Improved Survival With Radial Artery Versus Vein Conduits in Coronary Bypass Surgery With Left Internal Thoracic Artery to Left Anterior Descending Artery Grafting

Anoar Zacharias, MD; Robert H. Habib, PhD; Thomas A. Schwann, MD; Christopher J. Riordan, MD; Samuel J. Durham, MD; Aamir Shah, MD

Background—Given its proven survival benefit, left internal thoracic artery to left anterior descending (LITA-LAD) grafting has become a fundamental part of CABG. This grafting also led to increased use of other arterial conduits, of which the radial artery is most popular. Whether radial grafting improves survival beyond that achieved by LITA-LAD alone is not known.

Methods and Results—We compared 6-year outcomes in propensity-matched CABG-LITA-LAD patients (925 each) divided into those with radial grafts and those with vein-only grafting. Matched patients had essentially identical demographics, comorbidities, coronary disease, and operative data. Perioperative outcomes, including death (radial, 11 [1.2%]; vein, 10 [1.1%]), were similar for the 2 groups. Cumulative 0- to 6-year survival was better for radial patients (risk ratio, 0.675), particularly after 3 years (P = 0.03). Six-year survival in vein (86.8%) and radial (92.1%) patients indicated 67% greater overall vein mortality. Incidence rates of radial and vein repeated catheterization (190 of 925 [20.5%] versus 199 of 925 [21.5%]) and revascularization (8.8% versus 8.5%) were similar. Angiography data in restudied symptomatic patients showed a trend for greater radial patency. Vein failure (66 of 161 [41%]) was significantly worse than radial failure (46 of 157 [29.3%]) in patients receiving both types of grafts (P = 0.039).

Conclusions—Using radial as a second arterial conduit in CABG-LITA-LAD as opposed to vein grafting improves long-term outcomes as a result of decreased late deaths, especially after the third postoperative year. (Circulation. 2004; 109:1489-1496.)

Key Words: angiography • revascularization • coronary disease • restenosis

A long-term survival benefit of the left internal thoracic artery to left anterior descending (LITA-LAD) graft in CABG was demonstrated convincingly in the 1980s.1–3 This benefit presumably results from the superior patency of LITA grafts compared with saphenous vein grafts (SVGs).1–4 CABG-LITA-LAD has since become the standard of care.1–6 The optimal secondary conduit choice in CABG with LAD disease remains a topic of debate.

Surgeons have extrapolated LITA results to other arterial conduits and are using them for revascularization with increasing frequency.6–10 Right internal thoracic artery (RITA) grafts are used often and are reported to have superior patency compared with vein grafts.6–8 Recent analyses showed significantly better long-term survival when both ITA conduits are used compared with a single ITA.9,10 Bilateral use of ITA, however, is contraindicated in patients who are at increased risk of sternal wound complications.11–13 Moreover, in situ RITA conduits may not reach remote areas of the right coronary and circumflex branches, are more technically demanding (longer operative times) particularly if reoperation is necessary,14 and may not be sufficient for complete arterial revascularization. Also, RITA use as a free graft diminishes its long-term patency.15,16

Acar and colleagues17 reintroduced the radial artery as a viable conduit for CABG. Improved harvesting techniques,18 together with potential benefits of calcium channel blockers,19 have led to radial becoming an increasingly popular alternative/adjunct conduit.20,21 Early and intermediate-term angiographic data have so far indicated relatively better radial versus vein patency,22–25 yet, to date, improved long-term
TABLE 1. Comparison of Overall and Matched Radial Versus Vein Patient Data

