Comparison of type A versus type B shunts with diameter of 3.0 mm.

In sizes smaller than 2.5 mm in diameter, only type B shunts provide sufficient flow. However, in these cases stenting the anastomosis might be the primary reason for the shunt's use.

REFERENCES

de Muinck ED, Verkerke BJ, Rakhorst G, Lie KI. 1994. Myocardial protection during coronary angioplasty with autoperfusion and forced perfusion: an in vitro comparison. Int J Artif Organs 17:83-7.

Franzone AJ, Wallsh E, Stertzer SH, DePasquale NP, Bruno MS. 1977. Reduced incidence of intraoperative myocardial infarction during coronary bypass surgery with use of intracoronary shunt technique. Am J Cardiol 39:1017-20.

Gorge G, Erbel R, Haude M, et al. 1994. Continuous coronary perfusion balloon catheters in coronary dissections after percutaneous transluminal coronary angioplasty. Acute clinical results and 6-months follow-up. Eur Heart J 15:908-14.

Kamiya H, Watanabe G, Kanamori T. 2003. Flow simulation of the intracoronary shunt tube for off-pump coronary artery bypass. Eur J Cardiothorac Surg 23:665-9.

Kolessov VI. 1967. Mammary artery-coronary artery anastomosis as treatment for angina pectoris. J Thorac Cardiovasc Surg 54:535-44.

Muraki S, Morris CD, Budde JM, et al. 2002. Preserved myocardial blood flow and oxygen supply-demand balance with active coronary perfusion during simulated off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg 123:53-62.

Pfister AJ, Zaki MS, Garcia JM, et al. 1992. Coronary artery bypass without cardiopulmonary bypass. Ann Thorac Surg 54:1085-92.

Rivetti LA, Gandra S M. 1997. Initial experience using an intraluminal shunt during revascularization of the beating heart. Ann Thorac Surg 63:1742-7.

Trapp VG, Bisarya R. 1975. Placement of coronary artery bypass graft without pump oxygenator. Ann Thorac Surg 19:1-9.

Yeatman M, Caputo M, Narayan P, et al. 2002. Intracoronary shunts reduce transient intraoperative myocardial dysfunction during off-pump coronary operations. Ann Thorac Surg 73:1411-7.

REVIEW AND COMMENTARY

Editor's Commentary by Mark M. Levinson, MD, Hutchinson Hospital, Hutchinson, Kansas, USA:

The sudden rejuvenation of beating heart coronary grafting has presented a new and younger generation of cardiac surgeons with an old problem: how to perform a microsurgical anastomosis on a moving, bleeding target. For decades, the arrested heart on cardiopulmonary bypass was the international standard, and for many good reasons. A motionless, bloodless field provided a vast opportunity for surgeons of every different level of skill and training to achieve similar results. The arrested heart removed the barriers identified by the pioneers of coronary grafting who attempted the intrepid operation without a bloodless, motionless operative field.

Stabilizers have made a huge difference, leveling the playing field in the minds of surgeons as far as motion is concerned. Stabilizers do not make the coronary entirely motionless, but the reduced motion translation in combination with temporary stability when tissue is held with forceps does permit surgeons enough of a motionless paradigm to perform microsurgery with excellent results.

The remaining three challenges for the OPCAB surgeon then are (1) the incision/exposure, (2) vascular control, and (3) prevention of ischemia. For the sake of this commentary, I will not address the challenges of performing microsurgery through a micro-incision. However, points (2) and (3) are closely interrelated. To recreate the bloodless environment typical of an arrested heart case, local vascular control must be adequate. However, interruption of target vessel blood flow can lead to ischemia. It has been assumed in clinical cases that proximal stenosis from coronary artery disease (CAD) renders this point moot. However, this is not a predictable occurrence. Coronary ischemic events (ST elevation, MI, ventricular ectopy, regional wall motion changes) have been well described as occurring during temporary occlusion of a diseased native human coronary artery during beating heart surgery. It is true that general anesthesia reduces stress levels of circulating catecholamines compared to levels during the awake state, but there is still no question that acute temporary closure of a coronary artery with a tape or sling is an ischemic event.

There is no better laboratory for understanding the pathophysiology of temporary coronary occlusion in humans with coronary artery disease than the modern cardiac catheterization laboratory. Every day, thousands undergo percutaneous interventions which partially duplicate the scenario seen in the OPCAB theater, ie, temporary total occlusion of a stenosed target vessel. For those who remember the days before stenting, the treatment for acute failed PTCA with ischemia was the placement of a perfusion catheter. The original device was invented by Robert Stack at Duke University, and its many permutations have served well in saving countless patients from ischemic deaths on the way to the operating room. The introduction of the Stack catheter was, at its time, a major advance in the safety of coronary angioplasty as it quickly resolved the ischemia typical of an acute closure or dissected coronary artery. When the procedure was followed by immediate surgical revascularization, patients treated with perfusion catheters had much improved survival compared with those in the era before such devices.

The perfusion catheter is nothing more than a small, muliperforate tube that is threaded beyond the occlusion. Like the surgical shunts of today, the perfusion catheter derives its blood supply from the coronary artery or aorta proximal to the occlusion. However, the inner diameter is small and consequently the flows are small. Despite this limitation, the clinical relief of ischemia was usually dramatic, sometimes in desperate situations such as severe EKG changes or frank cardiac arrest.

The clinical experience with the perfusion catheter tantalizes us with a key question. Exactly how much coronary flow is enough flow to abort ischemia? No one can provide an answer to this question, other than to say, "When the ischemia goes away, that is enough flow!" If we follow the lead of our cardiologists, it is apparent that very little flow is still better than no flow. Relief (or prevention) of ischemia may not require very much flow at all. It is possible that as lit-

tle at 10 cc/min is enough to wash out acidosis and/or the harmful metabolites of ischemia, prevent secondary spasm, reduce the need for collaterals to dilate and "steal" from another obstructed bed, etc.

In my personal experience, the same analogy applies to intracoronary shunts. Clamping of a target vessel on the beating heart is definitely an ischemia-producing event. It is frequently tolerated for the 10 minutes needed to suture a distal anastomosis. It is tolerated often enough to give most surgeons a false sense of security that ischemia is "not a problem" and therefore they "don't need shunts." However, there are now several papers proving that subclinical ischemia is frequent during OPCAB conditions.

If the arguments above are accepted, then one must ask (1) do shunts really work, and (2) is it worth using a shunt? There is now ample evidence that shunts do work. They not only reduce arrythmias, reduce ST segment elevation, and reduce hemodynamic instability during cardiac positioning, but also provide a significant measure of secondary benefit when used. These secondary benefits include immediate confirmation of the patency of the anastomosis (when removed), improved vascular control (ie, significant reduction in bleeding), and insurance against back wall or purse-stringing of anastomotic sutures. The answer to the second question is up to each individual surgeon. In my practice, shunts are definitely worth using, for the reasons described.

The authors provide flow data on 2 commercial shunts. They do not provide statistical comparisons between them, but the main point of the authors is not missed. Both shunts provide more than enough flow. Fifty milliliters per minute is certainly adequate to prevent ischemia. It is no surprise that the flows are pressure dependent. This is a predictable result of the experiment. Intracoronary shunts are passive conduits and nothing more. They cannot recruit flow, just allow it to travel. All conduits have a peak flow. What is more important with this paper is that these commercial shunts achieve more than enough flow at physiologic blood pressures to be useful in preventing or treating ischemia. If the perfusion catheter is our guide, 50 to 100 cc/min of flow should be more than adequate to relieve the surgically induced ischemia.