The Journal of
Thoracic and Cardiovascular Surgery

Incomplete revascularization reduces survival benefit of coronary artery bypass grafting: Role of off-pump surgery

Mats J. Synnergren, Rolf Ekroth, Anders Odén, Helena Rexius and Lars Wiklund

J Thorac Cardiovasc Surg 2008;136:29-36
DOI: 10.1016/j.jtcvs.2007.07.059

Incomplete revascularization reduces survival benefit of coronary artery bypass grafting: Role of off-pump surgery

Mats J. Synnergren, MD, PhD, Rolf Ekroth, MD, PhD, Anders Odén, PhD, Helena Rexius, MD, PhD, and Lars Wiklund, MD, PhD

Objective: We sought to analyze the influence, if any, of incomplete revascularization and on/off-pump techniques on long-term mortality after coronary artery bypass grafting.

Methods: A total of 9408 patients undergoing coronary artery bypass grafting, 8461 on pump and 947 off pump, operated on between 1995 and 2004 were included in the study. Adjusted hazard function for long-term mortality was estimated with Poisson regression analysis in a model that included variables reflecting completeness of revascularization, operative method (on/off pump), and background risk factors for death.

Results: Mean follow-up after surgical intervention for survivors was 5.0 ± 2.8 years (range, 0.5–10.5 years), with a total follow-up of 45,076 patient years. Leaving 1 diseased vascular segment without a bypass graft in 2- or 3-vessel disease did not increase the hazard ratio for death in comparison with complete revascularization (hazard ratio, 1.05; 95% confidence interval, 0.87–1.27; $P = .60$). In contrast, leaving 2 vascular segments without a bypass graft in 3-vessel disease was associated with an increased hazard ratio for death (hazard ratio, 1.82; 95% confidence interval, 1.15–2.85; $P = .01$). Incomplete revascularization was more common in the off-pump group ($P < .001$) in our study. If adjusting for incomplete revascularization, there was no significant influence of the use of on/off-pump techniques on the hazard ratio for death (hazard ratio, 1.08; 95% confidence interval, 0.82–1.40; $P = .57$).

Conclusions: Incomplete revascularization of patients with 3-vessel disease is an independent risk factor for increased long-term mortality after coronary artery bypass grafting. In contrast, the use of on- or off-pump techniques had no significant effect on survival after adjusting for incomplete revascularization.

From the Department of Molecular and Clinical Medicine/Cardiothoracic Surgery, Sahlgrenska Academy at Göteborg University, Göteborg, Sweden.

Received for publication Jan 21, 2007; revisions received July 5, 2007; accepted for publication July 10, 2007.

Address for reprints: Mats J. Synnergren, MD, PhD, Children's Heart Centre, The Queen Silvia Children's Hospital, 416 85 Göteborg, Sweden (E-mail: mats.synnergren@vgregion.se).

J Thorac Cardiovasc Surg 2008;136:29-36

0022-5223/$34.00

doi:10.1016/j.jtcvs.2007.07.059

One of the major objectives of coronary artery bypass grafting (CABG) is to reduce the risk of fatal myocardial infarction. According to past studies, this is achieved in patients with coronary disease that affects a large part of the heart, most commonly patients with 3-vessel disease.[1-3] Conversely, it was shown in early studies that survival benefit was reduced if revascularization was incomplete (ie, when ≥1 of the major diseased vessels had not been bypassed).[4] The necessity of complete revascularization has been questioned, along with the introduction of percutaneous coronary intervention (PCI) and off-pump surgery. These techniques are less traumatic, in particular PCI, but complete revascularization can be more difficult to achieve. One argument for questioning the concept of completeness is that it is grounded on the outcome of operations performed more than 20 years ago, and because medication for secondary prevention has changed so much during the years, prior experience could be obsolete.

Abbreviations and Acronyms

CABG = coronary artery bypass grafting
CASS = Coronary Artery Surgery Study
CI = confidence interval
LAD = left anterior descending coronary artery
PCI = percutaneous coronary intervention

The purpose of the present study was to analyze the influence, if any, of incomplete revascularization and on/off-pump techniques on long-term mortality after CABG in a prospective consecutive series of 9408 patients operated on between 1995 and 2004.

Materials and Methods

Database

Between January 1, 1995, and December 31, 2004, 11,647 consecutive patients who underwent isolated CABG at Sahlgrenska University Hospital and Capio Heart Center were included in the Sahlgrenska University Hospital prospective heart surgery registry (Cor Base; Journalia AB, Kungälv, Sweden). Two thousand two hundred thirty-nine patients (2015 on pump and 224 off pump) were excluded from the study because of missing data in any of the included variables. The remaining 9408 patients, 8461 undergoing on-pump and 947 undergoing off-pump CABG, were included in the study.

