Non-invasive assessment of the composite radial artery and *in situ* left internal thoracic artery Y-graft for myocardial revascularization

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Coronary artery bypass graft; Echo-Doppler; Exercise test; Myocardial scintigraphy.

Background. **It is controversial whether composite arterial grafts can provide adequate blood flow for myocardial revascularization. We assessed at transthoracic echography and myocardial scintigraphy the composite radial artery-*in situ* left internal thoracic artery Y-graft.**

Methods. **In 32 of 36 consecutive patients who underwent myocardial revascularization using this composite arterial graft, successful postoperative transthoracic images of the main stem of the Y-graft were obtained at rest and early after standard exercise. The main stem diameter, cross-sectional area and blood flow velocity and volume were measured. The coronary flow reserve (CFR) was calculated. The patients were divided into three groups according to the number of coronary artery systems bypassed with the Y-graft: group I included 11 patients with one coronary system bypassed, group II 18 patients with two, and group III 3 patients with three coronary systems bypassed. In 14 patients myocardial scintigraphy was performed at rest and after stress.**

Results. **After exercise, the diameter, cross-sectional area, and blood flow velocity and volume increased. The mean CFR in group III was greater than in group I (p = 0.00045) and in group II (p = 0.049). In 2 patients, the nuclear stress test was positive (reversible ischemia in the distribution area of the Y-graft) and the mean CFR was lower than in the patients with a negative nuclear stress test (p = 0.046).**

Conclusions. **This composite arterial graft is a compliant conduit, able to regulate its flow capacity to myocardial demand. Non-invasive assessment of this Y-graft using transthoracic echography is possible, and correlates with the results of myocardial scintigraphy.**

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Introduction

Complete myocardial revascularization and long-term graft patency are the targets of coronary artery bypass surgery. Total arterial myocardial revascularization could be the best solution to the relatively frequent late failure of saphenous vein grafts. However, the scarce availability of arterial grafts limits this option[1].

The *in situ* internal thoracic artery (ITA) is the conduit of choice in coronary artery bypass grafting procedures because of its excellent patency, reduced cardiac events, and enhanced survival[2,3]. The literature reports excellent results following the simultaneous use of both *in situ* ITAs[3-5]. However, multivessel coronary artery disease, the increased risk of sternal separation in overweight and diabetic patients, and the insufficient length of the *in situ* right ITA to the postero-lateral coronary arteries make this pattern of arterial revascularization sometimes unsuitable for the achievement of complete myocardial revascularization. These problems can be overcome by the use of another arterial conduit. The radial artery (RA) has been used as a coronary artery bypass graft with satisfactory results[6-8]. Because free arterial grafts attached to the ascending aorta have a high failure rate, composite and sequential grafting techniques are preferable, and are in fact becoming more popular[7,9-16].

In coronary artery surgery, although the *in situ* left ITA in Y-configuration with the RA provides an apparently adequate blood flow[12-15,17] and satisfactory clinical results[7,9-16], it is still controversial how many coronary artery systems the main stem of this Y-graft can supply with sufficient blood flow, especially after stress. The purposes of this study were to test transthoracic echography in the assessment of the composite RA-*in situ* left ITA Y-graft, and to verify the ability of this composite arterial graft to provide adequate blood flow for multivessel myocardial revascularization.

Methods

Study patients. Between January 2001 and September 2002, 36 selected patients underwent myocardial revascularization using the composite RA-*in situ* left ITA Y-graft at our Department of Cardiac Surgery. A program of non-invasive assessment of this composite arterial graft during follow-up was devised.

The exclusion criteria from this prospective study were: previous myocardial infarction in the distribution area of the Y-graft, isolated < 50% stenosis of the left main coronary artery, coronary artery stenosis < 90% in the distribution area of the Y-graft, insulin-dependent diabetes mellitus, severe chronic obstructive pulmonary disease (forced expiratory volume in 1 s < 40%), a positive Allen's test of the non-dominant arm, and angiographic stenosis of the left ITA or left subclavian artery. Old age, obesity, hypercholesterolemia, non-insulin-dependent diabetes mellitus, previous cardiac surgery or percutaneous transluminal coronary angioplasty, a low left ventricular ejection fraction, moderate chronic obstructive pulmonary disease, and urgent surgical priority were not exclusion criteria.

