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Flow Measurement in Coronary Surgery

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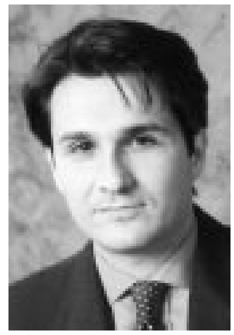

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ABSTRACT

Background: Many of the modern less invasive approaches to coronary artery bypass grafting (CABG) are performed without the use of the heart lung machine and cardiac asystole. Even after the introduction of mechanical stabilizers, the ability to achieve a technically perfect anastomosis is less certain in beating heart bypass surgery. Our group has begun to assess the surgical results of beating heart CABG using Transit Time Flow Measurement (TTFM). Our experience indicates that a meticulous and controlled method of assessing the results of intraoperative flow measurements can improve the quality of information and increases the accuracy of diagnosing technical problems with newly constructed bypass grafts. For this reason, we developed a standard algorithm for using and interpreting intraoperative TTFM.

Methods: From January to August of 1998, 161 patients underwent off-pump CABG with a total of 323 distal anastomoses (2.0 grafts per patient). All completed grafts were tested intraoperatively with TTFM and the decision to accept or revise any individual graft was based on a decision nomogram using key values readily available from the TTFM output.

Results: Thirty-two grafts (9.9%) were surgically revised based on unsatisfactory flow curves, the Pulsatile Index, or both. All revised grafts were found to have a significant technical error, such as an intimal flap, thrombus, conduit kinking, or dissection. There were no major complications, myocardial infarctions, or deaths in the entire series of patients.

Conclusions: Based on our favorable use of TTFM, we strongly recommend that patency of every graft be assessed whether the operation is performed off pump or on cardiopulmonary bypass. Guidelines for performing and interpreting TTFM ensure a high degree of confidence in the completed graft. The decision to revise a graft can be made based on simple parameters easily acquired from the TTFM device. Any concern about quality or quantity of flow should prompt immediate revision.

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INTRODUCTION

Our group has established a new standard for performing coronary artery bypass grafting without the use of heart lung support in the majority of our current patient referral group [Bergsland 1998]. We have previously reported on the results of 505 patients undergoing transternal multivessel off-pump coronary artery bypass (OPCAB) as compared to a historical control group of 2,869 patients operated with traditional hear-lung bypass and cardioplegia [Bergsland 1998]. Our initial results indicated that complications were fewer in the OPCAB group despite a greater number of redos, calcified ascending aortas, and immunocompromised patients when compared with the traditional group.

To ensure quality of the anastomosis in beating heart surgery, we have investigated the use of a specific flow-measurement device and a set of information parameters yielded by analysis of the flow curves. Transit time flow measurement (TTFM) is a new doppler-based technology that improves the accuracy of graft flow measurement and yields real-time waveforms of graft flow [Lausten 1996]. The use of the MediStim BF2004 transit-time flow meter has improved our surgical results by early detection of graft problems allowing immediate intraoperative revision.

Our experience with this technology in several hundred patients confirms our premise that off pump coronary revascularization can be performed safely with excellent intraoperative patency rates. This manuscript describes our intraoperative experience with TTFM in our most recent cohort of OPCAB patients.

MATERIALS AND METHODS

From January 1998 to August 1998, 161 patients underwent coronary revascularization without the use of the heart lung machine. A total of 323 distal anastomoses were created using saphenous vein and left internal mammary artery (LIMA) conduits, for a mean of 2.0 grafts per patient. There were 183 grafts to the anterior wall (left anterior descending and diagonal), 60 to the lateral wall (circumflex or marginal), 75 to the posterior wall (right coronary artery or posterior descending) and 5 to other minor coronary branches.

The MediStim Butterfly Model BF 2004 transit time flow meter (MediStim AS, Oslo, Norway) was used for assessment of every graft prior to closure of the chest. A standard algorithm for performance of the measurement, for quantitative analysis, and for waveform interpretation was developed and applied to each case.

Surgical Technique:

Once the target vessel was identified, a 4-0 pledgetted Prolene® suture is used to snare the coronary artery proximally. After 3 minutes of ischemic preconditioning, the snare was released and the coronary stabilizer put into place at the target site chosen for revascularization. After the arteriotomy was made, an intracoronary shunt (CardioThoracic System, Cupertino, CA) was positioned into the vessel lumen and the anastomosis was completed using continuous 7-0 Prolene® suture. The stabilizer was then removed and TTFMs obtained with the snare on and off. Flow values and flow curves were recorded for every graft. All measurements were repeated again prior to chest closure.

