

ACC/AHA Practice Guidelines

ACC/AHA Guidelines for Coronary Artery Bypass Graft Surgery: Executive Summary and Recommendations

A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Revise the 1991 Guidelines for Coronary Artery Bypass Graft Surgery)

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I. Introduction

The American College of Cardiology/American Heart Association (ACC/AHA) Task Force on Practice Guidelines was formed to make recommendations regarding the appropriate use of diagnostic tests and therapies for patients with known or suspected cardiovascular disease. Coronary artery bypass graft (CABG) surgery is among the most common operations performed in the world and accounts for more resources expended in cardiovascular medicine than any other single procedure. Since the original Guidelines were published in 1991, there has been considerable evolution in the surgical approach to coronary disease, and at the same time there have been advances in preventive, medical, and percutaneous catheter approaches to therapy. These revised guidelines are based on a computerized search of the English literature since 1989, a manual search of final articles, and expert opinion.

As with other ACC/AHA guidelines, this document uses ACC/AHA classifications I, II, and III as summarized below:

Class I: Conditions for which there is evidence and/or general agreement that a given procedure or treatment is useful and effective.

Class II: Conditions for which there is conflicting evidence and/or a divergence of opinion about the usefulness or efficacy of a procedure.

Class IIa: Weight of evidence/opinion is in favor of usefulness/efficacy.

Class IIb: Usefulness/efficacy is less well established by evidence/opinion.

Class III: Conditions for which there is evidence and/or general agreement that the procedure/treatment is not useful/effective and in some cases may be harmful.

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TABLE 1. Northern New England Cardiovascular Disease Study Group: Preoperative Estimation of Risk of Mortality, Cerebrovascular Accident (CVA), and Mediastinitis (for Use Only in Isolated CABG Surgery)

Preoperative Estimation of Risk of Mortality, Cerebrovascular Accident, and Mediastinitis			
For use only in isolated CABG surgery			
Directions: Locate outcome of interest, eg, mortality. Use the score in that column for each relevant preoperative variable, then sum these scores to get the total score. Take the total score and look up the approximate preoperative risk in the table below.			
Patient or Disease Characteristic	Mortality Score	CVA Score	Mediastinitis Score
Age 60-69	2	3.5	
Age 70-79	3	5	
Age ≥80	5	6	
Female sex	1.5		
EF<40%	1.5	1.5	2
Urgent surgery	2	1.5	1.5
Emergency surgery	5	2	3.5
Prior CABG	5	1.5	
PVD	2	2	
Diabetes			1.5
Dialysis or creatinine ≥2	4	2	2.5
COPD	1.5		3.5
Obesity (BMI 31-36)			2.5
Severe obesity (BMI ≥37)			3.5
Total Score			
Perioperative Risk			
Total Score	Mortality %	CVA %	Mediastinitis %
0	0.4	0.3	0.4
1	0.5	0.4	0.5
2	0.7	0.7	0.6
3	0.9	0.9	0.7
4	1.3	1.1	1.1
5	1.7	1.5	1.5
6	2.2	1.9	1.9
7	3.3	2.8	3.0
8	3.9	3.5	3.5
9	6.1	4.5	5.8
10	7.7	≥6.5	≥6.5
11	10.6		
12	13.7		
13	17.7		
14	≥28.3		

Calculation of Mortality Risk: An 80-year-old female with an EF<40% who is having elective CABG surgery, has had no prior CABG surgery, and has no other risk factors. Her total score = 5(age≥80) + 1.5(Female) + 1.5(EF<40%) = 8. Because her total score = 8, her predicted risk of mortality = 3.9%.

Definitions:

EF <40% (Left ventricular ejection fraction): The patient's current EF is less than 40%.

Urgent: Medical factors require patient to stay in hospital to have operation before discharge. The risk of immediate morbidity and death is believed to be low.

Emergency: Patient's cardiac disease dictates that surgery should be performed within hours to avoid unnecessary morbidity or death.

PVD (Peripheral vascular disease): Cerebrovascular disease, including prior CVA, prior TIA, prior carotid surgery, carotid stenosis by history or radiographic studies, or carotid bruit. Lower-extremity disease including claudication, amputation, prior lower-extremity bypass, absent pedal pulses, or lower-extremity ulcers.

Diabetes: Currently treated with oral medications or insulin.

Dialysis or creatinine ≥2: Peritoneal or hemodialysis dependent renal failure or creatinine ≥2 mg/dL.

COPD (Chronic obstructive pulmonary disease): Treated with bronchodilators or steroids.

Obesity: Find the approximate height and weight in the table below to classify the person as obese or severely obese. **Obesity:** BMI 31-36, **Severe obesity:** BMI ≥37.

Example: A patient 5'7" and weighing 200 lbs is classified as obese. If the patient weighed 236 lbs or more, he/she would be classified as severely obese.

Height (feet and inches)	Weight (lbs)	Weight (lbs) Severe Obesity	Height (feet and inches)	Weight (lbs)	Weight (lbs) Severe Obesity
	Obesity BMI 31-36	BMI ≥37		Obesity BMI 31-36	BMI ≥37
5'0"	158-184	≥189	5'8"	203-236	≥244
5'1"	164-190	≥195	5'9"	209-243	≥250
5'2"	169-196	≥202	5'10"	215-250	≥258
5'3"	175-203	≥208	5'11"	222-258	≥265
5'4"	180-209	≥215	6'0"	228-265	≥272
5'5"	186-217	≥222	6'1"	235-273	≥280
5'6"	191-222	≥228	6'2"	241-280	≥287
5'7"	198-229	≥236	6'3"	248-288	≥296

Data set and definitions for dependent variables:

The regression models that generated the scores for these prediction rules were based on 7290 patients receiving isolated CABG surgery between 1996 and 1998. The dependent variables and observed event rates are as follows: in-hospital mortality (2.93%); cerebrovascular accident, defined as a new focal neurological event persisting at least 24 hours (1.58%); and mediastinitis during the index admission, defined by positive deep culture and/or Gram stain and/or radiographic findings indicating infection and requiring re-operation (1.19%).

Northern New England Cardiovascular Disease Study Group 6/99

II. Outcomes

A. Hospital Outcomes

Seven core variables (priority of operation, age, prior heart surgery, sex, left ventricular [LV] ejection fraction [EF], percent stenosis of the left main coronary artery, and number of major coronary arteries with significant stenoses) are the most consistent predictors of mortality after coronary artery surgery. The greatest risk is correlated with the urgency of operation, advanced age, and 1 or more prior coronary bypass surgeries. Additional variables that are related to mortality include coronary angioplasty during index admission; recent myocardial infarction (MI); history of angina, ventricular arrhythmias, congestive heart failure, or mitral regurgitation; and comorbidities such as diabetes, cerebrovascular disease, peripheral vascular disease, chronic obstructive pulmonary disease, and renal dysfunction. Table 1 shows a method by which key patient variables can be used to predict an individual patient's operative risk of death, stroke, or mediastinitis.

B. Morbidity Associated With Bypass Surgery

1. Neurological Events

Neurological impairment after bypass surgery may be attributable to hypoxia, emboli, hemorrhage, and/or metabolic abnormalities. Postoperative neurological deficits have been divided into 2 types: type 1, associated with major, focal neurological deficits, stupor, or coma; and type 2, in which deterioration in intellectual function is evident. Adverse cerebral outcomes are observed in $\approx 6\%$ of patients after bypass surgery and are equally divided between type 1 and type 2 deficits. Predictors of cerebral complications after bypass surgery include advanced age and a history of hypertension. Particular predictors of type 1 deficits include proximal aortic atherosclerosis as defined by the surgeon at operation, history of prior neurological disease, use of the intra-aortic balloon pump, diabetes, hypertension, unstable angina, and increased age. Predictors of type 2 deficits include a history of excess alcohol consumption; dysrhythmias, including atrial fibrillation; hypertension; prior bypass surgery; peripheral vascular disease; and congestive heart failure. Estimation of a patient's risk for postoperative stroke can be calculated from Table 1.

2. Mediastinitis

Deep sternal wound infection occurs in 1% to 4% of patients after bypass surgery and carries a mortality of $\approx 25\%$. Predictors of this complication include obesity, reoperation, use of both internal mammary arteries at surgery, duration and complexity of surgery, and diabetes. An individual patient's risk of postoperative mediastinitis can be estimated from Table 1.

3. Renal Dysfunction

Postoperative renal dysfunction occurs in as many as 8% of patients. Among patients who develop postoperative renal dysfunction (defined as a postoperative serum creatinine level >2.0 mg/dL or an increase in baseline creatinine level of >0.7 mg/dL), 18% require dialysis. Overall mortality among patients who develop postoperative renal dysfunction is 19%

and approaches two thirds among patients requiring dialysis. Predictors of renal dysfunction include advanced age, a history of moderate or severe congestive heart failure, prior bypass surgery, type 1 diabetes, and prior renal disease. Table 2 can be used to estimate the risk for an individual patient. Patients with advanced preoperative renal dysfunction who undergo CABG surgery have an extraordinarily high rate of requiring postoperative dialysis. Among patients with a preoperative creatinine level >2.5 mg/dL, 40% to 50% require hemodialysis.

C. Long-Term Outcomes

Predictors of poor long-term survival after bypass surgery include advanced age, poor LVEF, diabetes, number of diseased vessels, and female sex. In some studies, additional predictors include angina class, hypertension, prior MI, renal dysfunction, and clinical congestive heart failure. Predictors of the recurrence of angina, late MI, or any cardiac event also include obesity and lack of use of an internal mammary artery, as well as those factors identified above. Of these events, the return of angina is the most common and is primarily related to late vein-graft atherosclerosis and occlusion.

