Radial Artery as a Graft for Coronary Artery Bypass Grafting

Junjiro Kobayashi, MD

The radial artery (RA) graft was revived in late 1980s when it was found that the graft was patent 13–18 years after coronary artery bypass grafting (CABG) after improvement of the technique in harvesting and the use of calcium-channel blockers. Recently, the RA became a reasonable alternative to the saphenous vein (SV) graft with the trend toward complete arterial revascularization and more frequent off-pump CABG to avoid aortic manipulation. To improve the quality of the RA conduit, harvesting technique and topical and systemic antispasmodic medication are important. The RA should be grafted to severe proximal stenosis (>90%) in the native coronary arteries to avoid flow competition, especially in the right coronary territory. The RA graft could be used as an aortocoronary or composite configuration with similar graft patency. Early graft patency of the RA conduit was as good as other arterial grafts, and better than SV graft in the circumflex and right coronary territories, in many studies, especially in diabetic patients. Long-term results of graft patency and cardiac-event-free survival compared with SV graft are still controversial in randomized controlled trials, probably because the incidence of flow competition and the definition of graft patency varied. (*Circ J* 2009; 73: 1178–1183)

Key Words: Coronary artery bypass; Left internal thoracic artery; Radial artery; Saphenous vein

The superiority of the left internal thoracic artery (LITA) over the saphenous vein (SV) in coronary artery bypass grafting (CABG) was widely accepted in angiographic studies in the 1980s.^{1,2} The clinical importance of the LITA to the left anterior descending artery (LAD) graft was emphasized in a long-term follow-up study comparing it with the SV over 20 years.³ The graft patency rate of the LITA to the LAD graft was approximately 90%, and that of SV grafts was 50–60% at 10 years after CABG.^{4,5} Because the SV developed intimal hyperplasia and graft atherosclerosis, which caused late graft occlusion, various arterial grafts have been adopted over the past 30 years. The right internal thoracic artery (RITA),^{6,7} the right gastroepiploic artery (GEA),^{8,9} the radial artery (RA),^{10,11} and the inferior epigastric artery (IEA)^{12,13} have been used in addition to the LITA. According to the database of Japanese Association for Coronary Artery Surgery in 2004, the LITA comprised 37.5% of the total grafts. Other arterial grafts were 14.5% (RITA), 14.7% (RA), and 9.1% (GEA). Arterial grafts accounted for 76% of total grafts in Japan, which is significantly higher than in Western countries. Here I review the current status of the RA graft as the second choice of arterial graft after the LITA.

Historical Perspective

The RA was first used in CABG by Carpentier et al in 1971.¹⁴ However, 2 years later, they recommended not using the RA because of the 35% incidence of narrowing or occlusion of this conduit, which was much higher than in

the SV graft by control angiography.¹⁵ Graft failure was caused by spasm and intimal hyperplasia after endothelial denudation from mechanical dilatation and the trauma of skeletonized harvesting. RA grafts were revived in late 1980s when, after initially believing that they were occluded, they were found to be patent 13–18 years after CABG.¹⁰ The technique of harvesting and the use of calcium-channel blockers has improved the early and late graft patency, and revived the use of the RA. The 5-year graft patency rate of the RA was 84% compared with 90% for the LITA. The study showed that the RA is a reasonable alternative to other graft materials that complement the LITA. Recently, the SV graft is being widely replaced by the RA. With the trend toward complete arterial revascularization and more frequent off-pump CABG (OPCAB) to avoid aortic manipulation, the use of the RA as a composite graft with the internal thoracic artery (ITA) has become more common.^{16,17}

Harvesting Technique

The RA is easily harvested and has excellent handling characteristics. However, preoperative evaluation and proper harvesting technique is mandatory for good short- and long-term patency rates and the possibility of improved survival. The most widely used clinical test for assessment of adequate ulnar collateral circulation to the hand is the Allen test. Other assessment techniques, such as pulse oximetry, digital plethysmography, and Duplex scanning, have been reported.¹⁸ Contraindications in addition to forearm ischemia are severe atherosclerosis with calcification, and dissection from prior cannulation. Thrombotic occlusion immediately before CABG because of preoperative cardiac catheterization is not a contraindication to use the RA after thrombectomy in the operating room. The most common complications after RA harvest are sensory abnormality and numbness, which occurs in 3–15% of patients.^{19,20}

