CORONARY ARTERY BYPASS GRAFTING IN PATIENTS WITH AN EJECTION FRACTION OF TWENTY PERCENT OR LESS

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Over a 7-year period, 5.8% ($n = 210$) of patients who underwent coronary artery bypass grafting at our institution had severely impaired global left ventricular function with an ejection fraction of 20% or less. Mean age at operation was 66 years (± 0.7 ; standard error), and 76% of patients were male. Primary indications for operation were unstable angina (73 patients, 35%), return of symptoms with previous bypass grafting (41 patients, 20%), congestive heart failure with reversible ischemia (55 patients, 26%), and recurrent ventricular arrhythmias (41 patients, 20%). Overall, actuarial survival ($n = 210$) was 82%, 79%, and 73% at 1, 2, and 5 years. Risk of death was highest early after the operation, and then declined rapidly to a constant level. Patients who did not receive retrograde coronary sinus cardioplegia ($p = 0.05$), older patients ($p = 0.004$), and those with preoperative ventricular arrhythmias ($p = 0.003$) or renal failure ($p < 0.0001$) had an increased risk of death early after operation. Patients with congestive symptoms and those requiring extensive or redo bypass grafting ($p = 0.02$) were found to be at an increased risk of death throughout the follow-up period. When the number of distal anastomoses performed increased, survival was found to decrease ($p < 0.003$), and to a greater extent in women than in men ($p = 0.02$). Of the four primary indications for operation, unstable angina yielded the highest risk-adjusted survival. Successful results after surgical revascularization in patients with severe impairment of ventricular function can be achieved by careful patient selection and management. (*J Thorac Cardiovasc Surg* 1996;111:1001-12)

Revascularization of ischemic myocardium in patients with severely impaired global left ventricular (LV) function remains a surgical challenge. Despite advances in surgical technique and myocardial protection, perioperative mortality and morbidity remain high¹⁻³ and long-term survival is poor.⁴ Death often results from progression of preoperative symptoms of congestive heart failure (CHF)⁴⁻⁷ or ventricular arrhythmias,^{3,8,9} even though revascularization may result in initial improvement.^{4-6, 10-13}

Because alternative surgical treatments (i.e.,

transplantation and cardiomyoplasty) are limited¹⁴ and the results of medical therapy are often unsatisfactory,¹ coronary artery bypass grafting (CABG) is often the only available treatment that will improve symptoms and longevity.^{2, 5, 10, 15} To quantify survival after CABG in these patients in whom the risk is high, and to characterize those most likely to benefit, we conducted a retrospective study.

Patients and methods

Patient selection. Between January 1, 1987, and December 31, 1992, 3621 patients underwent CABG at our institution. This study is based on the 210 patients (5.8% of total) with severe impairment of global LV function who met the following criteria: (1) an LV ejection fraction of 20% or less, as assessed by area/length measurement on biplane LV cineangiogram; (2) evidence of reversible ischemia in the distribution of one or more major coronary arteries on dipyridamole thallium scintigraphy; and (3) evidence of operable coronary artery disease (CAD) on coronary angiography. Patients with an LV aneurysm ($n = 11$), severe segmental dysfunction with scar on thallium scan ($n = 3$), and those with a grossly dilated cardiomyopathy (LV end-diastolic dimension > 70 mm by

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Table I. Preoperative clinical details

