Evaluation of Revascularization Subtypes in Octogenarians Undergoing Coronary Artery Bypass Grafting

Abdulhameed Aziz, MD; Anson M. Lee, MD; Michael K. Pasque, MD; Jennifer S. Lawton, MD; Nader Moazami, MD; Ralph J. Damiano, Jr, MD; Marc R. Moon, MD

Background—Recent data suggest that octogenarians’ long-term survival after complete coronary artery bypass graft revascularization is superior to incomplete revascularization. Discriminating between variable definitions of “complete” complicates interpretation of survival data. We aimed to clarify octogenarian long-term survival rates by stratifying revascularization subtypes.

Methods and Results—From 1986 to 2007, 580 patients 80 to 94 years of age underwent coronary artery bypass graft. Functional complete revascularization was defined as at least 1 graft to all diseased coronary vessels with >50% stenosis. Traditional complete revascularization was defined as 1 graft to each major arterial system with at least 50% stenosis. Incomplete revascularization was defined as leaving diseased, ungrafted regions. Revascularization was functional in 279 (48%), traditional in 181 (31%), and incomplete in 120 (21%). Long-term survival was evaluated by Kaplan-Meier analysis. Of 537 operative survivors, there were 402 late deaths. Cumulative long-term survival totaled 2890 patient-years. Late survival (Kaplan-Meier) was similar between functional (mean, 6.8 years) and traditional (6.7 years) groups (P=0.51), but diminished with incomplete (4.2 years) revascularization (P=0.007). Survival by group at 5 years was: 59±3% functional, 57±4% traditional, and 45±5% incomplete. Survival at 8 years was: 40±3% functional, 37±4% traditional, and 26±5% incomplete. To minimize selection bias in patients with limited life expectancy, Kaplan-Meier analysis was repeated including only patients with survival >12 months. Survival was again impaired with incomplete revascularization (P=0.04), and there was no difference between functional and traditional complete revascularization (P=0.73).

Conclusions—Bypassing all diseased arterial vessels after revascularization does not afford significant long-term survival advantage compared to a traditional approach. Incomplete revascularization, related to more extensive disease, is associated with an 18% decline in survival. These data suggest that it is important to avoid incomplete revascularization in octogenarians, but the supplementary endeavor required to perform functional complete revascularization does not improve survival. (Circulation. 2009;120[suppl 1]:S65–S69.)

Key Words: bypass ■ coronary disease ■ octogenarian ■ revascularization ■ surgery

Coronary artery disease is a leading cause of morbidity and mortality in the elderly. Along with percutaneous coronary intervention, an increasing number of patients in their 80s and even 90s are being referred for coronary artery bypass grafting (CABG).1,2 The United States population older than the age of 75 is expected to quadruple over the next 50 years, and recent literature emphasizes the importance of developing appropriate treatment algorithms for this aging patient cohort.3-6 Current data highlight an extended life expectancy for patients older than the age of 80 who undergo complete CABG,5-7-9 with improved long-term mortality compared to percutaneous interventions or medical therapy.1 Growing evidence has further validated more aggressive complete revascularization with arterial grafting as important objectives during surgical treatment whenever possible.4,5,8 Surprisingly, risks in octogenarians undergoing CABG are less then previously reported.1,3

An important goal of CABG, particularly in the octogenarian population, is achieving complete revascularization.4,7,8,10 However, inconsistent definitions of revascularization “completeness” complicate interpretation of mortality data and confound appropriate surgical planning.4,8,11 Traditionally, complete revascularization has been defined as placement of at least 1 graft to each of the 3 major vascular regions that included a 50% diameter lesion.10,12 Recently, a more functional definition of complete revascularization has been used, requiring revascularization of all diseased diagonal and obtuse marginal branches, as well as both the posterior descending and posterolateral branches of the right coronary artery when multiple lesions were present.11 The goal of the current
Functional complete revascularization was defined as placement of at least 1 graft to each of the 3 major arterial regions that included a 50% lesion. For traditional complete, it was not necessary to bypass all diseased major or primary vessels with at least 50% stenosis, ie, including all diseased diagonal branches of the left anterior descending artery, obtuse marginal branches of the circumflex coronary artery, and both the posterior descending and posterolateral branches of the right coronary artery. Traditional complete revascularization was defined as placement of at least 1 graft to each of the 3 major arterial regions that included a 50% lesion. For traditional complete, it was not necessary to bypass all diseased obtuse marginal or diagonal branches. Incomplete revascularization was defined as leaving diseased, ungrafted regions.

