

Long-Term Results of the Radial Artery Used for Myocardial Revascularization

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Background—No information is available on the long-term results of radial artery (RA) grafts used as coronary artery bypass conduits.

Methods and Results—In this report, we describe the long-term (105 ± 9 months) angiographic results of a series of 90 consecutive patients in whom the RA was used as a coronary artery bypass conduit directly anastomosed to the ascending aorta. The long-term patency and perfect patency rates of the RA were 91.6% and 88%, respectively, versus 97.5% and 96.3% for internal thoracic artery grafts. The severity of stenosis of the target vessel clearly influenced long-term RA patency, whereas location of the target vessel and long-term use of calcium channel blockers did not influence angiographic results. Preserved endothelial function and absence of flow-limiting, fibrous, intimal hyperplasia were also documented.

Conclusions—Ten years after surgery, RA grafts have excellent patency and perfect patency rates. Appropriate surgical technique and correct indication are the key factors for long-term RA patency. (*Circulation*. 2003;108:1350-1354.)

Key Words: bypass ■ revascularization ■ artery ■ surgery

Since its reintroduction into coronary artery surgery in the early 1990s, use of the radial artery (RA) has gained wide popularity, and several authors have reported favorable early and mid-term results. However, to date, no information has been available on long-term results. In this report, we describe the long-term angiographic results a series of 90 consecutive patients in whom the RA was used as a coronary artery bypass conduit directly anastomosed to the ascending aorta.

Methods

Patients

After approval by the Ethics Committee of the Catholic University, Rome, Italy, a study on the use of the RA as a coronary artery bypass conduit was started prospectively in January 1993. The initial objectives of the study were as follows: (1) to establish the early, mid-term, and long-term angiographic patency rates of the RA and (2) to evaluate the effect of RA removal on forearm circulation. With evolution of our knowledge on RA grafts, 2 subsequent objectives were established: (1) to clarify the vasoreactive properties of RA grafts and (2) to evaluate the clinical and angiographic effects of long-term therapy with calcium channel blockers.

Results for all of these objectives, with the exception of the long-term RA results, have been reported in previous publications.¹⁻⁶ In this report, we describe the long-term angiographic results of the first 90 consecutive, surviving patients in whom the RA was used as a coronary artery bypass conduit directly anastomosed to the ascending aorta. Cases in whom the RA was used as a composite

conduit proximally anastomosed to a mammary graft were not included in this analysis.

Patient Population and Surgical Technique

The main preoperative and intraoperative characteristics of the 90 patients are summarized in Table 1. The majority of patients were men in their sixth decade who had triple-vessel coronary disease and almost normal left ventricular function. All operations were performed by the same surgical team using cardiopulmonary bypass and cardioplegic arrest. The left internal thoracic artery (LITA) was usually used to graft the left anterior descending artery (LAD), whereas the RA was grafted to secondary target vessels (mainly obtuse marginal or posterior descending branches; 48 and 30 cases respectively). Great saphenous vein (GSV) grafts usually completed the myocardial revascularization, whereas the RITA and the gastroepiploic artery were used in a minority of cases.

In all cases before RA harvesting, adequacy of ulnar compensation was assessed with a previously described Doppler method.² The RA was always harvested from the nondominant arm; bilateral RA harvesting was never performed. In 1 case, the RA was divided in 2 separate grafts, so that the overall number of RA grafts was 91 in the 90 patients.

Long-term calcium channel blocker therapy (diltiazem, 120 mg/d) was prescribed for all patients for the first postoperative year. After the first 12 months, 51 patients suspended calcium channel blocker therapy for the following reasons: enrollment in a prospective, randomized, investigation (44 patients) as a result of a decision by the referring cardiologist and patient noncompliance (7 patients) (suspended group). The remaining 39 patients continued the calcium channel blocker therapy indefinitely (continued group). Comparison

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TABLE 1. Preoperative and Intraoperative Characteristics of 90 Patients

Male/female ratio	66/24
Mean±SD age, y	57.2±8.8
Cardiac risk factors, No. patients with:	
Diabetes	16
Smoking	53
Dyslipidemia	45
Hypertension	37
No. of patients with previous myocardial infarction	57
No. of diseased vessels	2.95±0.54
Mean ejection fraction	0.65±0.19
No. of anastomoses per patient	3.2
No. of RA anastomoses	96*

*Includes 5 sequential grafts.

of the mid-term results of these 2 groups of patients has been previously reported.⁶

Follow-Up

Each patient was followed up regularly at our institution 6 months after surgery and every year thereafter. At each time interval, clinical examination was performed, and the results of surface ECG, stress ²⁰¹Tl myocardial scintigraphy, 24-hour Holter monitoring, and transthoracic echocardiography were carefully reviewed. In case of death, all available clinical data were collected and reviewed to establish the cause of death. Death was considered cardiac in origin when it was preceded by objective evidence of myocardial ischemia or arrhythmia.

