Online address: www.hsforum.com/vol6/issue5/2003-19990.html

Intraoperative Color Doppler Ultrasound Assessment of Anastomoses of the Left Internal Mammary Artery to the Left Anterior Descending Coronary Artery during Off-Pump Coronary Artery Bypass Surgery Correlates with Angiographic Evaluation at the 8-Month Follow-up

(#2003-19990)

Ole Tjomsland, MD, PhD, Rune Wiseth, MD, PhD, Alexander Wahba, MD, PhD, Arve Tromsdal, MD, Stein O. Samstad, MD, PhD, Rune Haaverstad, MD, PhD

St. Elisabeth Heart Center and Institute of Circulation and Imaging Techniques, Norwegian University of Science and Technology, Trondheim, Norway

ABSTRACT

Objective: This study was performed to evaluate the correlation between intraoperative color Doppler ultrasound assessment of anastomoses of the left internal mammary artery (LIMA) to the left anterior descending coronary artery (LAD) performed on the beating heart and the angiographic assessment after 8 months.

Methods: Twenty patients (M/F ratio, 14:6; mean age, 62 ± 8 years) underwent epicardial color Doppler ultrasound imaging with a 10-MHz linear array GE Vingmed transducer combined with a GE Vingmed System FiVe. Transit-time flowmetry was used as intraoperative control. Follow-up coronary angiography after a median of 245 days (range, 128-320 days) allowed assessment of thrombolysis in myocardial infarction (TIMI) flow and FitzGibbon grading in all patients. Detailed quantitative coronary angiography was performed in 10 patients with an emphasis on comparing the LAD diameter at the toe of the anastomosis (D_1) and in the downstream LAD (D_2).

Results: Intraoperative ultrasound analysis revealed 19 patent LIMA-LAD anastomoses (95%). A >50% stenosis was detected in 1 anastomosis (5%), which was subsequently revised successfully. Follow-up angiographic evaluation showed TIMI-III flow and FitzGibbon grade A in 18 of 20 anastomoses (90%). One anastomosis was occluded, and one had FitzGibbon grade B stenosis. The D_1/D_2 ratios of the LAD measurements assessed with intraoperative ultrasound and follow-up quantitative coronary angiography were significantly correlated ($r^2 = 0.62$; $P < .01$).

Conclusion: Intraoperative color Doppler ultrasound allows a detailed evaluation of LIMA-LAD anastomoses during off-pump surgery, and the results correlate significantly with those of angiographic evaluation after 8 months. The present study shows that epicardial ultrasound is a promising tool for verification of LIMA-LAD anastomoses performed on the beating heart and may reduce the risk of impaired graft flow caused by technical errors.

INTRODUCTION

Long-term survival after coronary artery bypass grafting (CABG) surgery is highly dependent on the patency of the left internal mammary artery (LIMA) graft to the left anterior descending coronary artery (LAD) [Grover 1994]. Although the development of new stabilizers has led to a reduced movement of the target during the suture procedure of the anastomoses in off-pump coronary artery bypass (OPCAB) surgery, a high reported incidence of technical abnormalities of distal anastomoses requiring subsequent revision (up to 9.9%) [D'Ancona 1999] reflects the need for an intraoperative method capable of detecting anastomotic errors.

Intraoperative angiography has been considered the gold standard for evaluating the quality of anastomoses by enabling the immediate revision of technical errors. However, data from several studies have indicated that the incidence of "clinically silent" anastomotic lesions detected during intraoperative angiography [Barstad 1997, Elbeery 1998, Goldstein 1998, Hol 2001] is higher than that observed when the angiography is performed postoperatively prior to hospital discharge [Diegeler 1999, Jatene 2000]. Furthermore, Hol et al [Hol 2002] studied the importance of intraoperative angiographic findings for predicting long-term patency after off-pump surgery and found that 73% of the significant anastomotic lesions observed intraoperatively disappeared by the 3-month follow-up. These investigators concluded that intraoperative angiography is not a good predictor for later patency. Thus, it may be questioned what the intraoperative angiographic findings really represent, because perioperative angiographic evaluation of coronary grafts and anastomoses does not necessarily correlate significantly with short-term, midterm, or long-term patency.