RESULTS

We developed a standard algorithm for utilizing intraoperative TTFM data. Since normal flow measurement patterns have not been published, we revised the anastomosis if there was any doubt about its integrity.

The total number of revised grafts was 32 (9.9%): 17 LAD grafts, 7 circumflex or marginal grafts, 7 PDA grafts, and one to an acute marginal branch. At graft revision, six of the 32 explored grafts (18.8%) were found to be completely obstructed. Another nine grafts (28.1%) had minimal stenosis, 12 (37.5%) had an intimal flap or a clot in the native coronary. In five cases (15.6%), the conduit was kinked or a dissection of the LIMA was found.

All patients recovered without acute myocardial infarction. There were no major postoperative complications and no postoperative deaths. All patients are currently alive and symptom free at follow-up.

DISCUSSION

Flow assessment has been used in the past as a method of determining acute intraoperative graft failure Foxworthy et al. published the classic paper on the decision to revise grafts based on intraoperative flow measurement [Foxworthy 1985]. His group used an electromagnetic flow meter to assess every graft by performing maximal vasodilation and recruitment of maximal flow using intragraft injections of 20 mg of papaverine. The average increase in post-papaverine flow was 115% [Foxworthy 1985]. Grafts, which did not demonstrate at least a twofold increase in electromagnetic flow value after papaverine injection, were subject to mechanical probing of the anastomosis. Of the 32 grafts which were probed, 26 improved immediately (to 126% of baseline flow) indicating a minor but correctable problem with the distal anastomosis. If the flow still did not increase, then the grafts were revised.

Most devices used in past decades have been based on electromagnetics. These devices measure the deflection of the magnetic force created by the movement of the iron atoms in the hemoglobin complex. However, many variables affect the accuracy of electromagnetic flows.

Transit time flow measurement is based on the doppler principle. Lausten et al. verified improved accuracy with TTFM when compared with electromagnetic measurements [Lausten 1996]. Other authors have documented the use of the TTFM and doppler methods in cardiac surgery [Van Son 1993, Canver 1994, Louagie 1994, Walpoth 1996].

Our group has also developed a performance algorithm that tests the reactivity of the graft and the distal bed. The proximal snare also allows for detection of technical mistakes. For example, if a stenosis exists at the toe of the anastomosis, flow through the graft will be mainly retrograde and will decrease drastically whenever the proximal coronary snare is applied. If the native coronary has a non-critical lesion, absolute flow measurement may drop after the release of the snare due competition with native vessel flow.

Our practice is to perform TTFMs immediately after the anastomosis is completed and then again, several more times thereafter to detect spasm resulting from manipulation. TTFM readings should be made after removing the stabilizer and releasing all pericardial traction sutures since direct compression or distortion of the coronaries can result in false measurements. Close monitoring of the systemic pressure is also necessary when obtaining readings, especially when arterial grafts are used. Low systemic pressure and manipulation can cause spasm of the graft resulting in decreased absolute flow.

Competition between different grafts may also play a role in TTFM. Competitive flow from adjacent grafts supplying the same territory may affect the TTFM results. For this reason, whenever inadequate flow is measured, we test repeatedly while adjacent grafts are momentarily clamped to eliminate this effect. When venous grafts are used, measurement immediately before chest closure may reveal possible graft kinking.

The size of the probe used to measure flow is important. Only good contact with the flow probe can guarantee an accurate measurement. We utilize three different probe sizes for each case: 2, 2.5 and 3 millimeter. The flow probe should be applied so that the vessel lies within the sensing window and care should be taken not to compress the vessel. In addition, the probe should be exactly perpendicular to a straight, non-curved portion of the graft. Turbulence will decrease the sensitivity of the measurement. For this reason, it is recommended not to place the probe close to a stenosis, side branch or curved segments of the vessel For a pedicled internal mammary artery graft, a section should be skeletonized so that the acoustic window of the probe fits exactly over the IMA to ensure optimal contact. An aqueous gel is used to decrease the space between the probe transducer and the vessel wall, thereby improving contact and reducing interference.

The importance of TTFM for evaluating coronary artery bypass grafts lies in the interpretation of the data. A low value of mean flow is not "per se" an indicator of an inadequate anastomosis. Grafts placed to small or diffusely diseased target vessels may yield low values even with a technically perfect anastomosis. This obligates the surgeon to understand the characteristics of the TTFM waveforms and the meaning of the derived values. When interpreting a TTFM curve, there are some crucial numerical values derived from the flow tracing which are displayed on the accompanying monitor. The mean flow (Q), expressed as milliliters per minute, and The Pulsatile Index (PI) expressed as an absolute number.

