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The Impact of Coronary Artery Endarterectomy on Outcomes During Coronary Artery Bypass Grafting

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Abstract

Background—The impact of coronary artery endarterectomy during coronary artery bypass grafting (CABG) has been debated. We examined the early and late outcomes of CABG with endarterectomy (CE) compared to CABG alone.

Methods—Patients undergoing isolated CABG operations from 2003 to 2008 were retrospectively reviewed. We identified 99 patients who underwent CE and 3:1 propensity matched them to 297 CABG-alone patients based upon clinical factors: Society of Thoracic Surgeons (STS) predicted risk of mortality, age, gender, year of surgery, and ejection fraction. Patient risk factors as well as short-and long-term outcomes were compared by univariate and Kaplan-Meier analysis.

Results—Preoperative risk factors were similar between patients undergoing CE or CABG alone. Cross-clamp times (95.6 vs. 71.8 minutes, $p = 0.0001$) and perfusion times (121.8 vs. 92.7 minutes, $p = 0.0001$) were longer in patients undergoing CE. Operative mortality (4.0% vs. 1.3%, $p = 0.112$) and postoperative complications were not significantly different between groups. Patients undergoing coronary endarterectomy incurred longer ICU (75.06 vs. 48.64 hours, $p = 0.001$) and hospital stays (9.01 vs. 7.7 days, $p = 0.034$). Long-term mortality (mean follow-up = 27.7 ± 17.7 months) was equivalent despite revascularization technique ($p = 0.13$); however, patients undergoing CE encountered worse overall freedom from myocardial infarction (MI) ($p = 0.03$).

Conclusion—Patients undergoing CABG with coronary CE required longer ventilatory support and ICU stay yet have comparable operative mortality, major complication rates, and long-term survival to isolated CABG. Coronary endarterectomy should be considered an acceptable adjunct to CABG for patients with extensive coronary artery disease to achieve complete revascularization.

Patients who are referred for coronary artery bypass grafting (CABG) are increasingly more complex with multiple comorbidities, including diabetes, renal insufficiency, and peripheral vascular disease. In addition, many patients have undergone previous interventions for coronary disease.¹ Single- and double-vessel disease is often treated with percutaneous coronary intervention. As a result, patients referred for CABG often have advanced and diffuse coronary disease, which has made complete revascularization more challenging.

Coronary artery endarterectomy was initially introduced as a lone procedure for myocardial revascularization in the late 1950s;² however, it was soon replaced with the more successful

CABG. Whether or not the performance of CABG with concomitant coronary artery endarterectomy (CE) in patients with severe coronary disease provides more complete long-term revascularization remains unknown. Early experiences with CE reported higher rates of perioperative morbidity and mortality, while more recent data suggest that it can be performed safely with good early results.^{3,4} As a result of unknown long-term outcomes, many surgeons remain reluctant to perform CE.^{3,5} In this study, we examined the present-day outcomes in patients undergoing CE compared to patients undergoing CABG alone.

METHODS

Patient selection

This investigation was approved by the Human Investigation Committee of the University of Virginia Health System (HSR# 14635), including a waiver for the need to obtain patient consent. Patients undergoing isolated CABG operations were prospectively entered into our institutional, Society of Thoracic Surgeons (STS) database. Data include demographics, risk factors and comorbidities, intraoperative details, and postoperative complications. STS definitions and categories were used to describe all variables and postoperative outcomes, including primary causes of mortality.⁶ Specifically, perioperative myocardial infarction (MI) was defined as a CK-MB level ≥ 5 times the upper limit of normal within the first 24 postoperative hours or by the presence of at least one of the following after more than 24 postoperative hours during the same hospitalization: evolutionary ST-segment elevations, development of new Q waves in two continuous ECG leads, new left bundle branch block, or a CK-MB level of $\geq$ three times the upper limit of normal. Prolonged ventilation was defined as > 24 hours of postoperative mechanical ventilation. Long-term follow-up was complete in 98% of patients. Follow-up data related to long-term patient mortality and postoperative MI rates were obtained by linking our clinical database with records obtained in the University of Virginia Clinical Data Repository (CDR). The CDR performs quarterly review of patient medical records, including provider clinic notes, laboratory analysis, and echocardiograms, and receives reports from the Social Security Death index to document patient mortalities.