Angiographic control assessment was proposed to all patients at the early, mid-term, and long-term follow-up visits and at any time when there was scintigraphic evidence of inducible ischemia. At long-term follow-up (mean±SD, 105±9 months), 4 patients had died (3 from noncardiac and 1 from cardiac causes), and 3 patients refused control angiography. Because the RA was divided into 2 separate conduits in 1 patient, the number of RA grafts studied was 84.

Angiographic Studies

Angiographic studies were performed by way of the femoral approach; all grafts and native coronary arteries were selectively cannulated and visualized, and left ventriculography was performed. By following the methodology used for the mid-term angiographic control,³ RA grafts were classified into 4 subgroups: (1) perfectly patent, (2) patent with irregularity, (3) stringed, and (4) occluded.

In a subgroup of 8 patients, the in vivo endothelium-dependent and -independent vasodilatory capacity and the spastic tendency of RA and LITA grafts were studied by evaluating the responses to endovascular infusion of 10⁻⁵ mol/L serotonin hydrochloride (ICN Pharmaceuticals Inc), 2 mg isosorbide dinitrate, and 10⁻⁶ mol/L acetylcholine chloride (Miovisin), according to a previously described method.^{3,5}

Intravascular Ultrasound Assessment

Image Acquisition

Intravascular ultrasound (IVUS) images were obtained with the use of mechanical ultrasound imaging catheters at 40 MHz (2.9F, Atlantis, Cardiovascular Imaging Systems/Boston Scientific). After completion of coronary angiography, the patients were given 7000 U heparin in the arterial sheath and 300 µg nitroglycerin into the RA graft to prevent possible vasospasm. The imaging probe was positioned distally to the anastomosis and withdrawn at a constant speed of 1.0 mm/s by using a motorized pull-back device. IVUS studies were recorded on high-resolution S-VHS tapes for off-line analysis.

Quantitative IVUS Analysis

Cross sections were analyzed for every second of videotape with commercially available software (Tape Measure, INDEC Co). Adoption of an automated (1.0 mm/s) modality of acquisition and identification of the proximal or distal RA anastomosis permitted us to match IVUS and angiographic images. In the IVUS cross section corresponding to the site of maximal angiographic lumen narrowing, the following measurements were obtained: lumen area, total vessel area delimited by the external elastic membrane area, and plaque area.

Statistical Analysis

Data are expressed as mean±SD. Statistical analysis was performed with an unpaired, 2-tailed *t* test for means or the χ^2 test for categorical variables. ANOVA for repeated measures was used to test differences between ITA and RA grafts after vasoactive challenge; post hoc comparison was performed with a Newman-Keuls

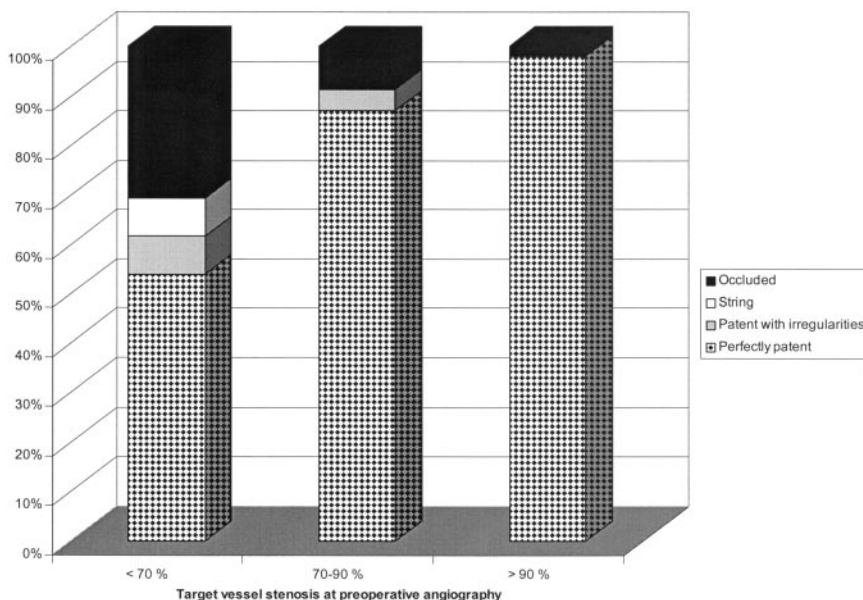


Figure 1. Long-term RA graft status in relation to target-vessel stenosis.

