The **Heart Surgery**

EDITORIAL

Intraoperative Graft Patency Verification: Should You Trust Your Fingertips?

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The main aim of coronary artery bypass grafting (CABG) is to increase blood flow to ischemic myocardium. Although this procedure is successfully performed in more than several hundred thousand patients per year in the United States, intraoperative graft patency verification is still considered optional in most centers. Grafts are assumed to be patent at the end of the operation, especially if the patient has no hemodynamic compromise and, if cardiopulmonary bypass (CPB) was used, that weaning from it is successful.

In the last decade, measurement of coronary graft flow has been almost abandoned due to the many limitations of this obsolete electromagnetic technique [Kolin 1964]. The increasing popularity of CABG performed on the beating heart without CPB, together with the introduction and improvement of ultrasound-based flow meters such as Doppler and Transit Time Flow Measurement (TTFM; Medi-Stim, Oslo, Norway), has revived some interests and concerns about the importance of intraoperative documentation of graft patency [Canver 1997]. Despite the tremendous improvements offered by the new technology in the field of rheology and flow measurement, a large number of cardiac surgeons are still very skeptical and often misinformed about the applicability and limitations of modern flow meters.

A recent survey conducted on a limited sample of 100 cardiac surgeons and sponsored by an internationally known medical company (Genzyme Surgical Products, Cambridge, MA), has shown some interesting findings about the current graft patency verification practice in the United States. The majority (68.1%) of those interviewed stated that manual palpation of the grafts is their current method to detect graft patency after CABG. More than 70% of the surgeons included had never used a flow meter in their practice. When questioned about the reasons for not using a graft patency verification system, most of the surgeons interviewed answered that flow meters are often difficult to use, interpretation of the findings are unclear, and revision rate is low enough that graft patency verification seems unnecessary. Although most of the surgeons declared that a flow meter is not routinely necessary, interestingly 86% of them stated that it is important to have a system available in the operating room if, in some selected cases, it is necessary. More than 20% of those interviewed recognized the compelling importance of intraoperative graft patency verification. More than 60% of the surgeons recognized the applicability of this technology in both off-pump and on-pump procedures. Thirty-seven percent of those interviewed stated that this technology is only applicable during off-pump procedures because, on pump, the chance of anastomotic mistakes is very low.

The surgeons were then questioned about the action that they would have taken in case of abnormal findings during intraoperative coronary graft-flow measurements. More than 50% of those interviewed stated they would revise the grafts in question. The remaining would either wait or use another method of graft patency verification. When asked about their normal graft revision rate during CABG, 88% of the surgeons declared an error rate of 4% or less with an average rate of 3.1%. The majority of the surgeons stated that poor native vessels were the most common cause of graft revision.

Finally, surgeons placed a dollar value on the ability to accurately measure graft patency intraoperatively. In U.S. dollars, the responses ranged from $0 to $1,000. Although this questionnaire was limited to a small number of surgeons, the findings are very interesting and probably applicable to all cardiac surgeons in the United States.

We began our experience with intraoperative graft patency verification in 1996 to document the feasibility of off-pump CABG. To date, more than 800 patients who have had off-pump surgeries have been tested using intraoperative TTFM and we feel very confident with the features offered by TTFM technology. We understand that graft testing with syringes, fingertips, and direct probing of the anastomoses seem to be more immediate than interpreting a

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flow curve, but this is not always the case. We believe the information given by flow meters may be misleading, especially when the operator does not fully understand the advantages and limitations of the present technology. Often the manufacturers are more interested in selling their product than clarifying its real applicability. Surgeons prefer, for this reason, to rely on their "accurate" tactile sense.

When choosing a flow meter, special features should be evaluated. The measurement must be stable, reproducible, and representative of the real flow within the constructed graft. Flow probes should be user friendly and easy to calibrate. The recorded data should be stored in the flow meter for future analysis and included in the patients' charts for documentation. Much of the skepticism about intraoperative graft patency verification is also based on failure of the electromagnetic technology. Electromagnetic devices measure the intensity of the electromagnetic field generated by the electrically charged red cells (iron bound to hemoglobin) that flow within a vessel. Actual blood flow value is derived from, and is directly proportional to, the intensity of the electromagnetic field generated. This technology has been abandoned and has been recently replaced by ultrasound devices.