III. Comparison of Medical Therapy Versus Surgical Revascularization

The comparison of medical therapy with coronary surgical revascularization is primarily based on randomized, clinical trials and large registries. Although clinical trials have provided valuable insights, there are limitations to their interpretation in the current era. Patient selection had primarily included individuals ≤ 65 years of age, very few included large cohorts of women, and for the most part, the studies evaluated patients at low risk who were clinically stable. In addition, because the studies were done in the late 1970s and early 1980s, only 1 of the trials used arterial grafts, and even that trial had no arterial grafts in 86% of patients. Newer modalities of cardioprotection during cardiopulmonary bypass were not used, nor were minimally invasive or off-bypass techniques. Finally, medical therapy was not optimized in the trials. Lipid-lowering therapy had not yet become standard, aspirin was not widely used, and β -blockers were used in just half of the patients. Angiotensin-converting enzyme inhibitors were not being routinely used in patients with congestive heart failure or dilated cardiomyopathy. Accordingly, although the clinical trials have provided important insights, their interpretation must be viewed with caution, given the evolution in all types of coronary therapies.

For the most part, stratification of patients in the trials was based on the number of vessels with anatomically significant disease, whether or not the major epicardial obstruction was proximal, and the extent of LV dysfunction as determined by global EF. The end point of the trials was primarily survival.

Overview: Randomized Trials

There were 3 major, randomized trials and several smaller ones. A collaborative meta-analysis of 7 trials with a total enrollment of 2649 patients has allowed comparison of

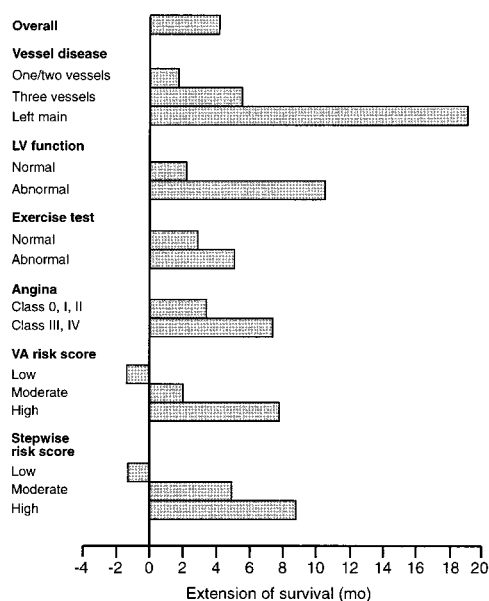
TABLE 2. Risk of Postoperative Renal Dysfunction (PRD) After Coronary Artery Bypass Graft Surgery

No. of Risk Factors	Combinations of Preoperative Risk Factors for PRD				Risk of PRD in Various Clinical Strata Depending on Risk Factors and Age		
	CHF	Reop	DM	Creat >1.4	<70 y	70–79 y	≥80 y
0	–	–	–	–	1.9% (n=909)	7.0% (n=330)	11.8% (n=68)
1	–	–	–	+	5.0% (n=80)	18.4% (n=76)	12.5% (n=16)
	–	–	+	–	5.9% (n=68)	4.8% (n=81)	0.0% (n=1)
	–	+	–	–	6.2% (n=130)	14.3% (n=56)	25.0% (n=4)
	+	–	–	–	7.6% (n=144)	12.3% (n=73)	29.4% (n=17)
2	–	–	+	+	22.2% (n=9)	0% (n=7)	0% (n=0)
	–	+	–	+	20.0% (n=25)	30.8% (n=13)	0% (n=0)
	–	+	+	–	37.6% (n=8)	33.3% (n=3)	0% (n=1)
	+	–	–	+	47.4% (n=19)	7.7% (n=26)	44.4% (n=9)
	+	–	+	–	25.9% (n=27)	18.2% (n=11)	0% (n=0)
	+	+	–	–	31.6% (n=19)	7.1% (n=14)	100.0% (n=1)
	+	+	+	–	31.6% (n=19)	7.1% (n=14)	100.0% (n=1)
3	–	+	+	+	100% (n=1)	100% (n=1)	0% (n=0)
	+	–	+	+	8.3% (n=12)	25% (n=4)	0% (n=1)
	+	+	–	+	0.0% (n=2)	33.3% (n=9)	0% (n=2)
	+	+	+	–	33.3% (n=3)	0% (n=0)	0% (n=0)
4	+	+	+	+	50.0% (n=2)	0% (n=0)	0% (n=0)

CHF indicates prior congestive heart failure; Reop, redo coronary bypass operation; DM, type 1 diabetes mellitus; Creat >1.4, preoperative serum creatinine level >1.4 mg/dL; n, observed number of patients within each clinical stratum; –, risk factor absent; and +, risk factor present.

Reprinted with permission from Managano CM, Diamondstone LS, Ramsay JG, Aggarwal A, Herskowitz A, Managano DT. Renal dysfunction after myocardial revascularization: risk factors, adverse outcomes, and hospital resource utilization: the Multicenter Study of Perioperative Ischemia Research Group. *Ann Intern Med.* 1998;128:194.

outcomes at 5 and 10 years (Tables 3, 4, and 5 and the Figure). Among all patients, the extension survival of CABG surgical patients compared with medically treated patients was 4.3 months at 10 years of follow-up. The benefit of CABG compared with medical therapy in various clinical subsets is presented below.



Extension of survival after 10 years of follow-up in various subgroups of patients, from a meta-analysis of 7 randomized studies. LV indicates left ventricular; VA, Veterans Administration.

1. Left Main Coronary Artery Disease

The trials defined significant left main coronary artery stenosis as a >50% reduction in lumen diameter. Median survival for surgically treated patients was 13.3 years versus 6.6 years in medically treated patients. Left main equivalent disease ($\geq 70\%$ stenosis in both the proximal left anterior descending [LAD] and proximal left circumflex arteries) appeared to behave similarly to true left main coronary artery disease. Median survival for surgical patients was 13.1 years versus 6.2 years for medically assigned patients. The benefit of surgery for left main coronary artery disease patients continued well beyond 10 years. By 15 years, it was estimated that two thirds of patients originally assigned to medical therapy and who survived would have had surgery. The 15-year cumulative survival for left main coronary artery disease patients having CABG surgery was 44% versus 31% for medical patients.

2. Three-Vessel Disease

If one defines 3-vessel disease as stenosis of 50% or more in all 3 major coronary territories, the overall extension of survival was 7 months in CABG patients compared with medically treated patients. Patients with class III or IV angina, those with more proximal and severe LAD stenosis, those with worse LV function, and/or those with more positive stress tests derived more benefit from surgery.

3. Proximal LAD Disease

In patients with severe, proximal LAD stenosis, the relative risk reduction due to bypass surgery compared with medical therapy was 42% at 5 years and 22% at 10 years. This was even more striking in patients with depressed LV function.

TABLE 3. Total Mortality at 5 and 10 Years

Trial	No. of Patients Randomized		5-Year Mortality			10-Year Mortality		
	CABG	Medical Treatment	CABG	Medical Treatment	Odds Ratio (95% CI)	CABG	Medical Treatment	Odds Ratio (95% CI)
VA	332	354	58	79	0.74 (0.50–1.08)	118	141	0.83 (0.61–1.14)
European	394	373	30	63	0.40 (0.26–0.64)	91	109	0.72 (0.52–0.99)
CASS	390	390	20	32	0.60 (0.34–1.08)	72	83	0.84 (0.59–1.19)
Texas	56	60	10	13	0.79 (0.31–1.97)	23	25	0.97 (0.46–2.04)
Oregon	51	49	4	8	0.44 (0.12–1.56)	14	14	0.94 (0.39–2.26)
New Zealand	51	49	5	7	0.65 (0.19–2.20)	15	16	0.94 (0.38–2.31)
New Zealand	50	50	8	8	1.00 (0.34–2.91)	17	16	1.15 (0.50–2.65)
Total	1324	1325	135 (10.2%)	210 (15.8%)	0.61 (0.48–0.77) <i>P</i> <0.0001	350 (26.4%)	404 (30.5%)	0.83 (0.70–0.98) <i>P</i> =0.03

CABG indicates coronary artery bypass graft; CI, confidence interval; VA, Veterans Administration; and CASS, Coronary Artery Surgery Study.

P values for heterogeneity across studies were 0.49, 0.84, and 0.95 at 5, 7, and 10 years, respectively.

Please refer to Table 7 in the full text of these guidelines (*J Am Coll Cardiol.* 1999;34:1275) for detailed information concerning the trials listed here in column 1.

4. LV Function

In patients with mildly to moderately depressed LV function, the poorer the LV function, the greater was the potential advantage of CABG surgery. Although the relative benefit was similar, the absolute benefit was greater because of the high-risk profile of these patients.

5. Symptoms and Quality of Life

Improvement in symptoms and quality of life after bypass surgery parallels the outcome data regarding survival. Beyond survival, bypass surgery may be indicated to alleviate symptoms of angina above and beyond medical therapy or to reduce the incidence of nonfatal complications like MI, congestive heart failure, and hospitalization. Registry studies have shown a reduction in late MI among highest-risk patients, such as those with 3-vessel disease, and/or those with severe angina. In pooled analyses, a benefit on the incidence of MI was not evident. This result likely reflected an early increase in MI perioperatively after CABG, which was balanced by fewer MIs over the long term among CABG recipients. Antianginal medications were required less frequently after bypass surgery. At 5 years, two thirds of bypass patients were symptom-free compared with 38% of medically assigned patients. By 10 years, however, these differences were no longer significant. This result is related to the attrition of vein grafts in the bypass group as well as crossover of medically assigned patients to bypass surgery.