A total of 1884 patients underwent primary, isolated CABG between 2003 and 2008, including 99 patients who underwent concomitant coronary endarterectomy. We utilized propensity matching to account for differences in patient characteristics and risk factors.⁷ A 3:1 propensity match was used to match 297 patients who underwent CABG alone to the 99 patients undergoing CE. Patients were robustly matched using greedy methodology based upon STS predicted risk of mortality (PROM), age, gender, year of surgery, and ejection fraction.

Operative technique

Coronary artery endarterectomy was performed at the surgeon's discretion when the target vessel to revascularize was severely calcified or diseased, precluding the safe performance of conventional CABG. All operations involving CE were performed using cardiopulmonary bypass (CPB), moderate hypothermia (32 °C to 34 °C), and single aortic cross-clamping. Saphenous vein and internal mammary artery (IMA) were used for grafts. All vessels undergoing endarterectomy were diffusely diseased with total occlusion and were judged to be poor candidates for a distal bypass anastomosis. In addition, endarterectomy was performed in vessels with a minimum outer diameter of 2 mm, and supplied an area of myocardium judged to be either viable or potentially viable following surgical revascularization. In cases of endarterectomy of the right coronary artery, an arteriotomy was made at the site of anastomosis, and the plaque was removed using an eversion traction technique. If the end-point of the plaque was not tapered and feathered, the arteriotomy was

extended. The distal end of a spatulated saphenous vein graft was used for revascularization and arteriotomy closure. In cases of endarterectomy of the left anterior descending artery, a similar, open eversion endarterectomy technique was used. In these cases, the left anterior descending (LAD) arteriotomy was typically very long. Thus, it was our preferred practice to close the arteriotomy with a generous saphenous vein patch prior to bypass grafting with the native IMA.

After completion of the operation, all patients were able to be weaned from CPB and transferred to the intensive care unit. All endarterectomy patients were treated postoperatively with Aspirin and Plavix for a minimum of three months, whereas conventional CABG patients were typically treated with Aspirin alone.

Statistical analysis

All statistical analyses were designed to test the null hypothesis that outcomes following CABG procedures would not be significantly different despite the use of concomitant coronary endarterectomy. All normally distributed continuous data are reported as mean $\pm$ standard deviation, while non-normally distributed data are presented as median [interquartile range]. Continuous data were compared using either analysis of variance (ANOVA) for normally distributed data or the Mann-Whitney U test for nonparametric data. Categorical variables were compared using either Pearson's chi-square or Fisher's exact tests and are expressed as a percentage of the group of origin. Group comparisons were unpaired. Overall survival and freedom from postoperative MI for each study group was assessed by Kaplan-Meier analysis with log-rank testing. Reported p-values are 2-tailed. Statistical significance was defined by p-values of less than 0.05. Data analyses were performed using SAS 9.1.3 (The SAS Institute, Cary, NC, USA).

RESULTS

Patient characteristics and operative data

Patient demographics and preoperative characteristics are presented in Table 1. There were no significant differences in preoperative demographics and risk factors between the two groups, with the exception of history of preoperative arrhythmias, which was more frequent among patients undergoing CE compared to those undergoing CABG alone (17.2 % vs. 6.7%, $p = 0.004$). Among preoperative arrhythmias, atrial fibrillation/flutter was the most common. Importantly, STS PROM was similar between study groups.