	All patients (n = 210)		ACC (n = 103)		ACC + RCSC (n = 107)		p <
	No.	%	No.	%	No.	%	
Age (mean 66 ± 0.7 yr) >70 yr	85	40.51	29	20	46	28	0.2
Female	51	24.3	21	20	30	28	0.2
Male	159	75.7	81	78.6	78	72.9	0.9
Coronary risk factors							
Hypertension	119	56.6	55	53	64	60	0.3
Diabetes mellitus	43	20.5	20	19.4	23	21.5	0.1
Smoking	92	43.8	42	40.7	50	46.7	
Family history	44	20.95	23	22	25	24	0.8
Hyperlipidemia	91	43.3	50	49	41	38	0.1
Clinical presentation							
Unstable angina	43	19	18	17.5	23	22	0.5
Recent myocardial infarction	30	14.3	16	15.5	17	23	0.97
Recurring angina after previous CABG	41	19	16	15.5	6.25	23	0.2
Stable angina—class IV	50	25	25	24.3	25	23.3	0.3
CHF with reversible ischemia	55	26.2	28	27	27	25	0.7
Ventricular arrhythmias (VT/VF)	41	19.52	21	20	20	18.7	0.8
Peripheral vascular disease	15	7.1	10	9.8	5	4.7	0.2
Cerebrovascular disease	13	6.2	7	6.9	6	5.6	0.7
Previous cerebrovascular accident	10	4.7	5	4.8	4	3.7	0.1
Chronic obstructive pulmonary disease	25	11.9	16	15.5	9	8.4	0.2
Chronic renal failure (dialysis)	9	4.3	6	5.8	3	2.8	0.3
ECG, Holter monitor, and echocardiographic findings							
Old myocardial infarction	60	28.57	28	27	32	30	0.2
Dilated cardiomyopathy (LVEDD <70 mm)	41	19	20	19.4	21	19.6	0.2
Cardiac catheterization and LV function							
Left main coronary stenosis	28	13.3	12	11.6	15	14	0.8
Triple vessel disease	210	100	103	100	107	100	—
IABP support	44	21	25	24	19	17.7	0.2

CABG, Coronary artery bypass graft; CHF, congestive cardiac failure; VT/VF, ventricular tachycardia/ventricular fibrillation; ECG, electrocardiographic; LVEDD, left ventricular end-diastolic dimension; LV, left ventricular; IABP, intraaortic balloon pump; ACC, antegrade cardioplegia; RCSC, retrograde cardioplegia.

Table II. Preoperative hemodynamic and echocardiographic findings in 210 patients

	Subgroup I (n = 73)	Subgroup II (n = 41)	Subgroup III (n = 55)	Subgroup IV (n = 41)
LVEDD (cm)	5.4 ± 0.6	5.2 ± 0.7	6 ± 0.8*	5.6 ± 0.7
Echo, all patients				
Mean PASP (mm Hg)	29 ± 3	28 ± 3	46 ± 0.8†	31 ± 2
Mean PCWP (mm Hg)	13 ± 2	14 ± 2.4	17 ± 2.6	14 ± 1.6
LVSWI (gm/m/m ²)	19 ± 2	23 ± 1.6	17 ± 2.8	22 ± 2
RVSWI (gm/m/m ²)	4.8 ± 0.2	4.2 ± 0.4	3.2 ± 0.6	3.8 ± 0.4
SVRI (dyne · sec · cm ⁻⁵) (median)	1600	1500	1360	1700

LVEDD, Left ventricular End-Diastolic dimension; PASP, pulmonary artery systolic pressure; PCWP, pulmonary capillary wedge pressure; LVSWI, left ventricular stroke work index; RVSWI, right ventricular stroke work index; SVRI, systemic vascular resistance index.

*Subgroup III versus subgroup II, $p < 0.03$.

†Subgroup III versus other subgroup, $p < 0.05$.

echocardiography) ($n = 3$) were excluded from this series. Preoperative patient characteristics are summarized in Table I.

Indications for revascularization. Patients were classified as having one of four *primary indications* for CABG: unstable or postinfarction angina (subgroup I, $n = 73$), recurrent angina after previous myocardial revasculariza-

tion (subgroup II, $n = 41$), CHF with reversible ischemia (subgroup III, $n = 55$), and ventricular arrhythmias resulting in sudden cardiac collapse ($n = 15$) or syncope ($n = 26$) (subgroup IV, $n = 41$). Table II provides hemodynamic and echocardiographic characteristics of patients in each subgroup. Table III summarizes their preoperative medications and cardiac support.

Table III. Preoperative medication and circulatory support

	Subgroup I (n = 73)	Subgroup II (n = 41)	Subgroup III (n = 55)	Subgroup IV (n = 41)
Digoxin	5	5	38	12
Diuretics	10	16	55	14
ACE inhibitors	Nil	4	26	6
Phosphodiesterase inhibitors	Nil	Nil	12	2
Class I antiarrhythmic drugs	12	6	14	41
Dopamine infusion	20	12	28	12
IABP support	6	4	15	16

ACE, Angiotensin-converting enzyme; IABP, intraaortic balloon pump.

