Evaluation of graft patency during minimally invasive coronary artery bypass grafting with Doppler flow analysis

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Ann Thorac Surg 2000;70:1350-1354

Evaluation of Graft Patency During Minimally Invasive Coronary Artery Bypass Grafting With Doppler Flow Analysis

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Background. **An objective method for determining intraoperative graft patency is an essential part of minimally invasive direct coronary artery bypass. This study compares angiography and Doppler methods for graft analysis during minimally invasive direct coronary artery bypass and presents long-term outcome in a cohort of patients.**

Methods. **Between March and October 1997, 35 patients had elective minimally invasive direct coronary artery bypass procedures in which the left internal mammary artery was anastomosed to the left anterior descending coronary artery. Immediate graft patency was determined with intraoperative angiography using selective injection of the left internal mammary artery from a femoral approach and with Doppler flow analysis using a 1-mm, 20-MHz Doppler probe placed directly on the graft.**

Results. **There was immediate perfect patency with brisk flow in 91% of patients (32 of 35). A normal Doppler study, defined as a diastolic predominant pattern with a diastolic flow velocity of greater than 15 cm/second, was found in all patients with normal angiograms. All patients with abnormal angiograms also had abnormal Doppler flow. Thus, Doppler analysis was 100% accurate for confirming graft patency and for detecting failed grafts. All abnormal grafts were successfully revised, which allowed 100% early patency. Operative mortality was 2.8% (1 of 35) and there have been no late deaths at a follow-up of more than 2 years. One patient required angioplasty of the anastomosis (1 of 34, 2.9%), but none have required subsequent surgical intervention.**

Conclusions. **Objective analysis of graft flow in the operating room is necessary to achieve 100% early graft patency with minimally invasive direct coronary artery bypass operations. Doppler analysis is the preferred initial method, because it is safe, accurate, and rapid.**

(Ann Thorac Surg 2000;70:1350–4)

Minimally invasive direct coronary artery bypass (MIDCAB) has been shown to be less expensive and less morbid than traditional operations [1]. However, the operation is technically demanding, and concerns about graft patency and long-term outcome have been raised [2, 3]. Doppler methods for determining flow in coronary bypass grafts have been published but are not widely used [4, 5]. In addition, these methods have not been directly compared with angiography, which is generally regarded as the standard for determining graft patency. In this report, we present our experience with concurrent intraoperative angiography and pulsed-Doppler flow measurements in 35 consecutive patients who had MIDCAB procedures in which the left internal mammary artery (LIMA) was grafted to the left anterior descending coronary artery (LAD). We also present long-term clinical follow-up of this cohort of patients at 2 years postoperatively.

Accepted for publication April 5, 2000.

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Material and Methods

Patients

Between March and October 1997, 35 consecutive patients with single-vessel disease of the LAD had MIDCAB and gave permission for intraoperative angiography. The mean age was 61 ± 10 years, ranging from 34 to 80 years of age, and most patients (25 of 35, 71%) were male. Three patients had previous coronary artery bypass grafting. Three patients in this series had MIDCAB after being refused for traditional operation because of associated conditions, such as hepatic cirrhosis (n = 1), active gastrointestinal bleeding (n = 1), and recent stroke (n = 1). Patients with multi-vessel disease who had MIDCAB as part of a staged revascularization with endoluminal techniques were not included in this study. All patients discharged from the hospital returned for an office visit 4 to 6 weeks postoperatively. Late follow-up was completed as of August 31, 1999 by office visit or telephone contact.

Operative Technique

Our technique of perioperative anesthesia management has been described previously [6]. A double-lumen endotracheal tube and a fourth interspace anterior thora-

Published by Elsevier Science Inc

0003-4975/00/$20.00
PII S0003-4975(00)01720-3

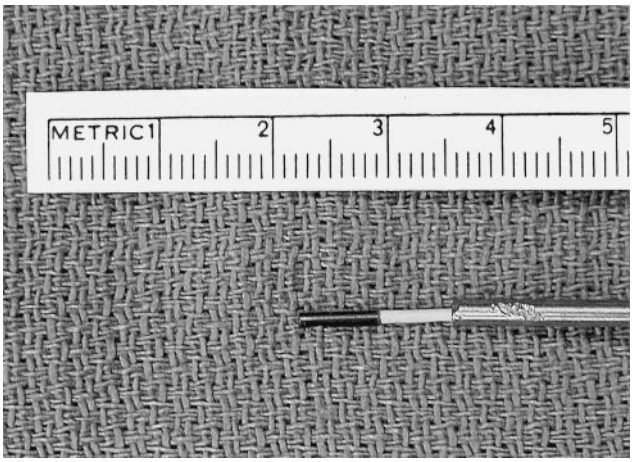

Fig 1. The 1-mm, 20-MHz Doppler probe is quite flexible and can be passed through a small metal suction tip to provide stability.