The term ultrasound has a generic definition that includes two different methods: Doppler and TTFM. The two systems rely on different properties of the ultrasound waves and, although the Doppler methods have shown good reliability both in vivo and in vitro [Segadal 1982], the TTFM technology offers many important advantages and is the most accurate system for intraoperative verification of coronary graft patency [Lundell 1993, Matre 1994, Laustsen 1996]. TTFM measurements are theoretically independent of internal or external vessel diameter, vessel shape, and Doppler angle. TTFM is also insensitive to the alignment between probe and vessel. The probe does not have to be in direct contact with the vessel and calibration is not necessary. The recordings are stable and data storage and analysis are routinely done. Many of these features are not offered by Doppler technology.

The TTFM device is very easy to use and requires no more than 30 seconds per measurement. Flow-probe size varies from 2 to 32 mm and the size of the flow probes used most frequently in cardiac surgery ranges between 2 and 3.5 mm. The flow probe consists of two small piezoelectric crystals, one upstream and one downstream, mounted on the same side of the vessel. Opposite to the crystals, there is a small metallic reflector. Each crystal produces a wide pulsed ultrasound beam covering the entire vessel width. The probe is connected to a computer that has more than 200 MB of memory and is programmed with software in Microsoft WINDOWS format. Both the amount of time necessary for an ultrasound beam emitted from the upstream crystal to arrive at the downstream crystal after being reflected, and for a signal from the downstream crystal to reach the upstream crystal are measured. Since ultrasound travels faster if transmitted in the same direction as flow, a small time difference between the two beams is calculated as the transit time of flow and thus, the actual flow is proportional to the transit time. All calculations are made automatically by the flow meter and are displayed, as ml/min. Measurements are not dependent on the angle between vessel and probe. The two crystals are mounted in a fixed position. An increase in the angle between the upstream probe and the vessel will always be compensated by a corresponding decrease of the angle between the downstream probe and the vessel and vice versa. As mentioned above, measurements are also independent of hematocrit level, heart rate, and thickness of the vessel wall. Flow curves, together with flow and pulsitile index (PI) values, are visualized in real time on a video screen, can be saved in the hard drive, and can be printed through a parallel port.

Correct interpretation of TTFM findings may be difficult if this technology is not routinely applied and if established protocols and rules for flow measurement are not followed. The flow meter is not a magical device that can be forgotten in the operating room only to provide an exact answer whenever we have doubts about the quality of the anastomosis. The operator should interpret flow curves and, although most of the TTFM findings have an immediate interpretation, there is a learning curve for the more difficult cases. Confidence with the flow meter increases with the number of cases in which this technology is applied. For TTFM to be correctly interpreted, flow curves, PI, and mean flow values should all be evaluated simultaneously. In a patent coronary graft, the hemodynamics are similar to those physiologically observed in the coronary circulation: blood flow should be mainly diastolic with minimal systolic peaks taking place during the isovolumetric ventricular contraction (QRS complex). To correctly interpret flow patterns, curves should always be coupled with the ECG tracing to differentiate the systolic from the diastolic component. The PI is a good indicator of the flow pattern and, consequently, of the quality of the anastomosis. This number is obtained by dividing the difference between the maximum and the minimum flow by the value of the mean flow. In our experience, the PI value should be between 1 and 5; the possibility of a technical error in the anastomosis increases for higher PI values [Laustsen 1996, D'Ancona 2000]. Mean flow is expressed as mL/min and its value is not necessarily a good indicator of the quality of the anastomosis. Mean flow is very dependent on the quality of the native coronary artery and low flow values can be expected in fully patent anastomoses [Laustsen 1996] whenever the target territory has poor run-off.

We believe that intraoperative graft patency verification should be routinely adopted in all cases and not exclusively in patients operated on with CPB. Today, the modern techniques of exposure and stabilization of the different coronary artery branches can, in the majority of the off-CPB cases, provide very stable conditions and excellent surgical exposure comparable to the cases using CPB. In spite of that, surgical mistakes are still possible and, most of the time, difficult to admit. Our revision rate off-CPB has recently decreased from 8% to 4% and, in most of the cases, a technical error was found at revision [Laustsen 1996]. Flow abnormalities related to poor quality of the revascularized territory may be easily detected if a standard

technique of measurement is correctly adopted.