Operative data are presented in Table 2. As a result of more advanced coronary disease, patients in the CE group more frequently underwent multiple (greater than two) bypass grafts compared to the isolated CABG group. The additional time to perform the grafts, including the endarterectomy, resulted in longer, aortic cross-clamp (95.6 ± 2.8 vs. 71.8 ± 1.6 minutes, $p < 0.001$) and CPB (121.8 ± 3.8 vs. 92.7 ± 1.9 minutes, $p < 0.001$) times in the endarterectomy group. The IMA was used in more than 95% of patients in both groups. Right IMA use occurred in 0.5% of cases, while right radial artery use was 1.5%. The location of CE included: right coronary artery (RCA) exclusively (80.0%), LAD exclusively (12.1%), RCA + Diagonal (1.0%), RCA + obtuse marginal (OM) (1.0%), RCA + posterior descending artery (PDA) (2.0%), RCA + LAD (1.0%), OM (3.0%), PDA (2.0%), and Circumflex (1.0%). The overall incidence of intraaortic balloon pump (IABP) insertion was 13.9% (CE = 15.2%, CABG 13.5%). The majority of IABP placement occurred in the preoperative setting (10.9%: CE = 10.1%, CABG = 33%). Indications for IABP placement included: hemodynamic instability (5.6%: CE = 6.1%, CABG = 5.4%), angina (3.8%: CE = 5.1%, CABG = 3.4%), prophylactic placement (3.3%: CE = 3.4%, CABG = 3.4%), weaning from CPB (1.0%: CE = 1.0%, CABG = 1.0%), and for support following percutaneous

transluminal coronary angioplasty (0.3%: CE = 0.0%, CABG = 0.3%). Moreover, during the study period, a total of seven surgeons performed CABG procedures, but only four surgeons performed operations with concomitant endarterectomy. Of these four surgeons, one surgeon performed 54.5% of CE while the others performed 21.2%, 12.1%, and 12.1%, respectively.

Perioperative complications

Postoperative complications and outcomes are presented in Table 3. Operative mortality was similar between the two groups (CE = 4% vs. CABG alone = 1.3%, $p = 0.11$). Among decedents, cardiac etiology was the primary cause of death in 75% of CE patients and 50% of CABG-alone patients. Pulmonary-related deaths accounted for 25% of CABG-alone patient mortalities. Also, the incidence of major postoperative complications including MI, stroke, renal failure, and multiorgan failure were similar between groups. There was a higher incidence of prolonged ventilation (>24 hours) in patients undergoing CE compared to CABG alone (16.2% vs. 8.1%, $p = 0.03$). Similarly, postoperative pneumonia was more common following CE compared to CABG alone (9.1% vs. 1.3%, $p < 0.001$).

Resource utilization

Resource utilization data are presented in Table 4. The higher incidence of respiratory complications in CE patients resulted in longer ICU stays (75.1 ± 11.1 vs. 48.6 ± 2.8 hours, $p < 0.001$) and higher rates of prolonged mechanical ventilation (16.2% vs. 8.1%, $p = 0.03$). Consequently, hospital length of stay for the patients undergoing CE was longer compared to those undergoing CABG alone (9.0 ± 0.6 vs. 7.7 ± 0.3 days, $p < 0.001$).

Long-term survival and freedom from postoperative myocardial infarction

After a mean follow-up of 27.7 ± 0.9 months (CE = 25.8 ± 1.7 months [$n = 98/99$], CABG alone = 28.4 ± 1.0 months [$n = 295/297$]), overall survival was equivalent among patients undergoing CE or CABG alone ($p = 0.13$, Fig. 1). In addition, while patients undergoing CABG had statistically higher overall freedom from MI ($p = 0.03$, Fig. 2), the majority of postoperative MIs occurred early during the follow-up period within both study groups. Alternatively, late freedom from MI rates was not significantly different between patient groups (CE = 73.1% vs. CABG = 71.8%, $p = 0.05$). Furthermore, among the 18 CE patients with postoperative MIs, five patients (27.8%) had infarctions localized to the endarterectomized vessel.

