Preliminary Experience With a Novel Intraoperative Fluorescence Imaging Technique to Evaluate the Patency of Bypass Grafts in Total Arterial Revascularization

David P. Taggart, MD, PhD, Bikram Choudhary, MBBS, Kyriakos Anastasiadis, MD, Yasir Abu-Omar, MRCS, Lognathen Balacumaraswami, FRCS, and David W. Pigott, FRCA

Department of Cardiothoracic Surgery, John Radcliffe Hospital, Oxford, United Kingdom

Background. **Early graft failure is a common cause of cardiac morbidity and mortality after coronary artery bypass grafting (CABG), and there is particular concern about graft patency in off-pump CABG. We describe our preliminary experience with a novel imaging technique (the SPY system), based on fluorescence of Indocyanine Green when exposed to near infrared light, for the intraoperative assessment of coronary graft patency.**

Methods. **Graft patency was assessed in patients undergoing off-pump and on-pump total arterial revascularization. The imaging technique requires injection of a 1-mL bolus of Indocyanine Green into the central venous line, followed by imaging with the SPY system.**

Results. **We assessed intraoperative graft patency in 213 conduits in 84 patients (mean, 2.54 grafts per patient), of which, 65 (77%) were done off-pump. It took approximately 3 minutes to image each graft. Skeletonized conduits provided better visualization than pedicled ones. Fluorescence, confirming graft patency, was observed in all but four (1.9%) conduits in 4 (5%) patients. In these latter cases, graft revision was necessitated.**

Conclusions. **Fluorescence imaging of coronary grafts using the SPY is a uniquely simple, safe, noninvasive, and reproducible technique for intraoperative confirmation of graft patency. In 4 patients, it necessitated revision of the initial intraoperative procedure. Quantification of graft flow would enhance the value of the system.**

(Ann Thorac Surg 2003;75:870–3)

Early graft failure is a major cause of cardiac morbidity and mortality after coronary artery bypass grafting (CABG). It is the most common cause of perioperative myocardial infarction, which is detectable in up to 9% of patients after CABG [1]. Concerns about quality of grafts and anastomoses are especially prevalent with off-pump coronary artery bypass grafting (OPCABG), and current studies show graft compromise in 5% to 20% of patients at discharge [2]. Postoperative angiography, used to assess graft patency before hospital discharge, has resulted in reoperation in some patients [3, 4].

Consequently, several techniques have been employed to assess intraoperative graft patency. These have included electromagnetic [5], ultrasound flow measurement [6], Doppler velocity waveform [7], epicardial echocardiographic [8], and conventional [9] and thermal coronary angiography [10] techniques. However, all have limitations and frequently provide indirect or poor resolution definition of the grafts and flow, as well as being subject to misinterpretation, as they are particularly operator dependent. Conventional coronary angiography remains the gold standard [9], but is highly invasive (requiring arterial puncture), increases operating time, and is infrequently available in the operating theater.

We describe our preliminary experience with a novel, simple, and rapid imaging technique for intraoperative assessment of coronary grafts. The technique is based on capture, by a charge-coupled device video camera, of fluorescence of Indocyanine Green (ICG) when illuminated with near infrared light using laser energy from the SPY imaging system (Novadaq Technologies Inc., Toronto, Canada).

Material and Methods

The SPY imaging system is based on fluorescence of ICG. The system has CE marking in Europe, which allows patient use in the European Community.

As ICG binds to plasma proteins it is confined to the intravascular compartment. ICG fluoresces when illuminated at 806 nm (near infrared light) using laser energy, and the fluorescence is captured by a charge-coupled device video camera at a rate of 30 images per second. The laser used by the SPY system has a total output of 2.2 W spread over an area of 7.5 × 7.5 cm on the surface of

Accepted for publication Sept 27, 2002.

Address reprint requests to Dr Taggart, Department of Cardiothoracic Surgery, John Radcliffe Hospital, Oxford, OX3 9DU, United Kingdom; e-mail: david.taggart@orh.nhs.uk.

Published by Elsevier Science Inc

0003-4975/03/$30.00
PII S0003-4975(02)04669-6

Table 1. The Breakdown of Coronary Targets Grafted and Conduits Used in the 84 Patients Undergoing CABG

Coronary Target	Bypass Conduit				
	RITA	LITA	RA	SV	GEA
LAD	36	38	1	2	0
OM	2	29	18	3	0
DIAG	1	5	9	2	0
PDA	2	1	31	8	1
Other	4	9	7	4	0

Sixty-five (77%) of these underwent off-pump CABG. Seventy-one (85%) underwent total arterial revascularization.

