Myocardial Revascularization With the Radial Artery: A Clinical and Angiographic Study

Francisco Diniz Affonso da Costa, MD, Iseu Affonso da Costa, MD, Robinson Poffo, MD, Décio Abuchaim, MD, Rogério Gaspar, MD, Lázaro Garcia, MD, and Djalma Luiz Faraco, MD

Department of Cardiac Surgery of the Santa Casa, Pontifícia Universidade Católica do Paraná, Curitiba, Paraná, Brasil

Background. It has been well documented that the use of the internal thoracic artery yields better long-term patency rates than saphenous vein grafts for coronary artery bypass grafting. This knowledge has prompted surgeons to use other arterial conduits such as the radial artery.

Methods. Between April 1994 and January 1996, radial artery grafts were used in 83 patients (mean age, 54.6 years) undergoing myocardial revascularization. All patients received diltiazem, 80 mg orally three times daily. Angiographic studies were performed in the early postoperative period in 61 patients, and 6 to 19 months later in 12 patients.

Results. There were four hospital deaths (4.8%), none of them due to cardiac causes. Perioperative myocardial infarction was observed in 3 patients, 1 related to a radial artery graft occlusion. Of 61 grafts studied early, 59 were patent (96.7%), but two grafts showed diffuse spasm. Twelve patients had a second angiogram after a mean interval of 8.7 months, and all grafts were patent. One patient who had a diffuse spasm at the early study had recurrent symptoms, and repeat angiogram showed further narrowing of the graft (string sign).

Conclusions. Our results suggest that with proper care, the radial artery may be used for coronary artery bypass grafting with good early results. Long-term follow-up and angiography studies will be needed to establish the merit of the radial artery as a graft for coronary artery operations.

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The modern era in the operative treatment of coronary arteriosclerosis started when Favaloro [1] popularized the saphenous veins as bypass grafts. The use of the internal thoracic artery (ITA) for the same purpose was pioneered by Kolessov [2] in Russia, and soon after was used by many surgeons in North America. The superiority of the ITAs in terms of long-term patency rates is widely documented [3–5]. For this reason, arterial conduits are believed to be better than the saphenous vein for coronary revascularization. The right ITA, right gastroepiploic artery, and inferior epigastric artery have also been used for myocardial revascularization [6–8].

The radial artery (RA) for coronary artery bypass grafting was initially proposed by Carpentier and associates [9] in 1973, but its use was discontinued when the authors and others reported a high incidence of narrowing or occlusion after a short period of follow-up [10, 11]. Interestingly, the angiograms of some of the grafts of the original Carpentier series showed well-functioning conduits after more than 15 years [12]. This prompted several authors to reassess the RA for coronary revascularization, especially with the use of calcium-blocking agents and some technical modifications in its harvesting and handling [12, 13].

We report our experience with this arterial graft and the results of postoperative angiograms.

Material and Methods

From April 8, 1994, to January 5, 1996, a series of 360 consecutive patients underwent myocardial revascularization at our institution. In 83 (23%), the RA was used as a bypass conduit. The RA was initially used in patients with inadequate saphenous veins (14 patients) and with scarred areas of the myocardium (15 patients). As the experience increased, 62 patients had the RA used in an attempt to revascularize the myocardium solely with arterial conduits.

Sixty-two patients were male (74%), and the age ranged from 31 to 74 years (mean ± standard deviation, 54.6 ± 9 years). Table 1 shows the clinical profile of the 83 patients.

The circulation of the hand was evaluated by the Allen test in every patient before operation. In addition, a Doppler echocardiographic flow investigation was carried out in 54 patients. On four occasions when the Allen test was doubtful, the decision to use the RA was made after a positive Doppler flow recording was obtained. Diltiazem, 80 mg orally three times daily, was administered via nasogastric tube during and after the operation.

The incision for dissection of the RA extended from the wrist to the elbow. The fascia was divided, and the muscular branches were cauterized or ligated. Both satellite veins were included in the pedicle. Gentle hydro-

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Address reprint requests to Dr da Costa, Rua Henrique Coelho Neto, 55, 82200-120 Curitiba Paraná, Brasil.