The options for RA harvest are pedicled or skeletonized with or without using the ultrasonic scalpel, and open vs endoscopic harvesting. Significantly greater blood flow is

(Received May 8, 2009; revised manuscript received May 11, 2009; accepted May 12, 2009; released online June 9, 2009)

Department of Cardiovascular Surgery, National Cardiovascular Center, Suita, Japan

Mailing address: Junjiro Kobayashi, MD, Department of Cardiovascular Surgery, National Cardiovascular Center, 5-7-1 Fujishiro-dai, Suita 565-8565, Japan. E-mail: jkobayas@hsp.nvcc.go.jp

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Table 1. Advantages and Disadvantages of the SV, RA, RITA, and GEA for CABG as a Second Graft to the LITA

	Advantage	Disadvantage
SV	Good handling Enough length for many anastomosis as for individual graft Decreased transfusion than with bilateral ITA use Decreased harvesting time than with bilateral ITA use	Poor short- and long-term patency Not available in varix patients Postoperative leg edema Poorer wound healing than the RA
RA	Length >20 cm Luminal diameter slightly larger than that of coronary arteries Good handling Decreased transfusion than with bilateral ITA use Decreased harvesting time than with bilateral ITA use	Very spasmodic Not always available (Allen test positive, unsuitable quality, CRF) Numbness and risk of motor dysfunction Arm wound
RITA	Excellent long-term patency Less spastic than RA Almost always usable Graftable to any territory as a composite free graft	Longer harvesting time Not graftable to PL or PDA as in-situ More bleeding and sternal infection than with RA harvest Difficult handling as a composite graft Thin arterial wall not suitable for aortic anastomosis
GEA	Graftable to any territory as in-situ graft Substitute for RA composite graft Available in redo CABG Suitable for MICS RCA anastomosis	Laparotomy (delayed oral intake) More spasmodic than the ITA Not better than SV patency Size variety not appropriate in some patients

SV, saphenous vein; RA, radial artery; RITA, right internal thoracic artery; GEA, gastroepiploic artery; CABG, coronary artery bypass grafting; LITA, left internal thoracic artery; ITA, internal thoracic artery; CRF, chronic renal failure; PL, posterolateral branch; PDA, posterior descending artery; MICS, minimally invasive cardiac surgery; RCA, right coronary artery.

reported in RA grafts harvested by ultrasonic scalpel than in traditionally harvested RA grafts;²¹ probably because of the larger RA caliber with the skeletonizing technique and better pharmacological preparation. In addition to systemic administration of nitroglycerin and diltiazem, antispasmodic agents are used topically. Papaverine, which is a short-acting phosphodiesterase inhibitor, is a widely used vasodilator for ITA and RA harvesting. As it is very acidic, a mixture of blood as a buffer is mandatory when it is infused into the lumen of the RA. Milrinone, which is a long-acting phosphodiesterase inhibitor, systemically used for heart failure as a dilator, has been administered intraluminally to prevent RA spasm, with good clinical results.²² Verapamil and nitroglycerin (VG solution) can effectively prevent spasm against a wide range of vasoconstrictors, with better preservation of endothelial function than papaverine.²³ The alpha-adrenoreceptor antagonist, phenoxybenzamine, and verapamil in heparinized blood are also used intraluminally and topically.²⁴

Advantage of RA Use

In Western countries, conventional CABG consists of LITA to the LAD and SV grafts to other coronary branches under cardiac arrest with cardiopulmonary bypass. Despite the easy access and adequate length for aortocoronary bypass, SV grafts have poor long-term patency.^{3–5} In any patient category, bilateral ITA use has been reported as better than only LITA use in late clinical results.^{25–27} However, bilateral ITA harvesting has shown a higher incidence of sternal wound infection in patients taking insulin or steroids, who are obesity or have chronic obstructive lung disease.^{28,29} In addition, the RITA to LAD graft crossing the midline of the chest may obstruct future reoperations for aortic valve surgery, but to avoid this situation the RITA is unable to reach the posterolateral coronary artery even if it passes through the transverse sinus.

