Complete Arterial Revascularization in Multivessel Coronary Artery Disease With 2 Conduits (Skeletonized Grafts and T Grafts)

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Background—Complete arterial CABG is a surgical option to improve long-term results in the treatment of coronary artery disease (CAD). Harvesting of multiple arterial grafts is commonly associated with prolonged operating times and increased trauma. By use of new operative techniques (skeletonized grafts and the T-graft approach), CABG in multivessel CAD is now possible with only 2 grafts. We present our experience in the use of these techniques on a routine basis.

Methods and Results—Between March 1996 and September 1999, 490 patients (aged 61±9 years, 20% female) underwent complete arterial CABG. Left ventricular ejection fraction ranged from 15% to 85% (mean 59±15%). Triple-vessel disease was present in 88% of the patients. The incidence of diabetes mellitus was 32% (14% insulin dependent). Either both internal thoracic arteries (ITAs) (23%) or the left ITA and radial artery (77%) were used as conduits. In 85% of the patients, a T graft was created. Mean operating time was 198±46 minutes; bypass time, 82±25 minutes; and ischemic time, 58±22 minutes. Two to 7 (mean 4.1±0.9) anastomoses were performed per patient. Perioperative intra-aortic balloon pump was necessary in 12 patients (2.4%). The rate of perioperative myocardial infarction was 1.2%. Sternal complications occurred in 1.0%, and in-hospital mortality was 2.2%. Postoperative coronary angiography in 172 patients (35%) documented excellent patency rates (left ITA 98.3%, right ITA 96.5%, and radial artery 96.6%).

Conclusions—Complete arterial revascularization in multivessel CAD is possible with the use of only 2 grafts with good perioperative results. This approach allows for complete arterial CABG on a routine basis. (Circulation. 2000;102[suppl III]:III-79-III-83.)

Key Words: cardiovascular diseases ▪ coronary disease ▪ surgery ▪ arteries ▪ revascularization

Coronary artery bypass grafting (CABG) with the use of the left internal thoracic artery (ITA) and vein grafts is the standard and widely accepted surgical approach in the treatment of coronary artery disease (CAD). Although perioperative results are excellent, an increased incidence of recurrent angina and of myocardial infarction 5 to 7 years after surgery has been described.1,2 These late complications result in impaired quality of life, morbidity, and mortality. A major determinant of this secondary development appears to be the degeneration of vein grafts used for conventional CABG.

Graft degeneration has been a well-recognized long-term complication after CABG since the early 1980s. An occlusion rate of ~50% after 10 years has been reported repeatedly; by comparison, the occlusion rate of the left ITA after 10 years is only 10% to 15%, which is significantly lower.3,4 Pulsatile stress has been assumed as an explanation for molecular and cellular changes in the vein after exposing it to arterial pressures.5 Consequently, efforts have been made to increase the number of arterial grafts in CABG. Bilateral ITAs, the gastroepiploic artery (GEA), and the radial artery (RA) have been used as conduits in selected patients.6 Although long-term results after coronary surgery have improved,7-10 specific problems of complete arterial revascularization procedures have led to concern about whether this approach is a safe and reproducible option.

Vasospasm of the arterial grafts is a serious perioperative complication and may result in ITA hypoperfusion syndrome with its high mortality.11 Harvesting of both ITAs, particularly in the diabetic patient, is associated with an increased incidence of sternal wound infections.12-14 CABG with the use of arterial conduits and the sequential anastomosing techniques have been described as more difficult techniques. Harvesting of multiple arterial conduits is more time consuming and may result in elevated operative trauma. Dissection of the GEA requires a laparotomy, which prolongs the opera-
In the majority of patients, the left ITA (n = 486 [99%]) was used as a second graft primarily in those patients with unacceptable collateral perfusion of the nondominant arm or in patients who refused harvesting of the RA. During surgery, we observed marked calcifications of the RA in 1.5% of patients. The RA was implanted in situ and anastomosed to the left ITA at an angle of 45° to 90° by use of the so-called Y- or T-graft configuration (Figure, configuration III; n = 318 [65%]).

The right ITA was used as a second graft primarily in those patients with unacceptable collateral perfusion of the nondominant arm or in patients who refused harvesting of the RA. During surgery, we observed marked calcifications of the RA in 1.5% (6 of 386) of the patients and inadequate size in 0.8% (3 of 386) of the patients, which made use of the RA as a conduit unreasonable. In patients with 2-vessel disease of the LAD and proximal RCA, the right ITA was implanted in situ and anastomosed to the RCA (Figure, configuration II; n = 55 [11%]). If its length was inadequate, the RA was implanted into the left ITA at an angle of 45° to 90° by use of the so-called Y- or T-graft configuration (Figure, configuration II; n = 318 [65%]).