<table>
<thead>
<tr>
<th>Risk factors</th>
<th>All Patients</th>
<th></th>
<th>Matched</th>
<th></th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Radial</td>
<td>Vein</td>
<td>Radial</td>
<td>Vein</td>
<td></td>
</tr>
<tr>
<td>Patients, n</td>
<td>1292</td>
<td>1869</td>
<td>925</td>
<td>925</td>
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<td>Male, %</td>
<td>76.9</td>
<td>63.3</td>
<td>71.9</td>
<td>71.5</td>
<td>NS*</td>
</tr>
<tr>
<td>Age, y</td>
<td>61±10</td>
<td>67±10</td>
<td>63±10</td>
<td>63±10</td>
<td>NS</td>
</tr>
<tr>
<td>BMI, kg/m²</td>
<td>30.5±5.7</td>
<td>29.1±5.4</td>
<td>30.0±5.6</td>
<td>30.1±5.5</td>
<td>NS</td>
</tr>
<tr>
<td>BSA, m²</td>
<td>2.1±0.2</td>
<td>2.0±0.2</td>
<td>2.0±0.2</td>
<td>2.0±0.2</td>
<td>NS</td>
</tr>
<tr>
<td>Diabetes, %</td>
<td>32.9</td>
<td>37.1</td>
<td>34.2</td>
<td>34.3</td>
<td>NS</td>
</tr>
<tr>
<td>Renal failure, %</td>
<td>1.2</td>
<td>4.5</td>
<td>1.6</td>
<td>1.7</td>
<td>NS</td>
</tr>
<tr>
<td>Hypertension, %</td>
<td>81.8</td>
<td>83.2</td>
<td>83.7</td>
<td>80.6</td>
<td>NS</td>
</tr>
<tr>
<td>Chronic lung disease, %</td>
<td>17.1</td>
<td>23.5</td>
<td>18.6</td>
<td>18.3</td>
<td>NS</td>
</tr>
<tr>
<td>Peripheral vascular disease, %</td>
<td>10.5</td>
<td>18.6</td>
<td>12.4</td>
<td>13.3</td>
<td>NS</td>
</tr>
<tr>
<td>Cerebrovascular disease, %</td>
<td>15.6</td>
<td>28.6</td>
<td>18.4</td>
<td>17.6</td>
<td>NS</td>
</tr>
<tr>
<td>Congestive heart failure, %</td>
<td>8.6</td>
<td>15.8</td>
<td>10.3</td>
<td>10.8</td>
<td>NS</td>
</tr>
<tr>
<td>Unstable angina, %</td>
<td>54.4</td>
<td>51.3</td>
<td>54.3</td>
<td>53.9</td>
<td>NS</td>
</tr>
<tr>
<td>Arrhythmia, %</td>
<td>10.1</td>
<td>16.2</td>
<td>12.0</td>
<td>12.5</td>
<td>NS</td>
</tr>
<tr>
<td>NYHA classification, %</td>
<td>23.0</td>
<td>15.4</td>
<td>21.6</td>
<td>19.5</td>
<td>NS</td>
</tr>
<tr>
<td>Coronary vessel disease, %</td>
<td>75.2</td>
<td>74.2</td>
<td>75.4</td>
<td>73.5</td>
<td>NS</td>
</tr>
<tr>
<td>Left main disease &gt;50%, %</td>
<td>20.2</td>
<td>22.0</td>
<td>20.5</td>
<td>20.4</td>
<td>NS</td>
</tr>
<tr>
<td>NYHA classification, %</td>
<td>23.0</td>
<td>15.4</td>
<td>21.6</td>
<td>19.5</td>
<td>NS</td>
</tr>
<tr>
<td>Coronary vessel disease, %</td>
<td>75.2</td>
<td>74.2</td>
<td>75.4</td>
<td>73.5</td>
<td>NS</td>
</tr>
<tr>
<td>Left main disease &gt;50%, %</td>
<td>20.2</td>
<td>22.0</td>
<td>20.5</td>
<td>20.4</td>
<td>NS</td>
</tr>
<tr>
<td>Intraoperative data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency, %</td>
<td>3.7</td>
<td>7.1</td>
<td>4.3</td>
<td>4.8</td>
<td>NS</td>
</tr>
<tr>
<td>Cross clamp, min</td>