The RA is more than 20 cm in length on average and able to reach any coronary territory when it is used as a composite graft. The RA has an inner diameter of 2–3 mm without size mismatch to the coronary arteries. Harvesting

of the RA is concurrently possible with LITA and SV harvesting. There are several observational studies that showed better early and late mortality and morbidity compared with SV grafts.^{30,31} Unlike the SV grafts, the RA grafts adapted to arterial pressure and flow, and changed diameter for optimal flow velocity. As the second arterial graft in addition to LITA to LAD anastomosis, cohort studies comparing the RITA and the RA showed the same clinical and angiographic results.^{32,33} In addition, perioperative bleeding and sternal wound infection are favorable with the RA compared with the RITA.³³

Other arterial grafts have their own disadvantages. The GEA, which is able to reach any coronary territory as an in-situ graft, has been widely used in Japan compared with Western countries. Use of in-situ GEA for CABG was first reported in 1987, and early graft patency ranged from 90% to 100%.^{8,9} Long-term graft patency at 10 years was not better than with SV grafts;³⁴ probably because of the size variation. GEA harvesting requires a longer skin incision and laparotomy, which delays oral intake. The GEA is also prone to flow competition compared with the LITA because the GEA is the third branch of the abdominal aorta and has 10–15 mmHg lower pressure at its end compared with the end of the LITA.^{35–37} Although skeletonized and composite use of the GEA for larger internal diameter and flow has been reported;³⁸ avoiding flow competition has not been proved.^{39–41}

The IEA was first reported as an alternative arterial graft to the SV in 1990.¹² It is relatively short and only suitable for grafting to diagonal or intermediate branches. The major complication of IEA harvesting is abdominal wall hematoma or infection. As the graft patency of the IEA is not better than SV grafts, it is no longer used widely.

Disadvantages of RA Use

One of disadvantages of the RA is the intense spasm. Basic study has delineated that the mechanism of severe spasm in the RA is more difficult to reverse compared with the LITA.⁴² The functioning of the RA in releasing endothelium-derived relaxing factors such as nitric oxide is the same

Table 2. Patency Rate of RA and Other Grafts

Reference	Year	Interval	RA	% of AC	LITA	RITA	GEA	IEA	SV
Acar ¹⁰	1992	<3 weeks	56/56 (100%)	100%	48/48 (100%)	11/11 (100%)			8/9 (88.9%)
		9.2 months	29/31 (93.5%)		28/28 (100%)	9/9 (100%)			
Calafiore ⁵⁵	1995	3.6 months	75/76 (98.7%)	0%				67/70 (95.7%)	
		21.2 months	33/35 (94.3%)					25/25 (100%)	
da Costa ⁵⁶	1996	8.7 months	59/61 (96.7%)	100%	21/32 (96.8%)	12/13 (92.3%)	1/1 (100%)		13/14 (92.8%)
Brodman ⁵⁷	1996	11.9 weeks	86/90 (95.5%)	100%					
Chen ⁵⁸	1996	11.6 weeks	90/94 (95.7%)	100%	62/62 (100%)				22/24 (93.3%)
Possati ⁵⁹	1998	59 months	57/62 (91.9%)	100%	57/58 (98.2%)	3/4 (75%)	9/10 (90%)		43/58 (74.1%)
Tatoulis ⁶⁰	1998	4.2 months	21/22 (95.7%)	90%	16/16 (100%)				
Acar ⁶¹	1998	5.6 years	54/64 (84.4%)	100%	44/47 (93.6%)				
Bhan ⁶²	1999	16.2 months	60/62 (96.8%)	100%	56/57 (98.2%)				
Amano ⁶³	2001	<3 months	137/139 (98.6%)	69%	99/100 (99.0%)	27/27 (100%)	48/50 (96.0%)		34/38 (89.5%)
		1.5 years	213/229 (93.0%)	65%	168/171 (98.2%)	27/27 (100%)	75/82 (91.4%)		71/79 (89.8%)
Iacò ⁶⁴	2001	18 days	88/89 (98.9%)	11%	82/82 (100%)			13/13 (100%)	4/4 (100%)
		48 months	87/91 (95.6%)	22%	63/93 (100%)		11/12 (91.7%)	10/11 (90.9%)	8/9 (88.8%)
Possati ⁶⁵	2003	105 months	77/84 (91.6%)	100%	80/82 (97.5%)	6/7 (85.7%)	14/15 (93.3%)		39/73 (53.4%)
Cameron ⁶⁶	2004	5.2 years	55/62 (88.7%)	96%	51/51 (100%)	17/18 (94.4%)			33/36 (91.6%)
Zacharias ⁶⁷	2004	1.8 years	111/157 (70.7%)	NA	370/394 (93.9%)				95/161 (59.0%)
Khot ⁶⁸	2004	565 days	204/398 (51.3%)	NA	243/269 (90.3%)	61/77 (79.2%)			174/272 (64.0%)