DISCUSSION

In this study, we have demonstrated similar short-term outcomes between patients undergoing isolated CABG operations $\pm$ concomitant coronary endarterectomy. Through propensity matching, we compared similar patients undergoing either operation with respect to preoperative risk to strengthen the validity of our data analyses. As a result, we observed similar operative mortality rates among patients undergoing isolated CABG with or without concomitant CE, and the incidence of short-term postoperative MI among endarterectomy patients was 1%. Late survival was also similar despite revascularization technique. However, early freedom from postoperative MI was worse for those undergoing CABG with CE compared to those undergoing CABG alone, while late freedom from MI rates was similar between cohorts. Moreover, the endarterectomy cohort incurred higher rates of prolonged ventilation and pneumonia, longer aortic cross-clamp and CPB times, and longer intensive care unit and hospital lengths of stay. We believe that these results provide important contributions to accumulating evidence examining short- and long-term results for the performance of endarterectomy as an adjunct to surgical coronary revascularization.

Studies have demonstrated that the completeness of coronary artery revascularization correlates with improved early and late outcomes following CABG.^{8,9} Achieving complete surgical revascularization in an increasingly complex patient population, however, may prove challenging. Most of these patients present with multiple comorbidities, and many have undergone previous percutaneous intervention. As a result, the use of endarterectomy as an adjunct to CABG offers an opportunity to achieve complete revascularization in the setting of advanced and diffuse disease. However, the benefits of coronary endarterectomy have been questioned due to concerns of increased morbidity and mortality and uncertain long-term graft patency.⁵

The results of this study concur with those of previously published series with respect to both short- and long-term mortality and MI rates following CABG with CE. Similar operative mortality rates of 2% to 8% in patients undergoing CABG with coronary CE have been reported in other series.^{3,4,10–13} In addition, we observed similar overall survival despite the use of endarterectomy; however, early freedom from MI was worse in patients undergoing concomitant endarterectomy. These findings may reflect a worse overall coronary artery plaque burden in the endarterectomy group or may be related to the long-term consequences of coronary thrombosis following endarterectomy. Furthermore, the observation that 28% of postoperative MIs within CE patients occurred in endarterectomized regions is consistent with results of other reported series.^{4,12,14} In fact, perioperative MI remains a primary complication following coronary endarterectomy and is believed to be due to removal of the endothelial lining after performing endarterectomy, resulting in thrombosis.¹⁵ For this reason, we employ dual antiplatelet therapy for all endarterectomy patients. It has been suggested that this treatment strategy is superior to monoplatelet therapy in patients undergoing coronary endarterectomy. Our practice is to maintain dual antiplatelet therapy for at least three months following endarterectomy. In addition, the use of heparin and/or warfarin in the postoperative period has been described to avoid acute thrombosis.^{16,17} We do not routinely employ anticoagulation for these patients. There are no guidelines regarding optimal antiplatelet or anticoagulation strategy in patients undergoing endarterectomy. The postoperative rate of MI in our endarterectomy patients (1%) was lower than the reported incidence of 1.5% to 19% in the literature.^{3,4, 10–13}

Other important findings and differences between the two groups compared in this study deserve attention. Patients undergoing endarterectomy encountered a higher incidence of prolonged ventilation and pneumonia, which may be related to acute lung injury following longer CPB and operative times. In addition, CE patients had a higher incidence of preoperative arrhythmias. While we believe that a higher incidence of pre-operative atrial fibrillation may predispose patients to the development of postoperative arrhythmias, we did not consider the presence of preoperative arrhythmia a significant enough variable on which to propensity match. In addition, a difference in the number of bypass grafts placed between study groups favored a higher number of grafts placed in the CE group, and the overall prevalence of preoperative angina was surprisingly low (64.4%). Although interesting, we are unable to extrapolate these findings to comment on their clinical significance; however with respect to graft numbers, we would not expect that more bypass grafts would result in higher postoperative MI rates. Regarding the prevalence of preoperative angina, it is possible that patients without preoperative angina alternatively presented with heart failure symptoms or these patients represent a population that does not often present with symptoms of angina such as females or diabetics. In fact, among those patients without angina, 70% were female and 51% were diabetic. The elevated prevalence of IABP use in this series largely represents those placed in the preoperative setting, while only 1% of all IABPs were used postoperatively to wean from CPB. In addition, longer operative times reflect prolonged aortic cross-clamp and perfusion times required for endarterectomy patients due to the added complexity of the procedure, a higher overall plaque burden, more diffuse

