Preamble

It is becoming more apparent each day that despite a strong national commitment to excellence in health care, the resources and personnel are finite. It is, therefore, appropriate that the medical profession examine the impact of developing technology on the practice and cost of medical care. Such analysis, carefully conducted, could potentially have an impact on the cost of medical care without diminishing the effectiveness of that care.

To this end, the American College of Cardiology and the American Heart Association in 1980 established a Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures with the following charge:

The Task Force shall address, when appropriate, the contribution, uniqueness, sensitivity, specificity, indications, contraindications and cost-effectiveness of such specific procedures.

The Task Force shall include a Chairman and six members, three representatives from the American Heart Association and three representatives from the American College of Cardiology. The Task Force may select ad hoc members as needed upon the approval of the Presidents of both organizations. Recommendations of the Task Force are forwarded to the President of each organization.

The members of the Task Force are: George A. Beller, MD, Roman W. DeSanctis, MD, Harold T. Dodge, MD, J. Ward Kennedy, MD, T. Joseph Reeves, MD, Sylvan Lee Weinberg, MD and Charles Fisch, MD, Chairman.

This document was reviewed by the officers and other responsible individuals of the two organizations and received final approval in October 1990. It is being published simultaneously in Circulation and the Journal of the American College of Cardiology. The potential impact of this document on the practice of cardiology and some of its unavoidable shortcomings are clearly set out in the introduction.

Charles Fisch, MD, FACC
I. Introduction

Since its introduction by Garrett and colleagues (1) and Favaloro and colleagues (2) in 1969, the coronary artery bypass graft operation has become the most completely studied operation in the history of surgery. It has been shown to be highly effective in the relief of severe angina and under some circumstances has the capability for considerably prolonging useful life. Nonetheless, outcome after the operation and its place in the overall management of patients with ischemic heart disease has not been easily defined because of 1) the multifactorial nature and inherent complexities of ischemic heart disease, 2) the multitude of treatment options that have become available, 3) the variability in the performance of the technical details of the operation and of the myocardial management, and 4) the variability in the methods of evaluating outcome after the operation and comparing it with that after other treatments. Even the minimal resources required to obtain good results have remained arguable, although this issue has been addressed on numerous occasions by governmental and nongovernmental groups since the report by the Inter-society Commission for Heart Disease Resources in 1972 (3).

The American College of Cardiology and the American Heart Association have designated a Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures. That Task Force appointed a Subcommittee to develop guidelines and indications for the coronary artery bypass operation. This is the report of the Subcommittee. It contains a distillation of current information, focused on present indications and practices. A new edition of this report will surely be indicated within 5 years, as new information becomes available.

In this report, general information relating to the indications for the coronary artery bypass graft operation (Section VI) has been derived from comparison of the operation’s benefits with those of initial medical treatment. Merely obtaining a consensus among experts, each of whom inevitably has his or her bias, is no longer appropriate because of the large amount of reliable information that is available. The general indications are presented in the framework developed in other Task Force reports (Table 1). However, this Subcommittee emphasizes that these general indications cannot take into account even the majority of the variables that are involved in most recommendations to patients. The treatment classes can better be defined for individual patients from the patient-specific depictions of time-related comparative benefits of the coronary bypass operation relative to medical treatment (for details see Section X).

The presence of percutaneous transluminal coronary angioplasty as a commonly used alternative form of interventional therapy is recognized, and the few comparisons that are possible have been made (Sections V and X). Recognizing the relative paucity of comparative information, the Subcommittee believed that this report needed to reflect some judgments as to the indications for the coronary bypass operation in an era when both medical treatment and coronary angioplasty are available. This was done in Section VI. More secure recommendations can be made in the future, when more information is available.

This entire report is intended to provide a framework that physicians can use in combination with other kinds of information and their best judgment as they offer recommendations to the patient, who in the last analysis makes the decision.

This Subcommittee expresses its appreciation for the constant support, advice and counsel of Charles Fisch, MD and Sylvan Lee Weinberg, MD from the parent Task Force. It is grateful for the support and considerable operational assistance of David Feild and Michael Forcinito of the American College of Cardiology. It also thanks Debbie Nuby, Brooks Counts and Nancy Ferguson for their enormous contributions to the preparation of the material for this report and of the final document itself.

II. The Coronary Artery Bypass Graft Operation

A. The Operation

The coronary artery bypass graft operation consists of the construction of new pathways (conduits) between the aorta (or other major arteries) and segments of coronary arteries beyond stenosing or obstructing lesions for the purpose of

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Table 1. Classification of Indications for the Coronary Artery Bypass Graft Operation

<table>
<thead>
<tr>
<th>Treatment Class</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>I</td>
<td>Conditions for which the operation is indicated on the basis of a demonstrated advantage over medical treatment in terms of longevity or relief of symptoms, or both.</td>
</tr>
<tr>
<td>II</td>
<td>Conditions for which the operation is acceptable treatment but for which its advantages over medical treatment have not yet been fully defined.</td>
</tr>
<tr>
<td>III</td>
<td>Conditions for which the operation is not generally considered to be indicated, because of lack of demonstrated advantage over medical treatment.</td>
</tr>
</tbody>
</table>
bringing blood to myocardium made ischemic by these lesions.

Cardiopulmonary bypass with a pump oxygenator is used for nearly all coronary bypass graft operations. Thus, in addition to the surgeon, cardiac anesthesiologist and surgical nurse, a competent perfusionist is required (see Section VIII).

Since the early years of the operation, reversed segments of autologous saphenous vein have been used as the conduit. Greater saphenous vein is expendable, generally available in sufficient length, appropriately sized to match the coronary arteries, capable of reaching beyond the stenoses of all diseased arteries, pliable enough to allow easy suturing and is autologous. When a greater saphenous vein is not available, the lesser saphenous vein may be used. Saphenous veins are used as free grafts, anastomosed proximally to the ascending aorta and distally to one or more coronary arteries. Because increasing experience has documented the time-dependent diminution of patency in saphenous vein bypass grafts (see Section III), the left internal mammary artery (internal thoracic artery) is now widely used, particularly for revascularization of the left anterior descending coronary artery system. The internal mammary artery, left attached to its origin from the left subclavian artery, is mobilized from the chest wall and anastomosed to the left anterior descending artery. The right internal mammary artery can often be used in a similar fashion. About 95% of internal mammary arteries used in this way by experienced surgeons are patent 10 years after the coronary bypass operation (4) (see Appendix, Fig. A1), and failure to use the internal mammary artery in this manner has been demonstrated to be a risk factor for premature late death after the operation (see Appendix, Fig. A2) (4–6). The use of the left or right internal mammary artery as a free graft from the ascending aorta to the left anterior descending artery provides almost comparable results (7). Currently available information indicates that the internal mammary artery should be used almost routinely for revascularizing the left anterior descending artery system in the coronary bypass operation.

Use of bilateral internal mammary artery grafting has become popular, but as yet the available evidence does not support the hypothesis that long-term survival is increased by its use (5,6,8), and the risk of sternal wound complications is increased by the double internal mammary artery procedure in obese or diabetic patients (9).

The patency advantage of the internal mammary artery when anastomosed to vessels other than the left anterior descending artery is uncertain (10). When neither internal mammary artery can be used, the right gastroepiploic artery, the inferior mesenteric artery or the inferior epigastric artery may be used, although long-term advantages of these arteries over saphenous vein grafts have not been demonstrated. Segments of radial artery, arm veins, allograft arteries and veins and synthetic tubes have been less satisfactory as conduits and should be used only as a last resort.

Current information (5,6) suggests that incomplete revascularization is a risk factor for premature death and other unfavorable outcome events after coronary bypass surgery. As a result, anastomoses have been made to vessels with a diameter as small as 1 mm, with acceptable patency rates, and there has been more extensive use of sequential grafting, in which a conduit is anastomosed to two or three coronary arteries distally. It has been suggested (5,6) that the use of sequential grafting predisposes to graft failure and thus is a risk factor for unfavorable events late postoperatively, but this remains arguable. Endarterectomy of the diseased coronary artery wall is occasionally utilized in combination with coronary artery bypass grafting and has yielded variable results.

Intraoperative hemostasis should be obtained by meticulous surgical technique, in preference to extensive use of blood products. The use of autologous preoperative or intraoperative blood donation, ultrafiltration devices in the pump oxygenator system, collection of intraoperatively shed blood by devices that wash and concentrate the erythrocytes, and the reinfusion of shed blood drained from the chest tubes during the early postoperative hours, minimize the amount of donor bank blood that must be used. In about 50% of patients undergoing primary coronary artery bypass grafting and without preoperative anemia, no homologous blood should be required. However, important bleeding tendencies develop in some patients and require specific therapy.

B. Myocardial Management

Patients with coronary artery disease are more susceptible to major and minor myocardial injury immediately preoperatively, during induction of anesthesia, and before cardiopulmonary bypass than are other patients, and precise management is necessary during these periods. Proper myocardial management therefore begins preoperatively, with optimization of the patient’s antianginal drug regimen. In general, beta-receptor and calcium channel blocking therapy, and intravenous nitroglycerin if that is being administered, should be continued until the patient comes to the operating room. Particular attention to avoidance of myocardial ischemia is necessary during induction of anesthesia and in the period before cardiopulmonary bypass.

Methods of myocardial management during cardiopulmonary bypass are variable, probably because uncomplicated cases good results are being obtained with all the methods that are commonly in use, and in complex and seriously ill patients few methods have been documented to result in less myocardial necrosis and better survival than any other. Most methods of myocardial management impose certain requirements on the sequencing and techniques of the coronary artery bypass operation, and changes from a successful method of myocardial management should not be made without the surgeon’s consideration of the possible unfavorable effect of the combination of his or her particular
technique of operation with a new method of myocardial management. The most important aspect of myocardial management is the continuous, thoughtful attention given to it by the surgeon and anesthesiologist throughout the operation.

One successfully used technique includes no periods of global myocardial ischemia during moderately hypothermic cardiopulmonary bypass. When this method is used, the operation may be facilitated and outcomes improved by continuous ventricular fibrillation (11). A second successfully used method is that of intermittent occlusion of the ascending aorta, often preceded by the administration of nifedipine, lidoflazine or similar agents (12,13). A third technique that has given good results is the use of a single period of profoundly hypothermic global myocardial ischemia, achieved by profoundly cooling the heart before cross-clamping and maintained by irrigating the pericardial space with cold saline solution (14). A fourth and commonly used technique is cold cardioplegia and a single period of global myocardial ischemia (15,16) with antegrade or retrograde infusion, or both, of a hyperkalemic solution. A fifth method that has given good results is cold sanguineous cardioplegia plus controlled initially hyperkalemic reperfusion and, under special circumstances, warm cardioplegic induction. This latter technique may have particular advantages when left ventricular function is chronically or acutely depressed preoperatively (17-20).

After cardiopulmonary bypass, arterial hypotension or hypertension is avoided by appropriate management of blood volume and by drug therapy, and heart rate and rhythm are controlled, when necessary, by pacing with temporary epicardial atrial and ventricular pacing wires. Ventricular arrhythmias are minimized by appropriate myocardial management during the coronary artery bypass operation, but drug therapy may occasionally be necessary early postoperatively.

Infrequently in uncomplicated cases with good myocardial management, but more commonly in patients who come to the operating room with acute or chronic severe impairment of left ventricular function, a temporary assist device is required after cardiopulmonary bypass. In this circumstance, the intraaortic balloon is used most commonly. Left ventricular and biventricular assist devices can be used when the balloon is ineffective, but the frequency of their need and their risk/benefit ratio when myocardial management has been optimal remain to be determined.

III. Status After the Coronary Bypass Operation (Outcome Events)

The coronary artery bypass graft operation has a favorable effect on symptoms and useful life expectancy in many patients. However, it does not cure arteriosclerotic heart disease, and in most patients at some point, usually many years after operation, clinical evidence of myocardial ischemia returns and is followed by death, which in more than half the patients is related to recurrent myocardial ischemia. This section addresses the nature of the post coronary artery bypass state by categorizing and describing the results of the operation in terms of the probability of freedom from unfavorable outcome events and the risk factors that work against optimal outcome.

The interval between coronary artery bypass surgery and the time of occurrence of unfavorable outcome events is highly variable and of great importance to the patient and to society. Therefore the results (the probability of freedom from an outcome event) are depicted in a time-related manner. This is accomplished by use of 1) the life table method (most commonly and advantageously that of Kaplan and Meier [21]), reinforced by multivariable estimates of relative risks by the Cox-Breslow method (22,23), or 2) a parametric method in the multivariable hazard function domain (24). The multivariable analyses identify risk factors that independently affect outcomes and determine the strength of their effect. The analyses must be multivariable, parsimonious and conducted with medical knowledge, because 1) the effects of risk factors are incremental, 2) some risk factors interact with others in specific ways, and 3) some characteristics that seem to be risk factors are surrogates for more fundamental risk factors.