6. Loss of Benefit of Surgery

After 10 to 12 years of follow-up, there was a tendency for the bypass surgery and medical therapy curves to converge, in regard to both survival as well as nonfatal outcomes. This convergence is due to a number of factors. First, the reduced life expectancy of patients with coronary disease (regardless of treatment) leads to a steady attrition. Second, the increased event rate in the late follow-up period of surgically assigned patients was likely related to the progression of native coronary disease and graft disease over time. Finally, medi-

cally assigned patients crossed over to surgery late, thus allowing the highest-risk medically assigned patients to gain from the benefit of surgery later in the course of follow-up. By 10 years, 37% to 50% of medically assigned patients had crossed over to surgery. Tables 3, 4, and 5 and the Figure provide estimates of long-term outcomes among patients randomized in the trials. These tables and the Figure can be used to estimate the general survival expectations in various anatomic categories.

IV. Comparison of Bypass Surgery With Percutaneous Revascularization

The results of a number of randomized, clinical trials comparing angioplasty and bypass surgery have been published. The trials excluded patients in whom survival had already been shown to be longer with bypass surgery than with medical therapy. Also, none of the trials was sufficiently large to detect relatively modest differences in survival between the 2 techniques. Most of the trials did not have a long-term follow-up, ie, 5 to 10 years, and therefore were unable to provide clear inferences regarding long-term benefit of the 2 techniques in similar populations. Also, and perhaps most notably, only ≈5% of screened patients with multivessel disease at enrolling institutions were included in the trials. Half of the patients approached were ineligible owing to left main coronary artery disease, insufficient symptoms, or other reasons. Even among a large group of patients with multivessel disease suitable for enrollment, only half were actually randomized. It appeared that physicians elected not to enroll many patients with 3-vessel disease in the trials but rather refer them for bypass surgery, whereas patients with 2-vessel disease tended to be referred for angioplasty rather than be enrolled in the trials.

Overall, procedural complications were low for both procedures but tended to be higher with CABG surgery (Table 6). For patients randomized to angioplasty, CABG was needed in ≈6% during the index hospitalization and in nearly

TABLE 4. Subgroup Results at 5 Years

Subgroup	Overall Numbers		Mortality Rates, %		Odds Ratio (95% CI)	P for CABG Surgery vs Medical Therapy
	Deaths	Patients	Surgical	Medical		
No. of diseased vessels						
1	21	271	5.4	9.9	0.54 (0.22–1.33)	0.18
2	92	859	9.7	11.7	0.84 (0.54–1.32)	0.45
3	189	1341	10.7	17.6	0.58 (0.42–0.80)	<0.001
Left main artery	39	150	15.8	36.5	0.32 (0.15–0.70)	0.004
No LAD disease						
1 or 2 Vessels	50	606	8.3	8.3	1.05 (0.58–1.90)	0.88
3 Vessels	46	410	7.7	14.5	0.47 (0.25–0.89)	0.02
Left main artery	16	51	18.5	45.8	0.27 (0.08–0.90)	0.03
Overall	112	1067	8.6	12.3	0.66 (0.44–1.00)	0.05
LAD disease present						
1 or 2 Vessels	63	524	9.2	14.6	0.58 (0.34–1.01)	0.05
3 Vessels	143	929	12.0	19.1	0.61 (0.42–0.88)	0.009
Left main artery	22	96	12.8	32.7	0.30 (0.11–0.84)	0.02
Overall	228	1549	11.2	18.3	0.58 (0.43–0.77)	0.001
LV function						
Normal	228	2095	8.5	13.3	0.61 (0.46–0.81)	<0.001
Abnormal	115	549	16.5	25.2	0.59 (0.39–0.91)	0.02
Exercise test status						
Missing	102	664	13.1	17.4	0.69 (0.45–1.07)	0.10
Normal	60	585	9.0	11.6	0.78 (0.45–1.35)	0.38
Abnormal	183	1400	9.4	16.8	0.52 (0.37–0.72)	<0.001
Severity of angina						
Class I, II	178	1716	8.3	12.5	0.63 (0.46–0.87)	0.005
Class III, IV	167	924	13.8	22.4	0.57 (0.40–0.81)	0.001

CI indicates confidence interval; CABG, coronary artery bypass graft; LAD, left anterior descending coronary artery; and LV, left ventricular.

For detailed information concerning probability value data, please see Table 8 in the full text of these guidelines (*J Am Coll Cardiol.* 1999;34:1276).

20% by 1 year. The initial cost and length of stay were lower for angioplasty than for CABG. Patients having angioplasty returned to work sooner and were able to exercise more at 1 month. The extent of revascularization achieved by bypass surgery was generally higher than with angioplasty. Long-term survival was difficult to evaluate owing to the short period of follow-up and the small sample size of the trials. However, for the Bypass Angioplasty Revascularization Investigation (BARI) trial, bypass patients had a 5-year survival of 89.3% compared with 86.3% for angioplasty. Secondary analysis revealed that in treated diabetic patients in the BARI trials, CABG led to significantly superior survival compared with percutaneous transluminal coronary angioplasty (PTCA). However, this finding was not evident in other trials. In long-term follow-up, the most striking difference was the 4- to 10-fold-higher likelihood of reintervention after initial PTCA. Quality of life, physical activity, employment, and cost were similar by 3 to 5 years after both procedures. The BARI trial suggested higher mortality associated with PTCA in several high-risk groups, including those with diabetes, unstable angina, and/or non-Q wave MI, and in patients with heart failure.

An analysis of registries generally shows data similar to those of the trials. However, a recent analysis of ≈60 000 patients who were treated in New York State in the early 1990s provides a 3-year survival analysis of patients undergoing CABG and PTCA. After adjustment for various covariates, bypass surgery in the New York State registry experience was associated with longer survival in patients with severe proximal LAD stenosis and/or 3-vessel disease. Contrariwise, patients with 1-vessel disease not involving the proximal LAD had improved survival with PTCA. Table 7 summarizes survival data from the New York State registry with respect to various cohorts of patients undergoing angioplasty or bypass surgery. These data can be used to estimate 3-year survival expectations for patients with various anatomic features.

V. Management Strategies

Reduction of Perioperative Mortality and Morbidity

1. Reducing the Risk of Type 1 Brain Injury After CABG
Postoperative neurological complications represent 1 of the most devastating consequences of CABG surgery. Type 1

TABLE 5. Subgroup Analysis of 5-Year Mortality by Risk Stratum

	Deaths, n	Patients, n	Medical Treatment Mortality Rate, %	Odds Ratio (95% CI)	P for CABG vs Medical Treatment
Risk strata derived by risk score*					
Lowest tertile	23	406	5.5	1.18 (0.51–2.71)	0.70
Middle tertile	90	930	11.5	0.63 (0.39–1.01)	0.05
Highest tertile	153	849	23.0	0.50 (0.35–0.72)	0.001
Risk strata by stepwise risk score†					
Lowest tertile	52	783	6.3	1.17 (0.66–2.07)	0.60
Middle tertile	85	784	13.9	0.55 (0.34–0.88)	0.01
Highest tertile	157	783	25.2	0.54 (0.37–0.77)	0.001

CI indicates confidence interval; CABG, coronary artery bypass graft.

Modified with permission from Yusuf S, Zucker D, Peduzzi P, Fisher LD, Takaro T, Kennedy JW, Davis K, Killip T, Passamani E, Norris R, et al. Effect of coronary artery bypass graft surgery on survival: overview of 10-year results from randomised trials by the Coronary Artery Bypass Graft Surgery Trialists Collaboration. *Lancet*. 1994;344:563–570.

*Veterans Administration–type risk score=(0.70×presence of class III/IV angina)+(0.37×history of hypertension)+(0.83×ST-segment depression at rest)+(0.39×history of myocardial infarction).

†Stepwise risk score=(0.015×age)+(0.56×presence of class III/IV angina)+(0.35×history of myocardial infarction)+(0.62×abnormal ejection fraction)+(0.53×proximal lesion >50% in the left anterior descending coronary artery)+(0.29×right coronary artery lesion >50%)+(0.43×history of diabetes)+(0.37×history of hypertension).

injury, in which a significant, permanent, neurological injury is sustained, occurs in ≈3% of patients overall and is responsible for a 21% mortality.

Atherosclerotic Ascending Aorta

An important predictor of this complication is the surgeon's identification of a severely atherosclerotic, ascending aorta before or during the bypass operation. Perioperative atheroembolism from aortic plaque is thought to be responsible for approximately one third of strokes after CABG. Atherosclerosis of the ascending aorta is strongly related to increased age. Thus, stroke risk is particularly increased in patients beyond 75 to 80 years of age. Preoperative, noninvasive testing to identify high-risk patients has variable accuracy. Computed tomography identifies the most severely involved aortas but underestimates mild or moderate involvement. Transesophageal echocardiography is useful for aortic arch examination, but examination of the ascending aorta may be limited by the intervening trachea. Intraoperative assessment with epi-aortic imaging is superior to both methods. Intraoperative palpation underestimates the high-risk aorta. The highest-risk aortic pattern is a protruding or mobile aortic arch plaque. An aggressive approach to the management of patients with severely diseased ascending aortas identified by intraoperative echocardiographic imaging reduces the risk of postoperative stroke. For patients with aortic walls ≤3 mm thick, standard treatment is used. For aortas >3 mm thick, the cannulation, clamp, or proximal anastomotic sites may be changed, or a no-clamp, fibrillatory arrest strategy may be used. For high-risk patients with multiple or circumferential involvement or those with extensive middle ascending aortic involvement, replacement of the ascending aorta under hypothermic circulatory arrest may be indicated. Alternatively, a combined approach with off-bypass, in situ internal mammary grafting to the LAD and percutaneous coronary intervention to treat other vessel stenoses has conceptual merit.