Table IV. Operative characteristics of patients receiving antegrade versus retrograde (coronary sinus) cardioplegia

Operative characteristics	No.	Percent of 210	Cardioplegia delivery				P (χ^2)
			Antegrade		Retrograde		
			No.	% of 103	No.	% of 107	
Bypass > 150 min	90	43	49	48	41	38	0.2
Crossclamp > 100 min	101	48	55	53	46	43	0.1
ITA used	41	19.5	25	24	16	15	0.1
Four or more distal grafts	132	62.9	76	74	56%	52	0.001
Mean bypass time (min)				123 $\pm$ 2.6		116 $\pm$ 1.8	
Mean crossclamp time (min)				88 $\pm$ 2.1		80 $\pm$ 2.1	

ITA, Internal thoracic artery.

Management. Emergency CABG (within 6 hours of a cardiac catheterization) was performed in 44 patients (21% of 210); six had unstable angina (subgroup I) and 38 had hemodynamic collapse (subgroup 4). Urgent CABG (between 6 and 48 hours) was performed in 100 patients (48%); 67 were in subgroup I, 15 in subgroup II, 15 in subgroup III, and 3 in subgroup IV. An intraaortic balloon pump was placed when, despite inotropic support, blood pressure was less than 90 mm Hg, cardiac index was less than 2.0 L/m², or LV end-diastolic pressure was greater than 20 mm Hg. All patients with known concomitant high-grade internal carotid stenosis (>85% on cerebral angiography) underwent simultaneous carotid endarterectomy and myocardial revascularization. Management of peripheral vascular lesions was by staged revascularization. In patients with end-stage renal disease, maintenance dialysis was resumed after myocardial revascularization.

A thermodilution catheter was routinely placed before induction of anesthesia. Standard cardiopulmonary bypass, moderate hypothermia (28° C), cold blood cardioplegia, and topical cooling were used in all patients. Before September 1988, cardioplegic solution was usually delivered via the antegrade route. Since October 1988, combined antegrade and retrograde cardioplegia (via the coronary sinus) has been attempted on all patients in whom the risk was high (including those who met criteria for this study). Patients were *not* randomized as to the route of delivery of the cardioplegic solution. Of the 210 patients in this study, 103 (48%) received antegrade cardioplegia only, and in 107 (51%), combined antegrade

Table V. Management of patients with documented or suspected ventricular arrhythmias after CABG: Electrophysiologic testing (n = 72)

Inducible sustained VT/VF (n = 47)
Pharmacologically resistant VT/VF (n = 17)
1. AICD (n = 13)
2. Endocardial ablation (n = 4) (failure of AICD)
VT/VF terminated by drugs (n = 30)
1. Amiodarone (n = 12)
2. Mexiletene (n = 6)
3. Procainamide (n = 4)
4. Encaide (n = 3)
5. Mixed (n = 5)
Noninducible VT/VF (n = 25) + other survivors (n = 107)
Class I antiarrhythmic drugs as indicated

VT/VF, Ventricular tachycardia/fibrillation; AICD, automatic implantable cardioverter-defibrillator. Survivors with preoperative VT/VF, n = 30/41; survivors with postoperative VT/VF, n = 14/23. All deaths occurred in patients who also had preoperative VT/VF. Survivors after sudden cardiac death in patients discharged after CABG, 7/9; syncope, n = 21.

and retrograde cardioplegia was used. In three patients coronary sinus perfusion was attempted but was unsuccessful, and they received only antegrade cardioplegia (and are counted among the 103 "antegrade only" patients). Tables I and IV list the preoperative and operative characteristics of the patients in the two cardioplegic delivery groups.

