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Routine Use of Unilateral and Bilateral Radial Arteries for Coronary Artery Bypass Graft Surgery

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Objectives. **This study sought to evaluate the routine use of radial artery (RA) grafts in patients undergoing coronary artery revascularization.**

Background. **Previous long-term studies have documented poor patency of saphenous vein grafts compared with internal thoracic artery (ITA) grafts.**

Methods. **We performed a prospective review of 175 of 249 consecutive patients.**

Results. **Fifty-four patients had bilateral RAs harvested. Mean number (±SD) of grafts/patient was 3.27 ± 0.93, with 2.76 ± 0.97 arterial grafts; a mean of 1.53 ± 0.68 grafts were performed with the RA. The operative mortality rate was 1.6%. No deaths were related to RA grafts, and there were no RA harvest site hematomas or infections. Transient dysesthesia 1 day to 4 weeks in duration occurred in the distribution of the lateral antebrachial cutaneous nerve in six extremities (2.6%). Elective cardiac catheterization in 60 patients at 12 weeks postoperatively demonstrated a 95.7% patency rate.**

Conclusions. **Because of potential benefit of long-term patency associated with arterial grafts, minimal morbidity and mortality associated with use of the RA and excellent short-term patency rates, we cautiously recommend use of one or both RAs as additional conduits to be used concomitantly with the ITA for arterial revascularization of the coronary arteries.**

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In 1971, Carpentier utilized the radial artery (RA) for coronary artery revascularization; however, it was abandoned soon after because of a high incidence of occlusion in the grafts secondary to spasm, traumatic harvesting and preparation techniques and the occasional occurrence of ischemia of the hand (1–6). Eighteen years later, with the discovery of patent RA grafts thought to be occluded in the earlier Carpentier study, Acar et al. (6) revived the RA as a viable arterial conduit for coronary artery bypass graft surgery (CABG). Early patency rates in the current surgical era are >90%; this rate is thought to be due to the introduction of better harvesting techniques, the advent and use of calcium channel blocking agents and the postoperative use of aspirin (6–9). From November 1993 to through February 1996, 175 of 249 consecutive patients undergoing CABG referred to a single surgeon received RA grafts. This communication reports our initial experience with routine use of the radial artery for CABG.

Methods

Patients. Institutional Review Board approval for the use of the RA in CABG was granted in June 1993. Since November 1993, all patients referred to a single surgeon (R.F.B.) for CABG meeting the inclusion criteria were evaluated for RA harvest. Use of bilateral RA harvesting was initiated in June 1994. Informed consent was signed preoperatively by all patients (130 male [74.3%], 45 female [25.7%]; mean age [±SD] 61.3 ± 10.7 years, range 1 to 88, 95% confidence interval [CI] 59.58 to 63.04; mean body surface area 1.95 ± .22 m^2, 95% CI 1.92 to 1.99; mean ejection fraction 59.1 ± 14.58%, range 10 to 85, 95% CI 56.75 to 61.48). Six patients (3.4%) had previous CABG. All patients were referred for coronary artery disease except a 1-year old child who was referred for repair of anomalous origin of the left coronary artery. One hundred eight patients (61.7%) received total arterial revascularization fashioned from a combination of internal thoracic artery (ITA) and RA conduits. The mean number of grafts was 3.27 ± 0.93 (range 1 to 6, 95% CI 3.12 to 3.42); there were 2.76 ± 0.97 (range 1 to 6, 95% CI 2.61 to 2.92) arterial grafts and 0.47 ± 0.65 (range 0 to 3, 95% CI 0.37 to 0.58) venous grafts. The mean number of distal anastomosis/patient with the RA was 1.53 ± 0.68 (range 1 to 4, 95% CI 1.42 to 1.64). Additional patient information is summarized in Table 1.

Assessment. Preoperative noninvasive assessment of forearm collateral flow in the first 100 patients to undergo RA harvest included modified Allen's test (10,11), pulse volume recordings (PVRs) (model PVR IV, Life Sciences, Inc.) (11,12), oximetric plethysmography with a calculated perfusion index (PI) (BIOX 3700 Pulse Oximeter, Ohmeda Inc.) (13–16) and color flow and pulsed Doppler scanning utilizing an ACUSON-128 Cardio-Vascular System with a 7.5-MHz

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Abbreviations and Acronyms

CABG = coronary artery bypass graft surgery
CI = confidence interval
ITA = internal thoracic artery
LAD = left anterior descending coronary artery
PI = perfusion index
PVR = pulse volume recording
RA = radial artery
RCA = right coronary artery
SVG = saphenous vein graft
UA = ulnar artery

phased array transducer (16). Both PVRs and PIs were acquired with sequential assessment of baseline flow followed by RA occlusion and then ulnar artery (UA) occlusion to assess patency of collateral blood flow and palmar arch continuity. Since Patient 100, all patients have had only PI and modified Allen's test performed.