The mean age of this series of patients was 54.5 ± 10.2 years (range 38 to 79 years). There were 31 (86.1%) men and 5 women (13.9%). Eighteen (50.0%) patients were in preoperative Canadian Cardiovascular Society (CCS) angina class 3 or 4, and 9 (25.0%) in preoperative New York Heart Association (NYHA) functional class III or IV. Four (11.1%) patients had a left ventricular ejection fraction < 35%. On the basis of the European system for cardiac operative risk evaluation (EuroSCORE) criteria only 2 (5.6%) patients were considered as being at high operative risk (95% confidence intervals for expected mortality 10.93 to 11.54%)[18] (Table I).

Table I. Preoperative data.

Arterial hypertension	25 (69.4%)
History of cigarette smoking	10 (27.8%)
Severe hypercholesterolemia (serum cholesterol concentration > 300 mg/dl)	1 (2.8%)
Obesity (BMI > 25 kg/m^2)	3 (8.3%)
NIDDM	9 (25.0%)
Previous MI	16 (44.4%)
Previous PTCA	4 (11.1%)
Previous CABG	1 (2.8%)
Left main coronary artery disease	6 (16.7%)
LVEF (%)	50.6 ± 8.5
NYHA functional class	2.1 ± 0.9
CCS angina class	2.7 ± 0.9
Moderate COPD (FEV_1 > 40%)	5 (13.9%)
Chronic renal failure (serum creatinine concentration > 2.0 mg/dl)	2 (5.5%)
Urgent surgical priority*	12 (33.3%)
EuroSCORE	1.9 ± 1.9

BMI = body mass index; CABG = coronary artery bypass grafting; CCS = Canadian Cardiovascular Society; COPD = chronic obstructive pulmonary disease; FEV_1 = forced expiratory volume in 1 s; LVEF = left ventricular ejection fraction; MI = myocardial infarction; NIDDM = non-insulin-dependent diabetes mellitus; NYHA = New York Heart Association; PTCA = percutaneous transluminal coronary angioplasty. * according to the Society of Thoracic Surgeons classification.

Surgical technique. After a median longitudinal sternotomy, the *in situ* left (and eventually right) ITA was prepared and skeletonized[5]. Simultaneously, the RA was harvested at the non-dominant arm[19]. The terminolateral Y-anastomosis between the RA and the *in situ* left ITA was completed before the standard cannulation for cardiopulmonary bypass, usually at the third intercostal branch of the left ITA and using the 8-0 polypropylene (Genzyme Biosurgery, Fall River, MA, USA) suture. The newly formed Y-graft penetrated the pericardial cavity through a window created in the pericardium anterior to the left phrenic nerve. Intermittent anterograde or retrograde cold crystalloid cardioplegia and mild systemic hypothermia (32 to 34°C) were employed. The left ITA and the RA were respectively used for the anterior coronary and for the posterior coronary anastomoses[11]. Although in 17 patients (47.2%) complete myocardial revascularization was achieved with this Y-graft only, in 19 myocardial revascularization was completed with the *in situ* right ITA (n = 14), RA segment (n = 4), or with the *in situ* right ITA and RA segment (n = 1).

Non-invasive assessment of the composite arterial Y-graft. *Transthoracic echographic examination.* At a mean of 6.7 ± 3.6 months (range 1 to 15.5 months) following cardiac surgery, transthoracic echographic evaluation of the main stem of the Y-graft was attempted in all the 36 patients after having obtained their written informed consent.

Transthoracic color Doppler echography was performed using a computed instrument (Vivid 3 Expert, GE Medical Systems, Solingen, Germany), equipped with a 5.0 and 7.5-MHz linear array transducer. The scanner head was placed in the left supraclavicular space with the patient in the supine position and breathing normally. The ultrasound beam was maintained as parallel as possible to the axis of blood flow in the main stem of the Y-graft. The diameter and cross-sectional area of the main stem were measured on B-mode imaging. The pulsed Doppler signals were then recorded. The peak systolic, peak diastolic, and mean blood flow velocities were determined on the basis of the shape of the Doppler signal curve. The blood flow volume was derived using the following formula: blood flow volume (ml/min) = cross-sectional area (mm^2) · velocity time integral (cm) · heart rate (min^{-1}) · 10^{-2}. The velocity time integral is the area between the line traced on the Doppler wave and the base line[20-22]. This evaluation was performed both at rest and early after a treadmill exercise test for 5 min on a flat surface at 5 km/hour. Systolic and diastolic blood pressures and heart rate were measured, and the double product was calculated before and after exercise (Table II).