CABG = coronary artery bypass grafting; DIAG = diagonal coronary artery; GEA = gastro-epiploic artery; LAD = left anterior descending coronary artery; LITA = left internal thoracic artery; OM = obtuse marginal coronary artery; PDA = posterior descending coronary artery; RA = radial artery; RITA = right internal thoracic artery; SV = saphenous vein.

the heart, avoiding the risk of thermal myocardial damage and eliminating any risk to the operating theater staff. Indocyanine Green (ICG) has been used for many years in ophthalmic video-angiography and is a very safe compound, with a reported risk of minor adverse reactions of less than one in a thousand.

After completion of the distal coronary artery anastomosis, 1 mL of ICG dye is injected through the central venous line and flushed through with 5 mL of normal saline. Screening is started at the time of injection, and the grafts are imaged as the fluorescent dye passes through them. Images are then recorded on videotape or computer hard drive. The procedure takes 3 to 4 minutes per anastomosis.

Results

We initially performed this technique in 84 patients assessing 213 conduits (see Table 1), all performed by one surgeon (DPT) with a mean of 2.54 grafts per patient. Sixty-five cases (77%) were OPCABG, the remaining cases being on-pump CABG or CABG combined with another cardiac procedure. The primary outcome measure was the rate of graft revision influenced by the information provided by the imaging system.

There were no mortalities and no adverse consequences associated with the use of the ICG dye.

Imaging took approximately 3 minutes per graft. Flow was visualized in all grafts confirming patency, and in the majority resulted in images of similar quality to that observed with conventional angiography (see Figs 1–4). As for conventional angiography, the still image is more difficult to interpret than the moving image. Although the anastomotic site was clearly visualized in three-quarters of cases, it was not usually possible to demonstrate precise anatomical detail. Skeletonized conduits (ie, internal thoracic arteries and radial arteries) permitted better visualization than pedicled ones.

Absent or poor flow in four grafts (5% of patients in this series), as detected by fluorescence imaging, necessitated graft revision. These cases are summarized below.

A 77-year-old patient underwent OPCABG including a left internal thoracic artery (LITA) to the left anterior descending artery (LAD) and right internal thoracic artery (RITA) to the distal right coronary artery (RCA). Flow in the LITA to the LAD was poorly visualized (Fig 1A), suggesting either an anastomotic problem or the presence of disease distal to the anastomosis. Consequently, a vein graft was placed to the distal coronary artery with excellent flow (Fig 1B).

A 55-year-old patient with single-vessel disease and good left ventricular function underwent LITA to LAD on pump. Flow in the LITA to the LAD was not visualized. The graft was revised and the anastomosis reconstructed distally, with excellent flow (Fig 2).