There was no significant difference in the proportion of included and excluded patients between the on-pump and off-pump groups. There was no systematic registration of the reason for incomplete revascularization.

Definitions

A stenosis of more than 50% on preoperative angiographic analysis was considered significant, with the need for revascularization.[5] Coronary stenoses were classified as located in any of 3 segments: the left anterior descending coronary artery (LAD) segment (LAD and diagonal arteries), the circumflex artery segment (intermediate coronary arteries and obtuse marginal branches), and the right coronary artery segment (posterior descending artery [regardless of dominance] and posterior lateral artery). Complete revascularization was defined as when at least 1 bypass had been performed on each segment with at least 1 stenosis. Incomplete revascularization was defined as when 1 or more diseased segments did not receive any bypass. Patients scheduled for reoperation were considered to have 3-vessel disease if they at any time presented with a stenosis in each of the 3 segments. Patients scheduled for reoperation with functioning grafts were considered to need a graft to a segment if there was an additional stenosis in that segment within reach for revascularization. Early mortality was defined as death for any reason within 30 days of the operation, and overall mortality was defined as death for any reason during the study period. The Cleveland Clinic risk score was used for perioperative mortality and morbidity risk stratification.[6] It includes the need for emergency CABG, renal dysfunction, left ventricular dysfunction, planned reoperation, age, previous vascular surgery, chronic lung disease, anemia, body weight, diabetes mellitus, and cerebrovascular disease, as well as including whether concomitant surgical intervention of mitral valve insufficiency or aortic valve stenosis was indicated. In patients with stable angina pectoris, the severity of symptoms was classified by using the Canadian Cardiovascular Society score.[7] Unstable angina was considered as new onset of severe angina, impairment of stable angina, angina at rest, or angina after myocardial infarction[8] in combination with the need for hospitalization until bypass surgery. Diabetes includes types I and II.

On/off-pump Selection

The choice of the on-pump or off-pump technique was the surgeon's preference. Factors that generally favored the off-pump technique were angiographically well-sized noncalcified arteries with epicardial location, extensive aortic calcifications, and relative contraindications for cardiopulmonary bypass (previous stroke). Occasionally, multiple comorbidity (diabetes, renal, and respiratory disease) was the indication for an off-pump operation.

End Point

The primary end point was all-cause mortality obtained from the population register administered by the Swedish National Tax Board. Specific cause of death was not available.

Statistical Analysis

The purpose of this study was to determine whether long-term survival after CABG was related to completeness of revascularization, use of either off-pump or on-pump surgery, or both. This issue was approached first through a comparison of survival curves for complete revascularization versus incomplete revascularization to 1 or 2 segments and off-pump CABG versus on-pump CABG. Cumulative survival was calculated according to the Kaplan–Meier method, followed by the log-rank test. This was followed by testing for differences in background variables between the on-pump and off-pump cohorts with the Student *t* test for continuous variables and the χ^2 test for categorical variables. Then, as the third step, a multivariate Poisson regression model was used to adjust the hazard ratio for death as a function of completeness of revascularization and on-pump versus off-pump surgery for background variables. The death hazard function after surgical treatment was estimated by use of Poisson regression.[9] The hazard function was of the form $\exp(\beta_0 + \beta_1 \cdot x_1 + \cdots + \beta_k \cdot x_k)$, where $x_1, \ldots,$ and x_k were values of the variables studied, and the β values were coefficients. The hazard function was continuous as a function of time since surgical intervention, current age, and all other continuous variables included in the model. A stepwise procedure was applied to achieve a multivariate model. Each variable was first studied together with time since surgical intervention, current age, and the interaction between the variable and a special function of time since surgical intervention. The special function was equal to the minimum of time and 0.5 years. The variables of significant importance were then included in a forward multivariate procedure. The hazard ratio can be calculated from the hazard function as the $\exp(Variable \times \beta)$ (yes = 1 and no = 0 for categorical variables and the difference in the numeric value of the variable for continuous variables). Poisson regression is an alternative to the Cox regression model because it can handle cumulative exposures and other time-dependent covariates. It is also

