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Skeletonization of the Radial Artery with the Ultrasonic Scalpel: Clinical and Angiographic Results

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ABSTRACT

Background: To improve the patency rate of the radial artery graft, we have been using a skeletonized harvesting technique since September 1, 2001. Our early reports confirmed better graft patency of the skeletonized radial graft than the conventional pedicled graft. However, its midterm results were unknown. We present our recent experience and follow-up results of radial artery grafting using the skeletonized harvesting technique.

Methods: Between September 1, 2001, and July 31, 2002, 391 patients underwent isolated coronary artery bypass surgery in our hospital group, excluding minimally invasive direct coronary bypass procedures via small thoracotomy or T-grafting. Among them, skeletonized radial grafting was performed in 246 patients (182 men and 64 women; mean age, 66.2 ± 9.5 years). Follow-up is to be completed by December 31, 2003. Perioperative, early angiographic, and follow-up results were analyzed.

Results: There were 1 hospital death and 5 incidences of postoperative myocardial infarction. None of these occurrences were related to radial artery bypass. Early angiography revealed that the stenosis-free graft patency rate of radial artery anastomoses (291/303 cases, 96.0%) was not significantly different from the patency rates of surgeries involving the use of other conduits (left internal mammary artery, 95.1%; right internal mammary artery, 93.8%; gastroepiploic artery, 93.1%; and saphenous vein, 98.2%). Follow-up was completed for all hospital survivors with a mean follow-up time of 1.4 ± 0.3 years. There were no cardiac deaths and 5 cardiac events, giving a cardiac event-free rate of 97.5%.

Conclusion: In our limited follow-up, cardiac events have been well controlled. Midterm follow-up angiographic study is necessary to confirm our clinical outcome data.

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INTRODUCTION

The radial artery has been widely used in coronary artery bypass grafting (CABG) since Acar and colleagues reported their revival of its use in 1992 [Acar 1992], and it has become a third conduit of choice after the left and right internal mammary arteries (LIMA and RIMA). The pharmacologic characteristics of the radial artery, especially the local production of nitric oxide, which has been considered to play a major role in relaxing vascular smooth muscle, inhibiting smooth muscle proliferation, and inhibiting platelet aggregation [Garg 1989], are known to be similar to those of the IMA [Buxton 1997]. Thus, the radial artery has been considered to be potentially as good an arterial conduit as the IMA. The graft patency rate of the radial artery is reported to be approximately 80% at 5 years [Acar 1998], which is lower than that of the IMA but better than the saphenous vein. Vasospasm related to the structural characteristics of the radial artery (rich in smooth muscle cells and a thick media) may play a role in radial artery failure, especially in the early postoperative period. Because vasospasm frequently occurs in the radial artery, the saphenous vein, which has a large caliber and which can deliver a high graft flow to the distal coronary artery, has continued to be used despite its high long-term graft failure rate. Papaverine, milrinone, and/or nitrates have been used to reverse vasospasm [Buxton 1966], and these agents are known to act on the media of the arterial wall but not on the adventitia. Skeletonized harvesting is a method for removing all adventitia from the main trunk of the artery, and skeletonization may maximize the effects of antivasospasm agents. In our institution, skeletonized techniques have been applied to the harvest of the radial artery since September 2000, and our early results have already been published [Amano 2002]. With skeletonization, the occurrence of vasospasm has been minimized, and the early angiographic results have been excellent. The skeletonized radial artery appears to behave as a large-caliber, high-flow, valveless, arterial conduit. We have abandoned pedicle harvesting of the radial artery, and skeletonized harvesting has

Table 1. Preoperative Patient Demographics (n = 246)*

Clinical characteristics	
Age (range), y	66.2 ± 9.5 (33-90)
Age greater than 75 y, n	50 (20.3%)
Female sex, n	64 (26.0%)
Cardiac profile, n	
Unstable angina	54 (22.0%)
Acute myocardial infarction	9 (3.7%)
Previous myocardial infarction	147 (59.8%)
History of congestive heart failure	28 (11.4%)
Poor ejection function (<40%)	25 (10.2%)
Atrial fibrillation	10 (4.1%)
Redo surgery	9 (3.7%)
Emergency surgery	17 (6.9%)
Angiographic profile	
Left main disease, n	57 (23.2%)
No. of diseased vessels (range)	2.7 ± 0.5 (1-3)
Three-vessel disease, n	183 (74.4%)
Coronary risk factors, n	
Hypertension	166 (67.5%)
Diabetes	123 (50.0%)
Insulin user	37 (15.0%)
Hyperlipidemia	114 (46.3%)
Smoking	94 (38.2%)
Obesity	19 (7.7%)
Family history	45 (18.3%)
Comorbidity, n	
Peripheral vascular disease	18 (7.3%)
Cerebral vascular accident	33 (13.4%)
Chronic obstructive pulmonary disease	14 (5.7%)
Calcified ascending aorta	13 (5.3%)
Renal dysfunction (serum creatinine >15g/dL)	2 (0.8%)
Hemodialysis	0 (0.0%)

*Data are presented as the mean ± SD where appropriate.

become our routine method. In this report, we present our current harvesting technique, additional early angiographic results, and clinical follow-up results after skeletonized radial artery grafting.