disease, and a higher percentage of patients receiving multiple grafts. Consequently, the higher incidence of pneumonia and prolonged ventilation explains the greater resource utilization of these patients with respect to ICU hours and length of stay, which is consistent with the results of other series.^{4,12}

There are a number of limitations to note. First, the retrospective design introduces the likelihood of selection bias. Secondly, despite a propensity-matched patient cohort, we are limited in our abilities to detect small differences between operative groups due to the relatively small number of patients in each group. Thus, there exists the possibility for Type II error. Coronary endarterectomy is performed in a highly selective fashion at our institution, and, thus, only a small percentage of our patients who undergo CABG will have concomitant endarterectomy. In fact, the performance of coronary endarterectomy in 5.2% of cases is disproportionately small compared to other published series.^{4,12} This study is also limited by a mean follow-up period of 27 months for survival and freedom from MI. It is possible that a longer follow-up period may help further to define differences in these two metrics. Moreover, we were unable to directly assess graft patency as postoperative or long-term assessment of graft patency by angiography or computed tomography angiography is not routinely performed after revascularization, and study outcomes did not include the incidence of recurrent angina or need for revascularization overtime.

CONCLUSION

We conclude that operative mortality and major complications following CABG with concomitant CE have paralleled the significant improvements in outcomes following CABG alone over the past few decades. These outcomes suggest that coronary endarterectomy can be performed with acceptable operative risk and little impact on overall patient survival. Patients undergoing endarterectomy appear to encounter lower early freedom from MI; however long-term freedom from MI rates is not significantly different from those for CABG alone. The optimal antiplatelet and/or anticoagulation strategy remain unknown. Coronary endarterectomy should be considered an acceptable adjunct to CABG for patients with extensive coronary artery disease to achieve complete revascularization.

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Figure 1.
Survival for patients undergoing coronary artery bypass grafting (CABG) + endarterectomy versus CABG alone.

Figure 2. Freedom from postoperative myocardial infarction in patients undergoing coronary artery bypass grafting (CABG) + endarterectomy versus CABG alone.

TABLE 1

Preoperative Risk Factors

	CABG/CE n = 99	Isolated CABG n = 297	p Value
Patient age (years)*	62.2 ± 10.4	62.0 ± 11.4	0.88
Gender			0.90
Male	70 (70.7%)	213 (71.7%)	
Female	29 (29.3%)	84 (28.3%)	
Cerebrovascular disease	21 (21.2%)	40 (13.5%)	0.077
Chronic lung disease			
Mild	8 (8.1%)	11 (3.7%)	0.21
Moderate	6 (6.1%)	10 (3.4%)	0.21
Severe	1 (1%)	5 (1.7%)	0.21
Diabetes	47 (47.5%)	124 (41.8%)	0.35
Dyslipidemia	90 (90.9%)	264 (88.9%)	0.71
Family history of CAD	58 (58.6%)	166 (55.9%)	0.73
Renal failure	8 (8.1%)	13 (4.4%)	0.19
Smoking	54 (54.5%)	169 (56.9%)	0.73
Previous procedures			
Coronary artery bypass grafting	1 (1%)	10 (3.4%)	0.31
Percutaneous coronary intervention	20 (20.2%)	57 (19.2%)	0.89
Valve surgery	2 (2%)	1 (0.3%)	0.16
Hypertension	85 (85.9%)	247 (83.2%)	0.64
Angina	62 (62.6%)	193 (65%)	0.72
Arrhythmia	17 (17.2%)	20 (6.7%)	0.004
Atrial fibrillation/flutter	13 (13.1%)	16 (5.4%)	0.01
Ventricular tachycardia/fibrillation	1 (1.0%)	3 (1.0%)	>0.99
Heart block (third degree)	3 (3.0%)	1 (0.3%)	0.05
Heart failure	29 (29.3%)	64 (21.5%)	0.13
Ejection fraction (%) [†]	45 [33–60]	45 [30–60]	0.62
Myocardial infarction	57 (57.6%)	161 (54.2%)	0.64
Peripheral arterial disease	17 (17.2%)	47 (15.8%)	0.75
STS PROM (%)	2.5 ± 2.8	2.1 ± 2.8	0.25