Satisfactory ultrasonic visualization of the main stem on B-mode imaging, and the typical biphasic Doppler waveform were obtained, both at rest and after exercise, in 32 patients (88.9%). In 2 patients with a bull neck it was impossible to visualize the main stem, and in another patient (with a postoperative myocardial infarction) the Doppler waveform had a large systolic peak followed by a much smaller diastolic component. In these 3 patients, the standard exercise test was not attempted at all. Finally, in 1 patient it was impossible to re-visualize the main stem after exercise.

The coronary flow reserve (CFR) of the Y-graft was calculated using the following formula: CFR = mean blood flow velocity after exercise (cm/s)/mean blood flow velocity at rest (cm/s). Because following stress the decrease in the mean artery pressure at rest (105.7 ± 9.5 mmHg) was not significant (100.0 ± 15.0 mmHg, p = 0.12), no correction for the changes in blood pressure due to the physiological exercise-induced vasodilation was necessary.

The 32 patients with a satisfactory transthoracic echographic assessment both at rest and after exercise were divided into three groups according to the number of coronary artery systems bypassed with the Y-graft: group I included 11 patients (34.4%) with one coronary system bypassed (left anterior descending coronary artery-LAD system), group II 18 patients (56.2%) with two coronary systems bypassed (LAD system + circumflex coronary artery-Cx or right coronary artery-RCA system), and group III 3 patients (9.4%) with three coronary systems bypassed (LAD system + Cx system + RCA system). The mean CFR was calculated for every group.

Myocardial scintigraphy. Myocardial scintigraphy at rest and after stress was performed in the first 14 consecutive patients with an adequate and complete transthoracic echographic evaluation. The Bruce's exercise test was used. A 12-lead electrocardiogram was recorded continuously. The test was considered positive for myocardial ischemia when a horizontal or downsloping ST depression of at least 0.1 mV was recorded 80 ms after the J-point by two adjacent leads.

Table II. Changes in systolic blood pressure (SBP), heart rate (HR), and double product (DP) after exercise.

Variable	At rest	After exercise	p
SBP (mmHg)	132.3 ± 9.6	167.7 ± 15.1	0.017
HR (min^{-1})	67.4 ± 8.8	81.4 ± 7.3	0.0013
DP (10^{-2} · mmHg/min)	89.3 ± 14.3	136.5 ± 18.4	0.042

At peak exercise (90% of the predicted maximal heart rate), 740 MBq technetium-99m sestamibi was administered in an anticubital vein. Exercise was then maintained for one more minute, and single photon emission computed tomography was performed within 45 to 60 min. After 24 hours, 740 MBq technetium-99m sestamibi was injected again and images were obtained at rest. This nuclear stress test was considered positive for myocardial ischemia if a reversible filling defect in the distribution area of the Y-graft was visible between the stress and resting images. The mean CFR was calculated both for the patients with a positive nuclear stress test as well as for those with a negative nuclear stress test.

Statistical analysis. Values are expressed as mean ± SD, or as percentages. The paired Student's t-test was used to compare the CCS angina class, NYHA functional class and left ventricular ejection fraction before surgery and at follow-up, and to compare the diameter of the Y-graft main stem and the blood flow volume and velocity through it at rest and after exercise. The unpaired Student's t-test was used to compare the mean CFRs. Statistical significance was assumed for a p value < 0.05.

Statistical analysis was performed using the MINITAB release 13 statistical software (MINITAB Inc., State College, PA, USA).

Results

Thirty-six Y-, 117 (3.2 per patient) coronary artery, and 153 arterial anastomoses were performed on the patients of this study. With the composite arterial Y-graft, 97 (2.7 per patient) coronary artery, and 133 arterial anastomoses were performed. The mean aortic cross-clamping time and the cardiopulmonary bypass time were 52.3 ± 16.8 and 89.4 ± 32.3 min, respectively.

No patient died early after cardiac surgery or during follow-up. Seven patients (19.4%) presented with at least one in-hospital complication: paroxysmal atrial fibrillation (n = 5), re-operation due to bleeding (n = 2), myocardial infarction (n = 1), and reversible respiratory failure (n = 1). In the patient who presented with a postoperative infero-lateral myocardial infarction and a dominant systolic Doppler waveform, repeat coronary angiography confirmed a slow run-off of the contrast medium through the RA of the Y-graft, with a moderate stenosis at the anastomosis between the RA and the postero-lateral branch of the RCA.