METHODS

Patients

The perioperative and remote data for patients who underwent isolated coronary artery bypass at Shin-Tokyo Hospital Group were prospectively put into a structured database. The patients who underwent minimally invasive direct coronary bypass via small minithoracotomy were excluded from this study. Cases of T-grafting using the IMA or the gastroepiploic artery as an inflow were also excluded, because it is difficult to interpret whether T-graft failure was due to an inflow or due to an outflow problem. Between September 1, 2000, and July 31, 2002, 391 consecutive patients met these criteria, and 246 patients (182 men, 64 women; mean age, 66.2 ± 9.5 years) received at least one radial artery bypass graft. All of the radial arteries used during this study period were harvested in a skeletonized fashion. Preoperative demographics for the patients are shown in Table 1.

Technique of Radial Artery Harvesting

Radial artery harvesting was avoided in patients with renal dysfunction or patients with positive Allen test. The radial artery was primarily harvested from the nondominant arm except in cases of bilateral harvesting.

A longitudinal skin incision was made from 2 cm proximal to the wrist crease to 2 cm distal to the antecubital fossa, following the medial border of the brachioradialis muscle. The fascia bridging the brachioradialis muscle on one side and the flexor carpi radialis and pronator teres on the opposite side was divided with an electrocautery so that the entire length of the radial artery was exposed. The thin layer of fascia covering the radial artery and satellite veins was opened longitudinally with sharp scissors. The space between the satellite veins and the radial artery was then dissected with the ultrasonic scalpel (Harmonic Scalpel; Ethicon Endo-Surgery, Cincinnati, OH, USA). Tight adhesions, occasionally observed at the catheterization site, were also dissected with the ultrasonic scalpel. The side branches were transected with the ultrasonic scalpel. Dissection was initially performed by applying the backside of the dissecting hook but was later switched to biting the side branch with the coagulating shears. Hemostasis achieved with the dissecting hook was sometimes incomplete, possibly because of poor angulation of the blade; however, with the coagulating shears it was much easier to complete hemostasis. Electrocautery was not used after the fascia was uncovered, thereby avoiding thermal injury to the main trunk. A diluted papaverine solution was occasionally sprayed onto the graft. Additional complete removal of the adventitia was carried out with microscissors. After transection of the distal end, a cannula was placed, and diluted warm milrinone (0.5 mg/mL) was injected through the cannula while the proximal end was temporally occluded. Mild gentle pressure was applied to optimize dilatation of the graft, and then the proximal end was transected. The harvested graft was flushed with warm milrinone solution and preserved in the solution until use. No drains were left in the radial artery harvesting site.

Coronary Artery Bypass Grafting

After the harvesting of the appropriate grafts, CABG was performed under cardiopulmonary bypass with normothermia (36°C) or under off-pump beating heart conditions. As a hospital policy, no ice slush or cold cardioplegia has been used for isolated CABG since 1990. Patients were individually selected for off-pump CABG [Amano 2001].

The main targets for the radial artery grafting were the circumflex artery and the right coronary artery (Table 2). A proximal anastomosis was made on the ascending aorta after a side-biting clamp was applied. We do not use a pericardial or vein patch for the proximal anastomosis of the radial artery. When atherosclerosis of the aorta was suspected, the radial artery was used as a composite Y graft, usually with the LIMA.