<td>48±20</td>
<td>43±17</td>
<td>46±19</td>
<td>45±19</td>
<td>NS</td>
</tr>
<tr>
<td>Perfusion time, min</td>
<td>79±32</td>
<td>72±29</td>
<td>77±30</td>
<td>76±33</td>
<td>NS</td>
</tr>
<tr>
<td>Grafts, n</td>
<td>3.4±0.9</td>
<td>3.1±0.8</td>
<td>3.3±0.8</td>
<td>3.2±0.2</td>
<td>NS</td>
</tr>
<tr>
<td>Vein</td>
<td>1.0±0.9</td>
<td>2.1±0.8</td>
<td>0.9±0.8</td>
<td>2.2±0.2</td>
<td>NS</td>
</tr>
<tr>
<td>Arterial</td>
<td>2.3±0.6</td>
<td>1.0±0.2</td>
<td>2.3±0.6</td>
<td>1.0±0.2</td>
<td>NS</td>
</tr>
<tr>
<td>Radial</td>
<td>1.3±0.6</td>
<td>...</td>
<td>1.3±0.5</td>
<td>...</td>
<td>NS</td>
</tr>
<tr>
<td>Postoperative data</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>IABP, %</td>
<td>7.0</td>
<td>10.1</td>
<td>7.6</td>
<td>8.0</td>
<td>NS</td>
</tr>
<tr>
<td>Blood transfusion, %</td>
<td>24.2</td>
<td>33.4</td>
<td>27.5</td>
<td>28.1</td>
<td>NS</td>
</tr>
<tr>
<td>Reoperation for bleeding, %</td>
<td>1.0</td>
<td>2.0</td>
<td>0.9</td>
<td>1.6</td>
<td>NS</td>
</tr>
<tr>
<td>Perioperative MI, %</td>
<td>0.7</td>
<td>1.0</td>
<td>0.6</td>
<td>0.8</td>
<td>NS</td>
</tr>
<tr>
<td>Sternal wound infection, %</td>
<td>1.2</td>
<td>1.0</td>
<td>1.4</td>
<td>0.6</td>
<td>0.17</td>
</tr>
<tr>
<td>Harvest site infection, %</td>
<td>0.2</td>
<td>1.1</td>
<td>0.3</td>
<td>1.2</td>
<td>0.06†</td>
</tr>
<tr>
<td>Septicemia, %</td>
<td>1.0</td>
<td>2.1</td>
<td>1.2</td>
<td>1.2</td>
<td>NS</td>
</tr>
<tr>
<td>Permanent stroke, %</td>
<td>0.5</td>
<td>1.6</td>
<td>0.4</td>
<td>1.3</td>
<td>0.08</td>
</tr>
<tr>
<td>Transient neurological event, %</td>
<td>2.0</td>
<td>2.8</td>
<td>1.6</td>
<td>2.6</td>
<td>0.20</td>
</tr>
<tr>
<td>Ventilator prolonged, %</td>
<td>5.3</td>
<td>7.4</td>
<td>5.8</td>
<td>5.8</td>
<td>NS</td>
</tr>
<tr>
<td>Renal failure, %</td>
<td>4.6</td>
<td>4.8</td>
<td>4.9</td>
<td>3.2</td>
<td>0.1</td>
</tr>
<tr>
<td>Multisystem failure, %</td>
<td>0.9</td>
<td>1.2</td>
<td>0.8</td>
<td>0.6</td>
<td>NS</td>
</tr>
<tr>
<td>Atrial fibrillation, %</td>
<td>18.7</td>
<td>19.6</td>
<td>19.0</td>
<td>17.0</td>
<td>NS</td>
</tr>
<tr>
<td>Operative mortality, %</td>
<td>1.3</td>
<td>2.5</td>
<td>1.2</td>
<td>1.1</td>
<td>NS</td>
</tr>
<tr>
<td>In-hospital, %</td>
<td>0.7</td>
<td>1.7</td>
<td>0.4</td>
<td>0.5</td>
<td>NS</td>
</tr>
<tr>
<td>PO LOS, d</td>
<td>6.2±6.9</td>
<td>7.3±7.8</td>
<td>6.3±5.8</td>
<td>6.4±5.5</td>
<td>NS</td>
</tr>
<tr>
<td>Total LOS, d</td>
<td>7.9±7.2</td>
<td>9.4±8.4</td>
<td>8.0±6.3</td>
<td>8.3±6.1</td>
<td>NS</td>
</tr>
<tr>
<td>Readmit ≤30 d, %</td>
<td>7.0</td>
<td>8.5</td>
<td>7.8</td>
<td>9.3</td>
<td>NS</td>
</tr>
</tbody>
</table>