Revascularization was functionally complete in 279 (48%), traditionally complete in 181 (31%), and incomplete in 120 (21%) patients. Incomplete revascularization was more common in the right coronary distribution (62%) than circumflex distribution (38%). The most common reasons documented for incomplete revascularization were calcified or diffusely diseased small distal vessels (74%), difficult exposure or an unstable patient (16%), infarcted myocardium distal to the nongrafted vessel (6%), and limited conduit (4%). In the traditional complete group, disease, unbypassed vessels included diagonals in 121 (67%) patients, distal right coronary tributaries in 70 (39%), and obtuse marginals in 28 (15%). Multiple regions were underbypassed in 36 patients. Major preoperative comorbidities categorized by revascularization subtype are summarized in Table 1. In the incomplete revascularization cohort, there was a greater predominance of peripheral vascular disease (P=0.04), elevated New York Heart Association class (P=0.05), and mitral regurgitation (P=0.01). There was no difference in gender, age, diabetes, left ventricular ejection fraction, history of myocardial infarction, or presence of unstable angina. The incidence of 3-vessel disease was lower in the functional complete group than in the incomplete (P=0.005) and traditional complete (P=0.04) groups. Multivariate regression analysis identified only 2 factors to be independent predictors of incomplete revascularization: (1) mitral regurgitation (P=0.03; OR, 1.7; 95% CI, 1.2–2.6; and (2) chronic obstructive pulmonary disease (P=0.02; OR, 1.9; 95% CI, 1.2–2.9).

Survival data were obtained for all patients during a 2-month closing interval ending June 2007 through interrogation of the Barnes-Jewish Hospital medical records database and the Social Security Death Index. Cumulative long-term survival totaled 2890 patient-years. Thirty-one percent (n=178) of patients were alive an average of 74±47 months postoperatively.

### Statistical Analysis
Operative mortality included any death that occurred during the initial hospitalization or within 30 days of operation for discharged patients. Long-term survival data included death from all causes. Continuous data are reported as mean±SD and were compared between groups using Student t test or ANOVA as appropriate. Actuarial survival estimates were calculated using the Kaplan-Meier method and were compared using the log-rank test. Variability of actuarial estimates is expressed as ±1 SEM. Univariate and multivariate analysis (stepwise backward regression) were used to determine the preoperative and intraoperative risk factors that were significant, including independent predictors of operative mortality and late death (SigmaStat 2.03; SPSS, Inc, Chicago, Ill). OR are reported with 95% CI. Twenty-three variables were analyzed: age, year of operation, surgeon, gender, hypertension, diabetes, chronic renal insufficiency, pulmonary disease, cerebrovascular disease, peripheral vascular disease, history of myocardial infarction, congestive heart failure, stable versus unstable angina, mitral regurgitation, New York Heart Association class, left ventricular ejection fraction, left main disease, mitral regurgitation (≥2+), elective versus nonelective (urgent/emergent) status, preoperative intra-aortic balloon pump, number of distal vessels bypassed, use of the internal mammary artery, and completeness of revascularization.

### Results
Operative characteristics are summarized in Table 2. Statistically significant variables between the 3 groups included...
cross-clamp time (P=0.007), cardiopulmonary bypass time (P=0.02), use of internal mammary artery (P=0.05), and number of grafts in the incomplete group (P=0.001). Interestingly, there was no difference in the number of grafts with traditional complete versus functional complete revascularization (P=0.21), despite the higher incidence of 3-vessel disease in the traditional complete group (P=0.04; Table 1). Off-pump CABG comprised a minority of this 21-year retrospective study (n=79; 14%) but, as expected, whereas all 299 procedures before 1998 were on-pump, 28% of 281 procedures since 1998 were off-pump. There was no difference between on-pump and off-pump CABG in the incidence of incomplete (25% versus 29%), traditional complete (34% versus 28%), or functional complete (41% versus 43%) revascularization (P=0.58; Table 2). Intra-aortic balloon pump use was similar between groups (P=0.26), of which 76% were inserted preoperatively.