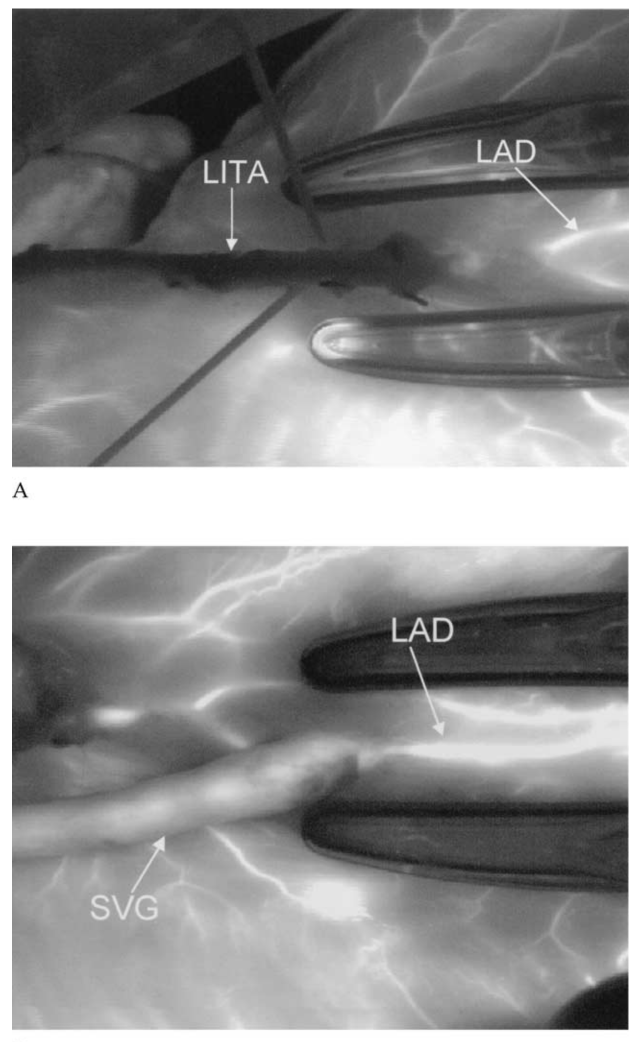


Fig 1. (A) SPY image showing an in situ left internal thoracic artery (LITA) graft to the left anterior descending (LAD) coronary artery. The native coronary arteries are occluded proximal to the anastomotic site using a sling so that flow in the coronary arteries is purely attributed to patency of the graft. Note that no fluorescence is seen in the LITA graft. As a result of this, a saphenous vein graft is placed onto the distal LAD (see B). (B) SPY image showing saphenous vein graft onto LAD. Note fluorescence in vein graft and native coronary artery. (SVG = saphenous vein graft.)

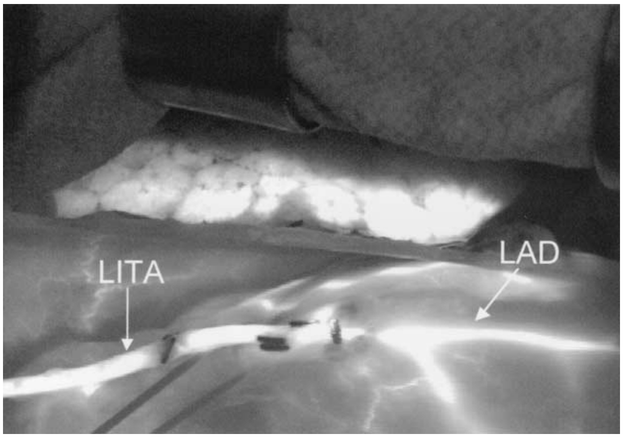


Fig 2. SPY image of in situ left internal thoracic artery (LITA) *graft to left anterior descending* (LAD) *coronary artery, taken after revision of the anastomosis. The initial image showed no fluorescence in the LITA graft.*

A 66-year-old patient with three-vessel disease underwent OPCABG, including an in situ RITA to the LAD and radial artery (RA) to the obtuse marginal coronary artery (OM). The proximal end of the RA was attached to the side of the RITA. The flow in the RITA to the LAD beyond the RITA-to-RA anastomosis was not visualized (Fig 3A). The RITA-to-RA anastomosis was reconstructed, with excellent flow (Fig 3B).

A 57-year-old patient with three-vessel disease and good left ventricular function underwent OPCABG, including an in situ RITA to the LAD and an in situ LITA to OM. The flow in the LITA to the OM was not visualized (Fig 4A). The LITA-to-OM was reconstructed distal to the initial site and adequate flow was visualized (Fig 4B).

Comment

The need for an intraoperative imaging system to assess graft patency is demonstrated by the plethora of techniques currently available [5–10], all of which have limitations. Early graft failure is a cause of perioperative myocardial infarction and may necessitate reoperation for revision of the relevant bypass grafts accordingly [6]. This is particularly true in the setting of off-pump total arterial revascularization and especially for bilateral ITA grafts, which may offer survival advantages [11], but are generally considered to be technically more challenging.

To our knowledge, this is the first report describing the use of this novel technique in the intraoperative setting of coronary artery surgery. Our preliminary results demonstrate that the SPY imaging system, based on fluorescence of ICG, is a safe, simple, rapid, repeatable method for the intraoperative assessment of graft conduits.

The strengths of the technique are its simplicity and safety. It is minimally invasive in that no arterial puncture is required, and avoids the need for ionizing radiation. ICG has been very widely used in a variety of clinical situations, and adverse reactions are very uncommon, having been reported in the region of 0.004% [12]. In most situations, the graft was well visualized within 3 minutes and provided semiquantitative estimates of flow with real-time images. A major attraction is that it provides information in a fashion similar to coronary angiography, with which the surgeon is familiar and can easily interpret.