At follow-up, significant improvements were observed in the CCS angina class (2.7 ± 0.9 to 1.1 ± 0.2, p = 0.00068), NYHA functional class (2.1 ± 0.9 to 1.6 ± 0.8, p = 0.00012) and left ventricular ejection fraction (50.6 ± 8.5 to 55.4 ± 9.1%, p = 0.00025). All the variables of the Y-graft main stem taken into consideration increased after exercise. However, although both the systolic and diastolic blood flow volumes and the mean systolic and diastolic blood flow velocities increased, the increase in the peak systolic and diastolic blood flow velocities was not significant because of a simultaneous significant increase in the main stem diameter of the Y-graft (Table III).

The mean CFR in group III (2.1 ± 0.1) was higher than that observed in both group I (1.3 ± 0.1, p = 0.00098) and group II (1.7 ± 0.3, p = 0.049). The mean CFR of group II was greater than that of group I (p = 0.00045) (Fig. 1).

Two of the 14 patients (14.3%) who underwent myocardial scintigraphy had a positive nuclear stress test. However, repeat coronary angiography showed no important stenosis along the Y-graft or at the coronary artery anastomoses. The first of these 2 patients was a 38-year-old woman with severe hypercholesterolemia and non-insulin-dependent diabetes mellitus causing serious and diffuse coronary artery disease, carotid artery stenosis and peripheral arterial disease. In these 2 patients, the mean CFR was significantly lower than that of the patients with a negative myocardial scintigraphy (1.0 ± 0.2 vs 1.6 ± 0.4, p = 0.046) (Fig. 2).

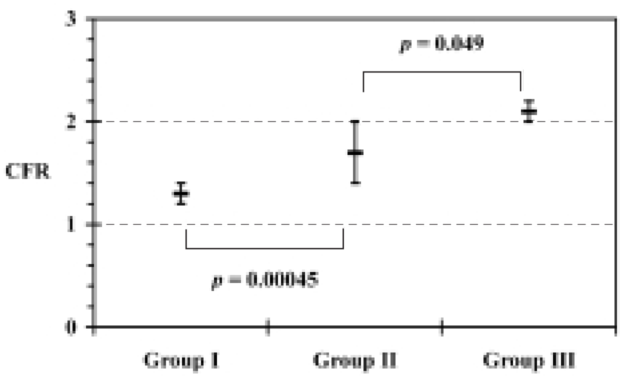

Figure 1. *Comparison of coronary flow reserve (CFR) in the 32 patients with a satisfactory transthoracic echographic assessment. The patients were divided into three groups according to the number of coronary artery systems bypassed with the Y-graft. The mean CFR was directly proportional to the number of coronary systems bypassed: mean CFR of group III > mean CFR of group II > mean CFR of group I.*

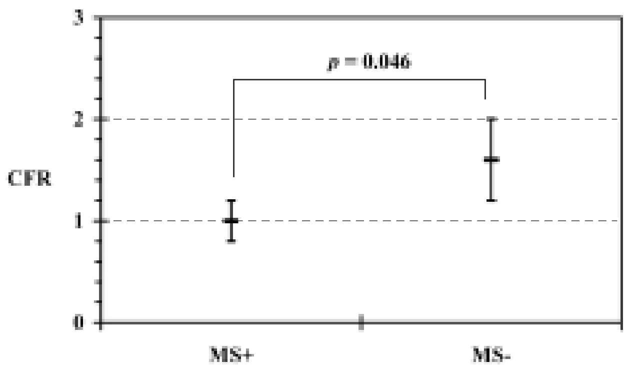

Figure 2. *Comparison of coronary flow reserve (CFR) in the 14 patients who underwent myocardial scintigraphy (MS). The patients were divided into two groups according to the results of the nuclear stress test: positive nuclear stress test (MS+, i.e. reversible ischemia in the distribution area of the Y-graft, 2 patients) or negative nuclear stress test (MS-, 12 patients). The mean CFR correlates with the results of MS.*

During the exercise tests, no clinical or electrocardiographic evidence of myocardial ischemia was found.