We have previously reported our initial experience with a new 10-MHz linear array transducer specially designed for

Presented at the 9th Annual CTT Meeting 2003, Miami Beach, Florida, USA, March 19-22, 2003.

Address correspondence and reprint requests to: Rune Haaverstad, MD, PhD, St. Elisabeth Heart Center, University Hospital of Trondheim, N-7018 Norway; 0047-73-86-70-00; fax: 0047-73-86-70-29 (e-mail: Rune.Haaverstad@medisin.ntnu.no).

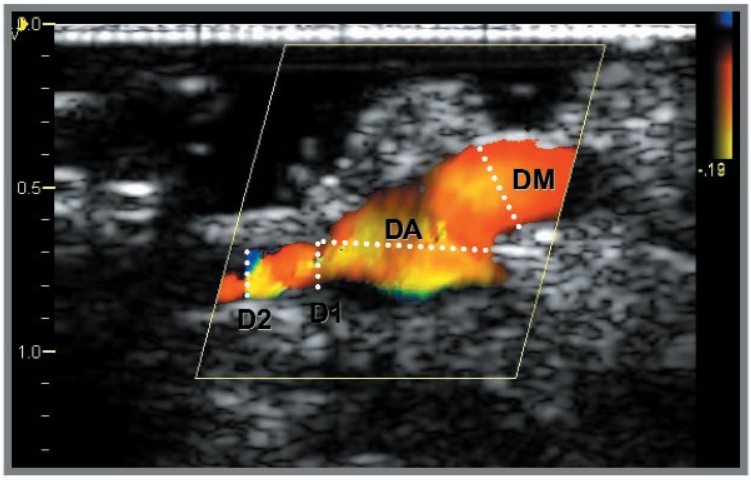

Figure 1. Parameters of the anastomosis of the left internal mammary artery (LIMA) to the left anterior descending coronary artery (LAD) viewed in the anterior-posterior plane and assessed by epicardial color Doppler ultrasound. D_A indicates the length of the anastomosis proper; D_M, the diameter of the LIMA; D_1, the LAD at the toe of the anastomosis; D_2, the LAD 5 to 10 mm distal to the anastomosis proper. The D_1/D_2 ratio is 1.

epicardial vascular ultrasound scanning during on-pump CABG and demonstrated its feasibility to detect and classify coronary artery stenoses [Haaverstad 2002b]. The severity score correlated significantly with the grading obtained from preoperative angiograms, and ultrasound imaging allowed the evaluation of the morphology of the anastomoses and a semiquantitative assessment of the flow velocity at the anastomotic site. Furthermore, we have demonstrated during off-pump surgery that the same transducer is feasible to use for epicardial color Doppler scanning for visualizing LIMA-LAD anastomoses and accurate measures of the anastomosis: the length of the anastomosis proper (D_A) and the diameters of the LIMA (D_M), the LAD at the toe of the anastomosis (D_1) and the LAD 5 to 10 mm distal to the anastomosis proper (D_2) [Haaverstad 2002a]. The aim of the present study was to compare intraoperative epicardial ultrasound assessment of geometry and patency of anastomoses after OPCAB surgery with angiographic findings after 8 months of follow-up.

MATERIALS AND METHODS

Patient Selection and Demographics

Twenty consecutive patients (14 men and 6 women; mean age, 62 ± 8 years) scheduled for elective OPCAB were included. Their clinical characteristics were stable angina (Canadian Cardiovascular Society (CCS) class II, 11 patients; CCS class III, 9 patients), 1- or 2-vessel coronary disease, and a mean ejection fraction of 69% ± 11%. The research protocol was approved by the Regional Ethics Committee in Medical Research. Informed consent was signed prior to patient inclusion in the study. All patients received a LIMA graft anastomosed to the LAD, and 13 patients received an additional graft. One patient had a right IMA graft to the right coronary artery, 1 patient had a radial artery graft to the posterior descending artery (PDA), 3 patients had a saphenous vein graft (SVG) to the right coronary artery, 2 patients received a SVG to the PDA, and 6 patients received a SVG to a diagonal branch.