IEA, inferior epigastric artery; AC, aortocoronary bypass; NA, not available. Other abbreviations see in Table 1.

as for other arterial grafts, as is its constriction function to vasoconstrictive factors. However, the RA has multiple tight muscle layers in the media, which has a higher density of muscle cells than other arterial grafts. Because of this, the RA wall has a higher maximum contractile force in response to vasoconstrictive agents, such as norepinephrine, serotonin, endothelin I, and angiotensin II. These chemical mediators are released after endothelial damage caused by surgical trauma and platelet aggregation.

RA grafts frequently show the flow competition phenomenon with mildly stenotic native coronary arteries.^{43–51} The use of the RA in composite grafts with the LITA as Y or T grafts showed similar graft patency as RA grafts used as an aortocoronary bypass.^{45–47} However, Gaudino et al found flow competition more frequently in the composite RA conduits than in the aortocoronary RA conduit.⁴⁸ Long-term patency of these competitive RA grafts was poor by angiographic analysis, though it was better than the SV when good forward flow was present.^{44,49,50} Other potential disadvantages of composite grafts compared with aortocoronary grafts are the relative technical difficulty and the reliance of a single inflow to supply all or many coronary territories.⁵¹ The SV graft still has a role as a graft to the moderately stenotic right coronary territory because of the high incidence of flow competition of composite RA grafts to the right coronary branches,^{11,43,44,47,51,52} and the poor early graft patency of the RITA to the right coronary artery.^{53,54} The advantage and disadvantage of the grafts are listed in **Table 1**.

Patency of RA Grafts

The long-term outcome after CABG depends on graft patency. Previous angiographic observational studies have shown that the RA achieved excellent short- (96–100%), mid- (94–97%), and long-term graft patency (84–96%) when used as either an aortocoronary bypass or a composite graft (**Table 2**).^{10,55–67} Patency rates of the RA have exceeded those of SV grafts at all time points and are comparable to other arterial grafts. Many reports have shown better outcomes of the RA compared with the SV,^{10,56,58,59,63–65,67} though some reported similar long-term graft patency.^{33,45,48,66}

Only the Cleveland Clinic reported worse graft patency of the RA than the SV.⁶⁸

Possati et al reported the long-term (105±9 months) graft patency of RA grafts in a series of 90 consecutive CABG patients.⁶⁵ The RA graft patency was 88%, which was less than that of the LITA (96%), but better than that of the SV (53%). Although these results are encouraging the use of the RA as a complementary arterial conduit with the LITA, there are only a few long-term studies assessing RA graft patency in the setting of a randomized controlled trial.

Randomized Controlled Trials

The Radial Artery Patency Study (RAPS) Investigators enrolled 561 patients in 13 centers.⁶⁹ In this trial, the RA graft was randomly assigned to bypass the major artery in either the right coronary territory or the circumflex coronary territory, with the SV graft used for the opposing territory, which had proximal lesions at least 70% diameter narrowing. Angiography for 440 RA grafts and 440 SV grafts was performed in 440 patients in 1 year. Desai et al reported that 8.2% of RA grafts and 13.6% of SV grafts were completely occluded ($P=0.009$).⁶⁹ Diffuse narrowing of the graft (string sign) was present in 7.0% of the RA grafts and only 0.9% of SV grafts ($P=0.001$). The absence of severe native vessel stenosis was a risk of graft occlusion and diffuse narrowing of the RA conduit (70–89% proximal stenosis: 81.7%; >90% proximal stenosis: 91.5%). Patency of the RA grafts was similar in the right coronary and circumflex arteries. These results are compatible with previous reports suggesting that the RA should be limited to grafting to native coronary vessels with a high degree of stenosis (>70%) because of graft sensitivity to competitive flow and diffuse narrowing.^{43–51} Diffuse narrowing of the RA graft is thought to be of little or no clinical consequence because the narrowed graft may improve or work well late in the follow-up. However, cardiologists consider the string sign of the RA graft as a failure. As the string sign at 1 year is unfavorable toward a functioning RA or SV graft, 15.2% of RA grafts and 14.5% of SV grafts are occluded or functioning poorly. In an early postoperative study, composite RA grafts with competitive flow without diffuse narrowing were present in 7.3% of