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TABLE 2. Long-Term Angiographic Results

	LITA (n=82)	RA (n=84)	RITA (n=7)	RGEA (n=15)	GSV (n=73)
Perfectly patent	79	74	6	12	39
Patent with irregularities	0	2	0	0	10
String	1	1	0	2	0
Occluded	2	7	1	1	24

RGEA indicates right gastroepiploic artery.

$P=0.23$ for comparison between RA and ITA and $P<0.0001$ for comparison between ITA and GSV and between RA and GSV.

test. The relative change in diameter (percentage) between the ITA and RA was compared with Fisher's exact test. Analysis was conducted with the use of commercially available software (Statistica for Windows 4.1, Statsoft Inc).

Results

Angiography

The main angiographic results are reported in Table 2. The long-term patency and perfect patency rates were 97.5% (80 of 82) and 96.3% (79 of 82), respectively, for the LITA; 91.6% (77 of 84) and 88% (74 of 84), respectively, for the RA; and 67.1% (49 of 73) and 53.4% (39 of 73), respectively, for the GSV. Statistical analysis demonstrated no difference between the RA and ITA ($P=0.23$) but significant probability values for the comparison between the ITA and GSV and the RA and GSV ($P<0.0001$ for both).

When RA patency was correlated to the severity of stenosis of the grafted vessel, we found that 7 of the 10 cases of RA malfunction occurred in patients in whom the artery was anastomosed to the coronary arteries with nonocclusive stenoses (see Figure 1). When RA patency was evaluated in relation to location of the target vessel, no difference between grafts used for the different coronary branches could be demonstrated.

Among the 84 grafts restudied in the long term, 62 had been subjected to angiography as long as 5 years after surgery. All RA grafts that were patent 5 years after surgery remained patent at long-term control assessment (Figure 2). Of note, 1 RA that had been anastomosed to a coronary vessel with a subcritical stenosis and that was stringed at mid-term angiography was found to be widely patent at later control angiography, concomitant with progression of the native coronary artery stenosis. When we compared the evolution over time of the angiographic status of RA and GSV grafts, we found that RA grafts remained substantially unchanged between the mid- and long-term control assessments, whereas a substantial proportion of GSV grafts developed disease in the same time interval (8 of 62 versus 28 of 39; $P<0.0001$). The endovascular vasoactive challenge performed in 8 cases demonstrated that the vasospastic reaction to serotonin infusion as well as the endothelium-dependent and -independent vasodilatory capacity of RA grafts were not different from those of ITA grafts (see Table 3).

IVUS Assessment

No complications occurred in the 5 RA grafts imaged with IVUS. In 1 case, a diffuse spasm occurred at the end of