Early postoperative morbidity rates are summarized in Table 3. There was a significant increase in prolonged ventilation (>24 hours) in the incomplete revascularization group (P<0.001), but no change in any of the other variables.

Operative mortality was 7.4±2.1% overall (43/580 patients), 4.1±1.0% (17/414) for elective, and 15.7±2.8% (26/166) for emergent procedures. Multivariate regression analysis identified 3 factors to be independent predictors of operative mortality: (1) chronic renal failure (P=0.04; OR, 2.5; 95% CI, 1.3–4.6); (2) urgent or emergent status (P<0.001; OR, 4.3; 95% CI, 2.3–8.2); and (3) incomplete revascularization (P=0.03; OR, 2.0; 95% CI, 1.2–3.2). Operative mortality was highest with incomplete revascularization (12%; 14/120), but there was no significant difference between traditional (8%; 14/181) or functional (5%; 15/279) complete revascularization (P=0.41).

Of 537 operative survivors, there were 402 late deaths. Multivariate regression analysis identified 5 factors to be independent predictors of late death: (1) advanced age (P=0.002); (2) diabetes mellitus (P=0.007; OR, 1.7; 95% CI, 1.2–2.6); (3) chronic renal insufficiency (P=0.005; OR, 4.4; 05% CI, 2.1–9.4); (4) history of myocardial infarction (P=0.03; OR, 1.8; 95% CI, 1.2–2.6); and (5) earlier operative year (P<0.001).

Stratifying by completeness of revascularization subtype, mean survival was 82 months (39–129 months, 25–75th quartile) for functional complete, 80 months (34–112 months) for traditional complete, and 66 months (13–106 months) for incomplete revascularization (Figure). Survival by group at 5 years was: 59±3% functional complete, 57±4% traditional complete, and 45±5% incomplete. Survival at 8 years was: 40±3% functional complete, 37±4% traditional complete, and 26±5% incomplete. Survival at 10 years was 28±3% functional complete, 20±4% traditional complete, and 21±5% incomplete. Survival was significantly impaired with incomplete versus functional complete (P=0.002) and with incomplete versus traditional complete (P=0.02), but there was no difference between functional complete and traditional complete (P=0.51).

To minimize selection bias toward the generally sicker incompletely revascularized population (with a demonstrated increased operative mortality rate), we repeated the survival analysis excluding all patients who died within 12 months of undergoing CABG. There were 463 patients with >12 months of follow-up, and the distribution in regard to completeness of revascularization was similar to the total cohort with 229 (49%) functional complete, 147 (32%) traditional complete, and 87 (19%) incomplete. Again, survival was impaired with incomplete compared to the functional complete revascularization (P=0.05), but the difference between incomplete and traditional complete revascularization was no longer statistically significant (P=0.11), because the curves begin to converge beyond 8 years. Among 1-year survivors, survival at 5 years was 69±3% functional complete, 68±4% traditional complete, and 59±6% incomplete. Survival at 8 years was 44±4% functional complete, 44±5% traditional.

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**Table 2. Intraoperative Clinical Characteristics Categorized by Revascularization Subtype**

<table>
<thead>
<tr>
<th>Operative Variables</th>
<th>Functional, n=279 (48%)</th>
<th>Traditional, n=181 (31%)</th>
<th>Incomplete, n=120 (21%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urgent/emergent status</td>
<td>77 (27%)</td>
<td>53 (29%)</td>
<td>36 (30%)</td>
<td>0.69</td>
</tr>
<tr>
<td>Off-pump CABG</td>
<td>34 (12%)</td>
<td>22 (12%)</td>
<td>23 (19%)</td>
<td>0.14</td>
</tr>
<tr>
<td>Cross-clamp time, min</td>
<td>65±29</td>
<td>72±33</td>
<td>60±27</td>
<td>0.007</td>
</tr>
<tr>
<td>Cardiopulmonary bypass time, min</td>
<td>126±38</td>
<td>127±39</td>
<td>115±33</td>
<td>0.02</td>
</tr>
<tr>
<td>Use of internal mammary artery</td>
<td>212 (76%)</td>
<td>138 (76%)</td>
<td>78 (65%)</td>
<td>0.05</td>
</tr>
<tr>
<td>Number of distal anastomoses</td>
<td>3.6±1.1</td>
<td>3.5±0.9</td>
<td>2.7±0.9</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Need for immediate postoperative intra-aortic balloon pump</td>
<td>45 (16%)</td>
<td>29 (16%)</td>
<td>27 (23%)</td>
<td>0.26</td>
</tr>
</tbody>
</table>