Atrial Fibrillation and Stroke

Chronic atrial fibrillation is a hazard for perioperative stroke. Intraoperative surgical manipulation or spontaneous resumption of sinus rhythm during the early postoperative period may lead to embolism of a left atrial clot. One approach to reduce this risk is the performance of preoperative, transesophageal echocardiography. The absence of a left atrial clot would suggest that the operation may proceed with acceptable risk. For elective patients, if a left atrial clot is identified, 3 to 4 weeks of anticoagulation therapy followed by restudy and then subsequent surgery is reasonable. Few clinical trial data are available to assist clinicians in this circumstance.

New-onset postoperative atrial fibrillation occurs in ≈30% of post-CABG patients, particularly on the second and third postoperative days, and is associated with a 2- to 3-fold increased risk of postoperative stroke. Risk factors include advanced age, chronic obstructive pulmonary disease, proximal right coronary disease, prolonged operation, atrial ischemia, and withdrawal of β-blockers. The role of anticoagulants in patients who develop post-CABG atrial fibrillation is unclear. Aggressive anticoagulation and cardioversion may reduce the neurological complications associated with this arrhythmia. Early cardioversion within 24 hours of the onset of atrial fibrillation can probably be performed safely without anticoagulation. However, persistence of the arrhythmia beyond this time argues for the use of oral anticoagulants to reduce stroke risk in patients who remain in atrial fibrillation and/or in those for whom later cardioversion is planned.

Recent MI, LV Thrombus, and Stroke

Patients with a recent, anterior MI and residual wall-motion abnormality are at increased risk for the development of an LV mural thrombus and its potential for embolization. For patients undergoing surgical revascularization after sustaining an anterior MI, preoperative screening with echocardiography may be appropriate to identify the presence of a clot.

TABLE 6. CABG vs PTCA: Randomized Controlled Trials

Trial*	Age, y (% Female)	CAD	N	Acute Outcome, %			Late Outcome, %						
				Death: CABG PTCA	QW-MI: CABG PTCA	Hosp CABG	Death	QW- MI	Angina	RR Total/PTCA/ CABG, %	Primary End Point	Primary End Point, %	F/U, y
BARI	61 (26%)	MV	1792	1.3	4.6	...	10.7	19.6	...	8/7/1	D	10.7	5
				1.1	2.1	6.3	13.7	21.3	...	54/34/31		13.7	
EAST	61 (26%)	MV	392	1.0	10.3	...	6.2	19.6	12	13/13/1	D+MI+T	27.3	3
				1.0	3.0†	10.1	7.1	16.6	20	54/41/22		28.8	
GABI	... (20%)	MV	359	2.5	8.0	...	6.5	9.4	26	6/5/1	A	26	1
				1.1	2.3†	8.5	2.6	4.5	29	44/27/21		29	
Toulouse	67 (23%)	MV	152	1.3	6.6	...	10.5	1.3	5.3	9/9/0	A	5.2	5
				1.3	3.9	3.9	13.2	5.3	21.1†	29/15/15		21.1†	
RITA	57 (19%)	SV+	1011	1.2	2.4	...	3.6	5.2	21.5	4/3/1	D+MI	8.6	2.5§
		MV‡		0.8	3.5	4.5	3.1	6.7	31.3	31/18/19		9.8	
ERACI	58 (13%)	MV	127	4.6	6.2	...	4.7	7.8	3.2	6/3/3	D+MI+A+RR	23	1
				1.5	6.3	1.5	9.5	7.8	4.8	37/14/22		53†	
MASS	56 (42%)	SV	142	1.4	1.4	...	...	...	2	0/0/0	D+MI+RR	3	3
		(LAD)		1.4	0	11	...	...	18	22/29/14		24†	
Lausanne	56 (20%)	SV	134	0	0	...	1.5	1.5	5	3/3/0	D+MI+RR	7.6	2§
		(LAD)		0	0	2.9	0	2.9	6	25/12/13		36.8†	
CABRI	60 (22%)	MV	1054	1.3	...	...	2.7	3.5	10.1	9/6/1	D	2.7	1
				1.3	...	...	3.9	4.9	13.9†	36/21/18		3.9	
Weighted average	60 (23%)			1.3	4.1	...	6.5	11.3	10.4	7.3			
				1.0	2.3	5.9	7.7	11.0	15.5	42.3			

CABG indicates coronary artery bypass graft; PTCA, percutaneous transluminal coronary angioplasty; CAD, coronary artery disease; QW, Q wave; MI, myocardial infarction; Hosp CABG, required CABG after PTCA and before hospital discharge; RR, repeated revascularization; F/U, follow-up; BARI, Bypass Angioplasty Revascularization Investigation; EAST, Emory Angioplasty Surgery Trial; GABI, German Angioplasty Bypass-surgery Investigation; RITA, Randomised Intervention Treatment of Angina; ERACI, Estudio Randomizado Argentino de Angioplastia vs Cirugia; MASS, Medicine, Angioplasty, or Surgery Study; CABRI, Coronary Angioplasty versus Bypass Revascularization Investigation; MV, multivessel; D, death; T, thallium defect; A, angina; SV, single vessel; and LAD, left anterior descending coronary artery.

*References found in the complete guidelines published in *J Am Coll Cardiol*. 1999;34:1262–1341.

† $P < 0.05$ comparing CABG and PTCA cohorts.

‡Included total occlusion.

§Planned 5-year follow-up (interim results).

Detection of an acute LV mural thrombus may call for long-term anticoagulation and reevaluation by echocardiography to ensure resolution or organization of the thrombus before coronary bypass surgery. Additionally, 3 to 6 months of anticoagulation therapy is appropriate for patients with persistent, anterior wall-motion abnormalities after coronary bypass surgery.

Recent, Antecedent Cerebrovascular Event

A recent, preoperative cerebrovascular accident represents a situation in which delaying surgery may reduce the perioperative neurological risk. In particular, evidence of a hemorrhagic component based on computed tomographic scan identifies high risk for the extension of neurological damage with cardiopulmonary bypass. It is generally believed that a delay of 4 weeks or more after a cerebrovascular accident is prudent, if coronary anatomy and symptoms permit, before proceeding with CABG.

Carotid Disease and Neurological Risk Reduction

Hemodynamically significant carotid stenoses are thought to be responsible for up to 30% of early postoperative strokes. The

trend for coronary surgery to be performed in an increasingly elderly population and the increasing prevalence of carotid disease in this same group of patients underscore the importance of this issue. Perioperative stroke risk is thought to be <2% when carotid stenoses are <50%, 10% when stenoses are 50% to 80%, and 11% to 19% in patients with stenoses >80%. Patients with untreated, bilateral, high-grade stenoses and/or occlusions have a 20% chance of stroke. Carotid endarterectomy for patients with high-grade stenosis is generally done preceding or coincident with coronary bypass surgery and, with proper teamwork in high-volume centers, is associated with a low risk for both short- and long-term neurological sequelae. Carotid endarterectomy performed in this fashion carries a low mortality (3.5%) and reduces early postoperative stroke risk to <4%, with a concomitant 5-year freedom from stroke of 88% to 96%.

The decision about who should undergo preoperative carotid screening is controversial. Predictors of important carotid stenosis include advanced age, female sex, known peripheral vascular disease, previous transient ischemic attack or stroke, a history of smoking, and left main coronary artery disease. Many centers screen all patients >65 years

TABLE 7. Three-Year Survival by Treatment in Each Anatomic Subgroup

Coronary Anatomy Group		Patients, n	Survival		P
			Observed, %	Adjusted, %	
1-Vessel, no LAD	CABG	507	89.2	92.4	0.003
	PTCA	11 233	95.4	95.3	
1-Vessel, nonproximal LAD	CABG	153	95.8	96.0	0.857
	PTCA	4130	95.7	95.7	
1-Vessel, proximal LAD	CABG	1917	95.8	96.6	0.010
	PTCA	5868	95.5	95.2	
2-Vessel, no LAD	CABG	1120	91.0	93.0	0.664
	PTCA	2729	93.4	92.6	
2-Vessel, nonproximal LAD	CABG	850	91.3	92.3	0.438
	PTCA	2300	93.3	93.1	
2-Vessel, proximal LAD	CABG	7242	93.5	93.8	<0.001
	PTCA	2376	92.8	91.7	
3-Vessel, nonproximal LAD	CABG	1984	90.1	90.3	0.002
	PTCA	660	86.7	86.0	
3-Vessel, proximal LAD	CABG	15 873	90.1	90.3	<0.001
	PTCA	634	88.2	86.1	

LAD indicates left anterior descending coronary artery; CABG, coronary artery bypass graft; and PTCA, percutaneous transluminal coronary angioplasty. Comparative observed and adjusted 3-year survival of patients treated with PTCA or CABG in various anatomic subgroups.