Table 1. Patient characteristics: On-pump versus off-pump bypass surgery

Characteristics	On-pump (n = 8461)	Off-pump (n = 947)	*P* value
Demographics			
Age, y (mean ± SD)	66 ± 9	64 ± 10	<.001
Female sex, n (%)	1785 (21)	256 (27)	<.001
Clinical data			
Cleveland Clinic risk score (mean ± SD)	1.6 ± 1.6	1.6 ± 1.8	.5
Planned reoperation, n (%)	176 (2)	38 (4)	<.001
Acute operation, n (%)*	49 (1)	5 (1)	.84
Serum creatinine, μmol/L (mean ± SD)	101 ± 45	103 ± 40	.36
BMI (mean ± SD)	27 ± 4	27 ± 4	.78
Chronic lung disease, n (%)	443 (5)	66 (7)	.03
Smoking, n (%)	1410 (17)	154 (16)	.75
Diabetes, n (%)	1727 (20)	169 (18)	.06
Stroke or TIA, n (%)	689 (8)	61 (7)	.07
Hypertension, n (%)	3751 (44)	353 (37)	<.001
Ejection fraction, % (mean ± SD)	57 ± 13	59 ± 13	<.001
Myocardial infarction, n (%)	4951 (59)	501 (53)	<.001
Unstable angina, n (%)	2403 (28)	237 (25)	.03
CCS I or II, n (%)	2295 (27)	254 (27)	.84
CCS III or IV, n (%)	5355 (63)	602 (64)	.87
Angiographic data			
One-vessel disease, n (%)	165 (2)	418 (44)	<.001
Two-vessel disease, n (%)	1794 (21)	328 (35)	<.001
Three-vessel disease, n (%)	6502 (77)	201 (21)	<.001
Left main stenosis, n (%)	2040 (24)	57 (6)	<.001
Proximal LAD stenosis, n (%)	4558 (54)	601 (63)	<.001

SD, Standard deviation; *BMI*, body mass index; *TIA*, transient ischemic attack; *CCS*, Canadian Cardiovascular Society score; *LAD*, left anterior descending coronary artery. *Operation within 24 hours of angiographic analysis.

possible to estimate the effects of hypothetic changes of the importance in the included variables. Results are presented as means ± standard deviation.

Results

Patients

Patient data are shown in Tables 1 and 2. The mean age at operation was 66 ± 9 years (range, 29–90 years), with 78% male patients. There was a significantly higher percentage of patients with 3-vessel disease among the on-pump group but a significantly lower percentage of patients in whom the index operation was a planned reoperation compared with the off-pump group. There was also a significantly higher percentage with hypertension, previous myocardial infarction, and older age in the on-pump group but a significantly lower percentage with female sex compared with the off-pump group. The patients in the on-pump group had significantly lower ejection fractions compared with the patients in the off-pump group (Table 2). Incomplete revascularization was more frequent with off-pump surgery (Table 2).

Table 2. Revascularization data: On-pump versus off-pump bypass surgery

Characteristics	On-pump	Off-pump	*P* value
All patients (n = 9408)	n = 8461	n = 957	
Complete revascularization, n (%)	7010 (83)	642 (68)	<.001
Incomplete revascularization: 1 segment, n (%)	1401 (17)	231 (24)	<.001
Incomplete revascularization: 2 segments, n (%)	50 (1)	74 (8)	<.001
Patients with 3-vessel disease (n = 6703)	n = 6502	n = 201	
Complete revascularization, n (%)	5169 (79)	41 (20)	<.001
Incomplete revascularization: 1 segment, n (%)	1284 (20)	86 (43)	<.001
Incomplete revascularization: 2 segments, n (%)	50 (1)	74 (37)	<.001

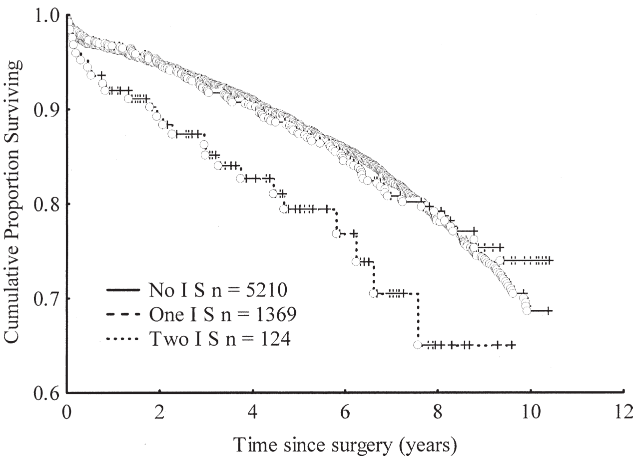

Figure 1. Cumulative survival (Kaplan–Meier) for patients with 3-vessel disease: complete versus incomplete revascularization (P = .009). *I S*, Incomplete segment.

