Off-pump bypass of the left anterior descending coronary artery: 23- to 34-year follow-up

Jay L. Ankeney, MD, and Darlene J. Goldstein, MD

Supplemental material is available online.

Objective: We sought to develop a baseline for long-term survival of patients after off-pump bypass of the left anterior descending coronary artery with the heart beating.

Methods: We reviewed results for 241 consecutive patients with significant obstruction of the left anterior descending coronary artery who underwent surgery between November 1969 and the end of 1980. The off-pump operative technique involved elevating and stabilizing a segment of the distal left anterior descending coronary artery with 4 traction sutures. Starting in 1973, an internal thoracic artery became the graft of choice, so that a total of 171 patients received an internal thoracic artery bypass graft, and 70 patients received a saphenous vein graft.

Results: The median survival of patients with internal thoracic artery grafts was 23.7 years versus 17.9 years for patients with venous grafts ($P < .02$). Early patency of arterial grafts was 95%, and late patency was 90%. There were 2 (0.8%) operative deaths. Seventy of the 74 patients still alive in 2003 were interviewed by telephone, and 40 (57%) did not require additional invasive treatment, which is consistent with our finding that more than 50% of our patients after bypass of the left anterior descending coronary remained stable without obstruction of the right or circumflex arteries. However, atherosclerosis progressed in 30 (43%) of the survivors, who underwent reinterventions.

Conclusions: Off-pump bypass of the left anterior descending coronary artery with an internal thoracic artery can be done on a beating heart safely and results in median survival of patients for more than 23 years.

From the Department of Cardiovascular Surgery, Case Western Reserve School of Medicine, The University Hospitals of Cleveland, Cleveland, Ohio.

Supported by the Jay L. Ankeney, MD, Endowed Professorship in Cardiothoracic Surgery.

Received for publication Nov 9, 2006; revisions received Jan 23, 2007; accepted for publication Jan 29, 2007.

Address for reprints: Jay L. Ankeney, MD, the Department of Cardiothoracic Surgery, University Hospitals of Cleveland, 11100 Euclid Ave, Cleveland, OH 44106 (E-mail: drankeney@aol.com).

J Thorac Cardiovasc Surg 2007;133:1499-1503

0022-5223/\$32.00

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doi:10.1016/j.jtcvs.2007.01.071

This study was undertaken to establish a baseline of long-term survival of patients who underwent off-pump bypass of the left anterior descending coronary artery (LAD). We reviewed 241 consecutive patients operated on from November 1969 through December 1980. The LAD was bypassed with a saphenous vein graft (SVG) in 70 patients and an internal thoracic artery (ITA) in 171 patients. The last year of the study was 2003, providing 23 to 34 years' follow-up.

Materials and Methods

Of the 241 patients, 183 were men with a median age of 55.2 years (range, 29–77 years). Fifty-eight patients were women with a median age of 56.3 years (range, 40–73 years). The patients' preoperative clinical profiles are summarized in Table 1.

All patients had significant obstruction of the LAD, which was defined as the narrowing of the vessel's lumen equal to or exceeding 50%. Preoperative angiograms showed 157 (65.2%) patients with coronary obstruction limited to the LAD. Eighty-four (34.8%) patients had additional obstructed arteries, including 39 (16.2%) patients with obstructed right coronary arteries (RCAs), 28 (11.7%) patients with obstruction of the circumflex coronary artery (CIRC), and 17 (7.0%) patients with obstruction of all 3 coronary arteries.

Abbreviations and Acronyms

CIRC = circumflex coronary artery
ITA = internal thoracic artery
LAD = left anterior descending coronary artery
LITA = left internal thoracic artery
PCI = percutaneous coronary intervention
RCA = right coronary artery
SVG = saphenous vein graft

Surgical Technique

All graft operations bypassing the LAD were performed off pump with the heart beating by using a previously described technique.^{1,2} Laparotomy pads placed behind the heart displaced it anteriorly, exposing the distal LAD. Two 3-0 silk sutures were passed under the LAD 3 to 5 cm apart, and a 4-0 silk suture was passed through the adventitia along each side of the elevated coronary segment. Gentle traction of the 4 sutures elevated and stabilized a distal segment of the LAD. If coronary occlusion was not complete without excessive traction of sutures passed under the LAD, a small bulldog vascular clamp was applied to attain a bloodless operative field. An anastomosis of an arterial or venous graft to a linear opening of a stabilized LAD was easily and accurately performed. The beating heart maintained circulation in all patients without conversion to cardiopulmonary bypass.