BMI indicates body mass index; BSA, body surface area; NYHA, New York Heart Association; IABP, intra-aortic balloon pump; MI, myocardial infarction; PO, postoperative; and LOS, length of stay. Categorical comparisons were done by χ² test. LOS data were compared by t test. *P > 0.2.
†Power of χ² test was <0.80.
outcomes with radial use have not been shown, particularly in conjunction with the potentially dominant survival benefit of the LITA-LAD graft. In the present study, we analyzed a large CABG-LITA-LAD experience with the primary aim of investigating whether use of radial versus vein as the second conduit of choice provides improved perioperative and long-term outcomes.

Methods

Patients

The Institutional Review Board approved this investigation. Study patients consisted of all isolated multi-graft CABG-LITA-LAD patients between January 1996 and December 2002, excluding reoperation, emergency salvage, concomitant carotid endarterectomy, or ITA-only grafting. Patients were divided into those receiving radial grafts with additional vein grafts when necessary (radial) or vein grafts only (vein). Aortocoronary grafting (~99%) was used unless aorta quality was suboptimal. Cardiopulmonary bypass (92%) and sequential grafting were used to a similar extent in both groups. Radial grafting was rarely used in emergency and peripheral vascular disease patients. Radial use increased from ~20% (1996) to ~50% (2002; detailed surgeon data in provided in the online Data Supplement).

Radial Harvesting

Hand collateral circulation and palmar arch status were assessed by modified Allen test and Doppler ultrasonography, respectively. Intraoperative plethysmography and oximetry were used before vessel removal. Radial harvesting was abandoned after exploration in case of small-vessel caliber and/or significant calcification. Harvesting was done as a pedicle without electrocautery at the same time of the LITA dissection and immersed in diluted papaverine. Mechanical dilatation was not used to avoid intimal injury. Intravenous calcium channel blockers (diltiazem) were administered intraoperatively and continued through day 1. Oral calcium channel blockers were prescribed for 2 months.

Propensity Matching

Study patients were drawn from observational data, and radial and vein groups were hence characterized by significant demographic and risk factor differences (Table 1). Because such differences substantially influence outcomes,26 we used propensity matching to overcome such confounding effects, with radial considered treatment.26,27 Briefly, the probability that a patient received a radial graft was defined by a propensity score via logistic multivariate modeling applied to all patients. Most risk factors, demographics, and operative variables were entered into the model regardless of significance level. Month of surgery was entered to account for increasing radial use over time. Highly redundant variables were avoided.

As expected, radial use propensity score distributions derived for radial versus vein patients were distinct (Figure 1). One-to-one propensity matching of radial patients with the closest unique vein match was obtained by a computer algorithm allowing a maximal difference of ±1%. Patient matching was done on the basis of propensity scores only (standard) and by propensity scores in addition to gender and triple-vessel disease status (yes/no) restrictions (restricted).

Follow-Up

Long-term survival data were secured from our service follow-up and verified from individual queries of the U.S. Social Security Death Index database (June 2003). Allowing for a 3-month lag, this corresponded to between 3 (minimum) and 87 (maximum) months of follow-up. Post-CABG recatheterization data were obtained from cardiac surgery and cardiac catheterization databases and from referring cardiologists and primary care physicians. All angiography reports were retrieved and reviewed, and graft data were entered into a dedicated database. A coronary graft was considered to have failed in case of complete occlusion, stenosis of ≥90%, or presence of extensive conduit narrowing or “string sign.” Cumulative patency calculations in restudied patients were done with the following guidelines: (1) Time of graft failure is the date of recatheterization when failure was documented; (2) grafts were presumed patent unless a subsequent recatheterization showed otherwise; and (3) patent grafts are censored at death.

Statistical Analysis

Continuous data were expressed as mean±SD. Univariate comparisons were done with χ2 or Fisher’s exact test for categorical variables and the unpaired t test or the nonparametric Mann-Whitney rank-sum test for continuous variables. Kaplan-Meier plots were derived for survival, recatheterization-free survival, revascularization-free survival, and graft patency (all compared via the log-rank test). Survival data were verified by bootstrapping (see online Data Supplement).28 Effects of explanatory variables on survival were derived by Cox proportional-hazard analysis. Model selection was done with backward elimination (Wald statistic confirmed by forward and stepwise selection), and variables with P<0.05 were retained (SPSS version 10.0, SPSS Inc).

Results

Patient Data Matching

The study population consisted of 3161 consecutive isolated multigraft CABG-LITA-LAD patients divided into 1292 radial (41%) and 1869 vein (59%) patients. A large majority of patients (~97%) had multivessel coronary disease. Overall radial and vein patient data are compared in Table 1. Briefly, vein patients were older (mean age, 67 versus 61 years), were more often female (37% versus 23%), were smaller, and had more comorbidities. Consequently, radial patients were associated with generally better operative outcomes (Table 1). Also, radial showed superior 0- to 6-year (P<0.001; Figure 2), recatheterization-free, and revascularization-free survival (both P<0.001; Figure I in the online Data Supplement).