Reprinted with permission from the New York State Registry as published in Hannan EL, Racz MJ, McCallister BD, Ryan TJ, Arani DT, Isom OW, Jones RH. A comparison of three-year survival after coronary artery bypass graft surgery and percutaneous transluminal coronary angioplasty. *J Am Coll Cardiol.* 1999;33:67.

old. Patients with left main coronary disease are often screened, as are those with a previous transient ischemic attack or stroke. Preoperative central nervous system symptoms suggestive of vertebral basilar insufficiency should lead to an evaluation before elective CABG.

When surgery of both carotid and coronary disease is planned, the most common approach is to perform the operation in a staged manner, in which the patient first has carotid surgery followed by coronary bypass in 1 to 5 days. Alternatively, especially if the patient has compelling cardiac symptoms or coronary anatomy, the operations may be performed during a single period of anesthesia, with the carotid endarterectomy immediately preceding coronary bypass. Neither strategy has been established as being superior. Stroke risk is increased if a reversed-stage procedure is used, in which the coronary bypass operation precedes the carotid endarterectomy by ≥ 1 day.

2. Reducing the Risk of Type 2 Brain Injury

Type 2 neurological complications are seen in $\approx 3\%$ of patients and are correlated with a 10% risk of postoperative death, with 40% of patients requiring additional care in a transitional facility after hospital discharge. Microembolization is thought to be a major contributor to the postoperative cerebral dysfunction after CABG. The release of microemboli during extracorporeal circulation, involving small gaseous or lipid emboli, may be responsible. The use of a 40- μm arterial-line filter on the heart-lung machine circuit and routine use of membrane oxygenators rather than bubble oxygenators may reduce such neurological injury. Additional

maneuvers to reduce type 2 neurological injury include the maintenance of steady, cerebral blood flow during cardiopulmonary bypass, avoidance of cerebral hyperthermia during and after cardiopulmonary bypass, meticulous control of perioperative hyperglycemia, and avoidance and limitation of postoperative cerebral edema.

3. Reducing the Risk of Perioperative Myocardial Dysfunction

Protection in Patients With Normal LV Function

There is no universally applicable myocardial protection technique. Among patients with preserved preoperative cardiac function, no strong argument can currently be made for warm versus cold and crystalloid versus blood cardioplegia. However, certain techniques may offer a wider margin of safety for special patient subsets.

Myocardial Protection for Acutely Depressed Cardiac Function

Several studies have suggested that blood cardioplegia (compared with crystalloid) may offer a greater margin of safety during CABG performed on patients with acute coronary occlusion, failed angioplasty, urgent revascularization for unstable angina, and/or chronically impaired LV function.

Protection for Chronically Depressed LV Function

The use of a prophylactic intra-aortic balloon pump as an adjunct to myocardial protection may reduce mortality in patients having CABG in the setting of severe LV dysfunction (eg, LVEF < 0.25). Placement of the intra-aortic balloon

pump immediately before operation appears to be as effective as placement on the day preceding bypass surgery.

Adjuncts to Myocardial Protection

Although it is widely appreciated that use of the internal mammary artery leads to improved long-term survival after coronary bypass surgery, it has also been documented that use of the internal mammary artery influences operative mortality itself. Thus, internal mammary artery use should be encouraged in the elderly, emergent, or acutely ischemic patient and other patient groups.

Inferior Infarct With Right Ventricular Involvement

An acutely infarcted right ventricle is at great risk for severe, postoperative dysfunction and predisposes the patient to a higher postoperative mortality. During operation, loss of the pericardial constraint may lead to acute dilatation of the dysfunctional right ventricle, which then fails to recover even with optimal myocardial protection and revascularization. The best defense against right ventricular dysfunction is its recognition during preoperative evaluation. When possible, CABG should be delayed for ≥ 4 weeks to allow the right ventricle to recover.

4. Reducing the Systemic Consequences of Cardiopulmonary Bypass

A variety of measures have been tried to reduce the systemic consequences of cardiopulmonary bypass, which elicits a diffuse inflammatory response that may cause transient or prolonged multisystem organ dysfunction. Administration of corticosteroids before cardiopulmonary bypass may reduce complement activation and release of proinflammatory cytokines. Proper timing and duration of corticosteroid application are incompletely resolved. The administration of the serine protease inhibitor aprotinin may attenuate complement activation and cytokine release during extracorporeal circulation. Unfortunately, aprotinin is relatively expensive. Another method to reduce the inflammatory response is perioperative leukocyte depletion through hematologic filtration.

5. Reducing the Risk of Perioperative Infections

Several methods exist to reduce the risk of wound infections in patients undergoing CABG. These begin with interval reporting to individual surgeons regarding their respective wound infection rates and adherence to sterile operative techniques. Additional strategies include skin preparation with topical antiseptics, clipping rather than shaving the skin, avoidance of hair removal, reduction of operating room traffic, laminar-flow ventilation, shorter operation, minimization of electrocautery, avoidance of bone wax, use of double-glove barrier techniques for the operating room team, and routine use of a pleural pericardial flap. Aggressive, perioperative glucose control in diabetics through the use of continuous, intravenous insulin infusion reduces perioperative hyperglycemia and its associated infection risk. Avoidance of homologous blood transfusions after CABG may reduce the risk of both viral and bacterial infections. This is due to an immunosuppressive effect of transfusion. Leukodepletion of transfused blood also reduces this effect. This can be accomplished by regional blood banks at the time of donation or at the bedside by use of a transfusion filter.

Preoperative antibiotic administration reduces the risk of postoperative infection 5-fold. Efficacy is dependent on adequate drug tissue levels before microbial exposure. Cephalosporins are currently the agents of choice. Table 8 identifies appropriate choices, doses, and routes of therapy. A 1-day course of intravenous antimicrobials is as effective as 48 hours or more. Therapy should be administered within 30 minutes of incision and again in the operating room if the operation exceeds 3 hours. Many centers deliver antibiotics just before incision. One fail-safe method is to have the anesthesiologist administer the cephalosporin after induction but before skin incision. If deep sternal wound infection does occur, aggressive surgical debridement and early vascularized muscle flap coverage are the most effective methods for treatment, along with long-term systemic antibiotics.

6. Prevention of Postoperative Dysrhythmias

Postoperative atrial fibrillation increases the length of stay, cost, and most important, the risk of stroke. Atrial fibrillation occurs in up to 30% of patients, usually on the second or third postoperative day. Methods to avoid atrial fibrillation are several. First, withdrawal of preoperative β -blockers in the postoperative period doubles the risk of atrial fibrillation after CABG. Thus, early reinitiation of β -blockers is critical for avoidance of this complication. Virtually every study of patients receiving β -blockers prophylactically has shown benefit in lowering the frequency of atrial fibrillation. Most have used the drug in the postoperative period, but greater benefit may occur if β -blockade is begun before the operation. More recently, small studies of propafenone, sotalol, and amiodarone have also shown effectiveness in reducing the risk of postoperative atrial fibrillation. Table 9 provides a review of pharmacological approaches in the randomized trials. Digoxin and calcium channel blockers have no consistent benefit for preventing atrial fibrillation after CABG, although they are frequently used to control its rate after it does occur. Currently, the routine preoperative or early postoperative administration of β -blockers is considered standard therapy to reduce the risk of atrial fibrillation after CABG.

7. Strategies to Reduce Perioperative Bleeding and Transfusion Risk

Transfusion Risk

Despite the increasing safety of homologous blood transfusion, concerns surrounding viral transmission during transfusion remain. Currently, the risks are likely very low and have been estimated to be 1/493 000 for human immunodeficiency virus, 1/641 000 for human T-cell lymphotropic virus, 1/103 000 for hepatitis C virus, and 1/63 000 for hepatitis B virus.

Perioperative Bleeding

Risk factors for blood transfusion after CABG include advanced age, low preoperative red blood cell volume, preoperative aspirin therapy, urgent operation, duration of cardiopulmonary bypass, recent thrombolytic therapy, reoperation, and differences in heparin management. Institutional protocols that establish minimum thresholds for transfusion lead to a reduced number of units transfused and the percentage of

TABLE 8. Prophylactic Antimicrobials for Coronary Artery Bypass Graft Surgery

Cephalosporins	Equivalent Efficacy IV Dosing Regimens Dose and Interval	Cost per Dose	Comments
Cefuroxime	1.5 g preoperatively 1.5 g after CPB 1.5 g Q12×48	\$6.33/1.5 g	First-line agents; low toxicity; pharmacokinetics vary; shorter prophylaxis duration <24 h may be equally efficacious for cefuroxime
Cefamandole, cefazolin	1 g preoperatively 1 g at sternotomy 1 g after CPB 1 g Q6×48 (Initial dose to be given 30–60 minutes before skin incision)	\$6.27/g \$0.90/g	
Vancomycin	1 g Q12/h/until lines/tubes out At least 2 doses (During 30–60-minute infusion timed to end before skin incision)	\$5.77/g	Reserved for penicillin-allergic; justified in periods of methicillin-resistant <i>Staphylococcus</i> species outbreaks; vancomycin-resistant <i>Enterococcus</i> problem is on horizon; more likely to require vasopressor agent perioperatively

CPB indicates cardiopulmonary bypass.