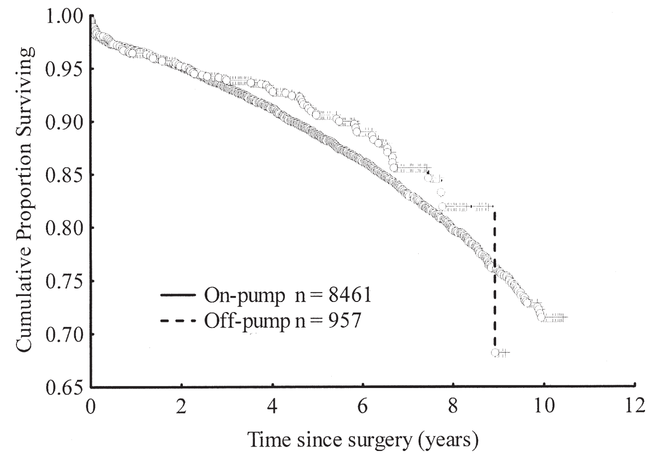

Figure 2. Cumulative survival (Kaplan–Meier) for all patients: off-pump versus on-pump CABG (P = .16).

Follow-up

Mean follow-up after surgical intervention for survivors was 5.0 ± 2.8 years (on-pump, 5.0 ± 2.8 years; off-pump, 4.6 ± 2.1 years; P = .002; range, 0.5–10.5 years), with a total follow-up of 45,076 patient-years.

Mortality

One thousand two hundred twelve patients died during the study period. The early mortality was 1.6% (on pump: 1.6% vs off pump: 1.1%, P = .28), and the overall mortality during follow-up was 12.9% (on pump: 13.3% vs off pump: 9.4%, $P < .001$).

Unadjusted Survival Curves

Survival curves, presented as Kaplan–Meier survival curves, demonstrate inferior survival in patients with 2 unbypassed vascular segments in comparison with patients with complete revascularization (Figure 1). The use of on- or off-pump techniques was associated with equal survival curves in the entire patient cohort (Figure 2), whereas in patients with 3-vessel disease, survival was inferior after off-pump procedures (Figure 3).

Background Risk Variables

All baseline risk characteristics shown in Table 1 were analyzed in relation to age, time after surgical intervention, the interaction between the variable and time after surgical intervention, and all-cause mortality by using Poisson regression. The most important risk variables were then included in a multivariate Poisson regression model and are shown in Table 3. They were used as background variables to adjust hazard ratios for death and survival curves. Hazard ratios for death in a patient having, for example, unstable angina versus a patient not having unstable angina at the time of surgical intervention can be calculated with the following formula:

$$\begin{aligned} \textit{Hazard ratio} &= \exp(\beta \cdot \textit{Unstable angina}; \textit{yes} = 1, \textit{no} = 0) \\ &= \exp(0.577 \cdot 1) = 1.78. \end{aligned}$$

Some variables change their importance over time. Unstable angina is such a variable. This is shown by the following formula:

$$\begin{aligned} \textit{Hazard ratio} &= \exp([\beta \cdot \textit{Unstable angina}; \textit{yes} = 1, \textit{no} = 0] \\ &+ [\beta \cdot \textit{Unstable angina} \cdot \min(\textit{time},\ 0.5); \\ \textit{yes} = 1, \textit{no} = 0 &\cdot \textit{Time},\ \textit{if time} \le 0.5]) = \exp(0.577 \cdot 1]) \\ &- [0.990 \times 1 \times \textit{Time}]. \end{aligned}$$

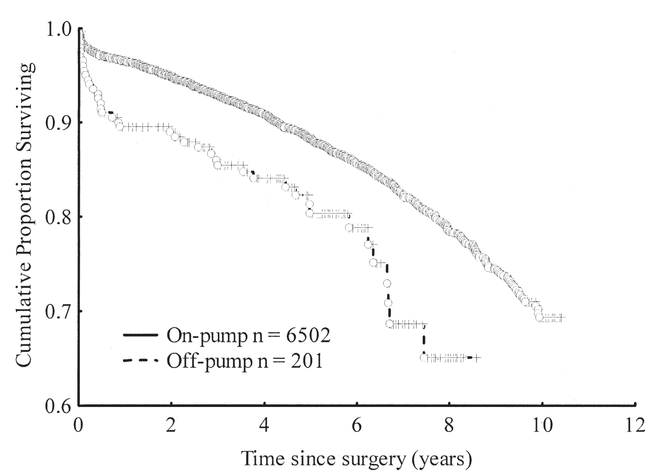

Figure 3. Cumulative survival (Kaplan–Meier) for patients with 3-vessel disease: off-pump versus on-pump CABG ($P < .001$).