total conduits.⁷⁰ The actuarial patency rate of these grafts on late angiography was only 33.9% at 3 years after OPCAB. RA grafting should not be considered in the setting of <75% proximal coronary obstruction, especially in the right coronary branches.

The RAPS Investigators also reported that diabetes (RR: 1.45, $P=0.03$), female gender (RR: 1.78, $P=0.02$), and small target vessel diameter (RR: 2.28, $P<0.01$) are multivariate predictors of graft failure.^{71,72} Graft occlusion was more common among diabetic patients (14% vs 10%) because of more frequent SV occlusion (19%) than RA occlusion (10%). The RA is protective in the small-sized coronary arteries with diffuse diabetic disease. With regard to gender, RA graft occlusion rate at 1 year was similar in men (8.6%) and women (5.3%) ($P=0.6$), whereas SV graft occlusion rates were lower in men (12.0%) than in women (23.3%). A history of peripheral vascular disease was associated with an elevated risk of RA occlusion, but not with SV occlusion. On the contrary, angiographic studies of patients at the Cleveland Clinic found poor graft patency in the RA (51%) compared with the SV (64%). With regard to sex, women had significantly worse RA graft patency (39%) than men (56%).⁶⁷

The Radial Artery Patency and Clinical Outcome (RAPCO) study was undertaken to compare angiographic patency and cardiac-event-free survival of the RA graft with that of the free RITA and SV during a 10-year period after CABG.⁷³ The RA was compared with the free RITA in patients <70 years of age and with the SV in patients aged >75 years. The 5-year interim results of this single center trial conducted by Buxton et al in Australia reported that there were no differences in angiographic graft failure and cardiac events of the patients with the RA compared with the RITA or SV. The 5-year patency rates between the RA and RITA were 95% vs 100%, respectively, and those between the RA and SV were 87% vs 94%. However, these results were based on a small number of angiographic studies, and SV graft patency was very much better than in previous reports. The final results up to 10 years should clarify the long-term RA graft patency.

The Radial Artery Versus Saphenous Vein Graft Patency (RSVP) trial was a single-center, prospective, randomized clinical trial designed to compare 5-year patency rates of RA and SV aortocoronary grafts to the circumflex coronary artery.⁷⁴ At 5 years, 103 patients among 142 enrolled patients underwent angiography. The graft patency of the RA (98.3%) was significantly ($P=0.04$) better than that of the SV (86.4%). Graft narrowing occurred in 10% of patent RA grafts and 23% of SV grafts ($P=0.01$).

Total arterial myocardial revascularization with a composite RITA or RA was compared with conventional CABG in a prospective randomized fashion by Muneretto et al.⁷⁵ At a mean follow-up of 12 months, the total arterial CABG group had a better outcome in terms of angina recurrence, need for percutaneous cardiac intervention, and actuarial freedom from cardiac events. The 1-year results for total arterial revascularization, in which the RA was used as a composite or aortocoronary conduit in addition to in-situ bilateral ITA grafting, vs conventional coronary CABG (CARRPO trial) showed similar graft patency, and cardiac-event-free rates at 1 year after CABG.⁷⁶

Summary and Recommendation

To improve the quality of the RA conduit, harvesting

technique and topical and systemic antispasmodic medication are important. The RA should be grafted to severe proximal stenosis (>90%) in the native coronary arteries to avoid flow competition. The RA graft can be used as an aortocoronary or composite configuration with the same graft patency. Early graft patency of the RA conduit is as good as other arterial grafts and better than the SV graft in the circumflex and right coronary territories in many studies, especially in diabetic patients. Long-term results of graft patency and cardiac-event-free survival compared with SV graft are still controversial in randomized controlled trials, probably because both the incidence of flow competition and the definition of graft patency varied.

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