Meticulous intraoperative antispasm care, including normothermia cardiopulmonary bypass, was undertaken, and the

Table 2. Distribution of Distal Anastomoses*

	LAD	Diagonal	CX	Proximal RCA	Distal RCA	Total
Left internal mammary artery	218 (76.8%)	51 (18.0%)	14 (4.9%)	0 (0.0%)	1 (0.4%)	284
Right internal mammary artery	23 (17.8%)	32 (24.8%)	61 (47.3%)	9 (7.0%)	4 (3.1%)	129
Radial artery	7 (1.8%)	51 (13.4%)	228 (59.7%)	26 (6.8%)	70 (18.3%)	382
Gastroepiploic artery	0 (0.0%)	0 (0.0%)	7 (7.2%)	4 (4.1%)	86 (88.7%)	97
Inferior epigastric artery	0 (0.0%)	1 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1
Saphenous vein	0 (0.0%)	0 (0.0%)	11 (25.0%)	6 (13.6%)	27 (61.4%)	44
Total	248 (26.5%)	135 (14.4%)	321 (34.3%)	45 (4.8%)	188 (20.1%)	937 (100.0%)

*LAD indicates left anterior descending artery; CX, circumflex artery (including the obtuse marginal branch, high lateral branch, and posterolateral branch); RCA, right coronary artery.

saline flush used for any occasions was warm. For on-pump CABG, we used a pressure line (Suma vein perfusion set; Ube Junken, Ube City, Japan) separated from the arterial cannula and hooked up to the harvested graft. This maneuver allowed the graft to self-expand with systemic pressure. For the prophylaxis of perioperative vasospasm, a calcium channel blocker such as diltiazem or nicorandil was started after the induction of general anesthesia and then continued for at least a year with oral maintenance doses. Intravenous milrinone was not routinely used.

Angiographic Control

Postoperative angiographic control was obtained within 3 months of surgery if the patients agreed to the procedure and was routinely performed via a transbrachial approach (from the brachial artery proximal to the stump of the radial artery) except for patients requiring images of the bilateral IMAs. The patency rates of other grafts were compared by analyzing the angiographic results of the patients who underwent isolated CABG during this study. The quality of the anastomosis was graded according to the Fitzgibbon classification [Fitzgibbon 1996]. Briefly, grade A stands for perfect graft patency, grade B for graft stenosis >50%, and grade O for occlusion. String sign, which is defined as a severe and extensive narrowing of the whole body of the graft [Acar 1992], was classified as a grade B anastomosis. If the patient remained angina free, coronary angiography was not routinely repeated.

Data Collection

Postoperative data were prospectively collected. Outpatient follow-up was completed by the end of December 2002. Remote myocardial infarction, angina, arrhythmia requiring hospitalization, congestive heart failure requiring hospitalization, coronary reintervention (percutaneous transluminal coronary angioplasty or redo-CABG), and sudden death were counted as cardiac events. Results are expressed as the mean ± SD.

RESULTS

Operative Results

Operative data are shown in Table 3. Radial arteries were harvested bilaterally from 2 patients, and the rest of the patients were harvested from the nondominant arm alone. There were no incidences of radial artery dissection or injury during the graft harvest. The mean number of distal anastomoses of the radial artery was 1.56 ± 0.90. A composite Y graft was made with the LIMA or RIMA in 42 cases. In addition to the radial artery, various other conduits were used, and the mean number of distal anastomoses was 3.8 ± 1.1. Completely arterial bypass procedures were accomplished in 211 patients (85.8%), and the saphenous vein was used in only 35 patients (14.2%).

In-Hospital Results

A summary of the postoperative courses is displayed in Table 4. There was 1 hospital death due to stroke. Major complications occurred in 35 patients (14.2%), including 5 incidences of postoperative myocardial infarction, but none were related to radial artery bypass. No postoperative bleeding from the radial graft occurred. One patient developed an arm wound infection that was treated with antibiotics. No postoperative hematomas were observed.

Table 3. Surgical Results (n = 246)*

No. of distal anastomoses (range)	3.8 ± 1.1 (1-8)
Off-pump CABG, n	199 (80.9%)
Bilateral internal mammary artery, n	117 (47.6%)
Total arterial revascularization, n	211 (85.8%)
No. of distal radial artery anastomoses (range)	1.56 ± 0.90 (1-4)
Sequential radial artery bypass, n	88 (35.8%)
Radial composite graft	42 (17.1%)
Coronary anastomosis time/vessel (range), min	11.4 ± 2.5 (7-24)
Clamp time (range), min	105 ± 53 (48-227)
Pump time (range), min	145 ± 53 (43-327)
Operation time (range), min	321 ± 71 (175-525)
Blood transfusion, n	59 (24.0%)
Left internal mammary artery, n	238 (96.7%)
Right internal mammary artery, n	121 (49.2%)
Radial artery, n	246 (100.0%)
Gastroepiploic artery, n	86 (35.0%)
Inferior epigastric artery, n	1 (0.4%)
Saphenous vein, n	35 (14.2%)

*Data are presented as the mean ± SD where appropriate. CABG indicates coronary artery bypass grafting.