Table 1. Preoperative Patient Characteristics

	No. of Patients
Urgency	
Emergent (operation within 24 h of catheterization)	11
Urgent (operation within 7 days of catheterization)	106
Elective	58
Canadian Cardiovascular Society classification for angina	
Class I	9
Class II	44
Class III	36
Class IV	86
Risk factors	
Diabetes	
Type I	23
Type II	34
	(10 diet controlled, 20 oral agents, 4 unknown)
Hypertension	107
Smoking history	110
Positive family history	68
Increased cholesterol levels (>250 mg/dl)	86
Previous myocardial infarction	117
Congestive heart failure	
Present admission	14
Previous admission	21
Renal failure (creatinine ≥2.5 mg/dl)	4
Ventricular arrhythmias	10
Chronic obstructive pulmonary disease	12
Previous cerebrovascular accident	11
Carotid disease	11
Calcified ascending aorta	8
Aortic/iliac disease	9
Femoral/popliteal disease	31
Hemodynamically unstable (blood pressure requires pressor or mechanical support)	9
Shock (systolic blood pressure ≤80 mm Hg or evidence of poor end-organ perfusion)	6
Preoperative use of intravenous nitroglycerin	44

Of the 249 patients (498 extremities) referred for CABG, 25 patients refused RA harvest, had emergent surgery or had other medical contraindications to RA harvest. The RAs were not evaluated in these patients. This left 448 extremities for evaluation. Seventeen patients had bilaterally positive results (34 extremities), and 16 patients had unilaterally positive results (16 extremities). Thus, of the 448 extremities evaluated, 50 (11.2%) were excluded because the preoperative evaluation indicated inadequate collateral cirulation to the hand. Of the 398 RAs available for harvesting, 229 (57.5%) were used.

Intraoperative protocols. Harvesting of the RAs was performed utilizing the technique of Reyes et al. (7). Care was taken to avoid damage to the intima, which may precipitate intimal hyperplasia, and has been implicated as a cause of graft failure in the past (3). The grafts were injected with diluted papaverine (King Pharmacuticals) and blood solution (60 mg papaverine/60 ml blood) to facilitate visualization of the grafts and to prevent spasm. Intravenous diltiazem (Marion Merrell Dow, Inc.) was begun intraoperatively in all patients; the protocol developed by Acar et al. (6) was initially utilized: a bolus of 0.15 to 0.25 mg/kg followed by a continuous infusion of 1 μg/kg per min. However, a 32% incidence (8 of 25) of hypotension, bradycardia and heart block in the first 25 patients was noted, which necessitated either temporary discontinuation or a reduction in the dosage of the intravenous infusion. On the basis of this experience, the diltiazem administration protocol was lowered to a bolus of 0.10 to 0.15 mg/kg followed by a continuous infusion of 0.25 to 0.5 μg/kg per min. The incidence of side effects has dramatically decreased since this adjustment (18 [14.4%] of 125). Long-term oral dosing of diltiazem was up to 240 mg/day (in either short- or long-term preparations).

Preoperative and postoperative protocols. Blood pressures were checked by alternating forearms before operation to determine the range of blood pressures in each arm. For bilateral harvesting, blood pressures were checked using the lower extremities after operation until day 4 postoperatively when the upper extremities were again utilized in alternating fashion. Phlebotomy was avoided in the volar aspect of the arm or arms to be utilized for operation preoperatively. Tourniquet placement was avoided in the brachial area postoperatively for all harvested forearms for the first 4 days. Intraoperatively, all hemodynamic variables were monitored utilizing Swan-Ganz (VIP model 93A-831H, Baxter Healthcare Corp.) catheters. For patients undergoing bilateral RA harvesting, a left subclavian vein multilumen catheter (Arrow-Howes model CS14703, Arrow International Inc.) was utilized for fluid and medication administration and to facilitate blood drawing. For patients undergoing unilateral RA harvesting, the contralateral upper extremity was utilized for all intravenous and arterial monitoring lines. Left femoral or axillary arterial lines were placed for patients undergoing bilateral RA harvesting. Standard cardiac anesthesia management was provided, which consisted of narcotic relaxants in the majority of patients. Recently, use of a low dose narcotic inhalation technique to allow early extu-