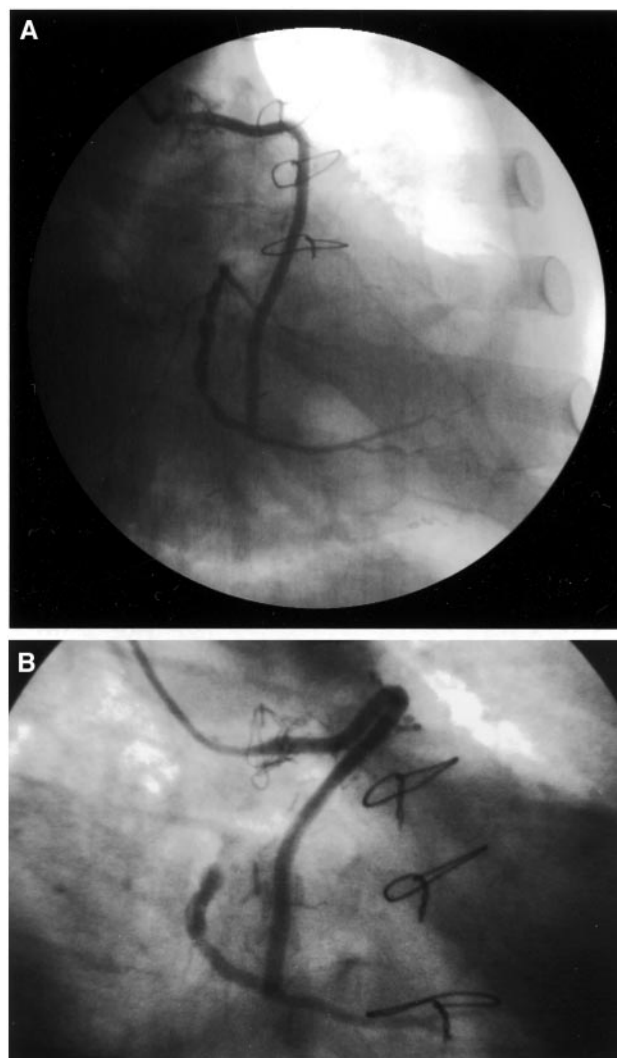


Figure 2. Perfectly patent RA to obtuse marginal branch at mid-term (A) and long-term (B) angiographic control assessment.

pull-back but resolved after administration of 300 μ g intragraft nitroglycerin. In 4 cases that were perfectly patent at angiography, IVUS excluded the presence of atherosclerotic plaques and revealed minimal intimal thickening (Figure 3). In the remaining RA, which exhibited some irregularities at angiography, IVUS confirmed the presence of limited atherosclerotic deposits and revealed moderate plaque burden at the site of maximal angiographic narrowing (Figure 4).

TABLE 3. Long-Term RA and ITA Diameter Changes After Endovascular Vasoactive Challenge

	RA Grafts	ITA Grafts	<i>P</i>
Baseline, mm	2.72 \pm 0.18	2.65 \pm 0.21	0.48
Serotonin, mm	2.54 \pm 0.22	2.58 \pm 0.18	0.69
Acetylcholine, mm	2.91 \pm 0.32	2.88 \pm 0.28	0.84
Isosorbide dinitrate, mm	2.87 \pm 0.26	2.81 \pm 0.25	0.64

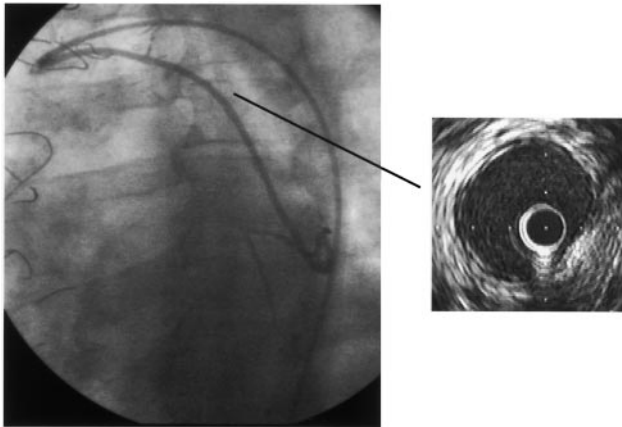


Figure 3. IVUS and angiographic appearance of perfect RA graft at long-term follow-up. Left, Angiographic left cranial view of RA graft anastomosed to large, obtuse marginal artery is displayed. RA graft is perfectly normal, without irregularities. IVUS confirms absence of irregularities along RA graft (right) and, at site of maximal lumen narrowing, only mild intimal thickness can be observed.

Effects of Long-Term Calcium Channel Blocker Therapy

Long-term angiography was performed in 37 patients in the continued group and in 47 patients in the suspended group. No difference in angiographic results of the RA grafts could be demonstrated between those who continued versus those who suspended calcium channel blocker therapy (see Table 4).

Discussion

The RA was reintroduced into coronary surgery during the early 1990s in an attempt to increase the number of available alternative arterial conduits and to facilitate achievement of totally arterial myocardial revascularization.^{1,7} After publication of the first favorable results,^{1,7-10} the RA gained wide popularity because of its favorable anatomic position, caliber,