Data taken from (1) Townsend TR, Reitz BA, Bilker WB, Bartlett JG. Clinical trial of cefamandole, cefazolin, and cefuroxime for antibiotic prophylaxis in cardiac operations. *J Thorac Cardiovasc Surg.* 1993;106:664–670. (2) Antimicrobial prophylaxis in surgery. *Med Lett Drugs Ther.* 1997;39:97–101. (3) Vuorisalo S, Pokela R, Syrjala H. Comparison of vancomycin and cefuroxime for infection prophylaxis in coronary artery bypass surgery. *Infect Control Hosp Epidemiol.* 1998;19:234–239. (4) Romanelli VA, Howie MB, Myerowitz PD, Zvara DA, Rezaei A, Jackman DL, Sinclair DS, McSweeney TD. Intraoperative and postoperative effects of vancomycin administration in cardiac surgery patients: a prospective, double-blind, randomized trial. *Crit Care Med.* 1993;21:1124–1131.

patients requiring blood. Additional strategies can reduce the transfusion requirement after CABG. For stable patients, aspirin and other antiplatelet drugs may be discontinued 7 days before elective CABG. Aprotinin, a serum protease inhibitor with antifibrinolytic activity, also decreases postoperative blood loss and transfusion requirements in high-risk patients. Although there has been some concern that aprotinin may reduce early graft patency, recent studies have failed to document this effect. Routine use of aprotinin is limited by its high cost. Multidisciplinary approaches to conserve blood in single institutions appear to be effective.

For patients without exclusions, such as low hemoglobin values, heart failure, unstable angina, left main coronary artery disease, or advanced anginal symptoms, self-donation of 1 to 3 units of red blood cells over 30 days before operation reduces the need for homologous transfusion during or after operation. Donation immediately before cardiopulmonary bypass yields a higher platelet and hemoglobin count compared with simple hemodilution without pre-cardiopulmonary bypass blood harvesting.

8. Antiplatelet Therapy for Saphenous Vein Graft Patency

Aspirin significantly reduces vein graft closure during the first postoperative year. The aspirin should be started within 24 hours after surgery because its benefit on saphenous vein

graft patency is lost when begun later. Dosing regimens from as little as 100 mg/d to as much as 325 mg TID appear to be efficacious. Ticlopidine offers no advantage over aspirin but is an alternative in truly aspirin-allergic patients. Life-threatening neutropenia is a rare but recognized side effect. Clopidogrel offers the potential for fewer side effects compared with ticlopidine as an alternative in aspirin-allergic patients. Its incidence of severe leukopenia is rare.

9. Pharmacological Management of Hyperlipidemia

Aggressive treatment of hypercholesterolemia reduces progression of atherosclerotic vein graft disease in patients after bypass surgery. Statin therapy has been shown to reduce saphenous vein graft disease progression over the ensuing years after bypass. Patients with unknown low-density lipoprotein (LDL) cholesterol levels after bypass should have cholesterol levels determined and treated pharmacologically if the LDL exceeds 100 mg/dL. Patients with treated LDL cholesterol should have their low-fat diet and cholesterol-lowering medications continued after bypass surgery to reduce subsequent graft attrition. Data regarding the benefit of cholesterol lowering after bypass surgery are most supported by studies that have used HMG CoA (3-hydroxy-3-methylglutaryl coenzyme A) reductase inhibitors, particularly targeting LDL levels to <100 mg/dL.

TABLE 9. Pharmacological Strategies for Prevention of Atrial Fibrillation (AF) After Coronary Artery Bypass Graft Surgery

Treatment	Timing	Dose/Route	AF Incidence, %	Comments
Frontline strategies				
Resumption of patient's preoperative β -blocker	Postoperative resumption	Same as preoperative	β -Blocker stopped; 38.1% Continued $P=0.02$ 17.1%	Resumption of β -blocker reduced AF by 45%
			β -Blocker stopped; 28% Continued $P=0.01$ 6%	Nearly 5-fold decrease in incidence; if no longer needed after revascularization, may taper as outpatient
β -Blockers (propranolol prototypical)	Postoperative initiation (10 ± 7 h postoperatively)	5 mg orally 4 times per day	Control 23% Propranolol 9.8% $P=0.02$	Reduced AF by 43%; inexpensive, low dose
Almost all β -blockers evaluated	Postoperatively	Varies	Significantly reduced vs placebo	Odds ratio 0.17; confidence interval 0.03–0.98 in favor of β -blocker over controls in meta-analysis
Atenolol	Preoperatively (begun 72 h before operation)	50 mg Orally twice a day	Control 37% Atenolol 3% $P=0.001$	Excellent option if preoperative phase practical
Sotalol	Preoperatively through postoperatively	160 mg AM of operation, then 160 mg BID PO	Control 29% Sotalol 10%	Class III properties; sotalol not tolerated in 10% of patients
Magnesium sulfate	Postoperatively	Continuous IV infusion for a total of 178 mEq over first 4 postoperative days	Control 28% Mg supplement 14% $P=0.02$	Goal is normal serum magnesium: ≥ 1 mmol/L, < 2 mEq/L, which is usually low after cardiopulmonary bypass
Alternative/niche strategies				
Amiodarone	Preoperatively through postoperatively	600 mg Orally daily for 7 days preoperatively; then 200 mg PO daily postoperatively; stop at discharge; total=4.8 g	Control 53% Amiodarone 25% $P=0.003$	Mixed group of coronary and valve patients, explaining very high AF incidence
Amiodarone	Postoperatively	300 mg Intravenous bolus; then 1.2 g over 24 h for 2 days; then 900 mg every 24 h for 2 days, for a total of 4.5 g	Control 21% Amiodarone 5% $P=0.05$	Coronary bypass patients only in this study
Propafenone	Postoperatively	300 mg Orally twice a day for 7 days	Propafenone 12% Atenolol 11% $P=NS$	Propafenone offers a less negative inotropic option for poor left ventricular function population

For details about the trials from which these data were derived, please refer to Table 13 of the full text of these guidelines (*J Am Coll Cardiol.* 1999;34:1294).

10. Hormonal Manipulation

While observational studies have suggested that hormone replacement therapy in postmenopausal women leads to a reduction in all-cause mortality, a recent, randomized trial for secondary coronary prevention failed to show a beneficial effect on the overall rate of coronary events. Thus, hormone replacement therapy should be considered in postmenopausal women after bypass when, in the physician's judgment, the potential coronary benefit is not offset by an increased risk of uterine or breast cancer.

11. Smoking Cessation

Smoking cessation is the single, most important risk-modification goal after CABG in patients who smoke.

Smoking cessation leads to less recurrent angina, improved physical function, fewer admissions, maintenance of employment, and improved survival. Treatment individualized to the patient is crucial. Depression may be an important complicating factor and should be approached with behavioral and drug therapy. Nicotine replacement with a transdermal patch, nasal spray, gum, or inhaler is beneficial. A sustained-release form of bupropion, an antidepressant similar to selective serotonin reuptake inhibitors, reduces the nicotine craving and anxiety of smokers who quit. All smokers should receive educational counseling and be offered smoking cessation therapy after CABG (Table 10).

TABLE 10. Proven Management Strategies to Reduce Perioperative and Late Morbidity and Mortality

Timing	Class Indication	Intervention	Comments
Preoperative			
Carotid screening	I	Carotid duplex ultrasound in defined population	Carotid endarterectomy if stenosis $\geq 80\%$
Perioperative			
Antimicrobials	I	Prophylactic antimicrobials	Table 8
Antifibrinolytics	Ila	Aprotinin in selected groups	Significant reduction in blood transfusion requirement
Antiarrhythmics	I	β -Blockers to prevent postoperative atrial fibrillation	Propafenone or amiodarone are alternatives if contraindication to β -blocker (Table 9)
Anti-inflammatory drugs	Ila	Minimize diffuse inflammatory response to cardiopulmonary bypass	
Postoperative			
Antiplatelet agents	I	Aspirin to prevent early vein-graft attrition	Ticlopidine or clopidogrel are alternatives if contraindications to aspirin
Lipid-lowering therapy	I	Cholesterol-lowering agent plus low-fat diet if low-density lipoprotein cholesterol >100 mg/dL	3-Hydroxy-3-methylglutaryl/coenzyme A reductase inhibitors preferred if elevated low-density lipoprotein is major aberration
Smoking cessation	I	Smoking cessation education, and offer counseling and pharmacotherapies	

12. Cardiac Rehabilitation

Cardiac rehabilitation, including early ambulation during hospitalization, outpatient prescriptive exercise, family education, and dietary and sexual counseling, has been shown to improve outcomes after CABG. The benefits include better physical mobility and perceived health. A higher proportion of rehabilitated patients are working at 3 years after CABG. The benefits of rehabilitation extend to the elderly and to women. Cardiac rehabilitation reinforces pharmacological therapy and smoking cessation and should be offered to all eligible patients after CABG.

13. Emotional Dysfunction and Psychosocial Considerations

Lack of social participation and low religious strength are independent predictors of death in elderly patients undergoing CABG. Although controversial, the high prevalence of depression after bypass surgery may reflect a high prevalence preoperatively. Cardiac rehabilitation has a highly beneficial effect in patients who are moderately or severely depressed. Evaluation of social supports and attempts to identify and treat underlying depression should be part of routine post-CABG care.

14. Rapid Sustained Recovery After Operation

Rapid recovery and early discharge are standard goals after CABG. The shortest in-hospital postoperative stays are followed by the fewest rehospitalizations. Important components of "fast-track" care are careful patient selection, patient and family education, early extubation, prophylac-

tic antiarrhythmic therapy, dietary considerations, early ambulation, early outpatient telephone follow-up, and careful coordination with other physicians and healthcare providers.