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Table 1. Clinical Data

Characteristic	n	Percentage
Patients	83	100
Hypertension	45	54
Smoking	49	57
Diabetes mellitus	21	25
Angina class III or IV	74	89
Previous myocardial infarction	39	46
Coronary angiogram		
Two-vessel disease	15	18
Three-vessel disease	56	67
Left main disease	12	14
Previous angioplasty	37	44
Previous myocardial revascularization	1	1
Emergency operation	8	9

static dilatation was performed with manual injection of heparin-treated blood containing papaverine 40 mg/L. No intraluminal probes were used. We obtained grafts measuring 15 to 20 cm in length and approximately 2.5 to 3.5 mm in diameter.

Operations were performed using extracorporeal circulation with moderate hypothermia (32°C). Intermittent cold blood cardioplegia, or more recently intermittent normothermic blood cardioplegia, was used for myocardial protection. The mean aortic clamping time was 44 minutes (range, 18 to 75 minutes), and the perfusion time was 73 minutes (range, 31 to 132 minutes).

Proximal anastomoses of the RA or ITAs were constructed at the aorta with partial occluding clamp using continuous 6-0 polypropylene sutures. Saphenous veins were anastomosed with running 5/0 polypropylene. Distal anastomoses of RA and ITA were performed with 7/0 polypropylene running sutures, whereas the saphenous veins were anastomosed with continuous 6/0 polypropylene.

Overall, we used 84 RA grafts (1 bilateral), 82 left ITA, 40 right ITA, 28 saphenous vein grafts, and 3 right gastroepiploic artery grafts. Because some of the grafts were used in a sequential fashion, the actual numbers of anastomoses were 116, 87, 41, 31, and 3, respectively. The specific sites and numbers of anastomoses with the RA are shown in Table 2.

Sixty-one patients (73%) consented to undergo angiography before hospital discharge. Some of them had a complete study, but others had just the RA graft injected. The RA grafts were then classified as follows: (1) patent; (2) patent but with mild or moderate, localized narrowing related to the tip of the catheter; (3) patent but with severe, localized narrowing related to the tip of the catheter; (4) patent but with severe, diffuse narrowing at the body of the graft; and (5) occluded.

Twelve patients had a second angiographic study 6 to 19 months later (mean, 8.7 months). In addition, 1 patient who had shown a diffuse narrowing at the early study was restudied at 4 months because of recurrent symptoms.

Table 2. Sites and Frequencies of Radial Artery Anastomoses

Site	No. of Grafts	No. of Anastomoses
LAD	6	6
DIA	8	8
Cx	3	3
OM	19	19
RCA or PIV	16	16
DIA—OM sequential	12	24
OM—OM sequential	13	26
PIV—PL	4	8
DIA—LAD	3	6
Total	84	116

Cx = circumflex artery; DIA = diagonal branch; LAD = left anterior descending artery; OM = obtuse marginal; PIV = posterior interventricular branch; PL = posterolateral branch; RCA = right coronary artery.

Results

There were four hospital deaths (4.8%). The causes of death were respiratory failure in 2 patients, mediastinitis in 1, and stroke in 1.

Only six patients required dopamine for more than 24 hours. No patient needed intraaortic balloon pump support.

Three patients suffered a perioperative myocardial infarction. In 1 of them, occlusion of an RA graft to the posterior interventricular branch was the cause, as demonstrated by the angiographic study.

Blood loss ranged from 250 to 2,000 mL (mean, 600 mL per patient). Two patients had reoperation for bleeding. Ventilatory support for more then 48 hours was necessary in 3 patients. Staphylococcal mediastinitis developed in 2 patients; both of them had had bilateral ITA grafts. One of them had a successful reconstructive procedure with muscular flaps, and the other died of the infection. One patient presented with superficial wound infection. No patient experienced ischemia in the hands. Temporary dysesthesia of the thumb was noted in 3 patients.

The results of early angiographic study in 61 patients are shown in Table 3. Among the RA grafts, two (3.2%) were occluded, three (4.9%) showed mild or moderate

Table 3. Early Angiographic Study

Site	Grafts Studied	Grafts Open	Distal Anastomoses Studied	Distal Anastomoses Open
RA	61	59 (96.7%)	86	82 (96.3%)
LITA	32	31 (96.8%)	33	32 (97.0%)
RITA	13	12 (92.3%)	13	12 (92.3%)
Saphenous vein	14	13 (92.8%)	29	28 (96.5%)
RGEA	1	1 (100%)	1	1 (100%)

LITA = left internal thoracic artery graft; RA = radial artery graft; RGEA = right gastroepiploic artery graft; RITA = right internal thoracic artery graft.