Beginning in 1973, the decision was made that the ITA would be the bypass vessel of choice. One hundred sixty-five LADs and 3 diagonal coronary arteries were bypassed with a left ITA (LITA), and 3 LADs were bypassed with a right ITA. For convenience, in this text the term ITA indi-

TABLE 2. Operative complications

	n	%
Patients without complications	191	79.2
Atrial arrhythmias	16	6.6
Ventricular arrhythmias	5	2.1
Perioperative myocardial ischemia	16	6.6
Wound infection	5	2.1
Cerebrovascular accident (transient)	2	0.8
Postpericardiotomy syndrome	4	1.7
Cardiac tamponade	1	0.4
Secondary wound closure	2	0.8
Pericarditis	1	0.4
Total	241	

cates use of either a right or left ITA as a graft. The ITA was used to bypass the LAD in 171 patients, and an SVG was used in 70 patients.

Patient Follow-up

Patients' physicians and cardiologists were contacted by mail and telephone, with very little response. Many physicians had died, and those who were retired did not have access to their patients' records. Physicians treating surviving patients were reluctant to provide clinical information because of the privacy rule under the Health Insurance Portability and Accountability Act.

The information in this report was primarily gained from reviewing clinical charts and reports, including 182 postoperative follow-up coronary angiograms. This review of records was augmented by personally interviewing 70 of the 74 patients alive in 2003. Surviving patients were well informed about their clinical status, additional studies, and procedures, including whether their original LAD bypass graft was functioning and which vessels required reintervention.

Results

There were 2 (0.8%) operative deaths. One occurred in a 45-year-old woman who had irreversible ventricular fibrillation 2 hours after the operation. Postmortem examination revealed undiagnosed left main coronary artery obstruction. The second death was due to an aortic dissection in a 68-year-old man who had an SVG bypass of the LAD.

Operative complications of the 241 patients are shown in Table 2. Two patients had transient cerebrovascular ischemia. Superficial wound infections occurred in 5 patients. One patient had re-exploration for cardiac tamponade, and another had a wound dehiscence that required secondary closure. Sixteen patients experienced atrial fibrillation, and 16 other patients showed evidence of myocardial ischemia with S-T segment changes and myocardial enzyme increases.

The 16 patients who showed evidence of myocardial ischemia at the time of their operations were reviewed as a

TABLE 1. Patient characteristics

Patients	241
Male patients	183
Female patients	58
Angina	175
Unstable angina	33
Impending infarction	22
Left main stenosis	3
Positive stress test result	42
Previous myocardial infarction	76
Congestive heart failure	4
Hypertension	43
Diabetes	9
Hypercholesterolemia	32
Left ventricular dysfunction	
Mild	45
Moderate	16
Severe	3
Family history	39
Smokers	45

TABLE 3. Results of Breslow test to compare survival data by number and indicate which coronary arteries were obstructed

Comparisons	<i>P</i> value
LAD vs LAD-RCA	<.37
LAD vs LAD-CIRC	<.0497
LAD vs LAD-RCA-CIRC	<.0001
LAD-RCA vs LAD-CIRC	<.28
LAD-RCA vs LAD-RCA-CIRC	<.0009
LAD-CIRC vs LAD-RCA-CIRC	.06

LAD, Left anterior descending coronary artery; *RCA*, right coronary artery; *CIRC*, circumflex coronary artery.

separate subgroup. The overall average survival of this subgroup was 19.2 years, and 3 patients of that subset were alive in 2003. It was gratifying to learn that these patients with perioperative myocardial ischemia did as well as the other patients in this study. Post-LAD bypass angiocardiograms in 15 of these patients only showed 4 small apical aneurysms.