15. Communication Between Caregivers

Maintenance of appropriate and timely communication between treating physicians regarding care of the patient is crucial. When possible, the primary care physician should follow up the patient during the perioperative course. The referral physician needs to provide clear, written reports of the findings and recommendations to the primary care physician, including discharge medications and dosages along with long-term goals.

VI. Impact of Evolving Technology

A. Less-Invasive Coronary Bypass Surgery

Technical modifications of CABG have been developed to decrease the morbidity of the operation, either by using limited incision or by eliminating cardiopulmonary bypass. Currently, "less-invasive" CABG surgery can be divided into 3 categories: (1) off-bypass CABG performed through a median sternotomy with a smaller skin incision, (2) minimally invasive direct CABG (MID-CAB) performed through a left anterior thoracotomy without cardiopulmonary bypass, and (3) port-access CABG with femoral-to-femoral cardiopulmonary bypass and cardioplegic arrest with limited incision.

Off-bypass coronary surgery is performed on a beating heart after reduction of cardiac motion with a variety of pharmacological and mechanical devices. These include slowing the heart with β -blockers and calcium channel blockers and use of a mechanical stabilizing device to isolate and stabilize the target vessel. Retraction techniques may elevate the heart to allow access to vessels on the lateral and inferior surfaces of the heart. Because this technique generally uses a median sternotomy, its primary benefit is the avoidance of cardiopulmonary bypass, not a less extensive incision.

MID-CAB refers to bypass surgery without median sternotomy and without the use of cardiopulmonary bypass. Generally, this is performed with a small left anterior thoracotomy, exposing the heart through the fourth intercostal interspace with access to the LAD and diagonal branches and occasionally, the anterior marginal vessels. The right coronary artery can be approached by using a right anterior thoracotomy. MID-CAB procedures are generally performed on only 1 or 2 coronary targets. Observational studies have suggested that MID-CAB is associated with a reduced average length of stay and an earlier return to work. Although initial reports of 2-year actuarial and event-free survival are encouraging, the data must be viewed with caution. Because the number of anastomoses performed on a beating heart is usually 1 or occasionally 2, the potential long-term effects of incomplete revascularization are unknown.

The closed-chest, port-access, video-assisted CABG operation uses cardiopulmonary bypass and cardioplegia of a globally arrested heart. Vascular access for cardiopulmonary bypass is achieved via the femoral artery and vein. A triple-lumen catheter with an inflatable balloon at its distal end is used to achieve endovascular aortic occlusion, cardioplegia delivery, and LV decompression. With cardiopulmonary bypass and cardioplegic arrest, CABG can be performed with video assistance on a still and decompressed heart through several small ports. In comparison with the MID-CAB, port access allows access to different areas of the heart, thus facilitating more complete revascularization, and the motionless heart may allow a more accurate anastomosis. Compared with conventional CABG, median sternotomy is avoided. However, potential morbidity of the port-access operation includes multiple wounds at port sites, the limited thoracotomy, and the groin dissection for femoral-femoral bypass. Vigorous scrutiny of the long-term benefits versus risks of port access is required.

B. Arterial and Alternate Conduits

Another area of evolving technology is the use of arterial and alternate conduits. The 5-year patency of coronary artery-vein bypass grafts is 74%, and at 10 years, just 41%. Contrariwise, patency rates of the internal mammary artery implanted into the LAD are as high as 83% at 10 years. As a consequence of improved patency, patients receiving an LAD graft with an internal mammary artery have improved survival compared with patients receiving only vein grafts. Currently, routine use of the left internal mammary artery for LAD grafting with supplemental saphenous vein grafts to

other coronary lesions is generally accepted as a standard grafting method. The use of bilateral internal mammary arteries appears to be safe and efficacious. However, there is a higher rate of deep sternal wound infection when both internal mammary arteries are used. This is particularly true for patients with obesity and diabetes and perhaps for those requiring prolonged ventilatory support. The benefits of bilateral internal mammary artery use include lower rates of recurrent angina, MI, and need for reoperation and a trend for better survival. Recently, the radial artery has been used more frequently as a conduit for coronary bypass surgery. Five-year patency appears to be in the range of 85% (compared with nearly 90% for the internal mammary graft). In patients for whom mammary artery, radial artery, and standard vein conduits are unavailable, the *in situ* right gastroepiploic artery, the inferior epigastric free artery graft, and either lesser saphenous or upper-extremity vein conduits have been used. Long-term patency of these alternative grafts has not been extensively studied.

C. Percutaneous Technology

Technological improvements in percutaneous coronary angioplasty have included the introduction of new devices and improved medical therapy of patients in whom angioplasty is performed. The most notable improvement has been the introduction of intracoronary stents that have reduced late restenosis and the frequency with which emergency bypass surgery is required after PTCA. Intracoronary stents have been used to treat saphenous vein graft stenosis in patients with previous CABG. However, stented patients still have an $\approx 25\%$ combined rate of death, MI, need for repeat CABG, or re-revascularization of the target vessel. For some patients, hybrid procedures may be the best choice, such as the combined use of CABG surgery and coronary angioplasty. Such an approach is relevant to the patient whose ascending aorta is involved with severe atherosclerosis, for which the implantation of free vein grafts or arterial grafts leads to risk for atheroembolism. In such a patient, the use of *in situ* internal mammary artery grafting without cardiopulmonary bypass combined with additional coronary angioplasty in other diseased vessels represents a strategy to provide complete revascularization without the concomitant risks of cardiopulmonary bypass and/or manipulation of the ascending aorta.

D. Transmyocardial Revascularization

A fourth area that is rapidly evolving is transmyocardial revascularization. The use of transmyocardial laser revascularization has generally been performed surgically for patients with severe angina refractory to medical therapy and who are not suitable candidates for standard surgical revascularization, PTCA, or heart transplant. While several studies have suggested improvement in angina severity with transmyocardial laser revascularization, the mechanism by which angina improves and the overall benefit on long-term angina and/or survival await further clarification.

VII. Special Patient Subsets

A. Elderly Patients

Elderly patients being considered for CABG have a higher average risk for mortality and morbidity in a direct relation to age, LV function, extent of coronary disease, and comorbid conditions and whether the procedure is urgent, emergent, or a reoperation. Nonetheless, functional recovery and sustained improvement in the quality of life can be achieved in the majority of such patients. The patient and physician together must explore the potential benefits of improved quality of life with the attendant risks of surgery versus alternative therapies that take into account baseline functional capacities and patient preferences. Age alone should not be a contraindication to CABG if it is thought that long-term benefits outweigh the procedural risk.

B. Women

A number of earlier reports had suggested that female sex was an independent risk factor for mortality and morbidity after CABG. More recent studies have suggested that women on average have a disadvantageous, preoperative clinical profile that accounts for much of this perceived difference. Thus, the issue is not necessarily sex itself but the comorbid conditions that are particularly associated with the later age at which women present for coronary surgery. Thus, CABG should not be delayed in or denied to women who have appropriate indications.

C. Diabetic Patients

Coronary heart disease is the leading cause of death among adult diabetics and accounts for 3 times as many deaths among diabetics as among nondiabetics. While CABG carries an increased morbidity and mortality in diabetics, data suggest that in appropriate candidates, the absolute risk reduction provided by successful revascularization remains high. The BARI trial suggested that diabetics with multivessel coronary disease derived advantage from bypass surgery compared with angioplasty. Several of the other randomized trials, albeit with smaller numbers of patients, failed to show this trend. Diabetics who are candidates for renal transplantation have a particularly high incidence of coronary artery disease, even in the absence of symptoms or signs. In appropriate candidates, CABG appears to offer morbidity and mortality benefit in such patients.

D. Patients With Chronic Obstructive Pulmonary Disease

Because CABG is associated with variable degrees of postoperative respiratory insufficiency, it is important to identify patients at particular risk for pulmonary complications. The intent is to treat reversible problems that may contribute to respiratory insufficiency in high-risk patients, with the hope of avoiding prolonged periods of mechanical ventilation after CABG. High-risk patients often benefit from preoperative antibiotics, bronchodilator therapy, a period of cessation from smoking, perioperative incentive spirometry, deep-breathing exercises, and chest physiotherapy. If pulmonary venous congestion or pleural effusions are identified, diuresis often improves lung performance.

Although preoperative spirometry directed to identifying patients with a low (eg, <1 L) 1-second forced expiratory volume has been used by some to qualify or disqualify candidates for CABG, clinical evaluation of lung function is likely as important if not more so. Patients with advanced chronic obstructive pulmonary disease are at particular risk for postoperative arrhythmias that may be fatal. While moderate to severe degrees of obstructive pulmonary disease represent a significant risk factor for early mortality and morbidity after CABG, it is also true that with careful preoperative assessment and treatment of the underlying pulmonary abnormality, many such patients are successfully carried through the operative procedure.

E. Patients With End-Stage Renal Disease

Coronary artery disease is the most important cause of mortality in patients with end-stage renal disease. Many of such patients have diabetes and other coronary risk factors, including hypertension, myocardial dysfunction, abnormal lipids, anemia, and increased plasma homocysteine levels. Although patients on chronic dialysis are at higher risk when undergoing coronary angioplasty or bypass, they are at even higher risk with conservative medical management. Thus, in patients with modest reductions in LV function, significant left main or 3-vessel disease, and/or unstable angina, coronary revascularization can lead to relief of coronary symptoms, improvement in overall functional status, and improved long-term survival in this select high-risk patient population.