Table 3. Variables included in the multivariate Poisson model

Variable	β	SD	*P* value
Constant	−3.767	0.531	<.001
Age	0.0515	0.00413	<.001
Time since beginning of 1970 (y)	−0.0431	0.0141	.0023
Min(time, 0.1)*	−20.973	1.900	<.001
Max(min[time-0.1,0.5-0.1],0)†	−1.282	0.457	.0050
Max(time-0.5,0)‡	0.159	0.0154	<.001
Cleveland Clinic risk score	0.277	0.0302	<.001
Cleveland Clinic risk score × min(time,0.5)§	−0.223	0.0688	<.001
Ejection fraction	−0.0171	0.00221	<.001
Smoking	0.452	0.0794	<.001
Serum creatinine, μmol/L	0.00207	0.000355	<.001
Diabetes	0.302	0.0678	<.001
Stroke or TIA	0.362	0.0849	<.001
Unstable angina	0.577	0.154	<.001
Unstable angina × min(time,0.5)§	−0.990	0.346	.0043

SD, Standard deviation; *TIA*, transient ischemic attack. *The corresponding β-coefficient gives the change over time for the interval 0 years to 0.1 years. †The corresponding β-coefficient gives the change over time for the interval 0.1 years to 0.5 years. ‡The corresponding β-coefficient gives the change over time for the interval 0.5 years and forward. §The corresponding β-coefficient gives the change over time for the interval 0 years to 0.5 years

This means that the hazard ratio of death 6 months after surgical intervention (0.5 years) is $\exp([0.577 \cdot 1] - [0.990 \cdot 1 \cdot 0.5]) = 1.09$. This is natural because the cause of unstable angina has been attended to by coronary artery bypass surgery. This demonstrates the strength in the multivariate Poisson regression model to adjust for estimated changes of importance over time in the ingoing risk variables.

Risk-adjusted Hazard Ratios

Completeness of revascularization. Leaving 1 diseased vascular segment without a bypass graft in 2- or 3-vessel disease did not increase the hazard ratio for death in comparison with complete revascularization (hazard ratio, 1.05; 95% confidence interval [CI], 0.87–1.27; *P* = .60; Figure 4). In contrast, leaving 2 vascular segments without a bypass graft in 3-vessel disease was associated with an increased hazard ratio for death (hazard ratio, 1.82; 95% CI, 1.15–2.85; *P* = .01, Figure 5).

When revascularization was incomplete, in the vast majority of cases the right (96%) and left (93%) circumflex coronary arteries were not grafted. Rarely, the LAD segment (11%) was left without a bypass graft. The proportion of patients with incomplete revascularization was analyzed as a function of calendar year. There was no correlation (ie, no significant change occurred during the study period).

On/off-pump techniques. The use of on/off-pump techniques did not significantly influence the hazard ratio for death when incomplete revascularization was included as a background risk variable (hazard ratio, 1.08; 95% CI, 0.82–1.40; *P* = .57; Figure 6).

Discussion

This study shows that incomplete revascularization in patients with 3-vessel disease when 2 segments are left without bypass grafts is an independent risk factor for long-term mortality after CABG. In our hands, the off-pump technique was associated with more frequent incomplete revascularization. Our analysis, however, could not detect any difference in hazard ratios of death related to the use of on-pump or off-pump techniques when the model was adjusted for incomplete revascularization.

Survival After CABG

In the early days of CABG, during the late 1970s and early 1980s, 3 major randomized studies compared CABG with

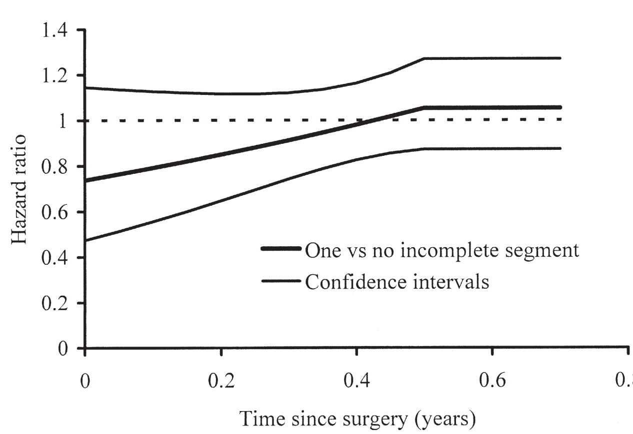

Figure 4. Hazard ratio for death in patients with 1 incomplete segment versus patients with no incomplete segments among patients with 3-vessel disease (*P* = .6).