cotomy were used in each case. The LIMA pedicle was harvested under direct vision with electrocautery and clips. The minithoracotomy exposure was facilitated by using the CTS Access MP retractor (PN# CMS-151; Cardio Thoracic Systems, Inc., Cupertino, CA). The pedicle was mobilized completely, extending from the fifth rib to the subclavian junction, and heparin (10,000 U) was administered. The distal half of the LIMA pedicle was skeletonized in order to inspect the artery and to increase the functional length.

The pericardium was opened after dividing the plane between the thymic and the pericardial fat pads and then extending the pericardial incision parallel to the phrenic nerve. The LAD invariably is in this region, and cephalad extension of the pericardial incision prevents kinking of the LIMA pedicle on the edge of the pericardium [7, 8]. Pericardial stay sutures were used to displace the heart anteriorly, and mechanical stabilization was used to facilitate the anastomosis in each case (CTS Access MV Stabilizer, PN# CMS,175; CardioThoracic Systems, Inc). A carbon dioxide blower was used to displace blood from the coronary arteriotomy, but an intraluminal shunt was not used unless bleeding was persistent or hemodynamic deterioration occurred. Arterial anastomosis was done with a running 7-0 polypropylene suture.

Intraoperative Assessment of Graft Flow

Color pulsed-Doppler flow analysis was done with a 1-mm, 20-MHz micro-Doppler probe (PN# P15 EME2005; Nicolet Biomedical, Madison, WI) and recorded on the Nicolet Pioneer TCD System, software version 2.31 (Fig 1). The software-determined Doppler interrogation depth was set at 1.0 mm and volume at 0.5 mm. The tip of the flow probe was applied gently onto the mammary artery at a 45-degree incidence, and flow readings were obtained within several seconds (Fig 2). Pertinent flow pattern data included peak and mean flow, as well as systolic-diastolic flow pattern.

Intraoperative selective angiography of the LIMA was done by a cardiologist (DLF) through the femoral approach. A 6F introducer was inserted using the Seldinger technique. The 6F IMA angiography catheter (Cordis Endovascular, Miami, FL) was then threaded over a guide wire into position at the orifice of the LIMA under C-arm high resolution fluoroscopy (OEC 9600, OEC Medical Systems, Inc, Salt Lake City, UT). Hand bolus injection of 3 to 8 mL of Hypaque 76 or Omnipaque 350 was delivered, and the LIMA graft was examined in anteroposterior, mild left anterior and right anterior oblique views. The angiograms were imaged with the 9-inch field, with further image magnification if necessary. The results were documented on videotape and X-ray spot film but were not recorded on cine-film. Graft and anastomotic success was judged by flow criteria according to Fitzgibbon and associates [9] as no flow (occluded), patent with 50% stenosis with restricted run-off (compromised), or widely patent with unrestricted run-off (normal).

Results

All cases were successfully completed without the need to perform sternotomy or to use cardiopulmonary bypass. Angiograms and Doppler flow recordings were obtained in each patient, and no complications occurred as a result of the evaluation techniques. Most patients (85%) were extubated in the operating room. The mean length of stay in the hospital after surgery was 4 days. There were no strokes, no reexplorations for bleeding, and no instances of perioperative myocardial infarction, as documented by electrocardiographic changes. There was one operative death in a high-risk patient with hepatic cirrhosis, who died from multisystem organ failure. Angiography and Doppler showed a satisfactory graft, and the patient had no evidence of myocardial ischemia after surgery. The remaining 34 patients were discharged to home and all were seen as outpatients at 6 to 8 weeks postoperatively. None had recurrent angina or required cardiac catheterization in the early postopera-