Surgical Technique

Median sternotomy was used in all cases. After full heparinization (3 mg/kg), the LIMA was harvested with its pedicle, and a diluted solution of papaverine was injected intraluminally. The activated coagulation time was not allowed to drift below 270 seconds. The LAD was identified and snared with a 4-0 pledgeted polypropylene suture (Prolene) proximal to the incision. After 3 to 5 minutes of ischemic preconditioning, the snare was released, and an epicardial stabilizer was used to immobilize the target site chosen for grafting. After the incision of the LAD, an intracoronary shunt (CardioThoracic Systems, Cupertino, CA, USA) was positioned into the vessel lumen, and the coronary anastomosis was performed with a continuous 7-0 or 8-0 Prolene suture. The LIMA pedicle was secured with an epicardial stitch on each side. After the graft was assessed, heparin was reversed with protamine, and the stabilizer was removed.

Epicardial Ultrasound Scanning

After completing the LIMA-LAD anastomosis and with the stabilizer still in place, we performed epicardial color Doppler scanning of the anastomosis by means of a 10-MHz linear array GE Vingmed transducer (footprint, 27.3 ± 9.6 mm) connected to a GE Vingmed System FiVe echocardiography unit (GE Vingmed, Horten, Norway). With sterile gel as a conduction medium, the sterilized transducer was applied directly onto the epicardium between the paddles of the stabilizer (Figure 1). Real-time ultrasound images and storage of data for later analysis were obtained within approximately 10 minutes for each patient. The ultrasound images were stored as digital data for later analysis with the EchoPAC software (GE Vingmed).

The quality of the images was rated good when both the anastomosis and the distal runoff in the coronary artery could

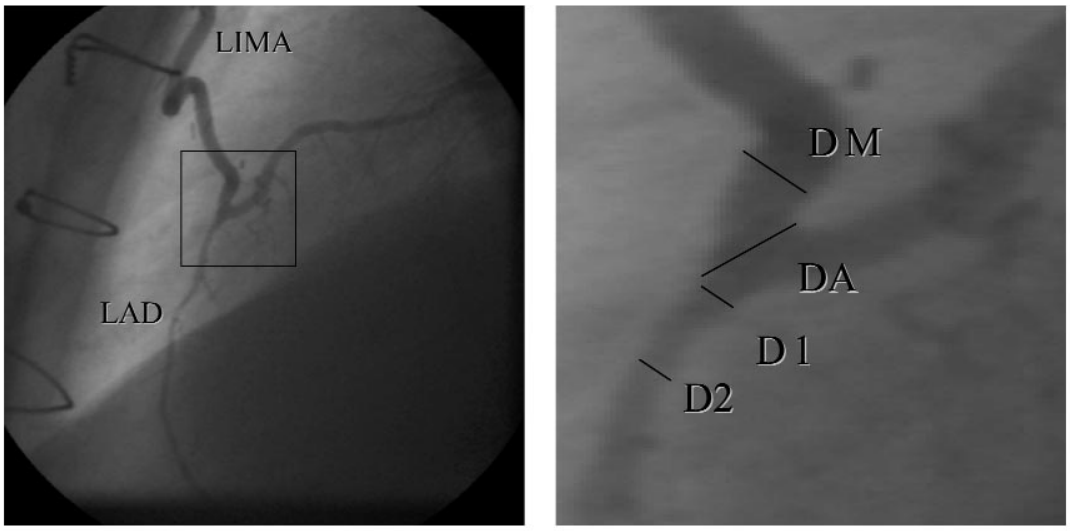

Figure 2. Quantitative coronary angiography of a fully patent anastomosis of the left internal mammary artery (LIMA) to the left anterior descending coronary artery (LAD) evaluated angiographically after 8 months of follow-up. D_A indicates the length of the anastomosis proper; D_M, the diameter of the LIMA; D_1, the LAD at the toe of the anastomosis; D_2, the LAD 5 to 10 mm distal to the anastomosis proper.

be well visualized. Images obtained from anterior-posterior and transverse planes were used to assess the quality and patency of the anastomosis. D_1 and D_2 were measured (Figure 1), and the D_1/D_2 ratio was calculated to visualize the geometry of the anastomoses.

Transit-Time Flowmetry

Intraoperatively and prior to chest closure, graft flow was measured with transit-time flowmetry (Butterfly flowmeter; Medi-Stim, Oslo, Norway) with sterile gel as the conduction medium.