Table 4. Postoperative Outcomes (n = 246)*

Intubation time (range), h	9.5 ± 6.7 (1-65)
Intensive care unit stay (range), d	2.2 ± 1.3 (1-13)
Postoperative stay (range), d	13.1 ± 9.9 (2-122)
Major complications, no. of patients	35 (14.2%)
Congestive heart failure	3 (1.2%)
Postoperative myocardial infarction	5 (2.0%)
Respiratory failure	6 (1.5%)
Pneumonia	1 (0.4%)
Severe arrhythmia	2 (0.8%)
Cerebral vascular accident	9 (3.7%)
Reexploration for bleeding	1 (0.4%)
Postoperative hemodialysis	1 (0.4%)
Mediastinitis	2 (0.8%)
Others	5 (2.0%)
In-hospital death	1 (0.4%)

*Data are presented as the mean ± SD where appropriate.

Remote Results

Postoperative follow-up (1.4 ± 0.3 years) was completed for all patients who survived (Table 5). During the follow-up period, a cardiac event occurred in 6 patients (2.5%). One patient developed angina related to the occlusion of the LIMA and radial artery graft. Percutaneous transluminal coronary angioplasty (PTCA) was performed in 4 patients and was targeted in 1 case to the coronary artery bypass of the angina patient in whom the radial artery graft had become occluded. There was 1 noncardiac death during this follow-up period.

Angiographic Study

Angiographic control within 3 months of surgery was obtained in 192 patients (78.0%) who had undergone bypass with the radial artery and in an additional 107 patients who had undergone isolated non–radial artery bypass during this study period, yielding a total of 299 patients (1203 distal anastomoses) evaluated by early-term angiography. Angiography revealed 6 radial artery anastomosis occlusions (2.0%).

Table 5. Remote Results*

No. of patients followed	245/245 (100%)
Follow-up period, y	1.4 ± 0.3
Total outpatient cardiac events	6 (2.5%)
Angina	1
PTCA	4
Congestive heart failure	1
Arrhythmia	0
Sudden death	0
Others	0
Distant death	1 (0.4%)
Cardiac death	0 (0%)
Noncardiac death	1 (0.4%)

*Data are presented as the mean ± SD where appropriate. PTCA indicates percutaneous transluminal coronary angioplasty.

Three were simple aortocoronary bypass occlusions, and the other 3 were segmental occlusions of the sequential bypass. String sign was observed in 2 patients (3 anastomoses), and anastomosis stenoses were observed in an additional 3 distal anastomoses (1 in a sequential bypass and 2 in simple aortocoronary bypasses). The early radial artery patency rate (grades A and B) and perfect patency rate (grade A only) were 98.0% and 96.0%, respectively. The graft patency rates for the other graft conduits are shown in Table 6. There were no statistical differences by chi-square tests among the conduits in terms of occlusion or stenosis.

Beyond 1 year after surgery (1.2 ± 0.2 year), no graft occlusions or stenoses were revealed in the 7 patients without symptoms who volunteered for repeat angiography.

DISCUSSION

In 1973, the first report of radial artery grafting was published by Carpentier and colleagues, but the initial results were disappointing [Carpentier 1973]. The early poor outcomes were most likely due to rough handling of the grafts and the lack of effective antivasospastic agents. In 1992, Acar and colleagues revived radial artery grafting [Acar 1992], and since then, the meticulously gentle handling of the radial artery with light traction, minimal touch, minimal electrocautery, and harvesting as a pedicle has been emphasized [Parolari 2000]. Skeletonized harvesting was not advised in previous studies [Dietl 1995]. Even after the ultrasonic scalpel, which produces less thermal damage to the vessels, was introduced for radial artery harvesting, pedicle harvesting remained the surgical "gold standard" [Ronan 2000, Psacioglu 1998]. Skeletonized radial artery harvesting with sharp scissors and clips was first reported in 2001 [Taggart 2001]. Because of technical difficulties with skeletonized radial artery harvesting before the advent of the ultrasonic scalpel and because of the lack of angiographic results, the skeletonized procedure by scissors did not become popular and was even criticized [Bizzarri 2002]. We published our initial data of skeletonized radial artery grafting using an ultrasonic scalpel in 2002 [Amano 2002], and our method of radial artery harvest was quite different from the "gold standard" procedure. We open the covering fascia over the radial artery, separate the satellite veins, remove the adventitia, cannulate the graft, inject an antivasospastic agent directly into the lumen, and give an intraluminal pressure to allow the graft expansion. Our goals in skeletonization are to remove as much excess adventitia as possible, to allow the graft to expand by injecting milrinone, to avoid thermal injury by using the ultrasonic scalpel, and to avoid temperature-related vasospastic reactions by keeping warm conditions. Vasoconstriction of the radial artery is stronger than with the IMA, and this vasospastic phenomenon is known to be mediated and processed in the endothelium and media [Buxton 1966]. The role of the adventitia is unknown. We hypothesize that the thick adventitia over the radial artery prevents vascular relaxation and dilation. Interestingly, the vasa vasorum, the nerves, and the lymphatic vessels are confined to the adventitia and do not enter the medial layer [van Son 1990]. This fact suggests that the removal of