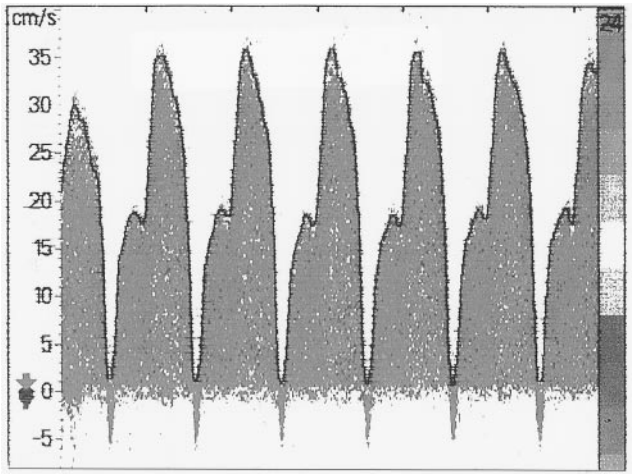

Fig 2. Normal flow velocity pattern in a left internal mammary to left anterior descending artery graft. There is pan-diastolic flow with a velocity of more than 30 cm/second, indicating a patent graft.

Table 1. Graft Flow Velocity

	Mean Diastolic Flow Velocity (cm/sec)	Mean Flow Velocity (cm/sec)
All patients (n = 35)	27.4 ± 12.1	18.8 ± 9.3
100% LAD occlusion (n = 7)	16.6 ± 4.2	9.3 ± 1.4
<100% LAD stenosis (n = 28)	31.9 ± 9.3[a]	21.7 ± 8.2[a]

[a] $p = 0.01$.

LAD = left anterior descending artery.

tive period. Three patients had minor complications, including wound seroma (n = 1), pericarditis (n = 1), and persistent incisional pain (n = 1). There were no wound infections.

Graft Flow

A normal Doppler signal, defined as a diastolic predominant, pan-diastolic tracing with a mean diastolic flow velocity greater than 15 cm/second, was found in 32 of 35 patients. The mean diastolic flow velocity was 27 cm/second, with a range of 15 to 40 cm/second (Fig 2). Patients with a chronic 100% LAD occlusion (n = 7) had a lower mean diastolic velocity than those whose vessel was not occluded (n = 28) (Table 1). Three patients had grossly abnormal flow tracings which showed a high systolic peak velocity with minimal diastolic flow or disorganized flow velocity signals (Figs 3 and 4). None of these patients had echocardiographic evidence of ischemia, hemodynamic instability, or any obvious abnormality of the graft. These same 3 patients also had abnormal grafts by angiography, consisting of one graft with complete occlusion and two with compromised flow. The other 32 patients had normal grafts by angiography. All of the grafts determined to be normal with angiography had normal Doppler signals and vice versa. Thus, each technique was 100% accurate for distinguishing between a functional and a compromised graft.

Causes of Graft Failure

The abnormal grafts were revised in the operating room. Of the three problem grafts, two resulted from an issue

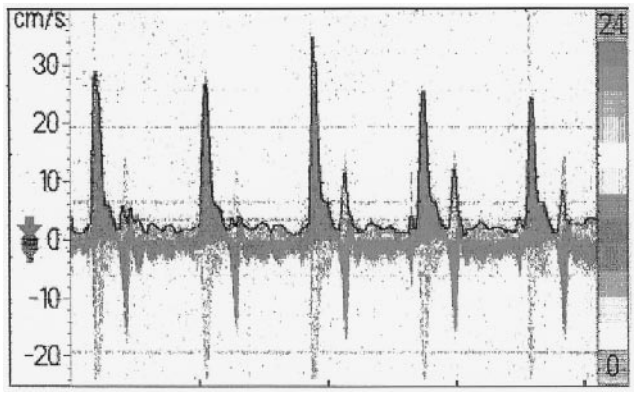

Fig 3. The tracing shows a spike with high initial systolic flow velocity but no significant diastolic flow. This indicates obstruction of the anastomosis resulting in poor diastolic flow.