Angiography

Follow-up coronary angiography after a median of 245 days (range, 128-320 days) was performed through a standard femoral access with 6F catheters. Both native coronary arteries and bypass grafts were visualized by selective catheterization with iohexol (Omnipaque; Amersham Health, Buckinghamshire, UK). The LIMA was visualized with a standard LIMA catheter. For both vein grafts and LIMA grafts, thrombolysis in myocardial infarction (TIMI) flow and FitzGibbon grading were assessed. In 10 patients, detailed quantitative coronary angiography of the LIMA-LAD anastomoses was performed at images obtained in the lateral view. Metal sutures in the sternum with a diameter of 1 mm were used for calibration. D_1 and D_2 were measured, and the D_1/D_2 ratio of the diameters was calculated and compared with the corresponding values obtained during intraoperative ultrasound analysis (Figure 2).

Statistical Analysis

Data normally distributed are described as the arithmetic mean, and SD was the measure of variability. The skewness test was used to test whether the data were normally distributed, and skewed data are presented as the median and the range. Linear regression was used to evaluate the correlation between the D_1/D_2 ratios evaluated with intraoperative epicardial ultrasound versus the ratios obtained with angiography after 8 months of follow-up. A P value $<.05$ was considered statistically significant. Statistical analyses were performed with the NCSS Statistical System program (NCSS, Kaysville, UT, USA).

RESULTS

No operative mortality and no myocardial infarction were observed. Epicardial scanning did not cause cardiac arrhythmia or hemodynamic instability in any of the patients. The transducer allowed an easy approach to the LIMA-LAD anastomoses. Intraoperative ultrasound assessment of the LIMA-LAD anastomoses did not prolong the total operative time for more than 10 minutes in any patient. The angiographic studies were performed without any complications.

Intraoperative ultrasound analysis revealed 19 patent LIMA-LAD anastomoses (95%). A >50% stenosis was detected in one anastomosis (5%), which was subsequently revised successfully. After the revision, epicardial ultrasound analysis revealed a patent anastomosis without signs of significant stenoses, and the transit-time flow rate increased from 22 to 40 mL/min. The mean transit-time flow in the LIMA-LAD grafts was 29 ± 17 mL/min, the mean flow in grafts to right coronary artery/ramus descendens posterior was 36 ± 16 mL/min, and the mean flow in grafts to diagonal branches was 37 ± 14 mL/min.

Follow-up angiographic evaluation showed TIMI-III flow and FitzGibbon grade A in 18 of 20 anastomoses (90%). One anastomosis with an intraoperative D_1/D_2 ratio of 0.87 that was close to the average was occluded. The successfully revised anastomosis had a FitzGibbon grade B stenosis at follow-up. The D_1/D_2 ratios of the LAD measurements assessed with

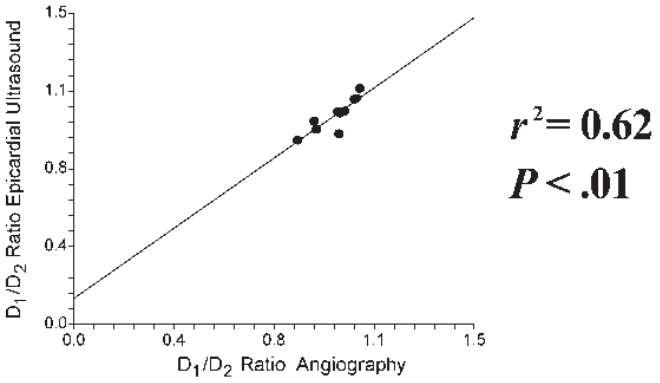

Figure 3. A significant correlation was observed between D_1/D_2 ratios assessed with epicardial ultrasound and quantitative coronary angiography. D_1 indicates the LAD at the toe of the anastomosis; D_2, the LAD 5 to 10 mm distal to the anastomosis proper.

intraoperative ultrasound and assessed with follow-up quantitative coronary angiography were significantly correlated ($r^2 = 0.62$; $P < .01$) (Figure 3).

COMMENT

The present study demonstrates that intraoperative color Doppler ultrasound allows a detailed evaluation of LIMA-LAD anastomoses during off-pump surgery, and these results are significantly correlated with those of angiographic evaluation after 8 months.