This is all necessary because patients with coronary artery disease requiring treatment have characteristics that may vary enormously from one patient to another. Many of these characteristics are prognostically important, whatever the form of treatment of the patient. Some patients have other important diseases that have an impact on outcome after coronary artery bypass surgery and other kinds of treatment, and thus on the indications for the various forms of therapy. The operation is complex (Section II), and can vary considerably among patients, surgeons and institutions. It follows that the simple depiction of the time-related freedom from an untoward event in a heterogeneous group of patients is of limited value in understanding the nature of the post coronary bypass state, the appropriateness and effectiveness of the bypass operation in comparison with alternative methods, and the probable outcome in a specific patient coming for treatment of ischemic heart disease.

A. Survival (Freedom From Death)

Death from any cause is a secure end point with which to judge the efficacy of coronary artery bypass surgery, and to compare it with alternative forms of therapy. In general, about 96.5% of heterogeneous groups of patients survive at least 1 month after the operation, and 95%, 88%, 75% and 60%, respectively, survive 1, 5, 10 or >15 years after the operation (Table 2). The time-related survival, and the hazard function are shown in Figure 1. (The hazard function depicts the instantaneous risk of an event, such as death, at each moment in time after the starting point in time [time zero], which here is the time of the bypass operation. It may
Table 2. Survival After the Coronary Artery Bypass Graft Operation*

<table>
<thead>
<tr>
<th>Report</th>
<th>Percent Freedom From Death</th>
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<tbody>
<tr>
<td></td>
<td>1 Year</td>
</tr>
<tr>
<td>European Randomized Trial (25)</td>
<td>96.8</td>
</tr>
<tr>
<td>CASS Randomized Trial (26,27)</td>
<td>98.5</td>
</tr>
<tr>
<td>VA Randomized Trial (28)</td>
<td>95</td>
</tr>
<tr>
<td>VA Randomized Trial, left main disease (29)</td>
<td>94</td>
</tr>
<tr>
<td>VA Randomized Trial, unstable angina (30,31)</td>
<td>97</td>
</tr>
<tr>
<td>CASS Registry (3 vessel disease, mild angina) (32)</td>
<td>96.8</td>
</tr>
<tr>
<td>CASS Registry (3 vessel disease, severe angina) (33)</td>
<td>95.1</td>
</tr>
<tr>
<td>Bishop lecture (UAB) (34)</td>
<td>99</td>
</tr>
<tr>
<td>Katholieke Universiteit, Leuven, Belgium (Sergeant and colleagues) (5,6)</td>
<td>98</td>
</tr>
</tbody>
</table>

*The differing prevalence of risk factors in the different groups is the most likely explanation for the differing percent survival data. CASS = Coronary Artery Surgery Study; UAB = University of Alabama at Birmingham; VA = Veterans Affairs.

be thought of as the rate at which that event is occurring at each point in time after time zero. The percent of patients free from the event [here the percent survival] at any point in time after time zero represents the accumulation of all the hazard functions, or rates, up to that point.)

The prevalence of risk factors in a group of patients, and the degree to which they are present in individual patients, decreases or increases the probability of death after coronary artery bypass surgery. The risk factors for death after the coronary bypass operation are shown in Table 3, and most of the preoperative risk factors are also risk factors for death in patients with arteriosclerotic coronary artery disease managed by any method. The risk factors for other unfavorable outcomes after the bypass operation are similar to these, although not identical. Many risk factors are specific to the early period after operation; others have their effect late postoperatively.

Patients may live comfortably and productively after coronary artery bypass surgery, or they may have other interval events and may undergo repeat bypass surgery, coronary angioplasty or even cardiac transplantation.

B. Modes of Death

The precise cause of death can uncommonly be assigned, and this is particularly true in the complex situation of ischemic heart disease. Modes of death can be assigned with reasonable reproducibility. Cardiac death is the most prevalent mode (Table 4).

Studies using cardiac death (rather than all deaths) as an end point after the coronary artery bypass operation have demonstrated that 1) the probability of cardiac death early postoperatively is less after operations performed in the recent era than in earlier years, 2) the more severe and extensive the coronary artery disease, the greater is the comparative benefit of the operation over medical treatment, and the less severe and extensive the disease the less the comparative benefit, and 3) the more severe the left ventricular dysfunction, the greater the comparative benefit of the operation (35) (see Appendix, Fig. B1 and B2). The risk factors and inferences when using cardiac death as the end point are similar to those derived when all deaths are used as the end point, and the two kinds of analyses reinforce each other.

C. Return of Angina

The evidence, both symptomatic and from graded exercise testing, is complete that the coronary artery bypass operation relieves angina in most patients. However, the return of angina is the most prevalent of the postoperative ischemic events (Fig. 2). The hazard function for return of angina begins to rise after about 5 years (Appendix, Fig. B3). The return of angina very early after coronary bypass surgery, typically recognized with resumption of activity, usually is due to incomplete revascularization or early closure of grafts. Angina occurring later usually is a reflection of narrowing or closure of one or more grafts or progression of native vessel disease, or both.

The risk factors for the return of angina are similar but not identical to those for death (see Appendix B). Nonuse of the internal mammary artery is not a risk factor (Appendix, Fig. B4), and this observation suggests that survival depends in a major way on a continuing blood supply to the left anterior descending artery with its septal branches, while angina may return as a result of recurrent or new ischemia in the distribution of the right or circumflex coronary systems without necessarily predicting death.
D. Perioperative and Postoperative Myocardial Infarction

Perioperative myocardial infarction is usually defined by the appearance of new Q waves on the ECG, but non Q wave perioperative myocardial infarction may occur (usually identified by changes in serum levels of myocardial enzymes) and may be significant clinically. Perioperative myocardial infarction is an important risk factor for later death (36) but its incidence has been reduced from about 5% to 8% in the Coronary Artery Surgery Study (CASS) era to about 2.5% currently (37,38) as methods of myocardial management before, during and early after operation have improved.

Although documentation is difficult, the evidence suggests that postoperative myocardial infarction after the perioperative period is uncommon in the first few years after bypass surgery, and by 5 years postoperatively about 95% of patients are still free of nonfatal and fatal postoperative myocardial infarction (Sergeant PT, Blackstone EH, Lesaffre E, Flameng W, Kirklin JW. Unpublished study, 1990). However, only about 85% and 65% are free of myocardial infarction 10 and 15 years, respectively, after operation. As in the case of angina, the hazard function for postoperative myocardial infarction begins to increase about 5 years after the coronary bypass operation. The risk factors for myocardial infarction after the operation are similar to those for death and other unfavorable events after the operation.

E. Sudden Cardiac Death After the Coronary Bypass Operation

Sudden cardiac death is uncommon in general after the bypass operation (see Table 4). By 10 years after undergoing the operation, 95% of patients are free of sudden death, as are about 90% by 15 years (39).

F. Heart Failure

Only 5% to 10% of deaths after the coronary bypass operation occur in patients with the syndrome of chronic heart failure (see Table 4). In part, this is because patients...
Table 3. Preoperative and Operative Risk Factors for Increasing the Probability of Death Early or Late After a Primary Coronary Artery Bypass Operation*

<table>
<thead>
<tr>
<th>Risk Factors</th>
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<tbody>
<tr>
<td>Demographic</td>
<td></td>
</tr>
<tr>
<td>Age at coronary bypass operation (older)</td>
<td></td>
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<tr>
<td>Body size (smaller)</td>
<td></td>
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<tr>
<td>Gender (female)</td>
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<tr>
<td>Clinical status</td>
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<tr>
<td>Angina (Canadian class 0 to IV) (more severe)</td>
<td></td>
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<tr>
<td>Unstable angina</td>
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<tr>
<td>Response to stress testing (more severe)</td>
<td></td>
</tr>
<tr>
<td>Acute myocardial infarction</td>
<td></td>
</tr>
<tr>
<td>Hemodynamic instability (grade 0 to 4) (more severe)</td>
<td></td>
</tr>
<tr>
<td>NYHA functional class (I to IV) (higher)</td>
<td></td>
</tr>
<tr>
<td>Distribution and severity of coronary artery disease (greater)</td>
<td></td>
</tr>
<tr>
<td>Left ventricular dysfunction (grade 0 to 4) (more severe)</td>
<td></td>
</tr>
<tr>
<td>Aggressiveness of arteriosclerotic process</td>
<td></td>
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<tr>
<td>Diffusely diseased coronary arteries</td>
<td></td>
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<tr>
<td>Peripheral vascular disease</td>
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<tr>
<td>Cerebrovascular disease</td>
<td></td>
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<tr>
<td>Hyperlipidemia (more severe)</td>
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<tr>
<td>Age at coronary bypass operation (younger)</td>
<td></td>
</tr>
<tr>
<td>Coexisting disease</td>
<td></td>
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<tr>
<td>Diabetes</td>
<td></td>
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<td>Hypertension</td>
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<tr>
<td>Pulmonary disease (more severe)</td>
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<tr>
<td>Stroke</td>
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<tr>
<td>Smoking</td>
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<tr>
<td>Surgical factors</td>
<td></td>
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<tr>
<td>Date of operation (earlier)</td>
<td></td>
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<tr>
<td>Nonuse of IMA to LAD</td>
<td></td>
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<tr>
<td>Incomplete revascularization</td>
<td></td>
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<tr>
<td>Perioperative myocardial infarction</td>
<td></td>
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<tr>
<td>(inadequate myocardial management)</td>
<td></td>
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<tr>
<td>Surgeon</td>
<td></td>
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<tr>
<td>Institutional factors</td>
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</tbody>
</table>

*This table is not the result of a specific multivariable analysis, but is a composite depiction of data from many studies. IMA = internal mammary artery; LAD = left anterior descending coronary artery; NYHA = New York Heart Association.

with ischemic heart disease and important chronic heart failure usually have severe left ventricular dysfunction as a result of extensive myocardial scarring, and are not advised to undergo bypass surgery (see Section VI).

G. Unsatisfactory Quality of Life

It is nearly impossible to quantify an unsatisfactory quality of life after the coronary bypass operation, even though it is one of the most important unfavorable outcome events. This relates in part to the fact that an unsatisfactory quality of life is a composite of at least freedom from limiting angina or heart failure, the preservation of a reasonable exercise capacity and reasonable freedom from the need for medication, rehospitalization and reintervention. Most surviving patients have a satisfactory quality of life early after the bypass operation, but the probability of retaining this quality begins gradually to decline after about 5 years (40). The rate of decline in the quality of life is probably similar to that of the freedom from angina (see Fig. 2).

As in all other outcome events, the probability of freedom from an unsatisfactory quality of life in an overall heterogeneous group is of limited value when considering individual patients. The risk factors for an unsatisfactory quality of life after the coronary bypass operation have not been rigorously defined but are probably a combination of those for the return of angina and those for failure to return to work.

H. Failure to Work

Failure to work is, like other unfavorable outcome events, a time-related phenomenon. However, the relation to time has been less thoroughly studied for this outcome event than for many other outcome events, but it is probably similar to that of angina. Thus freedom from failure to work probably begins to diminish about 5 years after the coronary bypass operation (40).
A common belief is that the coronary artery bypass operation does not improve the prevalence of gainful employment among patients with ischemic heart disease (41,42), but this has not been a universal finding (43,44). The failure to take into account the differing prevalences of risk factors for failure to work after the coronary bypass operation explains many of the discrepancies in results (44). Patients who were working before the operation have the highest prevalence of being employed after the operation (42,45). However, under favorable circumstances, as defined by the risk factors (Table 5), >80% of patients not working at the time of bypass surgery are working 1 year later; only ≤20% are working postoperatively when the risk factors are unfavorable (47,48). Likewise, patients who are free of angina after the bypass operation are considerably more likely to be working than are those with angina (45).

Further confusing this issue are the vagaries of disability programs and the reluctance of employers to rehire patients who have had bypass surgery even if they are asymptomatic.

1. Neurobehavioral and Neurologic Outcomes After Coronary Bypass Surgery

Unrelated to the cardiac aspects of the coronary bypass operation, the damaging effects of the cardiopulmonary bypass usually required for the operation result in neurobehavioral disturbances in some patients. These are sufficiently mild that they may not be apparent unless patients are tested specifically for them, and their prevalence has been somewhat reduced recently by the incorporation of appropriate filters in the arterial line from the pump oxygenator to the patient. As many as 75% of patients exhibit these subtle defects when tested 8 days after operation, but by 3 months postoperatively only about 10% to 30% exhibit them (49,50). The prevalence is unfavorably affected by postoperative anxiety and depression, and by older age (51). Only rarely are patients aware of or handicapped by these defects (52).