Table 2. Reasons for Nonuse of Radial Artery

Reason	No. of Patients (n = 74)
Catheterization laboratory to operating room	14
Positive bilateral assessment	17
Patient refused	13
Protocol not available	6
Poor physical condition	5
Single graft required	5
Renal failure; dialysis patient	4
Poor left ventricular function	5
Septic infection in wrist	1
Cardiologist said no	1
Rule out mediastinal cancer	1
Diffuse distal coronary artery disease	1
Reoperative procedure	1

bation was begun. Postoperatively, only narrow longitudinal gauze dressings were applied to the RA harvest sites.

Repetition of the preoperative noninvasive forearm assessment was performed postoperatively. Additional postoperative assessment included evaluation for infection, hand ischemia or dysesthesia in the distribution of the lateral antebrachial cutaneous nerve or superficial branch of the radial nerve. Elective postoperative angiographic assessment was performed (8) in 60 patients. Annual contact was made with patients for follow-up status.

Statistical methods. Data were analyzed using SPSS for Windows, Version 6.1. Mean values ± SD and 95% confidence intervals were calculated. Data were compared utilizing independent *t* tests. Statistical significance was set at $p = 0.05$.

Results

Patients. Of the 249 consecutive patients who were referred for CABG to a single surgeon, 175 underwent RA harvest. The reasons why the remainder of the patients did not undergo RA harvest is summarized in Table 2. A total of 229 RAs were harvested from the 175 patients (i.e., 54 patients had bilateral RAs harvested). Two patients had two separate aortocoronary grafts fashioned from one RA. One hundred seven patients (88.4%) had one RA harvested from the nondominant forearm; 14 (11.6%) had the RA harvested from the dominant forearm because of positive preoperative assessment in the nondominant forearm. The mean length of RA harvested was 18.66 ± 1.94 cm (range 7 to 24, 95% CI 18.34 to 18.97).

Intraoperative methods and results. Intraoperatively, in two patients the RA was deemed to not be suitable as a graft because of extensive atherosclerosis, and in an additional patient the RA was not utilized because the internal diameter was too small (1 mm). In the first patient, preoperative hemodynamic assessment suggested atherosclerosis as a possibility in the right arm because the pulsed Doppler scan demonstrated decreased flow velocities in the affected portion of the RA. In the second patient, in the left arm, low Doppler flow velocities were noted throughout the length of the RA. As measured by Doppler, the distal diameter was 2.7 mm compared with 3.7 mm in the middle portion. In this patient, the distal portion of his RA was occluded. In both patients, PVRs demonstrated no flow through the radial artery when the UA was occluded (Fig. 1), and diminished RA flow was noted with PI when the UA was occluded (Fig. 2). In the third patient, only the PI was performed before operation; results demonstrated adequate collateral circulation to the hand.

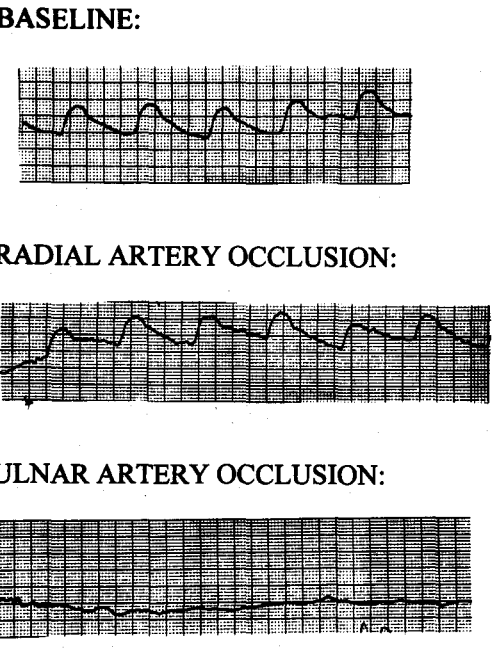

Figure 1. Pulse volume recording demonstrating inadequate perfusion of the thumb with UA occlusion. See text for further discussion.