Fig 1. Sequential angiographic studies in a patient with the radial artery anastomosed sequentially to two marginal branches of the circumflex artery. (A) Early study at 8 days showing severe spasm of the whole graft (string sign). (B) Normal appearance of the graft 14 months later.

localized narrowing, one (1.6%) showed severe localized narrowing, two (3.2%) had severe diffuse narrowing, and the remainder (53, 86.8%) were normal.

Three patients had mild to moderate and 1 had severe localized narrowing of the RA graft related to the tip of the catheter. All received an intracoronary infusion of nitroglycerin, with a good response in 2. Both patients with diffuse narrowing of the RA had no improvement with nitroglycerin injection.

Twelve patients were restudied after a mean of 8.7 months. In each of the 12 cases, widely patent grafts with no abnormality were demonstrated. One of the patients who presented with diffuse narrowing at the immediate postoperative study had an entirely normal conduit 14 months after the operation, as shown in Figure 1. Another patient in whom a moderate narrowing was noted at the discharge study showed a normally patent graft 7 months later. Figure 2 shows the angiograms at 7 days and at 19 months of an RA used to bypass a circumflex artery. The other patient who presented with diffuse narrowing at the immediate study was studied again within 4 months of the operation because of recurrent symptoms. The angiogram in this patient is shown in Figure 3.

Fig 2. Sequential angiographic studies. (A) Radial artery anastomosed to the circumflex artery at 7 days. (B) Same graft 19 months later.

Fig 3. Angiographic study showing string sign of a radial artery anastomosed to a marginal branch of the circumflex artery at 4 months.

One patient died 2 months after the operation of a presumed pulmonary thromboembolism. All other patients are well; 77 have no angina and 1 has medically controlled angina after a mean follow-up of 10 months.

Comment

With the present operative techniques and methods of myocardial protection, coronary revascularization can be performed with low morbidity and mortality rates. The goal now is to achieve better long-term results by improved selection of grafts.

In 1986, Loop and colleagues [14] clearly documented that the use of the left ITA grafted to the left anterior descending artery resulted in greater survival and graft patency rates at 10 years compared with conventional saphenous vein revascularization. More recently, Fiore and co-workers [4] and Galbut and associates [5] suggested that even better results after 15 to 17 years of follow-up can be achieved when both ITAs are used.

Use of both ITAs, however, even in conjunction with more complex techniques such as sequential anastomoses and free, T, or Y grafts, may not be sufficient to provide complete arterial revascularization and may actually be contraindicated in some circumstances [15]. Therefore, other arteries have been used as conduits, such as the gastroepiploic and the inferior epigastric [6, 8]. The use of the RA as an aortocoronary graft, initially proposed by Carpentier and associates [9] in 1973, was subsequently discontinued because of a high index of occlusion observed after 1 or 2 years.

In reviewing cases in which the RA had been used 14 to 17 years previously, Acar and colleagues [12] found that some of the grafts had normal function; these findings prompted reintroduction of the RA for myocardial revascularization. From 1989 to 1991, Acar and colleagues used the RA in 104 patients. Fifty of them were studied, yielding a 100% immediate and a 93.5% "late" patency rate at a mean follow-up of 9.2 moths after the operation. Calafiore and associates [16] included the RA in their cases of complex revascularization using only arterial grafts. Twenty-six of the grafts that were studied in the early postoperative period were patent, and the "late" patency rate was 94.1%. Dietl and Benoit [17] also reported excellent functional results with the RA graft.

In our series, the immediate graft patency rate was 96.7% (59 of 61). Of 86 anastomoses, 82 (95.3%) were patent. We think that at least three of our anastomoses failed for technical reasons or because of poor runoff, rather than because of the type of graft used.

The RA graft is reasonably easy to dissect and to handle. Although Calafiore and associates [16] recommended the use of composite grafts, we believe that comparable results can be obtained by direct suture of the graft to the aorta.