Gross neurologic defects, usually in the form of transient or permanent sequelae of strokes, are more serious but fortunately are considerably less common. They are more likely to result from embolization of atherosclerotic debris.

Table 5. Risk Factors for Time-Related Failure to Work After the Coronary Artery Bypass Operation*

<table>
<thead>
<tr>
<th>Demographic</th>
<th>Risk Factors</th>
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<tbody>
<tr>
<td>Age at operation (older)</td>
<td></td>
</tr>
<tr>
<td>Educational time (shorter)</td>
<td></td>
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<tr>
<td>Preoperative work conditions</td>
<td></td>
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<tr>
<td>Physical effort on the job (grade) (greater)</td>
<td></td>
</tr>
<tr>
<td>Duration of absence from work (longer)</td>
<td></td>
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<tr>
<td>Income from work (lower)</td>
<td></td>
</tr>
<tr>
<td>Clinical status</td>
<td></td>
</tr>
<tr>
<td>Duration of preoperative angina (years) (longer)</td>
<td></td>
</tr>
<tr>
<td>Severity of preoperative angina (greater)</td>
<td></td>
</tr>
<tr>
<td>Aggressiveness of arteriosclerotic process</td>
<td></td>
</tr>
<tr>
<td>Peripheral vascular disease (more)</td>
<td></td>
</tr>
<tr>
<td>Coexisting disease</td>
<td></td>
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<tr>
<td>Alcohol intake (more)</td>
<td></td>
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<tr>
<td>Surgical factors</td>
<td></td>
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<tr>
<td>Date of operation (earlier)</td>
<td></td>
</tr>
<tr>
<td>Postoperative factors</td>
<td></td>
</tr>
<tr>
<td>Duration of absence of angina after coronary bypass surgery (shorter)</td>
<td></td>
</tr>
<tr>
<td>Cardiac rehabilitation program (nonparticipation)</td>
<td></td>
</tr>
</tbody>
</table>

*Inferences based on the work of Boulay et al. (44) and Varnauskas et al. (46).
from the ascending aorta or from air embolization than from the damaging effects of cardiopulmonary bypass. The prevalence is about 0.5% in relatively young patients, but rises to about 5% in patients >70 years of age and to about 8% in those >75 years (53,54).

J. Graft Disease and Patency

The highest patency rates for coronary bypass grafts are associated with use of the left internal mammary (thoracic) artery to bypass important proximal stenoses of the left anterior descending coronary artery. These patency rates are approximately 95% at 10 years after operation (4), and closure of the mammary artery after that time is uncommon. Few factors appear to affect the patency rate of the internal mammary artery when anastomosed to the anterior descending artery. This favorable performance of the internal mammary artery when anastomosed to the left anterior descending coronary artery is probably due to its particular wall structure and function, and the potentially large runoff through the left anterior descending artery system. Internal mammary artery grafts to other vessels appear to have lower patency rates late postoperatively than do those to the left anterior descending artery, and these may be no greater than those of vein grafts (10).

The patency rates of the other arterial conduits currently in use (see Section II) have not as yet been reliably determined.

Saphenous vein grafts used as conduits in the coronary artery bypass operation develop diseases of their own, which contribute importantly to ultimate stenoses and occlusions. Diffuse intimal hyperplasia is a universal finding in vein grafts that have been in place for >1 year. Perhaps unrelated to this finding, about 10% of vein grafts close within the first few postoperative weeks, at least when antiplatelet therapy is not used. By 3 to 5 years after vein graft placement, frank atherosclerotic lesions are identifiable in many of these grafts (55). By 10 years after insertion, half of vein grafts still patent have undergone at least some arteriosclerotic changes (56). These changes result in localized or diffuse narrowings which progress at a highly variable rate.

The 10 year patency rate of vein grafts appears to be highly variable, and in some reports (57,58) only 50% to 60% overall are still patent. Other reports (4) indicate that the patency rate of vein grafts depends in part on the coronary artery to which they are anastomosed, with about 80% of those to the left anterior descending artery being patent at 10 years, and only 70% to 75% of those to other vessels. The mean yearly attrition rate of vein grafts after 10 years is about 5%/year$^{-1}$ (57,59). Arm veins have a still lower prevalence of patency (60), as do synthetic conduits.

Lesser distal runoff, determining as it does the flow through the graft, reduces saphenous vein graft patency rates. Therefore, patency rates are lower when the anastomosis is to small coronary arteries and to arteries supplying areas with considerable scar. Whether the placement of two or more distal anastomoses on a vein graft (sequential grafting) increases or decreases patency rates is arguable.

Patency rates of saphenous vein grafts can be improved by the administration of antiplatelet drugs (see Section VII).

K. Reintervention after Coronary Bypass Surgery

Reintervention, either a second bypass operation or coronary angioplasty, is sometimes indicated in the years after the first bypass operation, because of evidence of important recurrent myocardial ischemia. As would be expected, reintervention is uncommon within 5 years of the bypass operation but more frequent thereafter (Sergeant PT, Blackstone EH, Lesaffre E, Flameng W, Kirks JW. Unpublished study, 1990). A few patients require a third bypass operation, and a very few a fourth.

The early risks of a second bypass operation are about twice those of a first bypass operation. Most of the increased risks are related to an increased prevalence of unfavorable risk factors in patients undergoing a second bypass operation (60a).

IV. Comparisons of Coronary Artery Bypass Surgery With Medical Therapy

Comparisons of outcome after the coronary bypass operation with that after alternative forms of treatment are best done in terms of the time-related comparative benefit (appropriateness) of the bypass operation (35). End points in such comparisons may be freedom from death (survival), from angina, from fatal or nonfatal myocardial infarction, from sudden death or from the coronary bypass operation itself (repeat bypass operation if the initial therapy was the bypass operation, otherwise the first bypass operation after some other form of initial therapy). Death is the most unequivocal of these, and the available information suggests that the time-related comparative benefit of the coronary bypass operation is at least as great when any of the other end points are used. Therefore, and because of limitations of space, survival is the end point used for the comparisons in this section.

The methodology for making the comparisons used by the Subcommittee are presented in Appendix C.

The comparisons in this report refer to the initial coronary bypass operation in comparison with some other form of initial therapy. The "initial" refers to therapy at the time of decision-making, whether it is the first or a subsequent episode of decision-making. All analyses of outcome described in the report are by the so-called intention-to-treat principle, and patients are not deleted (censored) from the analyses if at some subsequent time a different treatment is used (61). Unfortunately, there is no valid way to compute
outcome after isolated medical treatment, coronary bypass surgery or coronary angioplasty in an era in which later crossover after any form of initial therapy is not only allowed but is often good management (61).

The comparisons in this section are based on the known risk factors but of necessity address only a single risk factor at a time. As such, they are useful in providing background information, but comparisons in this format are of limited value in decision-making for individual patients, because all of the patient-specific risk factors together, not just one alone, determine outcome in individual patients. Thus the patient-specific comparisons for individual patients, discussed in Section X, should be more useful as an aid to decision making.
A. Comparison According to Severity of Angina

In general, the more severe the angina, the less favorable the outcome after initial medical therapy, while outcome after the coronary artery bypass operation as initial therapy is relatively unaffected by the preoperative severity of angina (32-33) (Fig. 3). This relates to the fact that the severity of the angina is a surrogate (substitute) for the magnitude of the decrement in myocardial blood flow reserve, and this risk factor is neutralized by the coronary bypass operation when essentially complete revascularization is achieved. Thus the benefit of initial surgical treatment, compared with that of initial medical treatment, is in general greater, the more severe is the angina.

B. Comparison According to Objective Evidence of Ischemia

The inferences concerning angina, a symptom of reversible myocardial ischemia, are reinforced by similar comparative benefits when the amount of reversible myocardial ischemia is examined by electrocardiographic (ECG), functional or perfusion evidence of ischemia during graded exercise testing. The more severe the exercise-induced ischemia, the greater the comparative benefit of initial coronary bypass operation (see Appendix Fig. C1) (25).

C. Comparison According to Instability of Angina

Overall, patients with unstable angina and with continuing medical surveillance have a 5 year survival rate that is similar whether the initial treatment after the instability has subsided is surgical (the coronary bypass operation) or medical (see Appendix Fig. C2) (31). However, about 20% of patients initially given medical treatment are advised to have and actually undergo the coronary bypass operation within 6 months of the initial treatment and nearly 50% undergo the operation within 5 years (31). This observation emphasizes the importance of continuing surveillance of patients with unstable angina receiving initial medical therapy.

The importance of the interrelation of apparently independent risk factors is emphasized by the fact that, when unstable angina is combined with three vessel coronary artery disease, there is a considerable comparative benefit from initial surgical rather than initial medical treatment with a low early risk and for at least 5 years (31) (see Appendix Fig. C2), in contrast to the findings in a heterogeneous group of patients with unstable angina.

D. Comparison According to Location and Severity of the Stenoses

The early and late risks of the coronary bypass operation are not increased by the presence of left main coronary artery disease unless the stenosis is extremely severe (>90%) (6,34), but the risks of initial medical treatment are considerably increased. As a result, in general there is comparative benefit in favor of initial coronary bypass surgery rather than initial medical treatment, which becomes greater as the severity of the left main stenosis increases (29) (see Appendix Fig. C3).

In general, the greater the number of major coronary arteries with important stenoses, the less the time-related survival with initial medical treatment. Since the time-related survival after coronary bypass surgery is only weakly affected by the number of diseased vessels (33,35), the surgical benefit is greater, the greater the number of diseased vessels. The greater is the number of vessels with important proximal stenoses, the greater the comparative benefit of surgery, because survival after initial medical treatment declines as the number of proximal stenoses increases whereas that after coronary bypass surgery does not (see Appendix Fig. C4) (33).

A proximal stenosis in the left anterior descending coronary artery appears particularly to increase the comparative surgical benefit (25) (see Appendix Fig. C5).

E. Comparison According to Left Ventricular Function

In general, the more severe is the left ventricular dysfunction, the greater is the comparative benefit from surgery (see Appendix Fig. C6), even though the early and late results of the coronary bypass operation are somewhat less good in patients with important left ventricular dysfunction than in those with essentially normal left ventricular function (33,35). The comparative benefits of the coronary bypass operation are particularly great when associated risk factors such as extensive coronary artery disease and severe ischemia are also present (36).

Extreme left ventricular dysfunction is usually an indication of extensive left ventricular scarring, with little or no “reversible ischemia.” Under these circumstances, the prognosis with both initial medical and initial surgical treatment is limited. However, the precise level of ejection fraction (or CASS score) that is indicative of lack of any substantial surgical benefit is not yet established but is probably less than 0.2 or even 0.15 (see more detailed discussion in Section VI).

Patients with important left ventricular dysfunction but truly without reversible ischemia do not benefit from the operation.

F. Comparison According to Age

Currently available information indicates that the comparative advantages of coronary artery bypass surgery in patients >65 years of age are similar to those in younger patients. There must be an age level above which the comparative benefits of surgical treatment lessen, other factors being equal, but currently this level has not been identified. Surgical experiences suggest that it may be at >70 years of age, although hospital stay is longer and early complications more frequent in the very elderly (62-68).
G. Comparison According to Length of Follow-Up

The probability of survival after the coronary artery bypass operation and that after initial medical therapy have tended to approach each other by the time the follow-up periods have become 10 to 15 years in length (see Section XI and Fig. 6 and 7). The explanations for this are complex and include the probability that progression of atherosclerotic disease in vein grafts is more rapid than that in native coronary arteries. It remains to be determined whether aggressive risk factor modification after revascularization and widespread use of the internal mammary artery for grafting the left anterior descending artery will change this situation.