The Pulsatile index (PI) is a dynamic parameter obtained by dividing the difference between the maximum and minimum flow by the value of the mean flow. In our experience, the PI should be between one and five. The probability of a technical error in the anastomosis increases for higher PI values.

Understanding the flow curves is also essential to correctly interpreting the clinical significance of these numerical values (see Movie 1). The TTFM curve is pulsatile with a maximum, minimum and a mean flow value (Figure 1 and Movie 1). The minimum flow is the early systolic negative peak normally followed by a large positive diastolic peak (diastolic filling). Typically, flow in a patent coronary graft occurs in diastole. Therefore, only variations from the standard flow curve, together with high PI values and low flow, justify revision.

For example, in Figure 2 (), the flow curve of a LIMA-LAD graft changes drastically after coronary snaring. Flow is reduced to almost zero, the PI increases, and the flow curve shows mainly systolic flow. As the proximal snare is reapplied, retrograde flow is eliminated unmasking a problem with the outflow if the graft. Exploration of the anastomosis revealed a stenosis at the toe.

In Figure 3 (), a saphenous - RCA graft has a flow of only 6ml/min with a PI of 29. The flow curve, with positive systolic peak, is suggestive of a technical mistake. At re-exploration, the graft was found to be kinked. Figure 4 () shows the curve after graft revision.

As noted above, sometimes low-flows are present despite a perfect anastomoses. Figure 5 () shows a TTFM curve obtained from a LIMA - LAD graft where the mean flow is only seven ml/min but the PI and curve morphologies are perfect. This graft was not revised because both the mammary artery and the native coronary artery were very small in caliber.

In conclusion, we have routinely used TTFM in coronary artery bypass surgery to verify patency of every graft prior to chest closure. We have used the same flow equipment for hundreds of patients and developed a standard protocol for testing the completed graft with and without contribution of flow. Interpretation of the values obtained has allowed us to reach a decision whether or not to revise a graft. Based on our findings at revision, we believe this technology accurately diagnoses technical problems with a newly constructed bypass grafts. It should be used to assess every graft; even those created on the arrested heart with the assistance of the heart-lung machine.

In our experience, this device has proven to be very sensitive in detecting highly stenotic anastomoses. At this time, we can not make any comment about its ability to detect lower grade anastomotic stenosis. We believe that improvements in the technology of flow measurement will permit even more sensitive and specific flow-measurement devices. Further investigation and strict follow up studies are strongly encouraged by the present positive results.

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REVIEW AND COMMENTARY

1. Editorial Board Member EK34 writes:

This is an interesting semi-quantitative data on a 10% immediate failure rate. It would have been much better, however, if the authors compared this cohort to a group of on-pump patients with coronary grafts. This is retrospective and would have been a better prospective.

Authors' Response by Giuseppe D'Ancona, MD:

In our institution, TTFM is mainly used for off-pump coronary surgery. We do not have, for this reason, a comparative group for the grafts performed on-pump.

This is a prospective study: flow curves and flow values were read and interpreted at the time of operation following a scheduled and specific protocol.

2. Editorial Board Member SC389 writes:

The authors should expand on and list the advantages of TTFM compared to the doppler and the electromagnetic systems, as this is the essence of the paper. It should also describe in more detail how they maintain quality control and reproducibility of technique, as this measurement seems very operator dependent.

The authors' need a description of how they measure the flow in the lateral and posterior wall vessels with the heart dropped back in to the pericardial well, as it seems that it would be difficult to get there without distortion of the heart.

Authors' Response by Giuseppe D'Ancona, MD:

The TTFM is very accurate and easy to use. The measurements are not operator dependent and the interpretation of the curves is very specific. It gives a direct measurement of the flow differently from the other methods (electromagnetic and doppler), and the measured values and curves do not change with modification in ultrasound angle, blood velocity, or hematocrit.

The flow can be measured at any level in the graft. For this reason, the lateral and posterior grafts are tested very close to the proximal anastomosis without distorting the graft and compressing the heart.

3. Editorial Board Member LO23 writes:

This is an important observation as to the routine measuring of flow. There is, however, no statistical comparison with respect to time or experience of the surgeon as to the detection of reduced flow. The authors mention that multiple measurments should be taken but do not provide any data as to the validity of this statement.

Authors' Response by Giuseppe D'Ancona, MD:

TTFM is easy to use and from the beginning, the interpretation of the curves resulted correct. In our series, all the revised grafts were stenotic, even those evaluated at the beginning of our experience.

Flow values are sensitive to variations in blood pressure, graft spasm due to manipulation and air embolism. For this reason, we suggest reevaluating the flows whenever the first values are not satisfactory. This statement is based on our clinical experience.