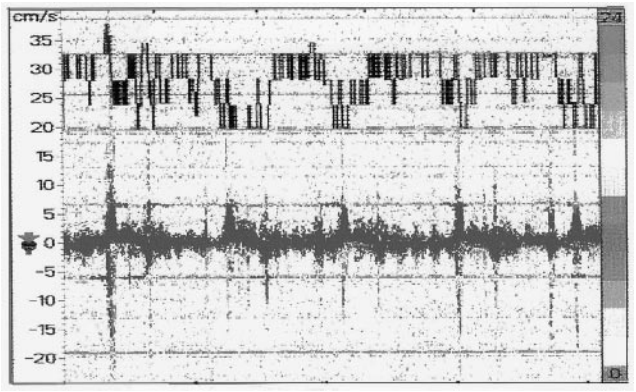

Fig 4. The tracing shows disorganized, low velocity flow indicating inadequate inflow to the mammary artery. This indicates that there is a problem with the mammary pedicle, such as a twisted pedicle, a proximal hematoma, or a dissected mammary artery.

with the LIMA pedicle and one from anastomotic failure. All grafts were revised successfully, and repeat confirmatory angiography and Doppler analyses were done. Therefore, all patients left the operating room with a patent LIMA to LAD graft with good flow.

Late Outcome

Long-term follow-up was obtained in all of the discharged patients. Angiography or stress testing were not obtained systematically, but all patients were contacted by telephone or office visit and carefully questioned about clinical status at a mean of 26 months (range, 22 to 30 months) postoperatively. There were no late deaths. One patient had recurrent angina and required angioplasty for an anastomotic stricture at 4 months postoperatively. Another patient developed a symptomatic new left main stenosis and had successful stenting of the left main coronary artery, which was done because the patient was protected by a patent LIMA to LAD graft. No patient required redo coronary artery bypass grafting. Therefore, at a mean follow-up time of over 2 years, 97% of patients (33 of 34) were free from target vessel (LAD) reintervention, and 94% (32/34) were free from any coronary reintervention. None of the 3 patients whose grafts were revised in the operating room had recurrent angina or required reintervention.

Comment

The initial experience with LAD revascularization with the LIMA on the beating heart was reported by Kolessov in 1967 [10]. However, this technique was largely forgotten after the development of coronary bypass using cardioplegic arrest, until the concept of beating heart coronary artery bypass grafting was revived by surgeons interested in reducing the morbidity associated with traditional sternotomy and cardiopulmonary bypass techniques [11, 12].

Long-term survival benefits after coronary revascularization with the internal mammary artery graft have been well documented [13]. Hence, a legitimate concern re-

garding coronary revascularization on the beating heart is the quality of the graft anastomosis. The early clinical experience with MIDCAB was complicated by cardiac motion, but this problem has been minimized by routine application of epicardial stabilizing devices [14].

Nonetheless, concern still exists that the patency of MIDCAB grafts is not equal to those done on the arrested heart, even when dedicated equipment is used. The review of the literature by Mack and associates [15] of angiographic outcomes after conventional coronary artery bypass grafting for LIMA grafts found early graft patency between 94% and 99%. A more recent report from Mack and associates [16] of early postoperative coronary angiography in 100 MIDCAB patients showed an overall patency of 97%, but this result included 6% of patients with 50% or less graft stenosis. Because of the greater technical difficulty of beating heart anastomoses, and the concern about immediate graft patency, it is essential to have a reliable, objective method to determine graft patency in the operating room. Several published reports have described intraoperative angiography, utilizing a femoral or radial artery approach [17, 18]. Angiography certainly gives a definitive answer about graft patency, but it is time-consuming, often requires cardiology assistance, and is not without risks, so we adopted pulsed Doppler flow velocity recordings as a method for confirming graft patency.

Our results demonstrate several important points. First, a normal pulsed Doppler result is equivalent to angiography in confirming a patent graft. When there is a diastolic-predominant flow pattern with a pan-diastolic flow velocity of more than 15 cm/second, all grafts were patent by angiography. Most of the grafts had a diastolic flow velocity greater than 25 cm/second, especially when the LAD was not chronically occluded. Second, a grossly abnormal flow velocity pattern was equivalent to angiography in confirming a nonfunctional graft. We have seen two types of failed grafts. In the first type there is a problem with the LIMA pedicle, which restricts inflow, leading to a pattern of very low velocity in the distal pedicle. In the other type there is an anastomotic problem resulting in satisfactory inflow but poor run-off, which results in a high systolic velocity peak with no diastolic flow. Third, failure of MIDCAB grafts is not always caused by anastomotic failure and can be caused by problems with the LIMA pedicle. And finally, grafts with satisfactory flow determined by Doppler methods have excellent long-term results. At 2 years follow-up, all surviving patients were without angina and 97% were free from reintervention on the LAD.