The TTFM probe should be perfectly fitted around the graft. Skeletonization of a small segment of the mammary artery is necessary to reduce the quantity of tissue interposed between the vessel and the probe. Aqueous gel is used to improve probe contact. TTFM has to be evaluated both with and without proximal snaring of the native coronary artery to detect any possible imperfection localized at the toe of the anastomosis and to exclude flow competition from the native vessel. Before making any measurements, adequate deairing of the grafts is performed using a 25-gauge needle. Adequate systemic blood pressure is maintained and traction on the pericardium is released to allow the heart to return to its anatomical position. TTFM should be repeated before chest closure and after protamine administration to confirm graft patency and to detect any possible graft kinking or compression.

We believe that prompt graft revision may very well be necessary whenever abnormalities in flow curves and values are found. Although it is very hard to admit technical mistakes, most of the time errors are not visually detectable, at least while performing the anastomosis. It is also true that this technology has been proven effective in detecting highly stenotic coronary anastomoses, and that data concerning the specificity and sensitivity of TTFM have never been published. A neural network pattern recognition analysis of graft-flow characteristics has been proposed by Cerrito et al. [1999] to improve TTFM detection of anastomotic errors. After a complex mathematical analysis of the flow curves, it is possible to detect stenoses that causes 50% or greater narrowing of the anastomoses. Less than critical stenoses cannot be detected by TTFM because no modifications in the hemodynamic performances of the grafts occur at this level.

Another limit of TTFM that will be possibly solved with increasing clinical experience is the lack of standard or nominal curves and flow values for different types of grafts and revascularized vessels. Standardization of the TTFM findings is difficult due to large biological variability between different subjects, as well as within the same subject. Interpretation of flow curves and TTFM findings is still empirical and is dependent on the surgeon's personal experience. Jaber et al. [1998] have tested the ability of 19 international surgeons to detect anastomotic errors by evaluating mean flow and flow wave-form morphology. We believe that the ability to correctly interpret TTFM findings develops with clinical and experimental experience and, for this reason, surgeons who have not been exposed to this type of technology cannot easily give it the proper level of importance. Flow patterns, PI values, flow values, and clinical findings (i.e., ECG tracing, hemodynamic values) should always be evaluated simultaneously to improve the applicability of TTFM. Absolute flow value does not necessarily reflect anastomosis quality because there are too many variables influencing absolute flow, including size of the graft and quality of the revascularized coronary artery. Instead, coronary flow reserve can better help to correctly diagnose anastomotic imperfections. Walpoth et al. [1996] have documented that quality of the anastomosis can be better defined by testing its dynamic ability to increase graft flow whenever myocardial oxygen requests are increased during infusion of adenosine. PI values are good indicators of the quality of the anastomoses. In our experience, high PI values are suggestive of anastomotic imperfections and the high PI values alone could justify coronary graft revision [Laustsen 1996]. Even though an absolute PI value has not been defined, we have empirically selected the limit of 5 based on our clinical experience with TTFM. Di Giammarco et al. [1999] proposed a value, derived from their clinical experience, of 2.5 as the limit of the PI value above which an anastomosis should be revised [Di Giammarco 1999].

Finally, the price for this technology cannot be defined with economical parameters. Even if interpretation of graft flows is still based on personal experience and empirical values, these are not good excuses for avoiding intraoperative graft patency verification. The flow meter should be used routinely as a surgical armamentarium to improve patient care and surgical results independently by the surgical technique adopted. Ability to interpret flow data will improve with use of the flow meter. Surgeons should not feel questioned or intimidated by the possible negative judgments of the flow meter. We understand the financial limitations imposed by hospital administrators but we believe that, in the future, surgeons that do not routinely adopt methods of intraoperative graft patency verification may be legally prosecuted in cases of perioperative complications. The use of fingertips to detect coronary graft patency after CABG will be seen, in years to come, in the same way as using the bare ear to detect paravalvular leaks after valve replacement.

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