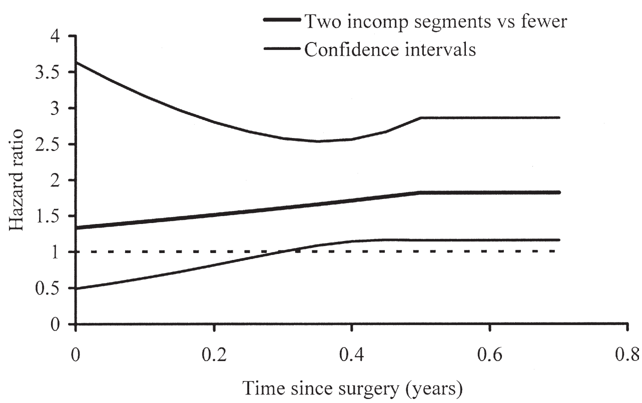

Figure 5. Hazard ratio for death in patients with 2 incomplete segments versus patients with 1 or no incomplete segments among patients with 3-vessel disease (P = .01).

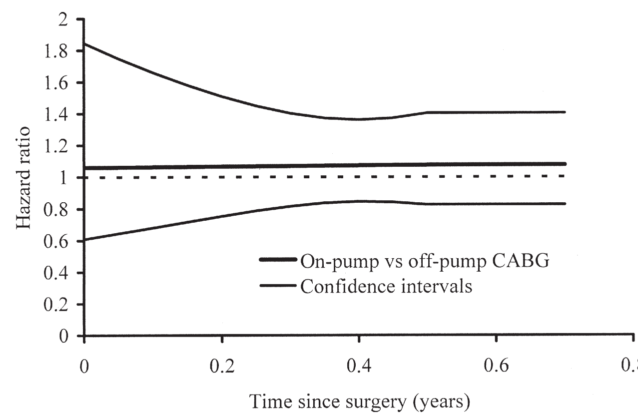

Figure 6. Hazard ratio for death in patients undergoing on-pump versus off-pump CABG in all included patients (P = .57).

pharmacologic treatment.[1-3] It was found that selected patients with a large part of the heart affected by coronary lesions and with increased risk of premature death fared better with CABG than with pharmacologic treatment. Thus current guidelines, such as Evidence-based cardiology (Salim Yusuf, BMJ Books, 2003),[10] state that patients with left main lesions, 3-vessel disease, or proximal LAD lesions have a survival benefit with CABG. However, the survival benefit of CABG is sometimes questioned. It is argued that the scientific evidence is old and newer pharmacologic agents might have reduced the risk of fatal myocardial infarction to such a degree that CABG has no further effect.

Incomplete Revascularization

The same argument that puts the survival benefit from CABG into question also applies to the necessity of complete revascularization. The studies that show that incompleteness is associated with a greater risk of premature death[4,11,12] have recruited all or most of their patients with the primary operations performed more than 20 years ago. Further doubt on the completeness concept is caused by reports from the Bypass Angioplasty Revascularization Investigation[13] and the Arterial Revascularization Therapies Study (ARTS),[15] which found no effect on survival by incomplete revascularization. The validity of these studies is, however, compromised by their patient mix. Both studies were designed to compare CABG with PCI. Therefore all patients had to be suitable for either technique, which is the reason why both studies are dominated by patients at low and moderate risk. In these patients no survival benefit can be expected, nor can incompleteness of revascularization be expected to affect survival.

In our study patients with 3-vessel disease who only received 1 graft, which in the majority of cases was to the LAD, had a worse outcome than those who had 2 or more regions bypassed. The validity of our finding could be challenged. There were only 124 patients with 3-vessel disease and only 1 bypass graft of a total of 9408 patients. Many other influences on survival could have been lost in our analysis of such a small group. This concern would implicate that other risk factors than those listed in Table 1 (and with no relationship to the Table 1 variables) explained both incomplete revascularization and increased risk of death during follow-up. This is possible, but it is in our view not probable that any unknown variable, with no association to conventional risk variables for death, could explain both incomplete revascularization and increased mortality during follow-up. Furthermore, our finding is conceivable and is in line with previous data.[4,11,12] The Coronary Artery Surgery Study (CASS),[4] which enrolled patients more than 20 years earlier, made a similar observation. In their study patients with mild angina had a worse survival when only 1 vessel in 3-vessel disease was bypassed, whereas 1 omitted bypass did not affect outcome. In contrast, already 1 omitted graft in patients with severe angina or poor left ventricular function increased the risk of fatal outcome. Differences in statistical design between our study and the CASS make comparisons hazardous. With this reservation, it appears that our study population, in which the majority of patients had severe angina, had a similar outcome as the patients with “mild angina” in the CASS. If so, this could reflect more efficient secondary prevention today than 20 years ago.

There is one crucial question. Does the poorer prognosis after incomplete revascularization reflect more advanced disease, or is there a causal relationship between undergrafting and outcome? The multivariate analysis in our study indicated that undergrafting per se is an independent risk factor (hazard ratio, 1.82; 95% CI, 1.15–2.85) with a greater effect than smoking (hazard ratio, 1.57; 95% CI, 1.34–1.84) and diabetes (hazard ratio, 1.35; 95% CI, 1.18–1.54). This in turn provided indirect evidence that bypass surgery still does have a survival benefit. Otherwise, 1, 2, or more grafts would have no implication on outcome.