H. Summary

The foregoing has described briefly the available information concerning the advantages, when they exist, of the coronary artery bypass operation over medical treatment. A broader, conceptually useful view of the role of interventional therapy in patients with ischemic heart disease can be obtained from Figure 4, adapted from the study by Califf et al. (35). Survival with medical treatment is dependent on 1) the number (and type) of coronary arteries whose stenoses have been completely "neutralized" by the bypass operation (represented by the isobars), and 2) the survival with medical treatment. It follows that the potential comparative benefit from the bypass operation is limited by the number of vessels with important stenoses to be neutralized. A more subtle implication is that survival after the operation is the least good in patients anticipated to have poor survival with medical treatment, even though the comparative benefit is the greatest; conversely, the survival rate is highest in patients anticipated to have good survival with medical treatment, even though the comparative benefit is the least in such patients. Study of Figure 4 indicates that, conceptually, even patients with single vessel disease, neutralized by the coronary bypass operation, achieve some comparative benefit with respect to survival (assuming that the risk of the interventional procedure itself is negligible). However, when left ventricular function is good and all other risk factors indicate a high probability of survival with medical treatment (95% freedom, along the horizontal axis), the comparative benefit is small, probably not identifiable, and of insufficient magnitude to indicate an advantage for the bypass procedure. The benefit is greater in patients with two and three vessel disease. When left ventricular dysfunction is present, and this and other risk factors move the patient to the left on the horizontal axis, the comparative benefits of one, two and three vessel disease become still larger and more easily identified.
Although these concepts were derived from an analysis in which the coronary bypass operation was the interventional therapy, they apply to coronary angioplasty as well. However, it must be remembered that the isobars in Figure 4 represent vessels whose stenoses have been completely neutralized by the intervention. When they are not, the figure does not apply.

V. Comparisons of the Coronary Bypass Graft Operation With Coronary Angioplasty

The paucity of proper risk-adjusted comparisons, and the absence of comparisons from randomized trials, among 1) coronary artery bypass grafting, 2) percutaneous transluminal coronary angioplasty, and 3) medical treatment, is severely limiting to this report and to clinical practice. The results of the ongoing trials designed to compare these treatments will not be known for a considerable period of time. Yet, ignoring the effect of the existence of coronary angioplasty on the indications for the coronary bypass operation is unrealistic (see Section VI for further details). Therefore, the comparative information that exists is presented.

Coronary angioplasty offers, in general, a major comparative advantage over the coronary bypass operation in that no surgical procedure and usually no cardiopulmonary bypass are required, the hospital stay is shorter, and procedure-related disability is generally less. This could make coronary angioplasty the advisable therapy in patients in whom the freedom from unfavorable outcome events after that procedure can reliably be shown to be similar to the freedom after the bypass operation.

A. Survival

Nonrisk-adjusted comparisons of survival out to 5 years in heterogeneous groups of patients have shown no or small differences in this regard between initial coronary bypass surgery and initial coronary angioplasty (69–73) (See Appendix Figure D1, which shows a small advantage of coronary angioplasty, not confirmed when risk-factor adjustment was made). Risk-adjusted comparisons are few, but they suggest that most elderly patients with three vessel coronary artery disease have a considerable comparative survival benefit from an initial coronary bypass operation over that obtained by initial coronary angioplasty (see Appendix Fig. D2); that some patients with two vessel disease receive a considerable comparative benefit from the bypass operation relative to angioplasty; and that few patients with one vessel disease have a comparative benefit from the bypass operation over angioplasty with respect to survival (73).

B. Freedom From Recurrence of Angina

Most comparative studies indicate that the duration of freedom from angina is less after initial coronary angioplasty than after initial coronary bypass surgery (69,71–75) (see Appendix Fig. D3), although in one of the studies with a follow-up of about 2 years the difference was small (74).

C. Freedom From Myocardial Infarction After the Procedure

Time-related freedom from myocardial infarction after the coronary bypass and after coronary angioplasty have been found to be similar in two studies (73,74). One study (70) found an advantage of the bypass operation in this regard.

D. Freedom From Crossover to Coronary Bypass Surgery After Coronary Angioplasty

Currently available information indicates that, in heterogeneous groups of patients undergoing coronary angioplasty, freedom from crossover to a subsequent coronary bypass operation is 85% to 90% within 1 year of angioplasty, 81% within 3 years (72), and 75% to 86% within 5 years (69,70,73,76). This crossover, like other end points, is affected by risk factors, and a risk factor-adjusted analysis in elderly patients showed the freedom from crossover within 5 years after coronary angioplasty to be 86%, 78% and 30% in patients with one, two and three vessel disease, respectively (73).

VI. Indications for the Coronary Artery Bypass Operation

A. Introduction

The coronary artery bypass operation is indicated for the relief of symptoms (primarily angina) that are unresponsive to medical treatment (or to coronary angioplasty), particularly when the duration of freedom from unfavorable events (death, myocardial infarction, return of angina) can with reasonable confidence be predicted to be appreciably longer than with other forms of treatment. The indications as discussed in this section are general, and derived, inasmuch as possible, from information about freedom from death (survival) and from other unfavorable outcome events after the coronary bypass operation (see Section III), and about the comparative benefit, positive or negative, of this operation compared with medical treatment (Section IV). However, a general discussion of indications must of necessity be an oversimplification as it can be based on only a few general risk factors. This has led to some differences of opinion about the treatment classes for the tables. Differences of opinion among experts would undoubtedly be very much less in individual patients in whom patient-specific predictions and comparisons had been made (see Section X).

Although only a relatively small amount of pertinent, comparative information is available about outcomes after coronary angioplasty (Sections V and X), the experience with the technique and the prevalence of its use must affect current judgments as to indications for the coronary bypass operation. Thus assignment of treatment class 1 indicates that the bypass operation has a comparative advantage over
medical treatment, and suggests but does not specifically indicate that it has an advantage over coronary angioplasty. (See Table 1 for description of treatment classes.) Assignment of treatment class II indicates that the comparative benefits of the bypass operation relative to medical treatment have not yet been fully defined, and suggests, but does not specifically indicate, that the same is true relative to coronary angioplasty. Assignment of treatment class III indicates that the bypass operation is generally considered not to be appropriate, specifically because of a lack of demonstrated advantage over medical treatment and, by suggestion, over coronary angioplasty.

The indications for the coronary artery bypass operation as discussed in this section are useful for background information, and as guides to be modified by more patient-specific predictions and comparisons (see Section X) than were possible within the confines of this report, and by clinical judgment. The adaptability of the patient to the stress and morbidity of the coronary bypass operation, and the patient’s other obligations and desires, must also be considered in detail by the physician as he makes therapeutic recommendations. The patient, after learning the physician’s recommendations and the risks and benefits of the procedure, should make the actual decision.

Most patients with ischemic heart disease require a number of therapeutic recommendations during the lifetime of their chronic condition, and the coronary artery bypass operation is a treatment that needs to be considered in many of these. The recommendation at any one time to use medical treatment or coronary angioplasty rather than the coronary bypass operation does not preclude the possibility that the bypass operation will be advisable at a subsequent time.

B. Limitations in the Method of Presentation

The current indications for the coronary artery bypass operation are presented in the traditional categories, using general statements and tables. The terms used in the tables are defined in Appendix E. Inevitably, some combinations in tables of this kind are recognized as occurring infrequently. This dilemma indicates the advantages of the more patient-specific predictions and comparisons (Section X) as bases for advice to patients.

The tables could not be made sufficiently detailed to take into account certain important but only occasionally pertinent situations. As examples, patients with two vessel disease with severe proximal stenoses of the left anterior descending and left circumflex arteries appear to have the same advantages from coronary bypass surgery as do patients with three vessel disease (25,77,78). They represent exceptions to the treatment class assigned to two vessel disease, and are in the treatment class for similar patients with three vessel disease. Severe proximal stenosis (>90%) of the left anterior descending coronary artery and multiple stenoses of this vessel appear to impose a poorer outcome with medical treatment and a greater comparative advantage of coronary bypass surgery than do other important stenoses of this artery (25). Important left main coronary artery disease is defined as a ≥50% reduction of luminal diameter, but the prognosis with medical treatment worsens and the comparative benefit of coronary bypass surgery increases as the severity of the stenosis increases beyond this (29,79). The advantages of the coronary bypass operation in patients with left main coronary artery disease may be greater in patients with a left dominant system, although this is unproved.

The tables apply only to patients with an ejection fraction >0.20. The indications for coronary bypass surgery in patients with an ejection fraction ≤0.20 require special consideration. First, the possible comparative benefits of the coronary bypass operation in patients with an ejection fraction between 0.10 and 0.20 have not been fully described, although evidence of benefit has been presented (80). Second, there appear to be circumstances in which the severely reduced ejection fraction is related to ischemic myocardial stunning (hibernation) rather than fixed scarring. Exercise or rest thallium-201 scintigraphy may be particularly helpful in distinguishing between scar and ischemia in such situations. In any event, the coronary bypass operation in these circumstances can be considered if it is performed under proper conditions, but not as routine therapy.

C. Timing of the Coronary Bypass Operation

All surgical procedures, including the coronary bypass operation, are most safely and efficiently performed as regularly scheduled procedures. With currently available information and treatment modalities, and under most circumstances, the bypass operation should be performed as an unscheduled emergency procedure only when there is refractory hemodynamic or ischemic instability. However, in the presence of such instability, an unscheduled (emergency) coronary bypass operation is indicated no matter what the time of day or night.

D. Indications for the Coronary Bypass Operation

I. Asymptomatic patients. Patients in this category are generally well, with no or very mild angina on strenuous exertion. The great majority of asymptomatic persons who undergo coronary angiography will have had noninvasive testing indicative of myocardial ischemia.

The coronary artery bypass operation is indicated only uncommonly for asymptomatic patients with no or mild myocardial ischemia with noninvasive stress testing, and treatment class I is, in general, limited to patients with important left main coronary artery stenosis (81) and those with important three vessel disease with severe proximal stenosis of a large left anterior descending coronary artery. When the noninvasive stress testing in asymptomatic pa-
Table 6. Treatment Class of the Coronary Artery Bypass Operation in Asymptomatic Patients

<table>
<thead>
<tr>
<th>Indication Class</th>
<th>CAD</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe (but EF &gt;0.20)</th>
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</thead>
<tbody>
<tr>
<td>Left Ventricular Dysfunction</td>
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<tr>
<td>A. No or Mild Myocardial Ischemia With Noninvasive Stress Testing</td>
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<td></td>
</tr>
<tr>
<td>Left main</td>
<td></td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
</tr>
<tr>
<td>3 vessel</td>
<td>II*</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
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<tr>
<td>2 vessel</td>
<td>III*</td>
<td>I</td>
<td>I</td>
<td>I</td>
<td>I</td>
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<tr>
<td>1 vessel</td>
<td>IIII</td>
<td>I</td>
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<tr>
<td>B. Moderate or Severe Myocardial Ischemia With Noninvasive Stress Testing</td>
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<tr>
<td>Left main</td>
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<tr>
<td>3 vessel</td>
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<tr>
<td>2 vessel</td>
<td>III*</td>
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<tr>
<td>1 vessel</td>
<td>IIII</td>
<td>I</td>
<td>I</td>
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</table>

*Class I if there is severe proximal left anterior descending and left circumflex coronary artery stenoses. †Class II if there is severe proximal stenosis in a large left anterior descending coronary artery. ‡Class I if there is severe proximal stenosis in a large left anterior descending coronary artery. CAD = coronary artery disease.

Table 7. Treatment Class of the Coronary Artery Bypass Operation in Patients With Chronic Stable Class I or II Angina

<table>
<thead>
<tr>
<th>Indication Class</th>
<th>CAD</th>
<th>None</th>
<th>Mild</th>
<th>Moderate</th>
<th>Severe (but EF &gt;0.20)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left Ventricular Dysfunction</td>
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<tr>
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<td>Left main</td>
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<tr>
<td>3 vessel</td>
<td>II*</td>
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<tr>
<td>2 vessel</td>
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<td>IIII</td>
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<tr>
<td>B. Moderate or Severe Myocardial Ischemia With Noninvasive Stress Testing</td>
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<tr>
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<td>3 vessel</td>
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<td>2 vessel</td>
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<tr>
<td>1 vessel</td>
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</tbody>
</table>

*Class I if there is severe proximal stenosis in a large left anterior descending coronary artery. †Class II if there is severe proximal stenosis in a large left anterior descending coronary artery.

3. Patients with chronic stable angina, class III to IV. Patients in this category are severely symptomatic and usually have one or more severe proximal stenoses. They may or may not undergo noninvasive testing for myocardial ischemia. In general, assignment of angina functional class III or IV indicates unsatisfactory response to medical treatment, whether the angina is of recent onset or chronic. Patients in these categories usually require expedient revascularization. The treatment classes are given in Table 8, but it should be noted that patients with angina class III or IV rarely have "no or mild myocardial ischemia with noninvasive stress testing."

4. Patients with unstable angina. This discussion includes but is not limited to patients with myocardial ischemia at rest and patients with postinfarction unstable angina. Unstable angina is taken as clear evidence of important reversible myocardial ischemia, and therefore aggressive evaluation and treatment are indicated. Emergency or urgent coronary bypass surgery is indicated only when intensive medical management fails to relieve the unstable angina. If the unstable state subsides within a few days of intense medical management, as is usually the case, the patient is studied further and recommendations are then made. The unstable angina syndrome predisposes a patient to recurrences of the unstable state or myocardial infarction, or both, and for this reason is a risk factor for death (31). Therefore, the indication for the coronary bypass operation (treatment class) in any of the previously described categories into which the patient may fall after study, becomes stronger when the unstable angina syndrome has recently (≤2 months) been present.