The value of the imaging system was illustrated by altering the intraoperative management of 4 patients, highlighting that graft flow compromise occurred in 5% of patients in this series and in 1.9% of all performed grafts.

There are currently limitations to the technique. First, the technique is only semiquantitative, in that it permits assessment of graft flow as “excellent,” “satisfactory,” or “poor,” but does not provide an exact measure of graft flow. Developments are currently underway that will permit the imaging system to give quantitative flow

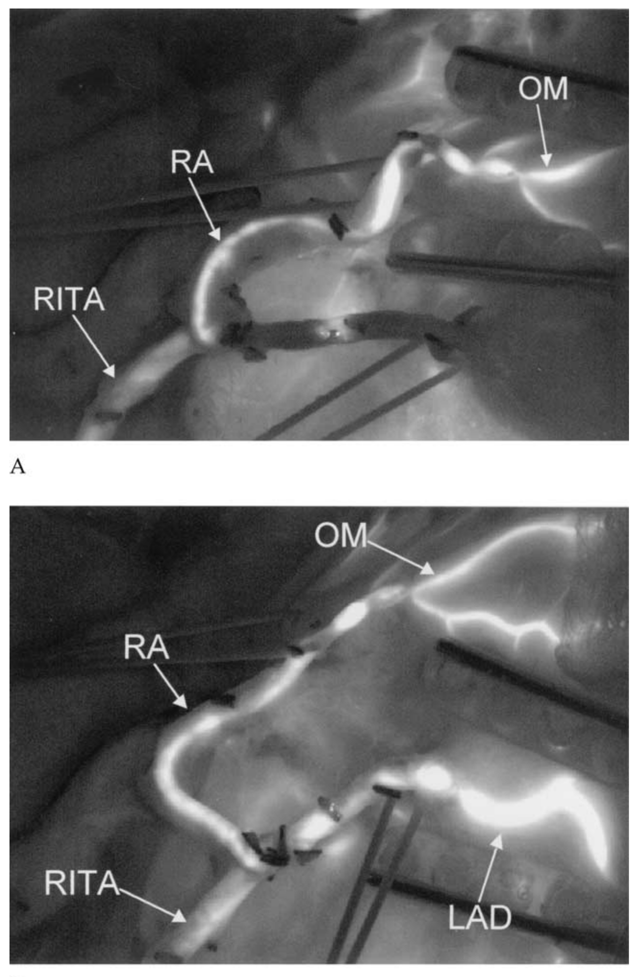
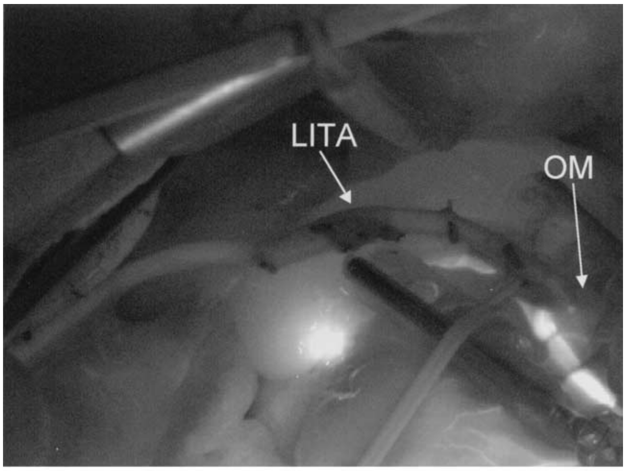
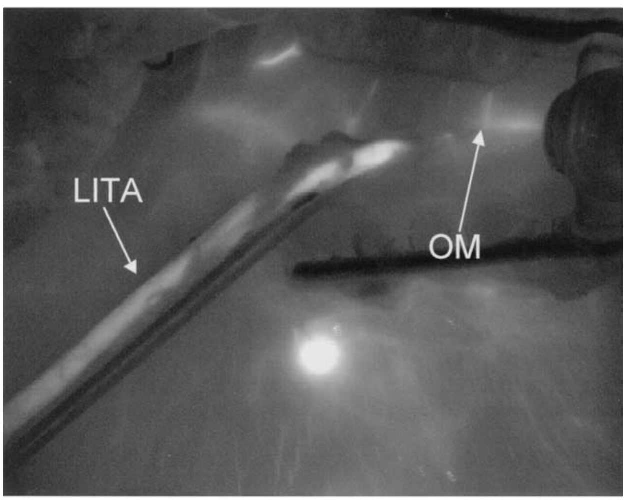