Both ITA and RA grafts are arterial conduits, but they differ in many aspects [10, 18]. The ITA has a thin media (330 μm) consisting mainly of elastic fibers, whereas the RA has a thick layer (500 μm) of muscular fibers. This might explain the greater tendency of the RA to spasm. Arterial free grafts may have a higher incidence of spasm compared with in situ arteries. Massa and co-workers [19] have shown experimentally that denervation of arterial grafts significantly interferes with the vasomotor tonus and the contractile response to chemical stimuli because the α-adrenergic postjunctional receptor function is altered. This may explain the existence of the string sign in some free grafts of the ITA, gastroepiploic artery, and RA [6–8, 12]. The use of papaverine and calcium blocking agents does not completely eliminate RA spasm, as shown by Acar and colleagues [12] and seen also in the present study.

Reasons for the excellent results of the ITA are many, including the fact of being an arterial graft that has its nutrition mainly from the vessel lumen, rich lymphatic drainage, and the production of prostacyclins and endothelium-derived relaxing factor [20, 21]. To what degree the RA may fulfill all these qualities has not been defined completely.

A major concern regarding use of the RA is intimal hyperplasia. Van Sons and colleagues [18] stated that the RA when used as a free graft has a tendency to intimal hyperplasia because the thick medial layer is more vulnerable to ischemia due to interruption of the vasa vasorum. In addition, the internal elastic fenestrations facilitate the migration of myocytes into the intima. The histologic studies by these authors show, however, that the vasa vasorum is confined to the adventitia, suggesting that the nutrition of the medial layer is a result of diffusion from the lumen.

In previous experiences [10, 11], the accelerated intimal hyperplasia of the RA occurred in the initial months and may be attributed to endothelial damage during handling of the graft. With adequate operative manipulation,

including avoidance of probes, use of gentle hydrostatic dilation with blood containing papaverine, use of calcium-channel blockers, and scrupulous avoidance of touching the endothelium with surgical instruments, favorable results have been documented in the more recent experiences [12, 13, 16, 17]. In our 12 patients studied more than 6 months after the operation, all had a good radiologic appearance. It seems unlikely that these grafts will undergo unfavorable changes after this time. The good clinical outcome of our other patients also suggests that the grafts are functioning well.

The favorable results of our study indicate that the RA can be used successfully for coronary revascularization and is an excellent option for patients with absent or varicose saphenous veins. However, longer clinical and angiographic follow-up is needed to determine its role as an aortocoronary graft.

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INVITED COMMENTARY

The significant number of patients who require primary or reoperative coronary artery bypass with limitation in available autogenous bypass graft conduit continues to stimulate the evaluation of a variety of graft sources. This article, as well as other recent studies that are referenced in it, justifies renewed enthusiasm for the radial artery graft, a conduit long avoided after discouraging reports by me and others two decades ago.

A reflection today on our early experience should not be allowed to cast serious reservations on these recent results using the radial artery conduit. Indeed, examination of our past methodology serves indirectly to endorse the importance of technical factors that contemporary reports emphasize. Our unsatisfactory outcomes using radial artery grafts resulted when many were harvested using electrocoagulation on the small branches of the artery, probes were passed intraluminally, saline solution was used for distention, calcium-blocking agents were not used, and many anastomoses were performed on the beating heart. Some of these factors are now known to contribute to reduced graft patency regardless of the conduit. At best, our initial trial reflected the delicacy of the radial artery and the reactivity that others have demonstrated with reports of the reversible "string sign" that has been repeatedly observed.

The foregoing report and other recent works have

updated and refined techniques that minimize trauma to the graft and modify vasoreactivity by the use of calcium-channel blockers. These measures appear essential to obtain results with the radial artery that are more reliable and acceptable. Resurgence of interest in the radial artery is to be expected. Additional reports of long-term success could well place this graft in a favorable position relative to the internal mammary artery in certain clinical settings. It now appears timely to structure studies that compare the mammary artery pedicle and free grafts with the radial artery. A prospective study with *complete* angiographic and clinical follow-up will be necessary to establish the relative merits of each bypass configuration.

Additional long-term follow-up information will hopefully soon be forthcoming. Nevertheless, the acceptable low frequency of arm morbidity that is generally observed and the very encouraging results that have been achieved through attention to important details of graft management such as highlighted again by da Costa and associates show the possibility of returning the radial artery graft to respectable status in the repertoire of alternative coronary artery bypass graft conduits.

R. Leighton Fisk, MD

1520 South Dobson Rd
Suite 308
Mesa, AZ 85202