To account for confounding effects of treatment group differences, 925 of 1292 radial patients (72%) were propensity matched to the same number of unique vein patients (Figure 1). Matched groups had essentially identical demographics, risk factors, and operative data (Table 1). Comparisons of key continuous variables (age, follow-up, perfusion,
ejection fraction, body surface area, and mass index) for matched patients are provided in the online Data Supplement (Figure II). All subsequent comparisons are done on matched groups.

**Coronary Grafts**

Coronary vessel disease and grafting data for both groups are detailed in Table I (online Data Supplement). Briefly, the overall number of completed grafts was similar for radial (3020 grafts: 946 LITA, 19 RITA, 1180 radial, 875 SVG) and vein (2997 grafts: 942 LITA, 24 RITA, and 2031 SVG), with similar distributions of graft target location and stenosis (Table II and Figure III). Sequential radial grafts were used in 200 patients (21.6%). All arterial grafting was achieved in 311 patients (33.6%) with a total of 468 radial grafts (1.5 per patient). The remaining 614 radial patients received a total of 712 radial grafts (1.16 per patient) and 875 vein grafts (1.43 per patient).

**Patient Outcomes**

Postoperative outcomes in matched patients, including rates of transfusion and use of intra-aortic balloon pump, are summarized in Table 1. Similar operative mortality, defined as in-hospital or out-of-hospital death within 30 days, rates were documented (11 radial [1.2%] versus 10 vein [1.1%]). Most postoperative complications, length of stays, and readmission rates were also similar.

Long-term follow-up was similar for radial (1364±687 days; range, 1 to 2702 days; median, 1380 days) and vein (1325±771 days; range, 3 to 2703 days; median, 1382 days) patient groups. A total of 47 late deaths (5.1%) were documented in the radial group occurring at 816±691 days. In vein patients, there were 72 late deaths (7.8%) occurring at 875±708 days. Cumulative 0- to 6-year survival was significantly better in the radial group ($P<0.03$; Figure 3, top). Here, estimated survival was 96.8% versus 96.1% at 1 year and 92.1% versus 86.8% after 6 years for radial and vein, respectively. Thus, the corresponding 0- to 6-year (13.2% versus 7.9%) and 1- to 6-year (9.3% versus 4.7%) mortality rates were 67% and 98% greater, respectively, in vein patients. Generally, survival was similar for the 2 groups up to about 6 months; after that, the incidence of late death was relatively greater in vein patients, particularly after the third post-CABG year (Figure 3, bottom).

Importantly, these survival results were closely reproduced via 3 complementary analyses. First, we obtained essentially identical survival trends using “restricted” matching groups (618 each; Figure 3, top). Second, analysis of 1000 bootstrap populations resulted in similar differences in averaged survival curves with relatively narrow confidence bounds (Fig-
Finally, radial use was an independent predictor of decreased 0- to 6-year mortality (risk ratio, 0.675; \( P = 0.04 \); Table 2), along with older age, diabetes, and ejection fraction <40%. The radial survival benefit was also true, albeit differently, when patients were subdivided on the basis of specific risk factors. In women, triple-vessel disease patients, younger patients (<65 years of age), and diabetic patients (Figure 4, left), improved survival is evident relatively early. Alternatively, their counterparts exhibited this benefit only after the third year after surgery (Figure 4, right).

For radial used, yes = 1 and no = 0. Model analysis included all risk factors/variables listed in Table 1.

One or more repeated angiographies were documented in a similar proportion of radial (190 of 925 [20.5%]) and vein (199 of 925 [21.5%]) patients. The average time to recatheterization did not differ between the 2 groups (radial: 668 ± 518 days; range, 4 to 2142 days; median, 558 days; vein: 649 ± 539 days; range, 3 to 2267 days; median, 532 days). A total of 264 catheterizations were performed in 190 radial patients, compared with 272 in 199 vein patients (both 1.4 per patient). Need for revascularization was also similar (radial, 81 [8.8%]; vein, 79 [8.5%]): repeated CABG in 4 versus 3, angioplasty in 15 versus 14, and stenting in 75 versus 71. Actuarial analysis showed relatively better catheterization-free and revascularization-free survival trends in radial patients (Figure 5, top), but these differences can be attributed almost entirely to fewer late deaths rather than to less frequent intervention (Figure 5, middle).