Off-pump Surgery

Off-pump coronary surgery has gained popularity because of an assumed reduced invasiveness by avoiding cannulation and extracorporeal perfusion. A number of studies have indeed shown that off-pump surgery is advantageous. Other studies have failed to detect a beneficial effect. Instead, many studies have reported a greater proportion of incomplete revascularization. Weather this has affected outcome has not been possible to establish. The effect of off-pump techniques on short-term and midterm outcomes has been reported in a great number of retrospective studies and in fewer prospective randomized studies. The results have been ambiguous.[15-19] According to the present analysis, off-pump surgery does not by itself influence long-term survival because there was no significant difference in risk ratios of death between off-pump and on-pump techniques. The risk of a type II error has been considered. There is indeed room for a substantial difference within the CI (0.82–1.40), but the P value (P = .57, Figure 6) indicates that the risk of an error is not large.

However, off-pump surgery, according to our data, is associated with a higher risk of incomplete revascularization. There are 2 possible explanations for this. First, in some patients optimal surgical access is more difficult to obtain, and the surgeon might have refrained from grafting to avoid severe hemodynamic instability or the vessel might have been considered unsuitable because of poor quality. It is probable that these alternatives are less common at high-volume off-pump centers. It could even be argued that the low off-pump volume at our institution and relative inexperience makes it impossible to make any generalizations from our findings. This argument is contradicted by recent systematic reviews and meta-analyses of randomized controlled trials. These indicate that off-pump surgery is associated with more frequent incomplete revascularization, more frequent graft occlusion, and repeat revascularization than on-pump surgery.[20-23]

Second, in some patients with a higher risk profile, the off pump-technique was chosen primarily to minimize patient trauma by combining the off-pump technique with target revascularization. Then one of several diseased arteries, nearly always the LAD, was proclaimed the culprit lesion, and the other diseased vessels were left to minimize the procedure. This option complicates the interpretation of our data. However, because risk variables that were used to select patients for this strategy are included in the risk model, the role of incomplete revascularization as an independent risk factor can be determined. Caputo and coworkers,[24] who also used an off-pump/target revascularization strategy, found that incomplete revascularization was associated with reduced survival, which is in agreement with our data.

Study Design and Limitations

The primary focus of this study was completeness of CABG versus long-term survival. For ethical reasons, a randomized design with complete versus incomplete revascularization is hardly permissible, and for this purpose, a registry observational study is the only possible study design. A secondary focus was the role of off-pump surgery. A prospective randomized study would have advantages in comparison with an observational study. A disadvantage, though, would be that a very large number of patients would be required. It would require more than 8000 patients to detect a difference in survival related to ungrafted vessels to obtain 80% power with a similar mix of patients as in this study. In reality, this means that the randomized approach will be impossible to pursue. The statistical methods of this study make it possible to identify independent risk factors against a variable background of a number of other risk factors to balance the disadvantage of the observational study. However, there were significant differences between the off-pump and on-pump groups in this study. This could have been a problem if there had been no overlap between groups. Fortunately, for our analyses, the overlap was extensive for all variables. The primary end point was death of all causes and was obtained from the population register administered by the Swedish National Tax Board, which registers all deaths occurring within and without all Swedish hospitals. Based on previous experience, complete follow-up can be assumed.

Conclusions

The present study shows that completeness of revascularization in patients with 3-vessel disease is a determinant of long-term survival after CABG. Off-pump CABG can, at least at small-volume off-pump centers, be associated with more frequent incomplete revascularization. However, we found no significant difference in risk ratio of death after adjusting for incomplete revascularization.

References

1. Eighteen-year follow-up in the Veterans Affairs Cooperative Study of Coronary Artery Bypass Surgery for stable angina. The VA Coronary Artery Bypass Surgery Cooperative Study Group. *Circulation*. Jul 1992;86(1):121-30.
2. Long-term results of prospective randomized study of coronary artery bypass surgery in stable angina pectoris. European Coronary Surgery Study Group. *Lancet*. Nov 27 1982;2(8309):1173-80.
3. Alderman EL, Bourassa MG, Cohen LS, et al. Ten-year follow-up of survival and myocardial infarction in the randomized Coronary Artery Surgery Study. *Circulation*. Nov 1990;82(5):1629-46.
4. Bell MR, Gersh BJ, Schaff HV, et al. Effect of completeness of revascularization on long-term outcome of patients with three-vessel