5. Patients with acute myocardial infarction. a. Uncomplicated Q wave myocardial infarction. The coronary artery bypass operation probably has little place in the management of most patients with uncomplicated acute Q wave myocardial
infarction, but the matter remains arguable (82-84). However, the place of urgent coronary bypass surgery in patients with uncomplicated acute myocardial infarction will ultimately be determined by its comparative benefit relative to thrombolytic therapy and, when needed, coronary angioplasty.

b. Uncomplicated non-Q wave myocardial infarction. Patients with non-Q wave acute myocardial infarction have in general the same indications for coronary bypass surgery, and for the same reasons, as do patients with unstable or postinfarction angina (see previous section). However, care must be taken to identify patients with left circumflex artery-related infarction and non-Q wave ECG changes, as these patients may, in fact, have had a transmural infarction and have the prognosis of that condition.

c. Myocardial infarction with hemodynamic deterioration. Acute hemodynamic deterioration in association with myocardial infarction is an emergency, but optimal therapy has not been fully defined. The intraaortic balloon pump is often highly effective, but delay in direct interventional therapy when hemodynamic deterioration continues may be disadvantageous. Coronary artery bypass surgery, with myocardial management tailored to patients with acute infarction and according to present knowledge, gives evidence of providing a considerably improved outcome over noninterventional methods of therapy in this setting (20).

6. Acute complications of coronary angioplasty. Only when there is coexisting acute hemodynamic deterioration is coronary artery bypass surgery performed immediately after unsuccessful coronary angioplasty associated with increased risk (6). When this circumstance develops in the interventional catheterization laboratory, and is not promptly relieved by percutaneous techniques, urgent coronary bypass surgery is indicated. The techniques of myocardial management described for use in patients with acute myocardial infarction in cardiogenic shock are applicable.

When the patient's condition is good after a complication of coronary angioplasty, the indications for coronary bypass surgery are not urgent, and the treatment classes previously described apply.

7. Previous coronary bypass surgery. Evidence of return of important myocardial ischemia should be required for consideration of another coronary bypass operation in a patient who has already undergone such a procedure. Cineangiography is a requisite for decision-making. If the offending disease is localized and in the native circulation or if the offending disease is in the bypassing conduits, and distal native vessels are seen to be open, another coronary bypass operation is usually indicated. When a repeat bypass operation is recommended, the indication should be strong and the patient's general health otherwise good, in view of the increased risks and uncertainties in the second operation (see Section III).

E. Theoretically Ideal Indication

Theoretically, the coronary bypass operation performed in an optimal manner at the appropriate time should have not only an appreciable comparative benefit over alternative forms of therapy, but also a high event-free survival for a prolonged period (≥15 years). However, a high event-free survival for ≥15 years is immutably denied by important fixed (at rest) left ventricular dysfunction at the time of the coronary bypass operation, even though the greatest comparative benefit is achieved in this situation. Thus, ideally the coronary bypass operation should be performed while left ventricular function remains normal or minimally impaired. However, performing the operation under these circumstances, rather than later in the life history of patients with ischemic heart disease, is discouraged by the current limitation on the duration of the operation's favorable effect imposed by progression of the atherosclerotic disease in the native coronary arteries and in the bypassing conduits. This limitation leads to the currently appropriate tendency to defer the operation for as long as is possible, although such a strategy often results in the development of important left ventricular dysfunction at rest.

The challenge for the future is to make safe the delay of the coronary bypass operation until extensive three vessel disease develops, by learning to predict the imminence of an acute ischemic syndrome such as myocardial infarction and resultant loss of normal left ventricular function. There are strong suggestions that alterations in the state (milieu) in the patient (instability of coronary atherosclerotic plaques [85], alterations in the thrombotic and thrombolytic mechanisms [86]) precede such an event, and progress is being made in identifying these alterations (87). Once identified, the alterations may possibly be reversed by medical treatment, and the infarction prevented and left ventricular function maintained. If such treatment is successful, the coronary bypass operation can then be deferred until extensive three vessel disease develops (if it does).

F. Contraindications to the Coronary Bypass Operation

A contraindication to the coronary bypass operation is absence of any open major artery ≥1 mm in diameter beyond the obstructing lesion. This contraindication no doubt occurs, but it is rare. Unless high quality cineangiograms have been made, this contraindication may be falsely diagnosed. Complete absence of viable myocardium in the area supplied by the stenosed or obstructed arteries is a contraindication to the coronary bypass operation, but this also is rare in the absence of an aneurysm involving the entire area.

Coexisting severe noncardiac conditions with a poor prognosis are relative contraindications to the coronary artery bypass operation. Extreme debility, mental and emotional deterioration and multiple system disease may contraindicate the operation. Older age in itself is not a contraindication to the bypass operation (see Section IV), but hospital morbidity and mortality and the prevalence of perioperative stroke are higher in patients older than about 75 years of age (88,89).
VII. Long-Term Management After the Coronary Bypass Operation

The clinical recognition of coronary artery disease sufficient to require the coronary bypass operation commits the patient and his or her physicians to a comprehensive and long-term plan for counseling, individualized medical interventions and monitoring and general medical care. The long-term treatment plan attempts to facilitate the complete recovery of the patient from the operation, promote early and long-term patency of grafts, control the risk factors for arteriosclerosis and diagnose and manage recurrent myocardial ischemia, should it occur.

A. Facilitation of Complete Recovery From the Coronary Bypass Operation

Cessation of cigarette smoking is a primary objective in preoperative and postoperative care. The patient should be informed of the importance of this both before and early after the operation.

The long-term treatment plan begins as soon as possible after the bypass operation, which may be as early as the 3rd or 4th postoperative day. It consists in large part of arranging the patient’s orderly transfer from the routines of in-hospital care to those in an ambulatory setting. Care is taken that administration of needed medications begun in the hospital is continued for the appropriate period after hospital discharge. The incidence of ventricular and atrial arrhythmias diminishes rapidly in the early in-hospital phase of recovery, but as many as 15% of patients may continue to experience them until the time of hospital discharge. These patients usually require only short-term (4 to 8 weeks) postdischarge treatment for the arrhythmia. Arrhythmias that persist after this time require special investigation.

The patient with treated hypertension before surgery frequently does not require the use of antihypertensive agents during the early convalescence. Therefore, it is appropriate not to prescribe these agents routinely early after operation, but to await a specific indication.

At the time of the early postdischarge evaluation, issues related to convalescence from the operation should be addressed with the patient and family, as well as any specific problems that may have been encountered in the hospital. Commonly, a chest roentgenogram, rest ECG, complete blood count and a biochemical profile are obtained at that time. Thereafter, one physician should assume the responsibility for long-term management, to assure continuity of care and constancy of goals. Whether the physician is a family practitioner, an internist or cardiologist is secondary in importance to his or her commitment, skill, availability for long-term care and acceptance by the patient.

During the 1st 6 to 8 weeks of convalescence from the coronary bypass operation, patients commonly have a poor appetite, insomnia, emotional depression, visual or memory or intellectual deficits, loss of sexual ability, lack of desire to return to work, and other potentially disabling manifestations of the postoperative state. Studies have documented the transient nature of most of these phenomena. Therefore, for the patient’s well-being and eventual complete recovery, the responsible physician should reassure the patient as to the likely transient nature of these disturbances, and help him or her to return to usual activities as rapidly as possible. During this period, excessive medications may predispose to symptoms, and minimization of medications for various specific indications is frequently beneficial.

A program of daily exercise should be started as soon as the patient leaves the hospital, and should emphasize regular walking for progressively longer periods of time. These programs should be individualized, based primarily on knowledge of the completeness of the operation and the left ventricular function. Formal programs of rehabilitation can be helpful in guiding some patients through this resumption of physical activity. Ultimately and unless specifically contraindicated, patients should be encouraged to obtain some form of regular physical activity on a daily basis and to increase this over the months after operation. Patients who were active and gainfully employed before surgery are urged to return to full activity and employment as soon as possible and, except in unusual circumstances, no later than 2 to 3 months after surgery.

B. Promotion of Patency of Grafts

The advantage of antiplatelet agents in promoting patency of vein grafts during the 1st postoperative year is well established (90-93). The precise protocol and the appropriate length of use of the drugs remain arguable, although the Veterans Administration randomized trial (92,93) has shown aspirin alone, in a dose of 325 mg daily beginning 6 h after operation, to be as effective as any other protocol. The aspirin (325 mg) should be started 6 h after the operation via the nasogastric tube which is then clamped for 1.5 h, and should thereafter be given in a similar dose once daily for at least 1 full year. Such a regimen is most effective early postoperatively and in vessels <2 mm in diameter (93,94).

Patency of the vein grafts for more than 1 year after bypass surgery may be enhanced by control of the risk factors for arteriosclerosis.

C. Control of the Risk Factors for Arteriosclerosis

Once the patient has recovered from the operation, he or she should be counseled about the importance of maintaining an appropriate body weight with caloric restriction if necessary, and optimally low blood lipid levels, control of hypertension and cessation of smoking. These features of care are important because elevated blood lipids have been shown to be an important risk factor for the atherosclerotic disease in saphenous vein bypass grafts (56,95-98) and because aggressive dietary and pharmacologic control of the serum cholesterol has been shown to retard the progression of vein graft
atherosclerosis (99). Specific types and combinations of pharmacologic intervention should depend on the type of lipid abnormality exhibited by the patient.

D. Diagnosis and Management of Recurrent Myocardial Ischemia

Electrocardiographic stress testing may be useful 6 weeks to 6 months after operation, particularly in patients in whom preoperative ischemia was "silent." Exercise stress testing is also valuable in identifying patients who have two or more ungrafted vessels or who may have had early graft closure (100,101). When a postoperative patient with an initially negative postoperative treadmill test later develops a positive test, it is usually a reliable indicator of progressive ischemia due to either graft closure or progression of disease in the native circulation (102). In addition, myocardial perfusion imaging with either exercise stress or dipyridamole infusion can enhance the detection of recurrent myocardial ischemia in patients who have ST-T wave abnormalities at rest.

Angina is likely to recur at some time after the bypass operation (see Section III). Although an argument can be made for the prophylactic use of nitrates, beta receptor blocking or calcium channel blocking agents when revascularization is incomplete, it is more rational to avoid the routine use of these agents until the return of ischemia has been documented. Once angina recurs and is persistent, or noninvasive stress testing yields positive results, or both, coronary arteriography and consideration of further interventional therapy are indicated. If the patient is elderly or has serious coexisting diseases, delay until symptoms become severe and unresponsive to medical therapy may be warranted.

VIII. Organization of a Cardiac Surgical Program for the Coronary Artery Bypass Operation (personnel, facilities, quality of care, case loads)

A. Personnel

All personnel involved in the management of patients undergoing the coronary artery bypass operation must understand and respect the need for leadership, mutual respect, collegiality and communication among the various professionals providing care to the patient. These lead to superb care without unnecessary tests and interventions or redundancy of effort, and thus without unnecessary escalation of costs and fragmentation of care.

1. Physicians. The coordinated expertise of many professionals is required to ensure optimal outcomes after coronary artery bypass surgery.

a. The cardiac surgeon. This physician should have primary responsibility for the patient during the operation and during the 1st 24 to 72 h after the operation, and longer if early convalescence is delayed. During this period, the surgeon should call on the knowledge and skills of a cardiologist, who should also be monitoring the patient’s course whenever this is advantageous to the patient. The surgeon should follow the patient closely during the remainder of the hospital stay and the first few days of outpatient care, even though institutional practice may place primary responsibility after the first 24 to 72 h with the cardiologist.

Preoperatively, the surgeon should evaluate the patient and records in detail. Except in absolute emergencies, a preoperative written note by the surgeon on the patient’s record should be mandatory. The note should describe the comparative benefits and risks of the coronary bypass operation (the bases for informed consent by the patient) and the surgeon’s opinion and recommendations.

The cardiac surgeon should in most instances be certified by the American Board of Thoracic Surgery or an equivalent certifying body in another country. The surgeon should have a thorough understanding of basic medical and surgical knowledge and particular information about cardiac surgical techniques, cardiopulmonary bypass and methods of myocardial management. The surgeon should have demonstrated, in addition, clinical competence in the preoperative evaluation of a potential candidate for surgery (including the interpretation of coronary cineangiograms and catheterization data), the surgical procedure itself and postoperative care (3,103).