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In patients who underwent another CABG after previous use of the left ITA (n = 2 [0.4%]) or in the presence of intraoperative dissection of the left ITA (n = 2 [0.4%]), the right ITA was used for revascularization of the RCA. In these patients, the RA was anastomosed to the branches of the LAD and/or CX system (Figure, configuration IV; n = 4 [0.8%]).

In the conventional group, the left ITA was used in situ for revascularization of the LAD. Sequential anastomoses for diagonal branches were performed as necessary. One vein graft was anastomosed to the branches of the CX and RCA in sequential fashion and inserted proximally into the ascending aorta.

**Surgical Technique**

Preparation of the ITA was performed by using the skeletonization technique. The left sternal wall was elevated with a Martin retractor. Loose alveolar tissue and parietal pleura behind the sternum were dissected by cautерization. After visualizing and palpating the ITA, the dissection was started in the third intercostal space. The transversus thoracis muscle and fascia were opened parallel and 5 to 8 mm medial to the internal thoracic vein by use of low cautery settings. After the internal thoracic vein was pushed anteriorly, and the ITA was exposed. Dissection continued to the internal thoracic vein by use of low cautery settings. After the thoracis muscle and fascia were grasped with forceps, the internal thoracic vein was dissected by cautерization. After visualizing and palpating the ITA, Loose alveolar tissue and parietal pleura behind the sternum were dissected by cautery or hemostats.

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Dissection of the RA was performed on the nondominant arm by cautery or hemostats. After complete preparation of the graft, heparin was given systematically (10,000 IU), and the vessel was divided distally. Diluted papaverine (50 mg/20 mL heparinized blood) was injected into the lumen of the artery, and the distal end of the graft was closed with a hemostat. The RA was additionally soaked in diluted diltiazem (25 mg/20 mL Ringer’s solution). No routine systemic therapy with vasodilators or calcium channel blockers was given during the operation or the postoperative course.

Extracorporeal circulation and mild systemic hypothermia (32°C to 34°C) were used on the vast majority of patients (n = 480) during surgery. Under cardiopulmonary arrest, the branches of the RCA and CX were anastomosed to the right ITA or RA. The left ITA was then used for revascularization of the LAD system. Sequential anastomoses were performed with both grafts as necessary. The T anastomosis between the left and right ITA or RA was created during the period of cardiac arrest.

In patients with a calcified aorta or severe cerebral atherosclerosis, the operations were performed on the beating heart without extracorporeal circulation (n = 2 [0.4%]); under conditions of ventricular fibrillation and deep hypothermia, extracorporeal circulation was used (n = 8 [1.6%]).

**Statistics**

Data were analyzed with the use of the StatView software package. All data are expressed as mean ± SD. Operative data for the 2 groups were compared by unpaired t test. Regarding categorical data, the comparison between the groups was performed with χ² tests.

**Results**

Two to 7 (mean 4.1 ± 0.9) anastomoses were performed per patient. The patterns of arrangements of conduits are shown in Table 2. Mean operating time was 198 ± 46 minutes, with a mean bypass time of 82 ± 25 minutes and a mean ischemic time of 58 ± 22 minutes. The implantation of an intra-aortic balloon pump was necessary in 12 patients (2.4%). In 2 patients who could not be weaned from bypass, transesophageal echocardiography showed hypokinesia of the anterior wall. An additional vein graft was placed on the LAD. With restored anterior wall function, both patients could be weaned from bypass and were finally discharged after an unremarkable course.

In the convCABG group, fewer anastomoses per patient were performed (3.9 ± 0.8, P < 0.05). The mean operating time was 198 ± 50 minutes and was thus not significantly different from that of the caCABG group. Bypass time was prolonged (88 ± 34, P < 0.05), and ischemic time was reduced (49 ± 17, P < 0.05). The incidence of intra-aortic balloon pump support was 3.2% in the convCABG group (n = 12) and was thus not significantly different from that of the caCABG group.