Table 6. Postoperative Angiographic Results*

Anastomoses Examined by Angiography	Total Distal Anastomoses, n	Grade B, n	Grade O, n	Grade A, n
Left internal mammary artery	348	15	2	331 (95.1%)
Right internal mammary artery	209	11	2	196 (93.8%)
Radial artery	303	6	6	291 (96.0%)
Gastroepiploic artery	131	7	2	122 (93.1%)
Inferior epigastric artery	2	1	0	1 (50.0%)
Saphenous vein	110	1	1	108 (98.2%)

*Grading of the anastomosis is according to the Fitzgibbon criteria. Angiograms for 299 patients (76.5%) were taken within 3 months of surgery.

the adventitia may not have an effect on vasospasm. However, the media of the side branches continue into the main trunk of the radial artery, and use of electrocautery to the side branches may cause vasospasm of the main trunk. Thus, we use the ultrasonic scalpel rather than electrocautery for the control of the side branches. Removal of the adventitia, adequate use of the ultrasonic scalpel, and the use of vasodilators all play a role in reversing vasospasm.

Completely vasospasm-free radial grafts have a large caliber and can deliver a high-volume flow. Moran and colleagues [Moran 2001] and Calafiore and colleagues [Calafiore 1995] reported that the radial artery should be used for grafting coronary arteries with lesions of 70% or greater stenosis, because a small-caliber pedicled radial artery may not deliver enough volume to the distal coronary artery. In our institution, the saphenous vein used to be the graft of choice for a mildly stenosed coronary artery; however, poor long-term graft patency in vein grafts is also well known [Buxton 1998]. Saphenous vein graft disease occurs due to fibrointimal hyperplasia and venous atherosclerosis, which are exacerbated at the site of the venous valve [Mills 1997]. Surgeons have been looking for an alternative valveless, high-flow conduit for years, and now we have skeletonized radial artery grafts with the characteristics of a large caliber, a high flow capability, and the nature of an arterial conduit that are perfectly suited for use in bypassing mildly stenosed coronary arteries.

Radial artery harvesting with the skeletonized technique.

In addition, sequential grafting can be carried out more easily with a skeletonized graft than with a pedicled graft, because skeletonized grafts have less adventitia, a good length, and a high flow capability. Another problem with harvesting the radial artery as a pedicle is the shortness of the graft length because of the adherence or sclerosis of the distal end of the radial artery from previous catheterization. This problem can be easily solved with skeletonization, because once the artery is skeletonized, a longer graft length can be obtained.

Previous reports demonstrated that early radial artery stenosis occurred in the postoperative period in 5% to 7% of the anastomoses [Acar 1998, Weinschelbaum 1997]. A literature review demonstrated a 98.1% early patency rate (grade A and B) and a 90.8% perfect patency rate (grade A alone) for the radial artery, giving a potential radial artery stenosis rate of 7.3% [Parolari 2000]. Our angiographic results showed an early stenosis rate of 2.0% and an occlusion rate of 2.0%, which are competitive or even better than the results of previous series. We may be underestimating the graft occlusion rate, because a small number of the patients underwent repeat angiography. Although most of the patients remained symptom free, this symptom-free interval may reflect the patency of other grafts. Confirmation of this hypothesis requires repeat angiography; however, repeat angiography for asymptomatic patients is not easy and may even be an ethical issue. The remote cardiac event-free rates that have been reported are 97.8% at 0.7 year [Lemma 2001] and 89.7% at 3 years [Weinschelbaum 2000]. Our limited clinical follow-up data appear to be competitive with these previous reports.

SUMMARY

Although skeletonized radial artery harvesting has not previously been recommended, early results with skeletonized grafting with the ultrasonic scalpel and appropriate antivasospastic maneuvers have been excellent. The benefits of radial artery skeletonization include the easy reversal of vasospasm, a large-caliber conduit, a sufficient conduit length, the ease of handling without adventitia, and the conduit's nature as an arterial graft. Confirmation of our data requires several studies, including repeat angiography, a study of nitric oxide and other mediators in the skeletonized radial artery graft, and a histopharmacologic study of the adventitia of the radial artery. A "gold standard" of radial artery harvesting may be revolutionized.

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