Fig 3. (A) SPY image showing in situ right internal thoracic artery (RITA) *graft to the left anterior descending* (LAD) *coronary artery. A composite pedicled radial artery* (RA) *graft was placed from the RITA to the obtuse marginal artery. Note that no fluorescence was seen in the RITA distal to the RA anastomosis, which was taken down and reconstructed (see B). (B) SPY image taken after revision of RA-to-RITA anastomosis, seen in A. Note fluorescence now seen in distal portion of RITA graft and in LAD coronary artery.* (OM = *obtuse marginal coronary artery.)*

CARDIOVASCULAR



A



B

*Fig 4. (A) SPY image showing in situ left internal thoracic artery (*LITA*) graft onto obtuse marginal coronary artery (*OM*). Note that no fluorescence was seen in LITA or native coronary, necessitating revision of the distal anastomosis (see B). (B) SPY image taken after revision of the distal anastomosis in A. Note the fluorescence in LITA and in the OM coronary artery.*

measurements. Second, the technique only allows precise definition of anastomotic quality in around three-quarters of grafts. This is because depth of penetration of the laser beam is only around 1 mm, and is therefore vulnerable to varying depths of the native coronary artery (eg, when intramyocardial). For the same reason, imaging can only occur when the chest is open and pedicled conduits are less well visualized than skeletonized ones. A more powerful, pulsed laser might resolve these limitations, and would be balanced against the fact that the device intentionally uses low-power laser energy so as to avoid thermal myocardial damage.

Conclusions

The fluorescence imaging technique of coronary grafts that is described has the advantages of safety, simplicity, reproducibility, repeatability, speed of assessment, and allows immediate surgical revision if necessary. Quantification of flow would further enhance its value.

The camera and dye were provided by Novadaq Technologies, Inc (Toronto, Ontario, Canada), for investigational purposes.

References

1. Taggart DP. Biochemical assessment of myocardial injury after cardiac surgery: effects of a platelet activating factor antagonist, bilateral internal thoracic artery grafts, and coronary endarterectomy. J Thorac Cardiovasc Surg 2000;120:651–9.
2. Poirier NC, Carrier M, Lesperance J, et al. Quantitative angiographic assessment of coronary anastomoses performed without cardiopulmonary bypass. J Thorac Cardiovasc Surg 1999;117:292–7.
3. Goldstein JA, Safian RD, Aliabadi D, et al. Intraoperative angiography to assess graft patency after minimally invasive coronary bypass. Ann Thorac Surg 1998;66:1978–82.
4. Subramanian VA. Less invasive arterial CABG on a beating heart. Ann Thorac Surg 1997;63:S68–71.
5. Louagie YA, Haxhe JP, Buche M, Schoevaerdts JC. Intraoperative electromagnetic flowmeter measurements in coronary artery bypass grafts. Ann Thorac Surg 1994;57:357–64.
6. Walpoth BH, Bosshard A, Genyk I, et al. Transit-time flow measurement for detection of early graft failure during myocardial revascularization. Ann Thorac Surg 1998;66: 1097–100.
7. Calafiore AM, Di Giammarco G, Teodori G, et al. Left anterior descending coronary artery grafting via left anterior small thoracotomy without cardiopulmonary bypass. Ann Thorac Surg 1996;61:1658–65.
8. Suematsu Y, Takamoto S, Ohtsuka T. Intraoperative echocardiographic imaging of coronary artery graft anastomoses during coronary artery bypass grafting with cardiopulmonary bypass. J Thorac Cardiovasc Surg 20001;122:1147–54.
9. Elbeery JR, Brown PM, Chitwood WR Jr. Intraoperative MIDCABG arteriography via the left radial artery: a comparison with Doppler ultrasound for assessment of graft patency. Ann Thorac Surg 1998;66:51–5.
10. Falk V, Walther T, Kitzinger H, et al. An experimental approach to quantitative thermal coronary angiography. Thorac Cardiovasc Surg 1998;46:25–7.
11. Taggart DP, D'Amico R, Altman DG. The effect of arterial revascularization on survival: a systematic review of studies comparing bilateral and single internal mammary arteries. Lancet 2001;358:870–5.
12. Speich R, Saesseli B, Hoffman U, et al. Anaphylactoid reactions to indocyanine-green administration. Ann Intern Med 1988:345–6.