Eighty-four patients (40%) required intraaortic balloon pump support for low cardiac output (preoperatively in

Fig. 1A. Time-related survival after CABG in patients with preoperative ejection fraction less than or equal to 20%. Circles represent individual deaths, positioned along the horizontal axis at the interval between operation and the time of death and, actuarially (Kaplan-Meier method), along the vertical axis. The vertical bars represent 70% confidence limits. Numbers in parentheses represent the number of patients continuing to be followed up after that time. The solid line represents the parametrically estimated survival, and the dashed lines enclose the 70% confidence limits of that estimate. The table provides parametric estimates at specified intervals.

44, postoperatively in 40). Three patients required an LV assist device when placement of a balloon pump alone did not permit discontinuation of cardiopulmonary bypass. Only patients with recurrent angina underwent a second coronary angiography.

There were 76 patients with a history (known or suspected) of ventricular arrhythmias. These patients include survivors of preoperative ventricular tachycardia/fibrillation (VT/VF) ($n = 30$), those with documented postoperative VT/VF ($n = 14$), patients with syncopal or presyncopal episodes during follow-up ($n = 25$), and survivors of sudden cardiac collapse requiring cardiopulmonary resuscitation ($n = 7$). Because these patients were at high risk for recurrent VT/VF, they underwent postoperative testing: Holter monitor studies were performed in all patients and 72 (95%) underwent programmed electrophysiologic testing. Management was based on the results of testing as depicted in Table V.

Follow-up. Perioperative information was obtained from hospital records. Complete cross-sectional follow-up (all 210 patients) was conducted between April 30 and June 30, 1994, by questionnaires, telephone conversations,

and review of outpatient records. Among survivors, the interval from operation to last contact averaged 43 months (± 17 months, 1 standard deviation), with a range of 15 to 86 months.

Definitions: *Unstable angina:* Persistent anginal symptoms with ST-T changes in the electrocardiogram necessitating nitroglycerin and heparin administration.

Postinfarction angina: Persistent angina symptoms with ST-T changes in the same area where q waves appeared earlier, or evidence of extension of infarct on thallium scan. Angina and functional classification are as described by Goldman, Hashimoto, and Cook.¹⁶

Operable CAD: Stenosed vessels with internal diameter less than 1 mm, or with a diameter greater than 1 mm in the absence of diffuse or distal disease. Some patients with operable CAD, especially in subgroups II and III, did have inoperable vessels in some distributions (i.e., small vessels with diffuse distal disease).

CHF: One or more episodes of fluid retention necessitating diuretic therapy within 3 months of operation.

Ischemic cardiomyopathy: Cardiac dilatation caused by ischemic myocardial degeneration.¹⁷

Fig. 1B. Hazard function for death after CABG. The hazard function has two phases, an early declining phase and a constant phase. The table provides hazard estimates at specified intervals.

Monomorphic VT: VT with uniform QRS morphology in leads I, aV_F, and V₁.

Polymorphic VT: VT with changes in axis (>45%) or altitude (>50%) or both.

Sustained VT: Monomorphic or polymorphic VT lasting for more than 30 seconds with a heart rate greater than 100 beats/min.

Standard electrophysiology protocol: A standard program of electrophysiologic stimulation used after antiarrhythmic medication was discontinued and cleared (at least 5 half-lives). During the protocol, patients may have experienced *induced VF*, defined as a disorganized rhythm with hemodynamic instability necessitating direct-current shock, or *sustained induced VT/VF*, defined as VT/VF lasting 30 seconds or more and necessitating termination of stimulation.

LV stroke work index is stroke work index (mean arterial pressure – pulmonary capillary wedge pressure) $\times$ 0.0136 gm/mm per square meter.

Right ventricular stroke work index is stroke work index (mean pulmonary artery pressure – right atrial pressure) $\times$ 0.0136 gm/mm per square meter.

Systemic vascular resistance index is (mean arterial pressure – right atrial pressure) $\times$ cardiac output $\times$ 80 dynes $\cdot$ sec $\cdot$ cm⁻⁵.