**Table 3. Postoperative Morbidity Categorized by Revascularization Subtype**

<table>
<thead>
<tr>
<th>Postoperative Variables</th>
<th>Functional, n=279 (48%)</th>
<th>Traditional, n=181 (31%)</th>
<th>Incomplete, n=120 (21%)</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Perioperative myocardial infarction</td>
<td>4 (1%)</td>
<td>2 (1%)</td>
<td>1 (1%)</td>
<td>0.52</td>
</tr>
<tr>
<td>Deep sternal wound infection</td>
<td>3 (1%)</td>
<td>1 (1%)</td>
<td>4 (3%)</td>
<td>0.11</td>
</tr>
<tr>
<td>Permanent cerebrovascular accident</td>
<td>12 (4%)</td>
<td>5 (3%)</td>
<td>8 (7%)</td>
<td>0.26</td>
</tr>
<tr>
<td>Prolonged ventilation</td>
<td>42 (15%)</td>
<td>34 (19%)</td>
<td>38 (32%)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Acute renal failure</td>
<td>17 (6%)</td>
<td>13 (7%)</td>
<td>14 (12%)</td>
<td>0.15</td>
</tr>
<tr>
<td>Length of stay, days</td>
<td>12±11</td>
<td>14±13</td>
<td>15±14</td>
<td>0.15</td>
</tr>
</tbody>
</table>
complete, and 34±6% incomplete. Survival at 10 years was 32±4% functional complete, 24±5% traditional complete, and 27±6% incomplete.

Discussion

Complete revascularization during CABG, whether functional complete or traditional complete, has been associated with improved short-term and mid-term outcomes in younger patients. Dacey et al recently demonstrated improved survival with CABG over percutaneous revascularization, likely attributable to the ability to perform more complete revascularization in the surgical cohort. In the current report, the beneficial impact of complete revascularization on early and late survival was also demonstrated in patients older than 80 years of age, corroborating previous work from our institution and others. The impairment in long-term survival for incompletely revascularized octogenarians parallels that of younger populations. However, in the current study, subanalysis of functional and traditional complete revascularization subtypes, as defined by data generated during the Bypass Angioplasty Revascularization Investigation trial, revealed no independent or additional survival advantage, either short-term or long-term, in patients who underwent bypass grafting to all diseased diagonal and obtuse marginal branches (functional complete) versus those in whom a more regional revascularization strategy was performed. Efforts to revascularize the 3 major arterial territories are clearly important in improving long-term survival in the elderly. However, from a survival perspective, the added effort to bypass all branch vessels may not be necessary.

The importance of adopting these more detailed revascularization definitions is particularly germane given the use of atypical terminology in previous reports and inconsistent consensus as to which arterial territories constitute “completeness.” The need for consensus in defining the impact of varying revascularization strategies is vital given the potentially increased intraoperative effort necessary to bypass all diseased vessels in elderly patients. As expected, incompletely revascularized octogenarians had a greater prevalence of peripheral vascular disease, higher New York Heart Association class, mitral regurgitation, and a higher incidence of 3-vessel disease. In addition, a trend toward more patients with preexisting pulmonary disease and prolonged postoperative ventilation time further supplants credence toward this obviously “sicker” population. Interestingly, between functional and traditional complete revascularization subtypes, there were no significant differences in any of the preoperative or intraoperative variables, with the exception of a greater percentage of 3-vessel disease in the traditional complete group. There was no further difference in the number of grafts with traditional complete versus functional complete revascularization, suggesting that the traditional complete group may represent patients with more extensive, diffuse disease than the functional complete group. Data from both the Bypass Angioplasty Revascularization Investigation and Coronary Artery Surgery Study trials give credence to the conclusion that >3 grafts and increasing the number of anastomoses in non-left anterior descending artery territories are unlikely to improve survival. On review of 10-year follow-up data presented here, we extend these findings to the octogenarian cohort as well.