A hospital coronary artery bypass surgery program should have as a minimum two qualified cardiac surgeons (103). For optimal outcomes, the practice of these cardiac surgeons should be concentrated in a single institution, in order to promote familiarization with its facilities, procedures, consultative and nursing resources and to ensure availability.

b. Surgical assistants. Under most circumstances, the coronary bypass operation, including removal and preparation of saphenous veins, can be well performed by a single surgeon and two assistants. The first assistant should be either a resident or other physician or a specially trained surgeon’s assistant. Use of surgeon’s assistants should have a favorable impact on procedural costs while maintaining high standards of care (see Section IX).

c. Anesthesiologists. Anesthesiologists assigned to cardiac surgery should have complete familiarity with the preoperative, intraoperative and early postoperative requirements of cardiac surgery and be able to participate as part of an efficient and coordinated team. This usually requires subspecialization by the anesthesiologist. Appropriate patient care as well as the allaying of concerns of the patient and family require a consultative visit to the patient by the anesthesiologist on the day before the operation, except in emergency situations. In the intensive care unit, the anesthesiologist’s knowledge and skills in the management of the respiratory system early postoperatively should be of particular benefit.

Cardiac anesthesiologists should in most instances be certified by the American Board of Anesthesiology or equivalent certifying body in another country and should have special training in the anesthetic and supportive requirements of open heart surgery. They should have skill and experience in the induction of anesthesia and intraoperative management of the
patient with myocardial ischemia, unstable angina, evolving myocardial infarction, cardiac arrhythmias and heart failure. They should have competence in the monitoring and management of the patient’s cardiorespiratory systems and of electrolyte and coagulation abnormalities.

d. Cardiologists. Optimally, the patient’s cardiologist should follow the patient’s course in the intensive care unit, even though primary responsibility in the 1st 24 to 72 h is with the surgeon. As the patient leaves the intensive care unit, the primary responsibility may shift to the cardiologist, who should call on the knowledge and skills of the surgeon as necessary.

Cardiologists participating in cardiac surgical programs should in most instances be diplomates of the subspecialty board for cardiovascular diseases of the American Board of Internal Medicine, or certified by an equivalent certifying body in another country. They should have experience in all aspects of the care of patients with coronary artery disease. Specialized skills in invasive cardiology, electrophysiology, echocardiography and cardiac pacing should be available within the institution.

e. Other physician specialists. Institutional practices may provide for concentration of effort in the intensive care unit by particularly qualified surgeons, anesthesiologists, cardiologists or others.

Coronary bypass surgery is most successful when there is cooperation, coordination and effective communication among multiple disciplines, without fragmentation of care and without unnecessary use of consultants. All the specialists and facilities of a general hospital may on occasion be needed, and these services should be available on a 24 h basis.

2. Nursing personnel.

a. Operating room. Generally, one surgical nurse or technician and a circulating nurse or technician are required for the performance of coronary artery bypass surgery. Just as is true of the other members of the operating room team, the surgical nurses should be especially qualified in cardiac surgical nursing and be prepared to be part of an efficient team under the direction of the surgeon. This usually requires commitment of these nurses to cardiac surgery.

The open heart nursing team also requires a director responsible for scheduling, training and quality of the nursing services for the cardiac operating rooms.

b. Intensive care units. Cardiac surgery intensive care nursing requires specialized training, to develop the theoretical knowledge and clinical skills required for the intensive care of cardiac surgical patients. Nurse to patient ratios should be 1:1 or 1:2 in the early postoperative hours and until the morning after the day of surgery. Recognizing that exceptions to this may be possible with extensive automation and well developed and tested protocols. Staffing levels should be adequate 24 hours a day.

Active coordination and mutual respect among nursing personnel, cardiac surgeons, cardiac anesthesiologists, cardiologists and, when required, consultants is essential in the intensive environment of the cardiac surgery intensive care unit.

c. Pre- and postintensive in-hospital care. Before the operation, an expanded explanation of the diagnostic and therapeutic procedures by the nurse can allay fears and facilitate understanding and cooperation. Nursing personnel in the areas to which the patient is transferred after the intensive care unit should be able to distinguish between minimally dangerous and potentially highly dangerous cardiac arrhythmias. They should be able to initiate resuscitative measures, and recognize the indications for these. They should be knowledgeable about the postbypass surgery treatment protocols and be able to implement them skillfully. The nursing personnel should be supportive of the patient in all ways and help the patient to begin the process of convalescence.

Instruction of the patient and family by the nursing personnel, at a time when the patient is most receptive regarding risk factor modification, may favorably influence long-term outcomes. Nursing personnel assignments should be adequate to meet these goals, and well designed programs can be cost effective.

3. Perfusionists. Trained perfusionists prepare, maintain and operate the pump-oxygenator and related equipment during the coronary artery bypass operation and during its uncommon use before or early after cardiac surgery. They should work under the direct supervision of a physician or physicians expert in all matters relating to cardiopulmonary bypass. Nearly always this is the cardiac surgeon or cardiac anesthesiologist or, preferably, an interactive team composed of both. Working under the direction of the cardiac surgeon or anesthesiologist, or both, the perfusionist may also be responsible for the operation of red blood cell-saving procedures and circulatory assist devices.

Because the duties of perfusionists vary widely among institutions and because the perfusionist should be part of a well coordinated physician-nursing-perfusionist team, each perfusionist should concentrate his or her practice in one hospital.

Perfusionists should be graduates of an approved perfusion technology training program or have equivalent training (104).

4. Other personnel. An active cardiac surgical program will usually require the support of a full complement of hospital professionals. These include pharmacists, dieticians, respiratory therapists, social workers and physical therapists with cardiac rehabilitation skills.

B. Facilities

1. Cardiac operating rooms. The requisite space and equipment of an operating room for open heart surgery have been described previously (3). The operating room should be 600 to 800 square feet (55 to 75 m²) in size, have adequate electrical grounding, oxygen and vacuum supply, proper illumination, and be capable of supporting the technical equipment utilized in cardiopulmonary bypass, including the pump-oxygenators, heat exchange equipment, cell saver, anesthetic apparatus and assist devices.
The availability and staffing of more than one cardiac operating room per surgeon considerably enhances the efficiency and productivity of a cardiac surgical program.

2. Cardiac surgery intensive care unit. A fully staffed and equipped cardiac surgery intensive care unit is required. It is questionable whether the needs of the cardiac surgical patient can be appropriately met in a general intensive care unit. The number of available intensive care unit beds should be approximately half the number of open heart operations performed per week. The unit should be under the direction of a qualified physician, optimally the cardiac surgeon, and should have a unit nurse director. It should have typical intensive care unit capabilities, including continuous electrocardiographic and hemodynamic monitoring and recording, and equipment and personnel for full ventilatory support.

The unit design should provide for direct visual assessment of the patients from the nursing stations. This unit should be in relatively close proximity to the operating room. Several patient areas should be large enough to accommodate multiple life support systems, such as intraaortic balloon pumps, ventricular and total circulatory assist devices and hemodialysis machines.

Portable chest roentgenographs should be available 24 hours a day. The unit should be able to obtain immediately arterial blood gas analyses, serum electrolyte measurements and certain other laboratory tests, and should be informed of the results as soon as they are available.

Most patients undergoing an elective coronary bypass operation are able to be transferred out of the intensive care unit the morning after surgery. Early transfer reduces delays and costs and ensures optimal utilization of expensive facilities.

3. Postintensive care ("stepdown facility"). Early safe transfer from the intensive care unit is facilitated by the availability of radiotelemetry for ECG monitoring in the area to which the patient is transferred. This is preferably a standard bed area, which may have both immediately preoperative cardiac patients as well as postoperative patients. This latter group should be in the majority.

Radiotelemetry allows rapid identification of important arrhythmias. Ideally, the telemetry should be monitored 24 h a day by technicians under the immediate direction of the nursing staff and under the overall direction of a cardiologist or cardiac surgeon.

4. Catheterization and angiographic facility. Coronary arteriography of diagnostic quality is a requisite to the performance of coronary artery bypass surgery, and must be available in any hospital with a cardiac surgery program. The optimal resources and facilities for performing cardiac catheterization and coronary angiography have been summarized previously (105,106).

5. Ambulatory pre- and postoperative care facility. Before surgery, it may be possible to identify some preoperative low risk patients who can be admitted to the hospital early on the morning of surgery without increased risk and with apparent institutional cost savings (107). However, it is not clear that such a strategy is advantageous to most patients or is cost-effective when all aspects of the patient care program are considered.

Early discharge of the patient from the hospital (on postoperative day 5 or 6) has been shown to be advantageous when provisions have been made for continuing close surveillance for the first 3 or 4 postdischarge days (108). This is made most effective by the availability of a well staffed and well equipped ambulatory patient care facility in which needed observation and tests can be performed.

C. Quality of Care

A cardiac surgery program should include regular, frequent and formal review in conference of all deaths and major complications. This should be attended by cardiac surgeons, cardiologists and pathologists, as well as residents and students in teaching institutions. Quality assurance programs, in-service educational programs and multiple layers of in-house administrative reports frequently add only expensive, inconvenience and undue consumption of time to that which can be accomplished by intense, conscientious and regular review of deaths and complications by the professional staff.

D. Case Loads

1. Historical information. Recommendations regarding minimal institutional levels of use for open heart surgery (200 to 300 operations annually) were first published by the InterSociety Commission for Heart Disease Resources in 1972 (3). Approximately one-half of the hospitals with open heart surgery programs in 1980 did not meet these lowest recommended case load volumes (109,110). Similar minimal annual case load recommendations specifically for coronary bypass surgery were proposed by an American College of Surgeons subcommittee in 1984 (103). The percentage of hospitals currently performing less than the minimal annual procedure volume appears to remain about the same despite the large increase in the number of coronary artery bypass operations performed, because of the extensive proliferation of hospitals with coronary bypass programs (111).

2. Recommendations. In general, a yearly minimum of 200 to 300 open heart operations, the majority of which are coronary artery bypass operations, should be performed in hospitals (institutions) caring for patients requiring surgery for ischemic heart disease. Hospitals in large and sparsely populated geographic areas may require a different, specifically derived recommendation.

In general, a yearly minimum of 100 to 150 open heart operations, the majority of which are coronary artery bypass operations, should be performed by each surgeon caring for patients with ischemic heart disease. Again, surgeons in large and sparsely populated geographic areas may require a different, specifically derived recommendation.

These recommendations about case load are general and should be applied with the knowledge that several reports
attest that it is possible for a particular low volume hospital or surgical group or surgeon to have good results (112-114).

3. Bases for recommendations. The issues, with respect to case load, are quality and appropriateness of the coronary bypass operation (at present, judged only by hospital mortality and morbidity), patient access, cost-effectiveness and institutional morale and costs.

a. Quality and appropriateness. A relation between cardiac surgical volume and mortality after coronary bypass surgery was suggested in 1979 from comparison of outcomes between hospitals with <200 coronary bypass operations annually (5.7% mortality) and hospitals with >200 annual coronary bypass operations (3.4% mortality) (115). These institutional volume effects may be even greater for emergency coronary bypass operations (111).

The most recent and thorough examinations of the relation of institutional and surgeon volume to hospital mortality are the reports from the Department of Health of the state of New York (101,102). In that state in 1989, hospital mortality for the coronary bypass operation (n = 12,448) was 3.66%. The relation between volume (surgeon and hospital) and outcome suggests that the statewide mortality would have been 2.67% had all operations been performed by surgeons doing at least 180 cardiac operations per year in hospitals in which at least 700 cardiac operations were performed yearly (Table 9).

The predicted effect of a criterion of 300 cases per year for an institution and 150 for a surgeon is in Table 10. Noteworthy is the suggestion that had this criterion been in place, the hospital mortality for the state of New York as a whole would have been 3.19%, lower than the actual one of 3.66%, but higher than the 2.67% predicted had criteria of ≥700 and ≥180 for institutions and surgeons been used. These analyses are supported by a multivariable risk factor analysis, in which decreasing surgeon and institutional volumes (as continuous variables) were risk factors for higher hospital mortality throughout the range of cases/year (116). Neither finding could be accounted for by chance alone, but the finding was even more secure in the case of surgeons (p < 0.001) than in the case of institutions (p = 0.04). It is noteworthy, however, that the differences are small.

Hannan and colleagues (117) (Hannan EL, Personal communication, 1990) also found that some institutions with small volumes had particularly unfavorable risk-adjusted hospital mortality rates compared with those of other low volume hospitals; and some high volume institutions had risk-adjusted mortality rates considerably higher than those of other high volume hospitals.