Statistical analysis. Values are expressed as mean $\pm$

standard error of the mean or, when stated, $\pm$ standard deviation. Univariate associations between concomitant variables and patient death were assessed by two-way contingency tables for discrete variables, by two-sample *t* test for continuous variables, and by logistic analysis for ordinal variables. Stratified Kaplan-Meier depictions¹⁸ were used to explore time-related differences between subgroups of patients with various combinations of potential risk factors.

The time-related risk of death was modeled by means of a generic three-phase hazard method.¹⁹ Hazard functions were also generated independently for the group of patients who received cardioplegic solution solely by the antegrade method and for those in whom cardioplegic solution was delivered by a combined antegrade/retrograde route.

Determinants of postoperative death were identified by multivariate analysis, within each phase of hazard. Variables listed in Table I were considered in the analysis. Transformations of scale for continuous and ordinal variables were made to optimize their linear relationship in the logistic domain. During the process of developing a parsimonious equation, variables were entered into the model sequentially by means of a direct, nonautomated technique. A maximum *p* value of 0.05 (likelihood ratio test) was accepted for retaining a variable in the model.

Fig. 2A. Time-related survival stratified by the route of cardioplegic delivery. The depiction is similar to that in Fig. 1A.

Table VI. Incremental risk factors for death after CABG in patients with an ejection fraction <20% (n = 210; 51 deaths)

Risk factor	Hazard Phase			
	Early		Constant	
	Coefficient + SE	p<	Coefficient ± SE	p<
Demographic				
Age (older)	0.07 ± 0.023	0.004		
Clinical history				
Renal dysfunction	2.0 ± 0.48	0.0001		
Preoperative VT or VF	1.1 ± 0.38	0.003		
Preoperative CHF			1.8 ± 0.82	0.02
Previous CABG			2.6 ± 0.88	0.004
Operative				
Nonuse of CS cardioplegia	0.7 ± 0.39	0.05		
No. of distal anastomoses ≥4				
Male (interaction)			0.7 ± 0.38	0.003
Female (interaction)			1.2 ± 0.34	0.0002
Intercepts	-6.7 ± 1.7	<0.0001	-11.4 ± 2.1	<0.0001

Log likelihood = -234.51.

Shaping parameters: $\rho = 1.867$; $\delta = 0$; $v = 2.595$; $m = 0$.

VT or VF, Ventricular tachycardia or fibrillation; CHF, congestive heart failure; CS, coronary sinus.

Fig. 2B. Hazard functions determined independently for the two routes of cardioplegic delivery. Note that the horizontal axis has been expanded to allow better visualization of early risk. The depiction is otherwise similar to that in Fig. 1B.

To illustrate the effect of individual risk factors, we generated nomograms (specific solutions of the multivariable equation) by solving the equation for different values of the variable of interest while simultaneously holding the value of all other variables constant. In graphic depictions, values are shown along with 70% confidence limits (± 1 standard deviation).

Results

Survival. There were 51 deaths (24% of 210). Twenty-one deaths occurred before hospital discharge (maximum postoperative stay was 45 days). Actuarial survival is depicted in Fig. 1A. The hazard function for death was biphasic, with an early declining and a later constant phase (Fig. 1B). Multivariate analysis identified determinates of postoperative survival, listed in Table VI.

Survival was superior in patients who received combined antegrade and retrograde cardioplegia, versus antegrade only, because of a reduction in the risk of death early after operation ($p = 0.05$,

Table VI, Figs. 2A and 2B). Actuarial survival in patients with preoperative VT/VF, identified as an early risk factor, is depicted in Fig. 3. Older age also increased early risk ($p = 0.004$), but its effect was weak and most pronounced when there were other risk factors.

When the number of distal anastomoses was large, risk of death was higher in both men ($p = 0.003$) and women ($p = 0.0002$). This negative association with survival was more pronounced in women than in men ($p = 0.02$, Fig. 4), and overall actuarial survival was higher in men ($p = 0.04$, Fig. 4). Patients with preoperative CHF had decreased survival (Fig. 5), and in women with CHF, predicted 5-year survival was only 20% (Fig. 5).