According to the Social Security Death Index, by the end of this review in December 2003, 167 (69.3%) of the original 241 patients had died, and 74 (30.7%) were still alive. Death certificates were requested from appropriate states to ascertain the patients' time and major cause of death. Of the 140 certificates available for review, cardiac was listed as the major cause of death for 72 (51.4%) patients, cancer for 25 (17.9%) patients, pulmonary for 21 (15.0%) patients, and cerebrovascular accident for 8 (5.7%) patients.

Our statistical analysis addressed the issue of each individual patient's actual survival after LAD bypass surgery compared with the amount of time they would have been expected to live as predicted by actuarial estimates based on US vital statistics compiled during the same period of time as the patients' operations.

Of the 241 patients, 112 survived longer than expected, and 129 survived for a shorter time than expected. The *P* value for the sign test was less than .3. There was no statistically significant difference in survival because about half of the operative patients survived longer and about half survived less long than they would have without having heart disease and undergoing bypass of their LAD. As detailed in 5-year increments, the 5-, 10-, 15-, 20-, 25-, and 30-year survivals were 93%, 82%, 73%, 56%, 41%, and 11%, respectively. Of the 70 patients interviewed in 2003, 40 (57%) did not require additional invasive procedures, but 30 (43%) underwent reinterventions.

Comparison of patients grouped by their type of graft indicated a median survival of 23.7 years for patients with ITA bypass grafts, which was longer than the 17.9-year median survival for those with SVG grafts. This difference was found to be significant by using the Breslow test ($P < .02$). Of 171

TABLE 4. Early and late patency of SVGs and ITA grafts

Grafts (n)	Early patency <2 y	Late patency as last known
ITA (107)	103/107 (96.3%)	96/107 (89.7%)
SVG (40)	31/40 (77.5%)	24/40 (60%)

patients with ITA grafts, 115 (67%) initially had disease limited to the LAD. Of those 115, 45 (39.1%) survived, and these patients comprised 60.8% of the 74 long-term survivors. The patients who originally had SVGs accounted for an additional 10 (14%) of the 74 long-term survivors.

Kaplan-Meier analysis (with the Breslow test) was used to examine survival by number and type of coronary arteries obstructed. This comparison revealed that survival of patients with obstruction of the LAD alone and patients with obstruction of the LAD and RCA was not significantly different ($P < .37$). Both groups survived significantly longer ($P < .0001$ and $P < .0009$, respectively) than patients with all 3 coronary arteries obstructed. In contrast, there was not a significant ($P = .06$) difference between the survival rate of patients with the 2-vessel combination of LAD and CIRC, although it was nearly significant. These findings suggest that patients with the combination of LAD and CIRC obstruction do not do as well as patients with LAD and RCA obstruction after ITA bypass of the LAD (Table 3).

Patency data were available for 40 of the 70 patients who had SVGs and 107 of the 171 patients with ITA grafts. During the first 2 years after bypass surgery, 9 (22.5%) of 40 SVGs closed. Over the ensuing years, an additional 7 SVGs closed, for a long-term patency of 60%.

Of the 107 ITA grafts, 4 (3.7%) closed within the first 2 years, for an early patency rate of 96% (103/107). By the end of the study, another 7 ITA grafts closed, for a long-term patency of 89.7% (96/107). There was significantly longer patency for the ITA grafts versus the SVGs ($P < .001$, Table 4).

By comparing preoperative and late postoperative angiograms of 78 patients after ITA grafting of the LAD, it was possible to monitor the postoperative obstruction of additional coronary arteries. The average time between the 2 compared angiograms was 11.4 years.

Additional coronary arteries did not become obstructed in 29 (37%) of the 78 patients after bypass of the LAD. However, progressive atherosclerosis in 49 (63%) patients obstructed an additional 27 RCAs and 42 CIRC. Regression of coronary atherosclerosis was not reported in any of the 182 postoperative angiograms because the atherosclerosis either stayed the same or increased.

Forty-nine patients underwent reinterventions, including 42 with ITA grafts and 7 with SVGs. Twenty-six of the 42 patients with ITA grafts were still alive in 2003, surviving an average of 27.2 years. The 26 survivors' freedom from

intervention averaged 17.2 years, during which time 19 patients acquired obstruction of all 3 coronary arteries, but 24 ITA grafts remained open.