disease undergoing coronary artery bypass surgery. A report from the Coronary Artery Surgery Study (CASS) Registry. *Circulation*. Aug 1992;86(2):446-57.
5. Botas J, Stadius ML, Bourassa MG, et al. Angiographic correlates of lesion relevance and suitability for percutaneous transluminal coronary angioplasty and coronary artery bypass grafting in the Bypass Angioplasty Revascularization Investigation study (BARI). *Am J Cardiol*. Apr 15 1996;77(10):805-14.
6. Higgins TL, Estafanous FG, Loop FD, et al. Stratification of morbidity and mortality outcome by preoperative risk factors in coronary artery bypass patients. A clinical severity score. *JAMA*. May 6 1992;267(17):2344-8.
7. Campeau L. Letter: Grading of angina pectoris. *Circulation*. Sep 1976;54(3):522-33.
8. Braunwald E. Unstable angina. A classification. *Circulation*. Aug 1989;80(2):410-4.
9. Breslow NE, Day NE. Statistical methods in cancer research. Volume II—The design and analysis of cohort studies. *IARC Sci Publ*. 1987;(82):131-5.
10. Salim Yusuf et al. Evidence-based cardiology. Second edition, Blackwell BMJ Books, Jan 2003.
11. Jones EL, Weintraub WS. The importance of completeness of revascularization during long-term follow-up after coronary artery operations. *J Thorac Cardiovasc Surg*. Aug 1996;112(2):227-37.
12. Scott R, Blackstone EH, McCarthy PM, et al. Isolated by-pass grafting of the left internal thoracic artery to the left anterior descending coronary artery: late consequences of incomplete revascularization. *J Thorac Cardiovasc Surg*. Jul 2000;120(1):173-84.
13. Comparison of coronary bypass surgery with angioplasty in patients with multivessel disease. The Bypass Angioplasty Revascularization Investigation (BARI) Investigators. *N Engl J Med*. Jul 25 1996;335(4):217-25.
14. Serruys PW, Unger F, Sousa JE, et al. Comparison of coronary-artery bypass surgery and stenting for the treatment of multivessel disease. *N Engl J Med*. Apr 12 2001;344(15):1117-24.
15. Williams ML, Muhlbaier LH, Schroder JN, et al. Risk-adjusted short- and long-term outcomes for on-pump versus off-pump coronary artery bypass surgery. *Circulation*. Aug 30 2005;112(9 Suppl):I366-70.
16. Al-Ruzzeh S, Ambler G, Asimakopoulos G, et al. Off-Pump Coronary Artery Bypass (OPCAB) surgery reduces risk-stratified morbidity and mortality: a United Kingdom Multi-Center Comparative Analysis of Early Clinical Outcome. *Circulation*. Sep 9 2003;108 Suppl 1:II1-8.
17. Racz MJ, Hannan EL, Isom OW, et al. A comparison of short- and long-term outcomes after off-pump and on-pump coronary artery bypass graft surgery with sternotomy. *J Am Coll Cardiol*. Feb 18 2004;43(4):557-64.
18. van Dijk D, Nierich AP, Jansen EW, et al. Early outcome after off-pump versus on-pump coronary bypass surgery: results from a randomized study. *Circulation*. Oct 9 2001;104(15):1761-6.
19. Angelini GD, Taylor FC, Reeves BC, et al. Early and midterm outcome after off-pump and on-pump surgery in Beating Heart Against Cardioplegic Arrest Studies (BHACAS 1 and 2): a pooled analysis of two randomised controlled trials. *Lancet*. Apr 6 2002;359(9313):1194-9.
20. Wijeysundera DN, Beattie WS, Djaiani G, et al. Off-pump coronary artery surgery for reducing mortality and morbidity: meta-analysis of randomized and observational studies. *J Am Coll Cardiol*. Sep 6 2005;46(5):872-82.
21. Parolari A, Alamanni F, Polvani G, et al. Meta-analysis of randomized trials comparing off-pump with on-pump coronary artery bypass graft patency. *Ann Thorac Surg*. 2005;80:2121-5.
22. Lim E, Drain A, Davies W, Edmonds L, Rosengard BR. A systematic review of randomized trials comparing revascularization rate and graft patency of off-pump and conventional coronary surgery. *J Thorac Cardiovasc Surg*. 2006;132:1409-13.
23. Takagi H, Tanabashi T, Kawai N, Kato T, Umemoto T. Off-pump coronary artery bypass sacrifices graft patency: meta-analysis of randomized trials. *J Thorac Cardiovasc Surg*. 2007;133:e2-3.
24. Caputo M, Reeves BC, Rajkaruna C, et al. Incomplete revascularization during OPCAB surgery is associated with reduced mid-term event-free survival. *Ann Thorac Surg*. Dec 2005;80(6):2141-7.