Discussion

The composite and sequential grafting techniques overcome the problem of the limited arterial graft availability for complete arterial myocardial revascularization procedures, and reduce the surgical manipulation of the aorta[7,9-12,16,23]. However, it is controversial whether composite arterial grafts can provide adequate blood flow for multivessel myocardial revascularization[13-15,17]. Moreover, sequential grafting with arterial conduits may not be convenient in every situation and demanding surgical techniques[11,15]. We used the RA to construct our Y-graft because its greater luminal diameter and conduit length compared with other arterial grafts facilitate sequential coronary artery anastomosis[6-8].

The exclusion criteria adopted in selecting the patients of our prospective study respond to the following requirements: to minimize the effect of the native coronary flow on the Y-graft blood flow, to obtain compliant coronary resistances, and to construct safe, flexible and functional composite arterial grafts: the postopera-

Table III. Changes in the Y-graft main stem diameter and blood flow (BF) volume and velocity after exercise.

Variable	At rest	After exercise	p
Diameter (mm)	3.0 ± 0.4	3.2 ± 0.4	0.00073
Total BF volume (ml/min)	94.1 ± 15.0	130.7 ± 24.5	0.0025
Systolic BF volume (ml/min)	33.9 ± 8.4	47.4 ± 16.7	0.031
Diastolic BF volume (ml/min)	60.1 ± 13.4	83.3 ± 20.8	0.013
Mean BF velocity (cm/s)	22.7 ± 3.7	27.5 ± 4.6	0.00035
Mean systolic BF velocity (cm/s)	8.3 ± 2.4	10.2 ± 3.8	0.00033
Mean diastolic BF velocity (cm/s)	14.4 ± 2.6	17.2 ± 3.1	0.0025
Peak systolic BF velocity (cm/s)	47.2 ± 14.3	47.7 ± 14.1	0.094
Peak diastolic BF velocity (cm/s)	28.8 ± 7.2	30.2 ± 7.5	0.074

tive complications in this series were rare and almost always reversible.

Our study demonstrates that, in selected patients who underwent myocardial revascularization with the RA-*in situ* left ITA Y-graft, it is almost always possible both to obtain satisfactory images of the Y-graft main stem as well as to perform a complete, functional and non-invasive hemodynamic evaluation of the Y-graft by means of transthoracic echography: this method proved satisfactory in almost 90% of the patients. Perhaps, as the investigators gain more experience this could hold true for almost all patients.

Moreover, our study shows that the coronary vasodilator reserve and autoregulation are maintained in the myocardial territory supplied by the RA-*in situ* left ITA Y-graft. This composite arterial graft is a compliant conduit, able to regulate its flow capacity to the myocardial requirements both at rest as well as during exercise. The values of CFR (i.e. flow capacity) of this Y-graft were directly proportional to the number of coronary artery systems bypassed. Because the myocardial demand of three coronary systems is markedly greater than that of one or two coronary systems, the flow capacity of this Y-graft must be directly proportional to the myocardial demand.

As has been previously reported[13,24], the growth potential of the left ITA graft as a living conduit is influenced both by the competitive native coronary flow and by myocardial demand. This adaptation potential is apparent even in the early postoperative phase, followed by a sustained growth potential in the late phase. In our series of selected patients with severe coronary artery stenosis, the influence of the competitive native coronary artery flow was standardized, the growth of the Y-graft depending on the myocardial demand.

Hence, our results suggest that transthoracic echography could be a valid and safe alternative to invasive procedures for the evaluation of the main stem of composite grafts with the *in situ* ITA.

Study limitations. The small number of enrolled patients, the evaluation of the Y-graft at different times during follow-up, and the fact that myocardial scintigraphy was performed in 14 patients only constitute the main limitations of this study.

Our values of CFR are generally lower than those reported in earlier studies[12-15,17] because they were not obtained after maximum coronary vasodilation achieved by means of intravenous infusion of adenosine. However, that is a seming limitation of our study. In effect, we were interested in the relative values of CFR depending on both the number of coronary artery systems bypassed with the Y-graft as well as on the results of myocardial scintigraphy, but we were not interested in the absolute values of CFR. Probably, the differences in the CFR values after maximum coronary vasodilation are even more evident.

Our results are not validated by invasive determination using a Doppler guidewire, which is presently the gold standard for the evaluation of the CFR in conscious humans[13]. Because at our Institution economic reasons limit postoperative coronary angiography in the asymptomatic patient, this procedure was postoperatively performed in 3 cases only: the 2 patients with a myocardial scintigraphy positive for ischemia, and the patient with a perioperative myocardial infarction.

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