Intraoperative angiography has been considered the gold standard for evaluating the LIMA-LAD anastomosis after OPCAB. However, data from several studies have indicated that the incidence of clinically silent anastomotic lesions detected during intraoperative angiography [Barstad 1997, Elbeery 1998, Goldstein 1998, Hol 2002] is higher than that observed with control angiography performed after surgery [Diegeler 1999, Berger 1999]. In the latter studies, no intraoperative quality control analysis of the LIMA-LAD anastomoses was performed. Hol et al found that 24% of the IMA grafts appeared with significant intraoperative lesions in a study evaluating the importance of the intraoperative angiogram on long-term patency [Hol 2002]. Two (5%) of the anastomoses were revised, and 11 anastomotic lesions were left untreated. Ten of these 11 lesions were located at the anastomoses proper, heel or toe. At the 3-month follow-up angiography analysis, 8 of the 11 grafts appeared angiographically normal [Hol 2002]. Elbeery and coworkers [Elbeery 1998] studied 50 IMA-LAD grafts after OPCAB surgery and found anastomotic occlusions with intraoperative angiography in 8% of grafts, whereas epicardial ultrasound analysis failed to identify any occlusions. Based on these findings, these investigators found intraoperative coronary angiography to be superior to epicardial ultrasound and recommended intraoperative angiography for quality control of grafts and anastomoses. On the contrary, we have presented our positive experience with the use of epicardial ultrasound analysis with updated epicardial ultrasound technology for evaluating coronary anastomoses in both on-pump and OPCAB surgery [Haaverstad 2002a, 2002b]. All LIMA-LAD anastomoses were visualized with accurate and reproducible measures of D_A, D_M, D_1, and D_2 (Figure 1), and no signs of significant lesions in the anastomoses were observed after termination. Furthermore, the flow velocities through the anastomoses were visualized by color Doppler coding, and except for the successfully revised graft, no signs of flow disturbances suggestive of significant stenosis were observed. One of the grafts found to be patent perioperatively was occluded at follow-up. This finding reflects the fact that the long-term patency of coronary bypass grafts depends on other factors besides the quality of the anastomoses, such as an impaired distal runoff in the native coronary artery. The present study was designed to evaluate the use of epicardial ultrasound as a tool to detect technical abnormalities of IMA-LAD anastomoses that might affect immediate surgical revision. Although a technically perfect anastomosis does not warrant long-term patency, the strong correlation in the present study between the intraoperative assessment of the LIMA-LAD anastomoses and the corresponding evaluation of the same anastomoses with follow-up angiography indicates a strong predictive value for epicardial ultrasound analysis in assessing long-term patency after OPCAB surgery.

Experience from previous studies suggests that intraoperative angiography as used in the cited studies may not be an optimal tool for evaluating the quality of coronary anastomoses after OPCAB surgery. Moreover, only a few operating theaters have the equipment necessary to perform intraoperative angiography, the procedure is time consuming, it is expensive, and the use of a contrast agent is mandatory.

There is no obvious explanation for the discrepancy between the incidence of significant anastomotic lesions (8%-24%) observed after intraoperative angiography in previous studies [Barstad 1997, Lazzara 1997] and the incidence of lesions (5%) observed after intraoperative epicardial ultrasound analysis in the present study. The degree of spasm in the LIMA graft may play a role. It has been shown that the free IMA flow rate doubles after the injection of papaverine [Yavuz 2001]. In the present study, we used papaverine routinely in the IMA grafts, and this practice may have led to a reduced incidence of spasm.

Several other methods have been used to assess the quality of grafts and anastomoses after CABG and OPCAB, including Doppler and transit-time flow measurements, the intraoperative fluorescence imaging technique (the SPY technique), and thermal or laser cameras.

The use of transit-time flowmetry is widespread, and the method provides valuable information regarding severe anastomotic stenosis and occlusions after CABG and OPCAB. However, the lowest acceptable flow value in the LIMA graft has not been defined, and no definitive limit for graft revision has been determined. Accordingly, the mean graft flow alone is not a sufficient tool for graft assessment unless the stenosis is greater than 75% to 90% [Jaber 1998]. Moreover, it has been demonstrated that intraoperative blood flow measurements alone cannot predict graft patency [Hol 2001].

