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-
TABLE 1. Demographic Data for caCABG Patients

<table>
<thead>
<tr>
<th>Age, y</th>
<th>61±9 (20–83)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex (female/male), n/n</td>
<td>98/392</td>
</tr>
<tr>
<td>Hypertension, n (%)</td>
<td>256 (52)</td>
</tr>
<tr>
<td>Hyperlipoproteinemia, n (%)</td>
<td>305 (62)</td>
</tr>
<tr>
<td>Active smoker, n (%)</td>
<td>119 (24)</td>
</tr>
<tr>
<td>Obesity, n (%)</td>
<td>226 (46)</td>
</tr>
<tr>
<td>Diabetes mellitus, n (%)</td>
<td>155 (32)</td>
</tr>
<tr>
<td>Oral medication</td>
<td>87 (18)</td>
</tr>
<tr>
<td>Insulin dependent</td>
<td>68 (14)</td>
</tr>
<tr>
<td>LVEF, %</td>
<td>59±15 (15–85)</td>
</tr>
<tr>
<td>LVEF &lt;35%, n (%)</td>
<td>45 (9.2)</td>
</tr>
<tr>
<td>CAD, n (%)</td>
<td>55 [11%]</td>
</tr>
<tr>
<td>Left main</td>
<td>192 (39)</td>
</tr>
<tr>
<td>1 vessel</td>
<td>0</td>
</tr>
<tr>
<td>2 vessel</td>
<td>61 (12)</td>
</tr>
<tr>
<td>3 vessel</td>
<td>429 (88)</td>
</tr>
<tr>
<td>Preoperative IABP, n (%)</td>
<td>6 (1.2)</td>
</tr>
<tr>
<td>Prior MI, n (%)</td>
<td>197 (40)</td>
</tr>
<tr>
<td>Prior PTCA, n (%)</td>
<td>114 (23)</td>
</tr>
<tr>
<td>Repeat cases, n (%)</td>
<td>23 (4.7)</td>
</tr>
</tbody>
</table>

Values are mean±SD (range) or number (percentage) of patients. Obesity indicates body mass index >25; LVEF, left ventricular ejection fraction; IABP, intra-aortic balloon pump; and MI, myocardial infarction.

Methods

Patients

In a retrospective study, we analyzed the data of 490 patients with multivessel CAD who underwent complete arterial CABG in our institution between March 1996 and September 1999. Demographic data are shown in Table 1. The indication for exclusive usage of arterial conduits was patient age of >70 years in 82% (n=401) and lack of vein grafts in 18% (n=89) of patients.

The operative data for these completely arterially revascularized patients (caCABG) group were compared with the data for all patients who underwent isolated conventional CABG (convCABG group) with the use of left ITA and vein grafts in 1998 (n=381). The convCABG group was significantly older (68±7 versus 61±9 years, P<0.05), showed a higher proportion of female patients (n=119 [31%] versus n=98 [26%], P<0.05), and had a lower left ventricular ejection fraction (56±17% versus 59±15%, P<0.05) than the caCABG group. There was no significant difference between the 2 groups with respect to the prevalence of 3-vessel disease (convCABG, n=329 [86%]; caCABG, n=429 [88%]), left main stenosis (convCABG, n=151 [40%]; caCABG, n=192 [39%]), and the proportion of coronary reoperation (convCABG, n=24 [6.3%]; caCABG, n=23 [4.7%]).

Surgical Strategy

The operations were performed with only 2 conduits in all patients. In the majority of patients, the left ITA (n=486 [99%]) was anastomosed to the left anterior descending coronary artery (LAD) system.

Graft configurations are as follows: I indicates left ITA and right ITA T-graft (n=97 [20%]) and left ITA and RA T-graft (n=318 [65%]; II, left ITA in situ and right ITA from aorta (n=9 [1.8%]) and left ITA in situ and RA from aorta (n=55 [11%]); III, left ITA in situ and right ITA in situ (n=7 [1.4%]); and IV, right ITA in situ and RA from aorta (n=9 [1.8%]). Circular area indicates T-graft anastomosis.

Technical modifications, such as skeletonization of the ITA, use of the RA as an additional conduit, and the T-graft approach, have been proposed recently. In conjunction with specific intraoperative vasodilatation, they offer the option of reducing the perioperative morbidity and mortality associated with complete arterial CABG. We present our results with the use of these techniques on a routine basis.
TABLE 2. Patterns of Arrangements of Conduits

<table>
<thead>
<tr>
<th>Configuration</th>
<th>I (n=415)</th>
<th>II (n=64)</th>
<th>III (n=7)</th>
<th>IV (n=4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graft 1</td>
<td>LITA in situ</td>
<td>LITA in situ</td>
<td>LITA in situ</td>
<td>RITA in situ</td>
</tr>
<tr>
<td>Graft 2</td>
<td>RITA/RA T-graft</td>
<td>RITA/RA in aorta</td>
<td>RITA in situ</td>
<td>RA in aorta</td>
</tr>
<tr>
<td>Anast/pt</td>
<td>4.3±0.9</td>
<td>3.3±0.9</td>
<td>2.7±0.5</td>
<td>3.3±1.0</td>
</tr>
<tr>
<td>Total anast</td>
<td>1770</td>
<td>210</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>LAD</td>
<td>413</td>
<td>64</td>
<td>7</td>
<td>3</td>
</tr>
<tr>
<td>D1</td>
<td>248</td>
<td>40</td>
<td>5</td>
<td>1</td>
</tr>
<tr>
<td>D2</td>
<td>33</td>
<td>6</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>OMB1</td>
<td>454</td>
<td>57</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>OMB2</td>
<td>139</td>
<td>13</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>OMB3</td>
<td>23</td>
<td>1</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>RPLV</td>
<td>119</td>
<td>15</td>
<td>...</td>
<td>1</td>
</tr>
<tr>
<td>PIA</td>
<td>327</td>
<td>14</td>
<td>...</td>
<td>...</td>
</tr>
<tr>
<td>RCA</td>
<td>14</td>
<td>...</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

Values are mean±SD or number of sites involved. LITA indicates left ITA; RITA, right ITA; Anast, anastomoses; pt, patient; D, diagonal; OMB, obtuse marginal branch; RPLV, posterior left ventricular branch of RCA; and PIA, posterior interventricular artery.

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 cautery. After visualizing and palpating the ITA, dissection was started in the third intercostal space. The transversus thoracic fascia was grasped with forceps, the internal thoracic vein dissected by cauterization. After visualizing and palpating the ITA, dissection continued to the internal thoracic vein by use of low cautery settings. After the branches of the RCA and CX system (Figure, configuration IV; n=4 [0.8%]), the ITA was used for revascularization of the LAD system. 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.

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.

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 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-
reintervention for dehiscence (n = 5) or infection (n = 5).

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.

In-hospital mortality, n (%) 11 (2.2%)
Intubation time, h 9.8 ± 6.2
Blood transfusions, n (%) 34 (7%)
ICU stay, d 1.5 ± 1.1

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 CABG 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,17,7,8,10 However, it is still controversial whether this approach has indeed a clear benefit.17 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,3,7,8,10 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.9 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,18,19 and decreases the time for pulmonary recovery.20 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 diameter19 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,21 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 al22 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 midterm patency rates appear superior.24 The harvesting technique has been standardized, and a low morbidity has been reported previously.16,23–25 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,26 excellent midterm patency rates
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 differences 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 cardiopulmonary 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 aorta. In these patients, complete revascularization in ventricular fibrillation with the use of extracorporeal circulation or clampable balloon pump is possible. To facilitate postoperative mobilization, we 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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