Our data showed a lower LIMA graft flow velocity when the native LAD was chronically occluded compared with the situation when the LAD was open but had a tight proximal stenosis (greater than 70%). The physiology of a vascular bed supplied entirely by collateral vessels is different from one supplied by a stenotic epicardial coronary artery. It is possible that the antegrade flow velocity would increase with time, but we have no data to support that hypothesis. From a practical viewpoint, a borderline low flow velocity (15 to 20 cm/second) is not a source of major concern if the LAD is chronically occluded but should arouse suspicion in a graft to a vessel with a tight stenosis. None of the grafts were done to vessels with less than 70% stenosis, so we do not have any data on the expected flow velocity in the presence of significant competitive flow.

Intraoperative Doppler techniques for graft assessment during MIDCAB have been described by others, but they have not used the system we employed. Elbeery and colleagues [19] reported on the use of continuous wave Doppler flow assessment of the LIMA graft with concurrent intraoperative angiography in 50 patients. They used a nonquantitative and subjective methodology for analysis of the Doppler flow signal (graded as: 0=no flow, 1+ = poor or questionable, and 2+ = good flow with diastolic augmentation), and demonstrated a 75% sensitivity and 93.5% specificity in correctly identifying anastomotic problems. Calafiore and colleagues utilized intraoperative pulsed-Doppler echocardiography to introduce objective documentation of the flow velocity and systolic/diastolic flow characteristics of the LIMA graft [20]. Graft flow volume determinations by transit -time flow measurement has been recommended for analyzing the patency of coronary grafts [21, 22].

These studies show that Doppler flow velocity and transit time flow measurements can distinguish between patent and functionally occluded grafts. It is not known whether these techniques can identify degrees of graft stenosis. An experimental study by Jaber and associates [22] showed that transit time flow measurement did not predict stenosis reliably unless it was more than 75%, which is not surprising because this is the level at which flow is obviously restricted. No comparable data are available for pulsed Doppler flow velocity measurements, but there is no reason to expect that the situation would be different. Calafiore and colleagues [23] used the Azoulay manuever during perioperative LIMA duplex interrogation to detect anastomotic stenosis. The Azoulay maneuver transiently augments venous return, which increases cardiac output and graft flow. Normal grafts show an increase in diastolic flow velocity whereas stenotic grafts do not. We have no experience with this technique, but it might be a helpful modification of our method.

The significance of mild to moderate degrees of anastomotic stenosis, in the absence of flow restriction, is not known. Recent studies by Mack and associates [16] and Wiklund and colleagues (Wiklund L, Brandup-Wognsen G, Bugge M, et al. Difficulties in interpretation of the coronary angiogram early after CABG on the beating heart [Abstract]. Presented at the 13th Annual Meeting of the European Association for Thoracic Surgery, Glasgow, Scotland, September 5–8, 1999:66, #88.) suggest that certain minor abnormalities noted at early angiography, such as small filling defects and anastomotic narrowing, are reversible and might resolve with time. They concluded that minor graft abnormalities found at perioperative angiography might not be clinically important, especially when graft flow is brisk. Our data support that hypothesis. At the completion of the operation, all grafts

in this study had good flow, as determined by both angiography and Doppler methods, and during the next 2 years only 1 patient had recurrent symptoms resulting from a problem with the LIMA to LAD graft.

This method for Doppler analysis uses the Nicolet Pioneer TCD system with the Nicolet 1-mm, 20-MHz probe. This system has been used extensively in neurosurgery, primarily for assessment of cerebral blood flow before and after cerebral aneurysm clipping. The device is flexible and has user-programmable variables, such as interrogation depth and volume, which permits sampling of flow velocity in the middle of the arterial lumen. In addition, systolic and diastolic flow velocity are displayed graphically in real time, which allows careful examination of diastolic flow rather than average flow velocity over the entire cardiac cycle. Doppler flow measurements are not as familiar as angiograms to surgeons, but they provide useful information and avoid the risks of contrast dye and injury to the LIMA by a catheter.

The major limitation of this study was that the angiograms were recorded in real time on a fluoroscopy monitor, and not on cine-film. Therefore, we were not able to examine the anastomotic site carefully for subtle degrees of stenosis. However, a cardiologist was present for each angiogram and made the final decision about the quality of the grafts as judged by flow characteristics. Another limitation was the relatively small size of the study. Because graft problems were uncommon we have limited data on failed or borderline-abnormal grafts.

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