Mean cardiopulmonary bypass time was 94.71 ± 34.62 min (range 23 to 241, 95% CI 89.09 to 100.33); mean cross-clamp time was 59.23 ± 22.93 min (range 0 to 160, 95% CI 55.5 to 62.95). Mean maximal creatine kinase level was 444.59 ± 394.66 IU/liter (range 0 to 2,989, 95% CI 380.49 to 508.7); mean maximal MB fraction was 8.95 ± 4.8% (range 0% to 33%, 95% CI 8.18 to 9.73).

Figure 2. Oximetric plethysmography and perfusion index demonstration inadequate perfusion of the thumb with UA occlusion. See text for further discussion. B = baseline; U = UA perfusion of the thumb with RA occlusion; R = RA perfusion of the thumb with UA occlusion.

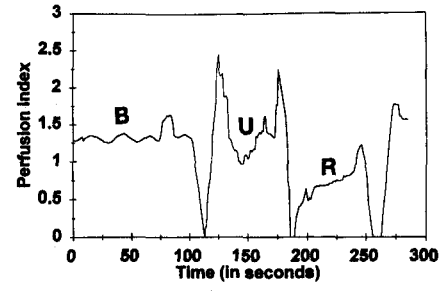

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Table 3. Radial Artery Graft Anastomosis

Vessel	No. of Anastomoses (n = 267)
LAD	15
Diagonal	34
Ramus	10
Cx	3
Obtuse marginal	136
RCA	69

Cx = circumflex coronary artery; LAD = left anterior descending coronary artery; RCA = right coronary artery.

Number and distribution of grafts. Table 3 summarizes the graft anastomosis fashioned with the RA, including 15 patients whose left anterior descending coronary artery (LAD) was bypassed with a RA conduit. By comparison, the majority of the left ITAs utilized were grafted onto the LAD (159 of 172 distal anastomosis in 163 patients), whereas the saphenous vein graft (SVG) was used for revascularizing the RCA system (60 of 85 SVG grafts). The remainder of the SVGs were to the obtuse marginal arteries (13 grafts), diagonal system (8 grafts) and 1 each to the distal LAD and to the ramus and circumflex systems. Sixty-five (42%) of the 154 right coronary artery (RCA) system arteries bypassed were 100% occluded; 37 (57%) were bypassed with an SVG and the remainder an RA graft (28 [43%]). With increasing experience, more Y grafts and sequential grafts were performed with the RA: A total of 54 RA grafts were utilized as Y grafts, and 20 were utilized as sequential grafts. Five patients had both Y grafts and sequential grafts performed; four of these patients had bilateral RA harvesting.

In an attempt to achieve total arterial revascularization, we minimized the use of SVGs. One hundred eight of the 175 patients received total arterial revascularization using a combination of ITA and RA grafts. In the first 50 patients, there was a mean of 3.02 grafts (range 2 to 5, 95% CI 2.79 to 3.25) with a mean of 2.38 ± 0.60 (range 1 to 4, 95% CI 2.21 to 2.55) arterial grafts/patient and 0.52 ± 0.65 (range 0 to 2, 95% CI 0.34 to 0.7) vein grafts. In the last 50 patients, there was a mean of 3.5 grafts/patient (range 2 to 6, 95% CI 3.19 to 3.81, $p = 0.014$), with 3.24 ± 1.15 (range 1 to 6, 95% CI 2.91 to 3.57, $p < 0.001$) arterial grafts and 0.26 ± 0.6 (range 0 to 2, 95% CI 0.09 to 0.43, $p = 0.018$) vein grafts. In the first 50 patients, 84% (124 of 148) of the total grafts performed were arterial; in the last 25 patients, 90% (75 of 83) were arterial ($p = 0.125$). Although not significantly different, the percent of arterial grafts utilized supports a change in our philosophy toward utilization of total arterial grafts. Additionally, the use of all arterial grafts significantly reduced cardiopulmonary bypass time (84.35 ± 27.59 min, 95% CI 76.73 to 87.78 for all arterial grafts vs. 109.57 ± 40.38 min, 95% CI 99.56 to 119.58 for patients who received mixed vein/artery grafts; $p < 0.001$). Cross-clamp time was similarly shorter for the patients with all arterial grafts (52.94 ± 22.79 min, 95% CI 49.1 to 57.73 vs. 66.32 ± 27.46 min, 95% CI 59.52 to 73.13; $p = 0.002$) for the patients with mixed grafts.

Postoperative results. Two patients who sustained a perioperative myocardial infarction died. In neither patient was the RA graft involved. The operative mortality rate for CABG in the RA group was 1.71% (three patients), with an overall mortality rate for the entire operative series of 1.6% (four patients).