In contrast, 16 patients with ITA grafts who survived an average of 11.1 years after undergoing reintervention had far advanced and aggressive coronary disease, and 8 of 16 bypass grafts failed to function.

Four of the 7 patients with an SVG graft who had reinterventional operations survived through 2003. Three of the 4 survivors' original SVG grafts were still functioning after 31, 32, and 33 years, respectively.

Because performing percutaneous coronary intervention (PCI) in patients with 100% obstruction can be challenging,³ we reviewed 30 patients with completely obstructed LADs. Nine were still alive in 2003, and the average survival for all 30 was 17.7 years. Six patients underwent reinterventions, including bypass of 2 failed LAD grafts.

Discussion

In 1973, the ITA was chosen as the graft of choice for bypassing the LAD because of Vineberg's⁴ pioneering work in the 1950s, demonstrating that the LITA buried in the anterior left ventricular myocardium remained open without blood flow. Angiogenesis developed and provided new blood vessels that joined with the LITA graft, which remained patent for 15 to 20 years. In some patients the buried LITA graft provided the only blood supply to the heart.

After completing this series of ITA bypasses of the LAD, others showed in the early 1980s that an ITA was indeed an excellent bypass graft with high early and late patency rates. This review corroborates their findings, even when the bypass operation was performed off pump with the heart beating.

One of the 2 operative deaths was due to an aortic dissection in a 68-year-old man who had an SVG bypass of the LAD. Postmortem examination showed an intimal tear several centimeters proximal to the venous aortic anastomosis. It can be argued that maintaining systemic pressure in the aorta, as occurred in our off-pump operations with the heart beating, made partially occluding an aorta more hazardous and difficult to perform a venous anastomosis than is possible with a collapsed aorta in patients receiving cardiopulmonary bypass with the heart stopped. The difference of operating on a distended and collapsed aorta might account for our reduced early patency with SVGs.

Since the mid-1990s, off-pump coronary bypass surgery has been performed with various instruments⁵⁻⁷ to stabilize a target coronary artery. The simple operative technique used in this series of off-pump LAD bypasses involved 4 traction sutures that elevated and stabilized a distal segment of the LAD and provided an uncluttered and bloodless operative field for an accurate anastomosis of an SVG or ITA graft.

The median survival for patients with ITA grafts was 23.7 years, and that for patients with SVGs was 17.9 years. The median survival for all patients was 22.6 years. These findings showing the superiority of the use of an ITA graft versus an SVG are similar to those reported by others.⁸

The survival of our patients was consistent with the patency characteristics of ITA grafts. During the first 2 years after LAD bypass, 95% of ITA grafts functioned and remained open over an extended number of years, with a late patency of 90%. As detailed in 5-year increments, 93% of patients were alive after 5 years, and after 20 years, more than half of the patients (56%) were still living.

As expected, there was a direct correlation between the patient's initial amount of disease and survival. Of the 70 surviving patients, 51 (73%) began with isolated obstruction of the LAD, 12 (17%) had obstruction of the LAD and RCA, and 6 (8.5%) had obstruction of the LAD and CIRC. Of the 17 patients who initially had obstruction of all 3 coronary arteries, only one was a long-term survivor. Therefore when selecting patients for this technique, our experience demonstrated that it might not be prudent to bypass the LAD alone when there are 3 vessels obstructed. For those patients, complete revascularization is indicated.⁹

Of the 70 survivors we interviewed in 2003, 40 (57%) required no additional interventional treatment. Fortunately, some patients required only an ITA bypass of the obstructed LAD for long-term survival because atherosclerosis in many patients after ITA bypass of the LAD remains stable.

On the other hand, 26 of the 70 surviving patients with ITA grafts experienced progressive atherosclerosis, and after an average of 17.2 years, 19 patients had obstruction of all 3 major coronary arteries. However, 24 of the 26 survivors had open LAD grafts that preserved left ventricular function. All 26 survived PCI and coronary artery bypass grafting reintervention.