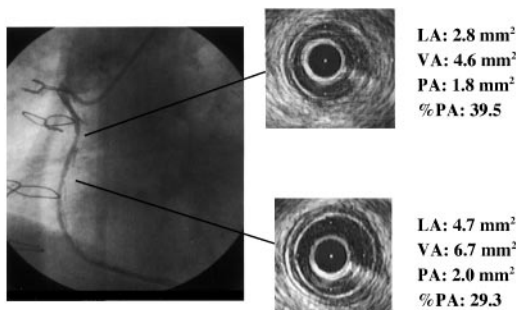


Figure 4. IVUS and angiographic appearance of irregular RA graft at long-term follow-up. Left, Angiographic left cranial view of RA graft anastomosed to right coronary artery is displayed. Graft exhibits moderate irregularities at angiography. At site of maximal lumen narrowing, as indicated by upper line, 35% diameter stenosis was measured at quantitative angiography. In corresponding IVUS cross section, moderate plaque burden leading to 39.5% reduction in lumen area was found. More distally (lower line) in normal angiographic segment, IVUS shows moderate plaque with minimal luminal reduction. Vessel shrinkage contributed to lumen reduction in upper diseased site, because vessel area is smaller than that measured in undiseased segment.

TABLE 4. Long-Term RA Angiographic Results in Relation to Calcium Channel Blocker Therapy After First Postoperative Year

	Continued Group (n=37)	Suspended Group (n=47)	P
Perfectly patent	32	42	0.95
Patent with irregularities	1	1	0.58
String	1	0	0.91
Occluded	3	4	0.73

Long-term angiography performed in 83 patients for 84 RA grafts.

length, and ease of harvest. Several authors reported excellent early and mid-term angiographic results,^{3,11-13} and serial angiographic and pharmacological studies demonstrated that even the feared hyperspastic tendency of this conduit tended to decrease with time.^{3,5} However, to date, no information was available on the long-term results of RA grafts, and all published angiographic studies have a follow-up period limited to a maximum of 5 years.

Our study reports the long-term results of the RA and testifies to the patency and perfect patency rates of 91.6% and 88%, respectively. These figures are not significantly lower than those for the LITA (97.5% and 96.3%, respectively) but are significantly better than those of GSV grafts (67.1% and 53.4%, respectively; $P < 0.0001$). With consideration that in our series the LITA was always used to graft the LAD and because of institutional policy, the RA was anastomosed to secondary target vessels, the long-term patency of the RA appears to be excellent and confirms the central role of this artery as a complementary arterial conduit for surgical myocardial revascularization.

Some authors have reported a reduced patency rate when the RA is anastomosed to the posterolateral or posterior descending branches¹⁴; in our series, however, the location of distal anastomoses did not influence the long-term angiographic results, and conduits used for diagonal or marginal branches had a patency rate similar to that of grafts directed to posterior and posterolateral target vessels. Similarly, long-term use of calcium channel blockers had no effect on the long-term RA angiographic results (Table 4), confirming the mid-term findings of our previous randomized investigation.⁶

The only factor that clearly influenced RA patency was the severity of stenosis of the target coronary vessel, because all RA failures occurred when the conduit revascularized vessels with nonocclusive stenoses (see Figure 1). The reversal of 1 case of string sign concomitant with the progression of coronary stenosis, though anecdotal, further highlights the influence of native, competitive flow on RA grafts, in accordance with what has already been reported by others and by ourselves.^{3,14}

Of note, in the subgroup of patients who underwent both mid- and long-term angiography, we found that all RA that were patent at 5 years remained opened at long-term follow-up, testifying that failure of RA grafts usually occurs in the first years after surgery. It seems likely that these early failures must be attributed to technical factors or incorrect indication. When technical problems are ruled out and the indication is correct, the attrition rate of RA grafts is extremely low, and this conduit does not appear to suffer

from the progressive atherosclerotic disease typical of GSV grafts.

Even the feared development of fibrous, intimal hyperplasia does not seem to take place in the RA graft 10 years after surgery. In fact, both pharmacological challenge and endovascular imaging have demonstrated that at long-term follow-up, RA grafts maintain good endothelial function and endothelium-dependent vasodilatory capacity, without signs of fibrous, intimal hyperplasia or endothelial dysfunction (Figures 3 and 4 and Table 3). Moreover, the vasoconstrictive reaction to endovascular serotonin infusion did not differ from that of ITA grafts, confirming the marked attenuation of the early vasospastic tendency of this artery that we had already described at the 5-year follow-up.³

In conclusion, almost 10 years after surgery, RA grafts have excellent patency and perfect patency rates. This conduit does not suffer from the progressive atherosclerotic disease typical of GSV grafts and maintains good endothelial function. Appropriate surgical technique and correct indication are the key factors for long-term RA patency; in contrast, the use of calcium channel blockers and location of the target vessel do not influence long-term RA graft status.

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