**Graft Patency**

For the 190 radial patients with \( \geq 1 \) repeated angiography, a total of 599 (242 radial, 161 vein, 191 LITA, 5 RITA) grafts

**TABLE 2. Predictors of 0- to 6-Year Mortality After CABG-LITA-LAD (Cox Proportional-Hazard Model Analysis) in Radial and Vein Patients**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Risk Ratio (95% CI)</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (per year)</td>
<td>1.044 (1.023–1.065)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Diabetes</td>
<td>1.488 (2.155–1.026)</td>
<td>0.036</td>
</tr>
<tr>
<td>Ejection fraction &lt;40%</td>
<td>1.536 (2.283–1.034)</td>
<td>0.034</td>
</tr>
<tr>
<td>Radial used</td>
<td>0.675 (0.984–0.462)</td>
<td>0.040</td>
</tr>
</tbody>
</table>

For radial used, yes = 1 and no = 0. Model analysis included all risk factors/variables listed in Table 1.

For radial used, yes = 1 and no = 0. Model analysis included all risk factors/variables listed in Table 1.

![Figure 4](http://circ.ahajournals.org/)

**Figure 4.** Comparison of 0- to 72-month CABG-LITA-LAD survival for demographics– (age, gender) and risk factor– (diabetes, vessel disease) based subgroups in matched radial and vein patients.
were restudied (3.2 per patient). Similarly, for the 199 vein patients, a total of 637 (427 vein, 203 LITA, 7 RITA) grafts were restudied (3.2 per patient). The corresponding cumulative patency rates for all the restudied LITA, radial, and vein grafts are shown in Figure 5 (bottom). Briefly, LITA patency was superior to that of radial and vein grafts (both \( P < 0.001 \)).

The 6-year radial graft patency trend was systematically greater than that of vein grafts, but these cumulative differences did not reach statistical significance by Kaplan-Meier analysis \( (P = 0.11, \text{log-rank test}) \).

Documented graft failure was lowest for LITA conduits (24 of 394 [6.1%]; \( P < 0.001 \) compared with both radial and vein grafts), which were used exclusively as LITA-LAD grafts. A total of 77 of 242 restudied radial grafts failed (31.8%). Of these, 31 of 85 (36.5%) occurred in 54 restudied patients with arterial grafts only compared with 46 of 157 failures (29.3%) in 137 radial patients with \( \geq 1 \) additional vein graft. Overall, 216 of 588 vein grafts (36.7%) were found to have failed. Vein graft failure rates derived from the radial (66 of 161 [41%]) and vein (150 of 427 [35.1%]) groups were similar \( (P = 0.22) \). Note, however, that when compared in the same patients, ie, radial patients with additional vein grafts, the documented 41% vein graft failure was significantly greater than the 29.3% radial graft failure \( (P = 0.039) \).

Discussion

Mounting evidence of greater arterial compared with vein patency has resulted in widespread efforts to maximize use of arterial conduits for CABG. The demonstrated superior long-term patency of the LITA-LAD graft, coupled with proven long-term survival benefit, has led to its becoming a fundamental component of CABG, at least whenever LAD disease is present (80% to 85%). Studies examining the benefits of additional arterial grafts when LITA-LAD is used are less conclusive.

Multiple groups have reported better CABG survival when both ITA conduits are used concomitantly compared with the use of a single ITA with additional vein grafts. However, these promising data have been clouded by contradictory reports and by the fact that not all included patients received LITA-LAD grafting, which may have a dominant effect on survival. Caputo and colleagues compared use of radial versus RITA as the second arterial conduit in combination with LITA and found better perioperative outcomes and improved event-free survival at 18 months using radial. However, their study included a relatively small number of unmatched patients (336 RITA, 325 radial) unevenly distributed over a 5-year period and drawn from an experience with a relatively low rate of multiple arterial conduit use (15%). Nevertheless, if independently confirmed, their findings are significant, given the many potential advantages to using radial artery conduits. Indeed, compared with RITA, radials (1) are larger and easier to work with; (2) are more straightforward to prepare; (3) are harvested concomitantly with LITA, reducing operative time; (4) are more amenable to revascularize remote branches than the RITA pedicle graft; and (5) avoid increased risk of sternal wound infections caused by bilateral ITA dissection.