Because performing PCI in a patient with a 100% obstructed LAD can be challenging, our experience with 30 patients who had 100% obstruction was quite favorable. Four of the LADs required endarterectomies, and an additional 7 patients had 100% obstruction of their RCAs, which did not undergo operations. Nine of the 30 patients were still alive at the end of our review, and the average survival for all patients in this group was 17.7 years.

Gruntzig and colleagues'¹⁰ introduction of angioplasty in 1979 has led to PCI becoming the preferred invasive treatment for coronary artery disease. This is especially true for treatment of patients with obstructed LADs.

Drug-eluting stents have been used for a relatively short period of time as initial treatment of obstructed LADs.¹¹⁻¹⁴ Time will tell whether drug-eluting stents can keep obstructed LAD coronary arteries open for 20 to 30 years with the same success as is possible with off-pump ITA grafts, as shown in this long-term follow-up review.

We extend special thanks to my secretary, Ms Nancy Nigolian, who maintained the accurate daily log of operative procedures that made this study possible; to Douglas Rowland for statistical analysis; and to Jay L. Ankeney, Jr, who helped to prepare the text.

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Statistical Analysis

In preliminary analyses, variables were characterized by the parametric descriptive statistics, the mean and standard deviation and/or the nonparametric descriptive statistics, and the median and interquartile range, as appropriate. Also, for some variables, the 95% confidence interval for the mean or median was calculated. Statistical differences between groups with respect to quantitative data were examined by using the parametric Student *t* test or the nonparametric Mann–Whitney *U* test, which is equivalent to the Wilcoxon rank sum test. Statistical differences between groups with respect to categoric data were examined by using the Fisher exact test or the χ^2 test, as appropriate.

For survival data and duration of patency, where some values were censored because of losses to follow-up or where survival had continued until the study ended, special techniques were necessary. To address the issue of overall survival experience of patients, individual patient's actual survival after the (first) operation was compared with the amount of time they would have been expected to live by actuarial estimates (based on US vital statistics covering the time of their operation) so that the actual ages when the operations occurred would not be obscured by using average or median ages. These comparisons for individual patients were then analyzed by using the sign test.

To examine the postoperative survival experiences of patient groups and duration of patency, the product-moment method of Kaplan–Meier was used to provide estimated postoperative survival curves where the data of surviving patients are fully incorporated, even when censoring occurs. These curves graphically depict the cumulative survival distribution over time. The key descriptive statistic for this distribution is the sample median, with a sense of its precision given by the 95% confidence interval of that estimate. To compare the Kaplan–Meier curves of 2 patient subgroups, the Breslow test was used because it is most appropriate when the curves cross or coincide in the later years (which is the situation with these data because most patients had operations as older adults). The Breslow test was preferable here because it gives greater weight to the occurrence of earlier deaths. The log-rank test, which is often used to compare Kaplan–Meier curves of 2 patient subgroups, is less conservative than the Breslow test in that it gives equal weight to the occurrence of all deaths observed during follow-up.

It is recognized that there was multiple testing of outcome data arising from individual patients; however, an adjustment of *P* values, such as correction by using the Bonferroni method, would have removed all instances of statistical significance. Also, because we were concerned with highlighting any potential differences, the uncorrected *P* values are presented.

TABLE E1. Survival of patients with perioperative myocardial ischemia

Patient identifier	Date of operation	Date of death	Type of graft		Open	Closed	Survival in years	Cause of death
36	1970	1974	SVG		1		4	Cardiac
62	1974	1984		ITA	1		10	Cancer
95	1975	1997		ITA	1		22	Cardiac
96	1971	1980	SVG		1		9	Cardiac
102	1972	1996		ITA	1		24	Cardiac
122	1975			ITA	1		28	No DC
131	1975			ITA		1	28	No DC
140	1977	1988	SVG				11	Trauma
142	1977	1985	SVG				8	Cardiac
153	1971	1988	SVG				17	Aneurysm
167	1970	2000	SVG				29	Pulmonary
201	1976	1999	SVG			1	23	Pulmonary
218	1977	1999		ITA	1		22	Cardiac
224	1972		SVG				31	No DC
226	1970	1989	SVG				19	Cardiac
265	1976	1997		ITA	1		23	Hepatic
Total			9	7	8	2	Average,19.2	

DC, Death certificate.