Concomitant procedures were performed in a minority of patients (n = 25) in the caCABG group. Ten patients (2%) with significant aortic valve disease underwent aortic valve replacement or repair. Ascending aortic replacement was performed in 2 patients (0.4%) with aneurysm of the ascend-
ing aorta. Significant mitral valve disease was found in 6 patients (1.2%) who received valve repair or replacement. In 1 patient (0.2%) with an emphysematous bulla in the right lung, a bullectomy was performed during the same operation.

Six patients (1.2%) with symptomatic stenosis of an internal carotid artery were subjected to carotid thromboendarterectomy; they developed perioperative cerebral infarction and died in pulmonary failure due to pneumonia. One male patient with a left ventricular ejection fraction of 35% and a female patient with a left ITA anastomosed to the CX or RCA. Sergeant et al,17 who found no benefit for bilateral ITA grafts, anastomosed the second ITA to a diagonal branch in a significant number of patients.

By use of multiple arterial grafts, such as both ITAs and the GEA, complete arterial coronary revascularization is possible in triple-vessel disease, and excellent long-term results have been reported. However, the concern over vasospasm, markedly prolonged operating time, and the increased incidence of sternal complications in the complete arterial approach has led to reservations toward a more widespread use. Recent modifications of the surgical technique now offer advantages that may minimize perioperative morbidity and mortality.

Harvesting of the ITA in skeletonized fashion reduces the risk of sternal complications, particularly in diabetic patients, and decreases the time for pulmonary recovery. With direct visual control of the graft, the recognition of damage, such as dissection, is easily possible. In addition, the resulting increases in length and graft diameter make the construction of sequential anastomoses easier. Free flow in these skeletonized ITA grafts is significantly higher compared with that in the conventional pedicled ITA graft, which can be expected to reduce the incidence of ITA hypoperfusion syndrome. In our experience, the need for intra-aortic balloon pumping, indicating the presence of ITA hypoperfusion syndrome, was infrequent despite a high percentage of T grafts, ie, ITAs supplying flow to all coronary branches. Huddleston et al22 reported equal long-term patency rates for skeletonized ITA grafts compared with the conventional pedicled ITA conduit.

In 1975, Carpentier et al26 introduced the RA as a conduit in coronary bypass surgery. After disappointing results in the first patients, Acar et al16 and Calafiore et al23 reintroduced the RA with excellent perioperative results. Compared with vein grafts, the mid-term patency rates appear superior. The harvesting technique has been standardized, and a low morbidity has been reported previously. Dissection is possible during preparation of the left ITA, which reduces operating time and may result in lower perioperative trauma. Although there is a higher propensity to vasospasm of the RA compared with the ITA, excellent mid-term patency rates

### TABLE 3. Postoperative Data for cCABG Patients

<table>
<thead>
<tr>
<th>Condition</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bleeding/reoperation, n (%)</td>
<td>1 (0.2%)</td>
</tr>
<tr>
<td>MI, n (%)</td>
<td>6 (1.2%)</td>
</tr>
<tr>
<td>Phrenic nerve injury, n (%)</td>
<td>2 (0.4%)</td>
</tr>
<tr>
<td>Cerebral infection, n (%)</td>
<td>9 (1.8%)</td>
</tr>
<tr>
<td>Sternum, n (%)</td>
<td>3 (0.6%)</td>
</tr>
<tr>
<td>Dehiscence</td>
<td>2 (0.4%)</td>
</tr>
<tr>
<td>Infection</td>
<td>0</td>
</tr>
<tr>
<td>Forearm (n=377), n (%)</td>
<td>34 (7%)</td>
</tr>
<tr>
<td>Circulatory injury</td>
<td>1.5±1.1</td>
</tr>
<tr>
<td>Deep infection</td>
<td>1 (0.3%)</td>
</tr>
<tr>
<td>Paresthesia</td>
<td>21 (5.6%)</td>
</tr>
<tr>
<td>Blood transfusions, n (%)</td>
<td>9.8±6.2</td>
</tr>
<tr>
<td>Intubation time, h</td>
<td>0</td>
</tr>
<tr>
<td>ICU stay, d</td>
<td>3 (0.6%)</td>
</tr>
<tr>
<td>In-hospital mortality, n (%)</td>
<td>11 (2.2%)</td>
</tr>
</tbody>
</table>

*Values are mean±SD or number (percentage) of patients. ICU indicates intensive care unit.*

**Postoperative Angiography**

One week after surgery, 172 patients (35%) gave their informed consent for a coronary angiography. In 140 of 145 patients (96.5%), the T-graft anastomosis was patent. Of the 263 left ITA anastomoses, 252 (95.8%) were patent. Of the 135 right ITA anastomoses, 129 were patent (95.6%). Of the 276 RA anastomoses, 269 (97.5%) were patent.