Sixty patients underwent postoperative angiographic evaluation 1 day to 40 weeks postoperatively (mean 11.9 ± 8.68 weeks). The patency rate was 95.7%; 86 (95.5%) of 90 RA grafts were perfectly patent (8). Fifty percent (n = 28) of patients who underwent catheterization were receiving a calcium channel blocker (45% received diltiazem [n = 25]); 82% (n = 46) were receiving aspirin; and 4 patients were receiving no medication.

Postoperative volar forearm complications were encountered in seven patients. One patient developed a small proximal incisional seroma that was successfully drained by needle aspiration. Six patients had transient dysesthesia of the thenar aspect of the hand that resolved in <1 day to 4 weeks. There were no wound infections, no loss of mobility of the harvested arm or loss of fine or gross motor control.

Follow-up. There were no complications during a mean follow-up period of 16.59 ± 7.87 months (range 0.01 to 29, 95% CI 15.32 to 17.86), including late development of arm or hand ischemia, loss of motor function or myocardial infarction. Seventy patients returned follow-up surveys at 1 year and 11 patients at 2 years. Seventy-two patients report no episodes of chest pain. Four patients utilize nitroglycerin for chest pain. Thirty-four (42%) of 81 patients continued to take diltiazem at 1 year postoperatively, with an additional 11 (13.5%) of 81 patients taking other calcium channel blockers. This number drops to 4 (36.4%) of 11 patients continuing to take diltiazem at 2 years, with an additional 1 (91%) of 11 patients taking other calcium channel blockers. The most frequently cited reason for discontinuation of the medication is physician preference, not side effects. Two patients died during follow-up: One patient with a preoperative ejection fraction of 22% died ~4 weeks postoperatively from cerebral anoxia after an episode of out of hospital sudden cardiac death assumed to be ventricular fibrillation. The second patient died ~9 months postoperatively. No details of her death are available; she had been taking amiodarone (Wyeth-Ayerst) preoperatively and postoperatively to control frequent episodes of rapid ventricular tachycardia.

Discussion

The benefits of excellent long-term patency of arterial grafts for coronary revascularization, particularly the left ITA and free right ITA, include improved long-term patient survival (17,18), thus the attempt to minimize the use of vein grafts with higher occlusion rates (19–21). Various arterial grafts have been utilized for CABG, including the inferior epigastric (22,23) and gastroepiploic arteries (24–26). Eighteen years after its clinical introduction, use of the RA was revived by Acar et al. (6) because of unexpected long-term patency in

grafts thought to be occluded at earlier catheterization. This discovery, together with the advent of calcium channel blockers, use of aspirin postoperatively and modifications of the harvesting technique, led Acar et al. (6) to repropose the RA as a viable arterial conduit for myocardial revascularization.

In our experience, the RA has had a high degree of acceptance by both patients and cardiologists. Patients experience less pain and easier ambulation postoperatively. The length of hospital stay is shorter for these patients: the median is 7 days for patients with RA grafts versus a median of 8 days for patients without RA grafts. A minimal number of patients experienced postoperative forearm complications; none required a second hospital admission or increased length of stay.

We continue to harvest unilateral and bilateral RAs to supplement the ITA for coronary revascularization. Use of the RA has provided us with an opportunity to perform more frequent total arterial revascularization. We have found the RA particularly useful in obese, diabetic patients with peripheral vascular disease. We have not experienced the learning curve with RA use that has been associated with the use of the gastroepiploic artery (26). From our experience, the RA is an excellent arterial conduit. Its thicker wall and large diameter are capable of withstanding systemic pressure. The average harvested length of 18.66 cm allows anastomosis to any of the coronary arteries and proximal aortic anastomosis if desired. With its high short-term patency rate, minimal postoperative complications and ease of harvest, we will continue to utilize the RA routinely, unilaterally or bilaterally, as a concomitant arterial graft with the ITA for myocardial revascularization. Low event-free and improved long-term survival due to higher long-term patency and avoidance of reoperative CABG surgery is the intended goal; these early results make us cautiously optimistic regrading the long-term postoperative benefits of total arterial revascularization.

Implications for further study. The long-term patency rate of the RA in the current surgical era will need to be determined. In addition, the role of long-term administration of calcium channel blockers in patients with RA grafts will need to be evaluated. Approximately 60% of our patients have had long-term discontinuance of their calcium channel blockers; therefore, the difference in long-term patency rates in patients with and without calcium channel blockers will also need to be assessed.

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