This study examined the potential outcome benefits of using radial as a second arterial graft as opposed to vein grafting—strictly in conjunction with the LITA-LAD graft—in well-matched patient groups. Perioperative outcomes, including operative deaths, and resource use were mostly similar (Table 1), yet univariate analyses showed a trend for lower vein harvest site wound infection rates in radial patients, a finding similar to that in a recent report. More importantly, we found significantly better 0- to 6-year CABG survival when radial is used as a second arterial conduit as opposed to vein (Figure 3). The separation in the observed survival trends started at 6 to 12 months after CABG and became more pronounced after the third year. Such a trend toward a greater difference in survival with
increasing time after CABG is analogous to that reported for
CABG with 2 ITA conduits compared with a single ITA with
additional vein grafts.9

A limitation of our analysis was that it was performed on
a retrospective observational CABG series. In addition, the
question of whether radial grafting improves CABG outcome
is perhaps best addressed via specifically designed prospec-
tive multicenter randomized trials. Fortunately, advances in
statistical methods have overcome many of the known short-
comings of observational data analyses.27,28 If used properly,
these methods may adequately answer such important clinical
questions.9 Here, we concomitantly used several available
methods to increase the confidence in and applicability of our
findings. The main approach was to propensity match radial
and vein patients in whom radial use was considered a
treatment. To match patients, we applied a strict matching
criteria of ±1% maximum propensity score difference, and
matching was done on a 1-to-1 basis, resulting in the same
number of unique patients in the 2 comparison groups
(avoiding population-size bias) rather than the more fre-
quently used decile- or quintile-based propensity matching
regardless of group size.9 This approach successfully identi-
cified 2 closely matched groups (Table I and Figure II). Next,
we applied a restricted form of the same 1-to-1 matching in
which patients were always matched to the same gender and
coronary vessel disease type. Analyses of the restricted-
matched patient groups produced survival data that were
essentially identical to those from standard matching findings
(Figures 3 and 4).

Another approach to test the effect of radial versus vein
grafting on survival was done via Cox multivariate modeling
applied to all matched patients. Here, too, radial grafting was
determined to be an independent predictor of better survival.
Finally, we used 1000-times bootstrapping to determine the
reproducibility and confidence bounds of the derived radial
and vein survival trends.26,28 Results of this computer-
tensive method agreed closely with the above-described
findings, and the computed survival trends were characterized
by narrow confidence bounds, indicating good reproducibility
(Figure 3, middle). We contend that convergence of all the
aforementioned methods significantly advances our main
finding of superior survival when radial grafting is preferred
in CABG-LITA-LAD.

Improved long-term CABG outcome when 2 arterial con-
duits are used is presumably linked to superior patency of
arterial grafts. A number of recent studies have demonstrated
superior patency relative to vein of all types of arterial
conduits, including radial.1–10,22–25 Ideally, graft patency is
best characterized by reexamination of all or a representative,
randomly drawn sample of patients. The available angiogra-
phy data were instead derived from patients restudied because
of recurrent cardiac symptoms and/or positive stress tests.
These data represented a substantial number of grafts derived
from ≈20% of patients. Overall, we find more vein than
radial failures. When we consider patients with both radial
and vein grafts (ie, patient is own control), we documented
significantly better radial patency (111 of 157 [71%] versus
95 of 161 [59%]; P=0.039). Also, using actuarial analysis,
we found that the cumulative patency derived for 588
restudied vein grafts was systematically worse between 1 and
6 years compared with radial, even if this finding is not
statistically significant (Figure 5; P=0.11). The lack of
significance may stem in part from the fact that the patency
data were derived from symptomatic patients exclusively
who reflected a worst-case scenario.35

Conclusions

Our results show that use of radial artery as a second arterial
duct as opposed to vein in CABG-LITA-LAD patients is
associated with improved long-term survival. The late death
hazard in vein patients was particularly greater after the third
year (Figure 3), and the benefits of radial were most profound
in young, diabetic, and triple-vessel disease patients (Figure
4). The improved survival with radial in CABG-LITA-LAD
is analogous to that found for 2 versus 1 ITA.9 Future direct
comparisons of radial versus RITA are needed because radial
may offer important advantages, including less morbidity.
Finally, compelling data have suggested that long-term radial
patency may depend significantly on coronary target quality
and location.35 These data suggest that the relative radial
to vein patency may not be uniform in all coronary vessel
systems, and studies investigating the optimal targeting of
radial and vein conduits in CABG are needed.

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Improved Survival With Radial Artery Versus Vein Conduits in Coronary Bypass Surgery With Left Internal Thoracic Artery to Left Anterior Descending Artery Grafting

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