Actuarial survival of patients, stratified by primary indication for operation (subgroups I to IV; see *Methods*) was not believably different (5-year survival was 73% for subgroup I, 52% for subgroup II, 55% for subgroup III, and 52% for subgroup IV;

Fig. 3. Time-related survival stratified by presence of preoperative ventricular arrhythmias (tachycardia or fibrillation). Symbols represent individual events: squares for patients who had preoperative arrhythmias and circles for patients who did not, positioned along the horizontal axis at the interval from operation to death and actuarially along the vertical axis. The vertical bars represent 70% confidence limits. Numbers in parentheses represent the number of patients continuing to be followed up after that time.

$p = 0.4$). However, by risk-adjusted analysis, patients who had unstable angina (subgroup I) had the highest survival, because patients in all other subgroups must, by definition, have one or more identified risk factors.

Of the 80 patients (40%) who required preoperative or postoperative balloon pump support, 26 patients (33%) died.

Ventricular arrhythmias. Patients treated by the electrophysiologic protocol (those identified at increased risk for arrhythmic complications) had a lower risk of sudden cardiac death (none vs 9) and greater actuarial freedom from postoperative VT/VF (83% vs 74% at 5 years), but these differences could be due to chance alone ($p =$ not significant, Fig. 6).

Functional status. Among those alive at the time of cross-sectional follow-up, New York Heart Association class was found to be lower than it was

before the operation (preoperative 3.48 ± 0.04 vs last contact 1.55 ± 0.05 ; $p = 0.005$).

Fifty patients had recurrent or progressive angina that required evaluation. The angina was severe in 14 patients and mild or equivocal in 36. Angiography disclosed a correctable lesion in six patients (all with severe angina), and they eventually underwent successful angioplasty. Progressive ischemic cardiomyopathy developed in 16 patients, and four were listed for cardiac transplantation.

Discussion

Patient survival. Multiple studies have shown that patients with severe global LV dysfunction caused by CAD respond better with myocardial revascularization than with medical therapy alone.^{2, 5, 10, 15} Surgical intervention is known to be most beneficial in patients who are at highest risk with conventional medical therapy.²⁰ When patients

Fig. 4. Time-related survival stratified by gender. The depiction is similar to that in Fig. 3.

have ischemic or acutely injured myocardium,^{1, 16} revascularization has been shown to prolong life expectancy,²¹ improve functional status,^{14, 20} and diminish the prevalence of sudden cardiac deaths caused by arrhythmias.^{8, 10} Because cardiac transplantation is limited by donor supply (and many of these patients would make poor candidates owing to advanced age and coexistent diseases), surgical revascularization may offer the only chance for significant improvement.

In the past, perioperative mortality after CABG in patients with poor LV function has been reported to be between 10% and 37%,¹⁻³ but more recent reports indicate a much lower mortality (2.3% to 5%), attributed to advances in myocardial management and surgical technique.^{9, 22-24} Studies have now documented 5-year survival after CABG approaching 80%.^{9, 15}

Myocardial protection. Studies indicate that blood cardioplegia is superior to asanguineous cardioplegia¹ and that retrograde coronary sinus cardioplegia may provide a more uniform myocardial

protection in patients with severe multivessel disease.^{25, 26} Our findings (although resulting from a nonrandomized experience) are in support of these concepts. We found the risk of death among patients who received retrograde cardioplegia to be lower, but only in the early postoperative period (Fig. 2B). These findings are consistent with the theory that retrograde delivery improves cardioplegic protection, which may result in a critical improvement in cardiac performance during the early postoperative period.

Unfavorable patient characteristics. Increased perioperative mortality after CABG in patients with depressed LV function has previously been associated with advanced age, female gender severity of CAD (left main disease, diffuse and multivessel CAD), inadequate myocardial protection, ventricular irritability, and development or persistence of CHF after the operation.^{1, 6} Our findings are consistent with these observations.

In this series, 40% of patients were 70 years old or older and their perioperative mortality was 14%.

Fig. 5. Time-related survival stratified by presence of preoperative CHF. Depiction is similar to that in Fig. 3.