CABG = coronary artery bypass grafting; MI = myocardial infarction; CAD = coronary artery disease; PCI = percutaneous coronary intervention.

* mean ± standard deviation;

[†] median [interquartile range];

TABLE 2**Intraoperative Factors**

	CABG/CE n = 99	Isolated CABG n = 297	p Value
Number of grafts			
One	0 (0%)	15 (5.1%)	0.02
Two	12 (12.1%)	54 (18.2%)	0.02
Three	87 (87.9%)	228 (76.7%)	0.02
IMA used	98 (99%)	289 (97.3%)	0.37
Cross-clamp time (min)	95.6 ± 2.8	71.8 ± 1.6	0.001
Perfusion time (min)	121.8 ± 3.8	92.7 ± 1.9	0.001
IABP insertion	15 (15.2%)	40 (13.5%)	0.74

IMA = internal mammary artery; IABP = intraaortic balloon pump.

TABLE 3**Postoperative Complications**

	CABG/CE n = 99	Isolated CABG n = 297	p Value
Cardiac			
Perioperative MI	1 (1%)	3 (1%)	1.0
Overall postoperative MI	18 (18.1%)	31 (10.4%)	0.05
Tamponade	2 (2%)	7 (2.4%)	1.0
Graft occlusion	0 (0%)	1 (0.3%)	1.0
Atrial fibrillation	14 (14.1%)	42 (14.1%)	1.0
Heart block	0 (0%)	3 (1%)	0.57
Cardiac arrest	4 (4%)	8 (2.7%)	0.5
Respiratory			
Reintubation	5 (5.1%)	6 (2%)	0.152
Prolonged ventilation*	16 (16.2%)	24 (8.1%)	0.032
Pneumonia	9 (9.1%)	4 (1.3%)	0.001
Pulmonary embolism	1 (1%)	1 (0.3%)	0.43
Other			
30-day readmission	14 (14.1%)	24 (8.1%)	0.11
Mortality	4 (4%)	4 (1.3%)	0.11
Multisystem organ failure	2 (2%)	1 (0.3%)	0.16
Renal failure	5 (5.1%)	9 (3%)	0.35
Postoperative dialysis	4 (4%)	4 (1.3%)	0.11
Stroke	3 (3%)	2 (0.7%)	0.1
Sepsis	2 (2%)	2 (0.7%)	0.261
Sternal wound infection	1 (1%)	0 (0%)	0.25
GI bleed	2 (2%)	2 (0.7%)	0.26
Acute limb ischemia	1 (1%)	1 (0.3%)	0.43

MI = myocardial infarction; GI = gastrointestinal.

* Prolonged ventilation = postoperative mechanical ventilation > 24 hours.

TABLE 4

Perioperative Resource Utilization

	CABG/CE	Isolated CABG	p Value
Postop ventilation hours	31.15 ± 8.5	12.86 ± 1.03	0.001
Total intensive care unit hours	75.06 ± 11.12	48.64 ± 2.83	0.001
Length of stay (days)			
Admission-Discharge	9.01 ± 0.64	7.71 ± 0.28	0.034
Admission-Surgery	1.43 ± 0.18	1.60 ± 0.11	0.47
Surgery-Discharge	7.58 ± 0.59	6.11 ± 0.25	0.009

CABG = coronary artery bypass grafting.