**Discussion**

The ITA is currently the conduit of choice in CAGB because of its superior patency and long-term results compared with vein grafts. Several groups have observed further long-term improvement of results after using left and right ITA for coronary revascularization procedures. However, it is still controversial whether this approach has indeed a clear benefit. The comparison of different patient cohorts and results is made more difficult by the various graft configurations that have been used. In most patients, the left ITA was anastomosed to the LAD, and the second ITA was anastomosed to the CX or RCA. Sergeant et al,17 who found no benefit for bilateral ITA grafts, anastomosed the second ITA to a diagonal branch in a significant number of patients.

Postoperative complications were rare (Table 3). Postoperative bleeding with the need for reoperation was seen in 0.2% of the patients, and 93% of the patients required no blood transfusions during their hospital stay. The overall incidence of sternal dehiscence or infection was 1%. Interestingly, this incidence was not elevated after bilateral harvesting of the ITA (1 of 113 patients [0.9%]). In the diabetic subgroup of patients, 3 of 155 (1.9%) required sternal reintervention for dehiscence (n=2) or infection (n=1).

After harvesting of the RA (n=377), no evidence of impaired blood flow to the respective hand was observed. The main postoperative discomfort was due to temporary paresthesia in the thumb of the operated forearm in 5.6% of the patients.

Overall hospital mortality was 2.2% (n=11). Of the patients who received only arterial grafts, 2 underwent concomitant carotid thromboendarterectomy; they developed perioperative cerebral infarction and died in pulmonary failure due to pneumonia. One male patient with a left ventricular ejection fraction of 35% and a female patient with a left ventricular ejection fraction of 53% underwent a second CABG without remaining vein grafts. Complete arterial revascularization was performed with the use of the left and right ITA in one patient and the left ITA and RA in the other. Both died in cardiac failure after a prolonged intensive care stay.

The mortality rate for elective complete arterial CABG in patients excluding concomitant procedures (n=25) or coronary reoperations (n=25) was 1.6% (7 of 440 patients). The overall mortality rate in the conventional group was 2.6% (n=10) and thus not significantly different.
have been reported. A laparotomy, which is necessary for harvesting of the GEA with its specific perioperative disadvantages, is avoidable. In addition, by use of Allen’s test, preoperative bedside testing of an adequate collateral circulation is possible. To facilitate postoperative mobilization, we have used the RA on the nondominant arm.

T grafts achieve the goal of complete arterial revascularization in multivessel CAD with only 2 grafts. In this configuration, a second graft, originally the right ITA, is connected to the left ITA in a T-shaped 90° anastomosis. The left ITA is anastomosed to the LAD and its branches; the second graft, to the branches of the CX and RCA. Tatoulis et al and Sundt et al have used this approach with the left ITA and RA. Because total bypass flow is dependent on the flow in the left ITA, there may be skepticism concerning whether flow reserve in the left ITA is sufficient. Intravascular flow measurement studies made by our group using a Doppler guidewire documented adequate blood supply through the left ITA and sufficient coronary flow reserve 1 week and 6 months after surgery.

By use of only 2 arterial grafts and avoidance of the harvesting of multiple arterial conduits, the operating time is reduced compared with previous approaches of arterial revascularization. In our own experience, we found no difference in the operating times between the convCABG and the caCABG groups. The longer ischemic times in the caCABG group are due to the fact that T-graft anastomoses were performed during cardioplegic arrest; this did not result in an increased incidence of the intra-aortic balloon pump. The compatibility of these 2 cohorts, however, is limited, because they were not randomized and were different with respect to demographic data. For these reasons, any further analysis does not appear to be warranted.

Besides economic advantages in using only 2 grafts, the avoidance of a proximal anastomosis is particularly beneficial in patients with calcifications of the ascending aorta. In these patients, complete revascularization in ventricular fibrillation with the use of extracorporeal circulation or in the beating heart is possible. This can be expected to minimize the embolic complications associated with clamping of an atherosclerotic aorta.

On the basis of our experience, arterial CABG is currently performed on a routine basis in our institution in all patients aged <70 years or lacking vein grafts, thus allowing the application in >50% of all patients with CAD. With use of this surgical approach, particularly in young and diabetic patients, complete arterial CABG is a safe procedure with a low perioperative morbidity and mortality and offers the option of improved long-term results after CABG.

References
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