Fig. 6. Time-related freedom from ventricular arrhythmias, in all patients and stratified by use of electrophysiologically (EP) guided therapy. The table provides survival at specified intervals. The numbers below the horizontal axis give the number of patients who were continuing to be followed up in each group. The dashed lines enclose the 70% confidence limits. Note that each event is represented twice, once in the All Survivors curve and again in either the EP Guided Survivors curve or Non-EP Guided Survivors curve. The vertical axis was broken to improve visualization of differences.

Risk-adjusted analysis confirmed advanced age as a risk factor for death early after operation (see Table VI), but with a weak coefficient, age alone was a poor predictor of 5-year survival. Only when other risk factors were present did the predicted 5-year mortality for a 70-year-old patient exceed 30%. These observations suggest that in an otherwise healthy patient, CABG should not be denied solely on the basis of advanced age.

Survival in medically treated patients with severely impaired LV function and congestive symptoms has been reported to be as low as 18% at 5 years.⁵ Despite higher initial risk, CABG does improve symptoms and prolong survival when these patients have reversible ischemia and operable CAD.^{4, 6, 7, 14, 22, 27} Thus, although we have identified CHF as a risk factor for death, CABG may substantially improve survival in many of these patients.

Patients with grossly dilated ischemic cardiomyopathy (LV end-diastolic dimension >70 mm) are poor candidates for CABG and are perhaps better treated by cardiomyoplasty or cardiac transplantation.^{28, 29} Dynamic cardiomyoplasty can improve LV function and CHF; however, because it requires more than 2 weeks of skeletal muscle preconditioning, it would be unsuitable in patients who require immediate therapy.^{27, 28}

The risk factors reported in this study provide for patient-specific estimates of survival. When multiple risk factors are present in a patient with minimal extracardiac disease, transplantation would likely be a better option. For example, a woman with diffuse distal disease or CHF may have a predicted 5-year survival of less than 20%. If this patient was an acceptable candidate, transplantation would be recommended.

Ventricular arrhythmias. Ventricular arrhythmias are a common cause of sudden death in the natural history of patients with reduced ventricular function.^{2, 10, 30-32} Even after successful revascularization, the risk of recurrence of arrhythmias is high,^{11, 12} necessitating specific postoperative management.

Preoperative and postoperative electrophysiologic testing, to guide specific pharmacologic therapy, has been shown to reduce arrhythmic complications.^{8, 11-13, 22} In patients who have a pharmacologically resistant condition, an implantable cardioverter-defibrillator is recommended.^{27, 33-35} In this series, preoperative electrophysiologic testing was not performed; however, selected patients had

postoperative testing (see *Methods*) and were treated with specific antiarrhythmic medication or an implantable cardioverter-defibrillator (see Table V). Ideally, all patients should have had preoperative electrophysiologically testing, directing placement of an implantable cardioverter-defibrillator or permanent implantable leads at the time of revascularization.⁹

Our results indicate that patients who were identified at high risk for arrhythmic complications (those with sustained inducible ventricular arrhythmias) benefited from electrophysiologically guided management. None of the patients who receiving electrophysiologically guided management had a sudden cardiac death, and ventricular arrhythmias were less prevalent in this high-risk group than in the remaining patients (17% vs. 26%, $p =$ not significant). When arrhythmic complications did occur after electrophysiologically guided treatment, they were probably due to the development of drug resistance.

Some patients whose initial electrophysiologically studies were negative (without inducible sustained VT/VF) did have VT/VF during the follow-up period. Because arrhythmic complications rarely occur when results of a recent electrophysiologically examination are negative,³⁰⁻³⁵ periodic postoperative testing might have helped a few patients, but the cost of such a strategy would be prohibitive. In the near future, smaller endocardial pacing and defibrillating systems, which can be placed percutaneously, may be an effective option for these patients.³⁶

Conclusion

CABG in patients with severely impaired LV function appears beneficial if ischemia is reversible (salvageable myocardium) and the vessels are operable. Use of retrograde (coronary sinus) cardioplegia decreases early mortality. A management strategy that addressed congestive symptoms and ventricular arrhythmias resulted in acceptable survival. If characteristics associated with poor survival are identified, improved patient selection may be possible. An effective, timely revascularization with good myocardial protection improves survival in the early phase.

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