The relation of the appropriateness of the coronary bypass operation to institutional and surgeon volume has not been determined.

b. Patient access. A recommendation against low volume cardiac surgery programs raises issues of patient access and the large nonreimbursable costs incurred by the patient and family when an individual undergoes the coronary bypass operation in a remote institution. However, an analysis of market and regulatory influences on the availability of coronary bypass surgery in hospitals in the United States found that the larger the number of local hospitals, the more likely it will be that a majority of the hospitals will offer the coronary bypass operation. and 80% of low volume hospitals (<200 cases per year) had one or more nearby hospitals with a surgical program that included the coronary bypass operation (118).

Large geographic areas that are sparsely populated have a particular problem of access. These areas should require greater flexibility of case load guidelines, although referral of cases to large centers outside their areas should be considered.

c. Cost-effectiveness. Costs per cardiac surgery procedure have been shown to increase with decrease in institutional cardiac surgical volumes (119). The relative costs were particularly great when the volume was 100 cases per year or less (120). Also, larger institutional volumes of cardiac surgery correlate not only with a lower mortality rate, but also are associated with a shorter length of hospital stay (111), and thus lower costs per case can be expected.

d. Institutional morale and costs. The proliferation of small cardiac surgery programs tends to result in the referral of high risk patients (with poor outcomes, frequent complications and longer lengths of stay in intensive care units and in the hospital) to centers. This tends to concentrate low risk patients in smaller programs. This disparity of case mix can result not only in morale problems among the personnel in the larger programs, but also in financial burdens for these

<table>
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<tr>
<th>Surgeon Volume (cases/surgeon)</th>
<th>Hospital Volume (cases/institution)</th>
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<tbody>
<tr>
<td>&lt;100</td>
<td>28-199</td>
</tr>
<tr>
<td>101-179</td>
<td>200-699</td>
</tr>
<tr>
<td>≥180</td>
<td>≥700</td>
</tr>
</tbody>
</table>

*All volumes refer to all cardiac surgery cases, not just the coronary bypass operation. Statewide mortality (1989) was 3.66%. Thus a risk-adjusted (for patient-specific incremental risk factors) mortality rate indicates >3.66% less good performance than in New York State as a whole; a rate <3.66% indicates better performance. In this table and table 10, the percents refer to risk-adjusted hospital mortality. Adapted with permission from Hannan et al. (116).

Table 9. The Relation of Risk-Adjusted Hospital Mortality After Coronary Artery Bypass Grafting to Institution and Surgeon Cardiac Surgery Volumes in the State of New York in 1989 (n = 12,448)*

<table>
<thead>
<tr>
<th>Surgeon Volume (cases/surgeon)</th>
<th>Hospital Volume (cases/institution)</th>
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<tbody>
<tr>
<td>&lt;100</td>
<td>13.36%</td>
</tr>
<tr>
<td>101-179</td>
<td>4.69%</td>
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<tr>
<td>≥180</td>
<td>6.06%</td>
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*Prepared from a study in the state of New York in 1989 (Hannan EL, Personal communication, 1990).
centers because of a larger cost per case. Nonetheless, the transfer of patients with complex problems to experienced centers is often in the best interests of these patients.

4. Precautions and pitfalls. Possibly, the correlation between high volume and superior results (in terms of hospital mortality) is not due to the high volume itself, but rather to the possibility that a surgeon or institution of high quality tends to attract more patients. A high volume institution generally finds it easier to attract highly competent surgeons and other personnel than do low volume institutions.

Some studies of the relation between volume and hospital mortality have not taken into account differing prevalences of patient risk factors. This can lead to erroneous and unfair conclusions and practices. It is hoped that the exemplary recent reports by Hannan and colleagues (116,117) from the state of New York, based in part on the important work done previously by Parsonnet and colleagues (121), will stimulate the further development of properly performed studies and public reports in these areas.

IX. Costs and Charges of the Coronary Artery Bypass Operation

A. Background

The cost of health care in the United States has been rising and reached $548 billion in 1988. This figure is twice the amount spent in 1980 and is 11% of the gross national product. The charges for the coronary bypass operation have been considered to be a major factor in these rising costs of health care.

Between 1981 and 1986, the number of coronary bypass procedures increased from 159,000 to 284,000, and Medicare beneficiaries accounted for >25% of this volume. Estimates from Medicare have indicated that 63,000 hospital bills were processed in 1985 related to the coronary bypass operation, resulting in >$1.5 billion in charges to Medicare (122).

These facts are not necessarily evidence of inappropriate use of the coronary bypass operation. Furthermore, if an average current total charge of about $40,000 (for the bypass operation, hospitalization, and so forth) is assumed for 300,000 coronary bypass procedures per year, the total charges would be about $12 billion, or about 2% of the total cost of health care in the United States.

B. Risk Factors for Higher Charges

The most often noted risk factor for higher charges is geographic location. In 1982 to 1983, the average total charge nationally for the coronary bypass operation and associated procedures and hospitalization was $21,800. The highest average charge, $29.500, was in the Pacific region, while the lowest, $18,300, was in the East South Central region (123). By 1986 the average charge was $30,430, and ranged from almost $40,000 in the Pacific region to $27,000 in the West North Central states.

Some risk factors for higher charges in general have been identified. However, at least some of those identified are actually surrogates of more fundamental risk factors. For example, the occurrence of sternal wound infection has been reported to add an average of $41,559 to the hospital bill, while respiratory failure added $28,756 and left ventricular failure added $5,186 (124). A valid argument could be made for considering diabetes, obesity or inadequate operating room techniques as the fundamental risk factors for the added charges associated with sternal wound infection. Preoperative chronic obstructive lung disease, the damaging effects of cardiopulmonary bypass and inadequate effort for early extubation and discharge from the intensive care unit are probably the fundamental risk factors for the added charges associated with respiratory failure. Preoperative left ventricular dysfunction, and inadequate myocardial management during the coronary bypass operation, may be the fundamental risk factors associated with the added charges attributed to left ventricular failure. These considerations emphasize the increasing prevalence and importance of risk factors in patients currently undergoing the coronary bypass operation, and the need for strong research and education programs designed to reduce costs by improving patient care protocols.

Longer hospital stay after the coronary bypass operation is generally associated with higher charges, and risk factors for longer stay are generally, therefore, also risk factors for higher charges. Older patients, women, patients requiring emergency surgery and those with severe angina, diabetes, renal dysfunction or low ejection fraction have been shown to be more likely to have complications and therefore to require a long hospital stay (125). Although the charges associated with these risk factors may gradually be reduced by new knowledge generated by research and by education, many of the risk factors are probably for the moment immutable. Nonetheless, it is many of these very patients who receive the greatest comparative benefit from the coronary bypass operation (see Sections IV and V).

High hospital mortality may also be associated with increased total charges, in spite of short hospital stays, because of the unusually large number of personnel and devices used in the perioperative period in many patients who die. The importance of these is clear from the fact that many deaths after the coronary bypass operation occur early postoperatively (in one institution [Kirklin JW, Blackstone EH. Personal communication, 1990] 30% occurred within the first 48 postoperative hours, and 50% within 9 days). Most of the patients who die early postoperatively are seriously ill from the moment the operation has been completed, and during the interval between operation and death are intensively treated. The interventions often include the use of intraaortic balloon pumping, extracorporeal membrane oxygenation, ventilator assist devices, prolonged respiratory support, hemodialysis and extensive pharmacologic intervention. This, and the associated personnel requirements, all emphasize the economic as well as individual importance of obtaining the lowest possible hospital mortal-
ity and morbidity rates consistent with continuing to perform the coronary bypass operation on all patients in whom it is appropriate.

C. Precautions and Pitfalls

Identifying the cost of the coronary bypass operation, and comparing it with those of alternative forms of treatment, would appear to be a straightforward process. The charges for each hospital stay and professional contact could be gathered from computerized bills. These charges could then be totaled for some stated period of time and compared with those for coronary angioplasty, noninterventional medical treatment and other alternative forms of treatment. They could also then be compared according to geographic region, type and size of hospitals, method of practice (individual versus group practice), or method of billing (itemized versus global fee).

However, the variability in charges made for the coronary bypass procedure reflects both variability in actual costs, and variability in the proportion of the charge that comes from overhead and related factors. This is because the charge includes 1) the actual cost of performing the procedure, 2) the overhead for supporting those hospital or professional services whose actual costs exceed the reimbursement, 3) the overhead for meeting ongoing and often unrelated costs that must be shared among users of the institution, and 4) the overhead to cover projected costs of future expansion and equipment purchases in general. The differences between charges and costs, determined by a variety of factors, must be understood in assessing the financial impact of reducing or increasing the number of cardiac procedures performed.

Additionally, any consideration of restricting the use of the coronary bypass operation in patients in whom it is indicated must take into account other results of such restrictions. Patient disability will become greater. The accumulated costs of medication, recurrent hospital stays and subsequent myocardial infarctions and congestive heart failure will increase and may become greater than those of the coronary bypass operation.

In summary, any deliberate reduction in the number of coronary bypass procedures by rationing, in order to reduce costs, needs to consider the other fiscal, as well as human, effects of such a program.

D. Recommendations

A concerted effort should be made by the medical profession to reduce the costs of the coronary bypass operation without reducing its benefits. Since it is a commonly performed operation about which a great deal is now known, areas in which significant cost reductions can be made without sacrifice in quality should be identifiable. Unnecessary components of care relating to the coronary bypass operation should be eliminated, and one mechanism for this is the forming of appropriate guidelines and indications for the coronary bypass operation. The difficulties of accomplishing these eliminations are recognized, and include the threat to the survival of some institutions and to the livelihood of some individuals in some specialties and areas of service.

The recommendations are as follows:

1. This report has described the variables (risk factors) upon which the recommendation for one or another form of therapy can appropriately be made (Sections IV, V, VI and X). Examinations and tests that do not relate directly to identifying the values of these variables (risk factors) should not be performed as service items, although they may be necessary in research protocols.

2. Redundancy in the provision of services within an institution should be avoided.

3. Properly trained surgeon’s assistants, rather than fully qualified surgeons, have been demonstrated to be highly competent in removing saphenous veins, opening and closing surgical incisions, acting as first assistant during CABG operations and participating in preoperative and postoperative care under the supervision of qualified cardiothoracic surgeons. Since the length of the educational process leading to qualification as a Surgeon’s Assistant in cardiothoracic surgery is much shorter than that leading to the MD degree and qualification as a cardiothoracic surgeon, and the overall responsibilities are less, the compensation of this group of health care workers is considerably less than that of qualified surgeons. More widespread substitution of surgeons’ assistants, in both teaching and nonteaching settings, should reduce the costs related to the coronary bypass operation without reducing patient benefit and the quality of care.

4. The postoperative care of the majority of patients undergoing routine coronary artery bypass grafting is simple and straightforward. Particularly in such patients, unnecessary components of care and testing should be avoided.

5. Complications may increase costs in all these areas, and therefore before, during and after the operation techniques and practices that reduce complications without endangering comparative benefits should be used.

X. Patient-Specific Guidelines and Indications for the Coronary Artery Bypass Operation

General information on outcome after the coronary artery bypass operation is contained in Section III, but it is not specific to any given patient because a number of risk factors determine the outcome in specific patients. Comparisons between outcome after the coronary bypass operation and noninterventional medical treatment are presented in Section IV, and comparisons between outcome after the coronary bypass operation and coronary angioplasty in Section V. These comparisons are group-specific and not specific to an individual patient and, although more helpful than simple
comparisons in heterogeneous groups of patients, remain of limited value. The indications presented in Section VI are based on a limited number of risk factors, but they are not optimally useful to the physician in working with an individual patient because patients have a large number of independent risk factors, many of which could not be taken into account in the general discussion and tables in Section VI. This section describes patient-specific predictions and comparisons (see Appendix F for methodology) that are optimally useful to the physician in making recommendations to individual patients. The technique for generating patient-specific predictions and comparisons is also optimal for exploring the strength of an individual risk factor, for with it the values for all other risk factors can be held constant.

A. Background

Physicians have traditionally advised patients on the basis of the "odds of success" of alternative forms of therapy, and the "risks and imponderables" associated with each. In recent years sufficient information has been obtained about outcomes that the comparative benefits and risks of the coronary bypass operation can be computed for an individual patient with his or her patient-specific risk factors.

Many physicians have not had the privilege of using computed patient-specific predictions and comparisons as a basis for recommendations to patients. Therefore, this section provides a limited number of examples, based on the equations (mathematical models) currently available for these purposes, and describes the potential future availability of techniques that simplify for physicians and institutions the making of patient-specific predictions and comparisons.