The SPY technique is an interesting tool for imaging coronary grafts and artery branches, although it provides only 1-dimensional information, it is difficult to study anatomical details in the anastomoses, and it requires a contrast agent.

CONCLUSIONS

The epicardial color Doppler scanning technique used in the present study allows an accurate visualization of the LIMA-LAD anastomoses and their components, measures the length of the anastomosis proper, and determines the diameters of the downstream LAD and the LIMA graft. Furthermore, it provides color Doppler flow assessment and the blood flow velocity at the anastomotic site. The necessary measurements are easily obtained without risk of complications, are not time consuming, and provide important information about the geometry and the flow pattern of the anastomosis. The high correlation between the geometry of the anastomoses found with preoperative epicardial ultrasound analysis and that found with angiography after 8 months of follow-up indicates that epicardial ultrasound analysis during OPCAB surgery is a promising method for assessing the patency of the anastomoses.

REFERENCES

Barstad RM, Fosse E, Vatne K, et al. 1997. Intraoperative angiography in minimally invasive direct coronary artery bypass grafting. Ann Thorac Surg 64:1835-9.

Berger PB, Alderman EL, Nadel A, Schaff HV. 1999. Frequency of early occlusion and stenosis in a left internal mammary artery to left anterior descending artery bypass graft after surgery through a median sternotomy on conventional bypass: benchmark for minimally invasive direct coronary artery bypass. Circulation 100:2353-8.

D'Ancona G, Karamanoukian HC, Salerno TA, Schmid S, Bergsland J. 1999. Flow measurement in coronary surgery. Heart Surg Forum 2:121-4.

Diegeler A, Matin M, Kayser S, et al. 1999. Angiographic results after minimally invasive coronary bypass grafting using the minimally invasive direct coronary bypass grafting (MIDCAB) approach. Eur J Cardiothorac Surg 15:680-4.

Elbeery JR, Brown PM, Chitwood WR Jr. 1998. Intraoperative MIDCABG arteriography via the left radial artery: a comparison with Doppler ultrasound for assessment of graft patency. Ann Thorac Surg 66:51-5.

Goldstein JA, Safian RD, Aliabadi D, et al. 1998. Intraoperative angiography to assess graft patency after minimally invasive coronary bypass. Ann Thorac Surg 66:1978-82.

Grover FL, Johnson RR, Marshall G, Hammermeister KE. 1994. Impact of mammary grafts on coronary bypass operative mortality and morbidity: Department of Veterans Affairs Cardiac Surgeons. Ann Thorac Surg 57:559-68.

Haaverstad R, Vitale N, Tjomsland O, Tromsdal A, Torp H, Samstad SO. 2002. Intraoperative color Doppler ultrasound assessment of LIMA-to-LAD anastomoses in off-pump coronary artery bypass grafting. Ann Thorac Surg 74:S1390-4.

Haaverstad R, Vitale N, Williams RI, Fraser AG. 2002. Epicardial colour-Doppler scanning of coronary artery stenoses and graft anastomoses. Scand Cardiovasc J 36:95-9.

Hol PK, Fosse E, Lundblad R, et al. 2002. The importance of intraoperative angiographic findings for predicting long-term patency in coronary artery bypass operations. Ann Thorac Surg 73:813-8.

Hol PK, Fosse E, Mork BE, et al. 2001. Graft control by transit time flow measurement and intraoperative angiography in coronary artery bypass surgery. Heart Surg Forum 4:254-7.

Jaber SF, Koenig SC, BhaskerRao B, et al. 1998. Role of graft flow measurements technique in anastomotic quality assessment in minimally invasive CABG. Ann Thorac Surg 66:1087-92.

Jatene FB, Pego-Fernandes PM, Hueb AC, et al. 2000. Angiographic evaluation of graft patency in minimally invasive direct coronary artery bypass grafting. Ann Thorac Surg 70:1066-9.

Lazzara RR, McMellan BA, Kidwell FE, Combs DT, Hanlon JT, Young EK. 1997. Intraoperative angiography during minimally invasive direct coronary artery bypass operations. Ann Thorac Surg 64:1725-7.

Yavuz S, Celkan A, Goncu T, Turk T, Ozdemir IA. 2001. Effect of papaverine applications on blood flow of the internal mammary artery. Ann Thorac Cardiovasc Surg 7:84-8.