The current report and many others suggest that incomplete revascularization is suboptimal, but can the adverse outcome in survival be altered? Do patients die by virtue of their revascularization status, or do they die because those who undergo incomplete revascularization are “more sick”? In this report, incomplete revascularization was associated with peripheral vascular disease, 3-vessel disease, heart failure class, and chronic pulmonary disease. Whereas operative mortality was independently associated with incomplete revascularization, multivariate analysis determined that late death was more dependent on specific patient comorbidities that are consistently associated with diminished survival, including diabetes mellitus, chronic renal disease, history of myocardial infarction, and advanced age. Previous studies have identified diffusely diseased small vessels, calcification, and infarcted myocardium distal to the vessel as the most common for leaving a diseased region incompletely revascularized. Whereas voluntarily performing incomplete revascularization should obviously be avoided, the diminution in involuntary incomplete revascularization occurrence may require innovative solutions. Previous reports have also clearly documented the benefit of internal mammary grafting in octogenarians. The use of multiple arterial bypass grafts and aggressive medical management may potentially improve outcome this particularly diseased patient cohort, but this remains speculative. Lastly as has been suggested by others, interpretation of coronary angiography and functional studies of ischemia should use a team approach when appropriate, involving the surgeon and both the clinical and interventional cardiologists in preoperative decision-making. A collaborative approach specifically focusing on which regions of the heart warrant revascularization may optimize preoperative revascularization planning.

This study was limited in its retrospective nature, including potential selection bias as to which patients underwent different revascularization options. Although we pursued a multivariate analysis to account for selection bias, such biases are impossible...
to completely eliminate given the necessary study structure for this investigation. Changing perioperative trends in the care of octogenarians with coronary artery disease, improvements in medical management, more aggressive percutaneous interventions, and more liberal use of arterial conduits for bypass grafting may have had greater changes on more recent data accumulation, although we did not specifically evaluate or subcategorize the entire cohort by year for the purpose of this study. We based our evaluation of completeness of revascularization on the dictated catheterization report rather than intraoperative findings (which were inconsistent) or a retrospective review of each patient’s images. Ideally, completeness of revascularization would have been based on a retrospective review of each patient’s images. However, most of the studies were recorded on cine films and were no longer available.

Another limitation is that the impact of functional complete revascularization on late angina relief or functional status was not evaluated in this study. Improved angina relief may be a potential reason to perform functional complete revascularization, in addition to diabetic acceleration of atherosclerotic disease, left ventricular dysfunction, and use in the elderly when life expectancy is expected beyond 10 years.11,14 As poignantly stated by Vander Salm et al11 in their 2002 review of the Bypass Angioplasty Revascularization Investigation study, “Surgeons have almost universally, and perhaps even logically, concluded that no stenoses in vessels of bypassable size should be left unbypassed. We also realize that advice to the contrary may be viewed as heretical.” Their review of the Bypass Angioplasty Revascularization Investigation study suggested an apparent survival disadvantage of placing >1 graft in any system other than the left anterior descending artery. Notwithstanding, the retrospective approach of Vander Salm’s study certainly lends to bias that we have further attempted to minimize in the current report. Finally, the perioperative myocardial infarction rate in our series was small compared to other large studies.11 Because our institution does not routinely check enzymes postoperatively, this data includes only clinically relevant myocardial infarctions (ECG changes, clinical status changes prompting enzyme evaluation, wall motion abnormalities on echocardiography, etc).

In summary, the current report demonstrated that octogenarians undergoing traditional complete revascularization had a similar medical history, operative course, and expected late outcome compared to the functionally complete revascularization cohort in our 21-year institutional experience. The data suggest that in octogenarians, a “conservative” revascularization strategy with 1 graft to each major coronary artery with disease, and no more than 2 to the left anterior descending artery distribution, is reasonable. Incomplete revascularization was clearly associated with diminished late survival compared to any form of complete revascularization. Thus, although the elderly cohort often has considerable medical comorbidities and severe arterial disease that can adversely impact the technical ease of revascularization, we advocate avoidance of incomplete revascularization of a major arterial territory that is viable and could potentially be revascularized.

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References
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