F. Reoperative Patients

Operative survival and long-term benefit of reoperative CABG are distinctly inferior to first-time operations. Patients undergoing repeated CABG have higher rates of postoperative bleeding, perioperative MI, and neurological and pulmonary complications. Nevertheless, reasonable 5- and 10-year survival rates after reoperation for coronary disease can be achieved, and the operation is appropriate if the severity of symptoms and anticipated benefit justify the immediate risk. Data suggest that the need for reoperation is less common in patients undergoing internal mammary artery grafting to the LAD. More recently, short-term follow-up studies suggest that patients undergoing multiple arterial grafts have even lower rates of reoperation. These early results are consistent with the known superior graft patency of arterial conduits compared with vein grafts.

G. Concomitant Peripheral Vascular Disease

The presence of clinical and subclinical peripheral vascular disease is a strong predictor of increased hospital and long-term mortality rates in patients undergoing CABG. However, the absolute benefit offered by coronary revascularization is elevated in patients with peripheral vascular disease, particularly those with 3-vessel coronary disease, more advanced angina, and/or a depressed LVEF. Excess perioperative mortality in such patients is related to an increased incidence of heart failure and dysrhythmias rather than peripheral arterial complications.

H. Poor LV Function

Patients with severe LV dysfunction have increased perioperative and long-term mortality compared with patients with normal

LV function. However, studies suggest that the beneficial effects of myocardial revascularization in patients with ischemic heart disease and severe LV dysfunction are sizeable when compared with medically treated patients of similar status in terms of symptom relief, exercise tolerance, and survival.

I. CABG in Acute Coronary Syndromes

Coronary bypass surgery offers a survival advantage compared with medical therapy in patients with unstable angina and LV dysfunction, particularly in the presence of 3-vessel disease. However, the risk of bypass surgery in patients with unstable or postinfarction angina or early after non-Q wave infarction and during acute MI is increased severalfold compared with patients with stable angina. Although this risk is not necessarily higher than that with medical therapy, it has led to the argument to consider angioplasty or to delay CABG in such patients if medical stabilization can be easily accomplished.

VIII. Institutional and Operator Competence

Studies suggest that mortality after CABG is higher when carried out in institutions that annually perform fewer than a minimum number of cases. Similar conclusions have been drawn regarding individual surgeons' volumes. This observation strengthens the argument for careful outcome tracking and supports the monitoring of institutions or individuals who annually perform <100 cases. It is also true that there is a wide variation in risk-adjusted mortality rates in low-volume situations. Thus, some institutions and practitioners maintain excellent outcomes despite relatively low volumes.

Outcome reporting in the form of risk-adjusted mortality rates after bypass has been effective in reducing mortality rates nationwide. Public release of hospital and physician-specific mortality rates has not been shown to drive this improvement and has failed to effectively guide consumers or alter physician referral patterns.

IX. Cost-Effectiveness of Bypass Surgery

A variety of studies of CABG have found the technique to be cost-effective in patients for whom survival and/or symptomatic benefit is demonstrable. Within these subsets, the cost-effectiveness of CABG compares favorably with that of other accepted medical therapies.

When compared with PTCA, the initial hospital cost of CABG is significantly higher. However, by 5 years, the cumulative cost of PTCA compared with initial surgical therapy is within 5% of CABG, or a difference of <\$3000. Observational studies showing a poorer survival effect of PTCA in patients with more advanced disease suggest that there may be a significant cost gradient for PTCA as the extent of disease increases, which is not apparent for coronary bypass surgery.

X. Indications

A. Indications for CABG in Asymptomatic or Mild Angina

Class I

1. Significant left main coronary artery stenosis.
2. Left main equivalent: significant ($\geq 70\%$) stenosis of proximal LAD and proximal left circumflex artery.
3. Three-vessel disease. (Survival benefit is greater in patients with abnormal LV function; eg, with an EF <0.50.)

Class IIa

1. Proximal LAD stenosis with 1- or 2-vessel disease.*

Class IIb

1. One- or 2-vessel disease not involving the proximal LAD.†

Class III

See text.

B. Indications for CABG in Stable Angina

Class I

1. Significant left main coronary artery stenosis.
2. Left main equivalent: significant ($\geq 70\%$) stenosis of proximal LAD and proximal left circumflex artery.
3. Three-vessel disease. (Survival benefit is greater when LVEF is <0.50.)
4. Two-vessel disease with significant proximal LAD stenosis and either EF <0.50 or demonstrable ischemia on noninvasive testing.
5. One- or 2-vessel coronary artery disease without significant proximal LAD stenosis, but with a large area of viable myocardium and high-risk criteria on noninvasive testing.
6. Disabling angina despite maximal medical therapy, when surgery can be performed with acceptable risk. If angina is not typical, objective evidence of ischemia should be obtained.

Class IIa

1. Proximal LAD stenosis with 1-vessel disease.*
2. One- or 2-vessel coronary artery disease without significant proximal LAD stenosis, but with a moderate area of viable myocardium and demonstrable ischemia on noninvasive testing.

Class III

1. One- or 2-vessel disease not involving significant proximal LAD stenosis, in patients (I) who have mild symptoms that are unlikely due to myocardial ischemia or have not received an adequate trial of medical therapy and (A) have only a small area of viable myocardium or (B) have no demonstrable ischemia on noninvasive testing.
2. Borderline coronary stenoses (50% to 60% diameter in locations other than the left main coronary artery)

*Becomes Class I if extensive ischemia documented by noninvasive study and/or an LVEF <0.50%.

†If a large area of viable myocardium and high-risk criteria on noninvasive testing, becomes Class I.

and no demonstrable ischemia on noninvasive testing.

3. Insignificant (<50% diameter) coronary stenosis.

C. Indications for CABG in Unstable Angina/Non-Q Wave MI

Class I

1. Significant left main coronary artery stenosis.
2. Left main equivalent: significant ($\geq 70\%$) stenosis of proximal LAD and proximal left circumflex artery.
3. Ongoing ischemia not responsive to maximal non-surgical therapy.

Class IIa

1. Proximal LAD stenosis with 1- or 2-vessel disease.*

Class IIb

2. One- or 2-vessel disease not involving the proximal LAD.†

Class III

See text.

D. Indications for CABG in ST-Segment Elevation (Q-Wave) MI

Class I

None.

Class IIa

1. Ongoing ischemia/infarction not responsive to maximal nonsurgical therapy.

Class IIb

1. Progressive LV pump failure with coronary stenosis compromising viable myocardium outside the initial infarct area.
2. Primary reperfusion in the early hours (≤ 6 to 12 hours) of an evolving ST-segment elevation MI.

Class III

1. Primary reperfusion late (≥ 12 hours) in evolving ST-segment elevation MI without ongoing ischemia.

E. Indications for CABG in Poor LV Function

Class I

1. Significant left main coronary artery stenosis.
2. Left main equivalent: significant ($\geq 70\%$) stenosis of proximal LAD and proximal left circumflex artery.
3. Proximal LAD stenosis with 2- or 3-vessel disease.

Class IIa

1. Poor LV function with significant viable, noncontracting, revascularizable myocardium without any of the aforementioned anatomic patterns.

Class III

1. Poor LV function without evidence of intermittent ischemia and without evidence of significant revascularizable, viable myocardium.

F. Indications for CABG in Life-Threatening Ventricular Arrhythmias

Class I

1. Left main coronary artery stenosis.
2. Three-vessel coronary disease.

Class IIa

1. Bypassable 1- or 2-vessel disease causing life-threatening ventricular arrhythmias.‡
2. Proximal LAD disease with 1- or 2-vessel disease.‡

Class III

1. Ventricular tachycardia with scar and no evidence of ischemia.

G. Indications for CABG After Failed PTCA

Class I

1. Ongoing ischemia or threatened occlusion with significant myocardium at risk.
2. Hemodynamic compromise.

Class IIa

1. Foreign body in crucial anatomic position.
2. Hemodynamic compromise in patients with impairment of coagulation system and without previous sternotomy.

Class IIb

1. Hemodynamic compromise in patients with impairment of coagulation system and with previous sternotomy.

Class III

1. Absence of ischemia.
2. Inability to revascularize owing to target anatomy or no-reflow state.

H. Indications for CABG in Patients With Previous CABG

Class I

1. Disabling angina despite maximal noninvasive therapy. (If angina is not typical, then objective evidence of ischemia should be obtained.)

Class IIa

1. Bypassable distal vessel(s) with a large area of threatened myocardium on noninvasive studies.

Class IIb

1. Ischemia in the non-LAD distribution with a patent internal mammary graft to the LAD supplying functioning myocardium and without an aggressive attempt at medical management and/or percutaneous revascularization.

Class III

See text.

KEY WORDS: ACC/AHA Practice Guidelines ■ bypass ■ angioplasty ■ morbidity ■ mortality ■ revascularization ■ risk factors

*Becomes Class I if extensive ischemia documented by noninvasive study and/or an LVEF <0.50.

†If a large area of viable myocardium and high-risk criteria on noninvasive testing, becomes Class I.

‡Becomes Class I if arrhythmia is resuscitated sudden cardiac death or sustained ventricular tachycardia.

ACC/AHA Guidelines for Coronary Artery Bypass Graft Surgery: Executive Summary and Recommendations: A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Revise the 1991 Guidelines for Coronary Artery Bypass Graft Surgery)

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