The information currently available for these purposes is limited because of several factors. The medical profession has, for the most part, not used its medical expertise to guide statisticians in the direction of analyses that would be clinically useful. Statisticians have, for the most part, preferred to use classical methods, rather than to add to them new methods more appropriate to patient care. The major randomized trials have generally not encompassed within their reports the types of analyses required for predicting and comparing for individual patients, and most of them have been unwilling even to share their data bases with others prepared to make such analyses. A notable exception is the United States Department of Veterans Affairs, which has shared with this Subcommittee certain parts of the data base (that of patients randomly assigned to initial medical treatment) from two of their randomized trials. The equations derived from these data are useful and are included in the report.

Further development of patient-specific predictions and comparisons can ultimately result not only in better, but in more economic health care for patients with ischemic heart disease. These can indicate, for a specific patient at a given time, the comparative benefit and risk of noninterventional medical therapy, the coronary bypass operation and coronary angioplasty. When sufficient information is available, predic-

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A 67 year old man without hypertension has moderately severe stable angina (Canadian class III), and a history of a single previous myocardial infarction. His exercise test is strongly positive. He has an 80% proximal stenosis in the left anterior descending coronary artery, 30% stenosis in a large marginal branch of the circumflex artery and a 20% stenosis in the mid-right coronary artery (right dominant system with "single vessel disease"). His left ventricular ejection fraction is 0.55.

The benefit, with respect to survival, of initial coronary bypass surgery (and of initial coronary angioplasty) compared with that of initial medical treatment is illustrated in Figure 5. The treatment class of the coronary bypass operation with respect to survival would be II.

Example 2

A 65 year old nonhypertensive man has moderately severe stable angina (Canadian class III) and a history of two previous myocardial infarctions. His exercise stress test is strongly positive. He has three vessel disease with an 80% proximal stenosis in his left anterior descending coronary artery, 70% stenosis in a large marginal branch of the circumflex artery and a 75% stenosis in his mid-right coronary artery (right dominant system). His left ventricular ejection fraction is 0.40.

The comparative benefit with respect to survival, of initial coronary bypass surgery (and of initial coronary angioplasty)
compared with initial medical treatment is illustrated in Figure 6. The treatment class of the coronary bypass operation with respect to survival would be I.

C. Treatment Class Determined by Patient-Specific Comparisons

The patient-specific comparisons are optimal for defining the treatment class (Table 1) for the coronary bypass operation in comparison with medical treatment (or coronary angioplasty) in an individual patient. However, defining the treatment class is only one step in the process by which the physician, using all available information and his or her own best judgment, determines recommendations to the patient.

Treatment class I can be considered to apply to situations (patients) in which there is 1) a computed time-related greater probability of freedom from important unfavorable events such as death after the coronary bypass operation than after initial medical treatment (or after coronary angioplasty), and the 70% confidence intervals of the freedom after the coronary bypass operation are widely separated from those after other treatments, and 2) the 90% confidence intervals of the comparative benefit of the coronary bypass operation do not touch or overlap zero benefit for that period of time. Currently, this prescribed degree of certainty of the comparative benefit of the coronary bypass operation can be reached only when the comparative benefit is considerable. When more data from larger groups of patients become available, the confidence intervals should become more narrow and the prescribed degree of certainty may be reached when the comparative benefit of the bypass operation is small. Then an arbitrary definition may be required as to the magnitude of the comparative benefit that would make the coronary bypass operation indicated and advisable.

Treatment class II applies to situations (patients) in which there is 1) a computed time-related greater probability of freedom after the coronary bypass operation than after
Figure 6. Nomograms depicting the predicted patient-specific comparative benefit of the coronary artery bypass (CABG) operation, using the internal mammary artery to the left anterior descending coronary artery (and of coronary angioplasty [PTCA]) compared with initial medical treatment in the 65 year old man with three vessel coronary artery disease (example 2). A, Predicted percent survival. B, Comparative benefit. There is a considerable comparative benefit (and no comparative benefit of coronary angioplasty) of an initial coronary bypass operation over initial medical treatment, and this is very unlikely to be due to chance alone. C, Predicted hazard functions. D, Hazard ratios. The hazard ratio for an initial coronary artery bypass operation compared with initial medical treatment is considerably <1, and the difference from 1 is very unlikely to be due to chance alone.

Medical treatment (or coronary angioplasty), but the 70% confidence intervals of the freedom after the bypass operation touch or overlap for a considerable part of the time with those of medical treatment, and 2) the 90% confidence intervals of the comparative benefit include (overlap with) zero benefit for a considerable period of time.

Treatment class III applies to situations (patients) in which there is no computed time-related comparative benefit of the coronary bypass operation over medical treatment. (The rationale for these definitions are in "Task Force Subcommittee Methodology" in Appendix C).

Similar treatment classes should soon be definable for the coronary bypass operation in comparison with coronary angioplasty or any other form of treatment.

XI. Bases for Health Care Policy Concerning the Coronary Artery Bypass Operation

Private and public health care policy concerning patients with ischemic heart disease should have as part of its bases appropriate time-related information concerning unfavorable outcome events after alternative forms of treatment. Whereas Section X relates primarily to individual patients, this section relates primarily to groups of patients. This section discusses A) appropriateness of the coronary bypass operation, B) quality of care, and C) cumulative years of freedom from an unfavorable event.

Health care policy must of course consider costs as well, and this matter has been discussed briefly in Section IX. Detailed consideration of cost of the coronary bypass operation in relation to benefit and health care policy is beyond the scope of this report.

A. Appropriateness of the Coronary Bypass Operation

Widespread inappropriate use of the coronary bypass operation, or of coronary angioplasty, would be economically
wasteful as well as disadvantageous to the individual patient. However, the definition of inappropriateness (and, conversely, of appropriateness) has not been accomplished with any unanimity of opinion. Therefore, many studies of these matters have resorted to consensus opinion, derived in one manner or another. All such studies are seriously flawed by the biases, stated or unstated, of each member of the panel of experts, and by the bias underlying the selection of the members of the panel. At present, enough information about the coronary artery bypass operation exists, as summarized in this report, that the seeking of consensus opinion is no longer necessary.

Appropriateness of a procedure is generally sought retrospectively. In this regard, it is similar to quality of care, discussed in the next part of this section. Appropriateness of a procedure, such as the coronary bypass operation, should be assessed on the basis of the time-related results of the procedure. Appropriateness is analogous to the indications for the operation, except that the indications are sought prospectively, before the procedure. Thus the methodology for determining the patient-specific indications for a procedure (see Section XI) also applies to determining appropriateness.

An interventional procedure can be considered to have been appropriate (as compared with medical treatment) for an individual patient when its treatment class is I (as defined by patient-specific criteria in part C of Section XI). The appropriateness of a procedure that, for an individual patient, is in treatment class II is uncertain, and it should be decided administratively. Comparative costs should probably be considered. New procedures will often fall into treatment class II, because of the small numbers of patients for analysis with resultant wide confidence intervals and the relatively short period of follow-up. Therefore, new and promising procedures in treatment class II may be considered appropriate for a few years. A procedure can be considered inappropriate when its treatment class is III.

The same procedure can be used to evaluate the appropriateness of one type of interventional procedure (such as coronary angioplasty) in comparison with that of another (such as the coronary bypass operation).

B. Quality of Care

Quality of care in the case of the coronary bypass operation is currently judged on the basis of hospital mortality. An assessment of quality of care on this basis has been done in an exemplary manner by the Department of Health of the state of New York. There, Hannan and colleagues (116,117) have developed a reporting system from each of the 30 hospitals in the state performing cardiac surgery, and that system has provided data for multivariable analysis and identification of the incremental risk factors for hospital death in their population of patients. With use of the derived risk factor equation, an expected hospital mortality with its 95% confidence intervals was computed for each hospital in the state. The expected hospital mortality was defined as the mortality to be expected had that hospital’s specific patients, with their patient-specific risk factors, been operated on, so to speak, by the state of New York as a whole. Hospitals whose actual mortality rate was above the 95% confidence intervals of the expected mortality rate could be considered to be failing to deliver care of good quality. With further refinements, these techniques were used to rank the hospitals in the state according to quality of care as judged by risk-adjusted hospital mortality.

Ideally, morbidity and length of hospital stay, as well as mortality, should be computed and compared in a similar risk-adjusted manner, and considered in an overall evaluation of quality of care in the case of the coronary bypass operation. The physical and emotional comfort of the patients and family also require consideration in this regard.

In the quest for a low hospital mortality rate, it must always be remembered that the coronary bypass operation may, in the best of hands, currently have a relatively high hospital mortality in certain types of cases, and still have for these cases a larger and near-certain comparative benefit (appropriateness) when compared with alternative forms of treatment.

C. Cumulative Years of Freedom From an Unfavorable Event

Most physicians and patients think in terms of and use the time-related probability of freedom from alternative forms of therapy. Life insurance actuaries and government often use the cumulative years of freedom from an unfavorable event, also termed the percent retention of potential time of freedom from an unfavorable event. This latter criterion is appropriate when the goal is preservation of total years of life of a skilled work force, or the calculation of costs in terms of preservation of the maximal number of years of life, or consideration of the resources necessary to pay pensions and annuities of a given population. The important point is that a different answer is obtained, depending on the criteria used, and failure to understand this could create confusion and lead to unnecessary conflict.

An example is presented in Figures 7 and 8. In Figure 7, the information is depicted in the form used throughout this ACC/AHA Task Force Subcommittee Report, with the time-related probability of survival after coronary bypass and after initial medical treatment depicted on the left side and the hazard function on the right. With use of the derived equations, the probabilities have been extended to 16 years, in order to see clearly the time when they cross. The “crossing point” is at a different interval after starting treatment in the survival plot (10.7 years), compared with the hazard function (6.6 years).

In Figure 8, the same information is presented in terms of the percent retention of potential lifetime (freedom from death) (126–128). In this criterion, the survival curves after the coronary bypass operation and that after initial medical treatment cross twice, and the last crossing is at 16.1 years.

These three different times, at which the curves come together and then cross, result from three different criteria, or methods of presenting the information.
Figure 7 (above). Percent survival and hazard function for death, and the comparative benefits in these regards, of randomly assigned coronary bypass surgery compared with randomly assigned initial medical treatment (28). A, Survival. Note the two survival curves come together 10.7 years after the start of therapy. B, Comparative surgical benefit of the coronary bypass operation (surgical benefit). The comparative benefit becomes zero 10.7 years after beginning therapy. C, Hazard functions. They become the same 6.6 years after the start of the treatment strategies. D, Comparative hazard ratio. The ratio becomes 1 (instantaneous risk of death becomes the same for both treatment strategies) at 6.6 years.

Figure 8 (below). Percent retention of potential lifetime, and the comparative benefit in this regard, of randomly assigned coronary bypass surgery compared with randomly assigned initial medical treatment (28). A, Percent retention of the potential lifetime. Note that these become the same 16.1 years after the start of treatment. B, Comparative surgical benefit. The comparative benefit becomes zero at 16.1 years.
Appendix A

The Coronary Artery Bypass Graft Operation (Section II)

Figure A1 (above). Patency of internal mammary artery and saphenous vein grafts at 1 year intervals after insertion. Reproduced, with permission, from Loop et al. (4).

Figure A2 (below). Illustration of the advantage, in terms of predicted survival (A), and hazard function (B), of the use of the internal mammary artery (IMA) in the coronary artery bypass operation in an elderly patient in the current era. The advantage of use of the internal mammary artery is not apparent until about the 4th postoperative year. Data based on nomogram of a specific solution of a multivariable risk factor equation for death (5,6).
Appendix B

Status After the Coronary Bypass Operation (Outcome Events)
(Section III)

Figure B1. Relation between the number of importantly stenosed vessels and the comparative benefit of surgery (the coronary artery bypass operation compared with initial medical treatment) in terms of risk factor-adjusted freedom from cardiovascular death. Reproduced with permission from Califf et al. (35).

Figure B2. Relation between left ventricular dysfunction (ejection fraction) and the comparative benefit of surgery (the coronary artery bypass operation compared with initial medical treatment), in terms of risk factor-adjusted freedom from cardiovascular death. Reproduced with permission from Califf et al. (35).
Figure B3. Hazard function for postbypass return of angina in a heterogeneous group of patients (5,6).

Figure B4. Comparative benefit of the use of the internal mammary artery (IMA) versus use of vein grafts only, in terms of freedom from angina. A, Nomogram of the risk-adjusted time-related probability of freedom from angina after the coronary artery bypass (CABG) operation, according to whether the internal mammary artery was or was not used (a specific solution of the KUL multivariable equation for freedom from return of angina [5]). The nomogram has two curves, but they are virtually the same. B, Comparative benefit of use of the internal mammary artery. The slight discrepancy of B compared with A is due to the greatly expanded vertical axis in B.
Appendix C

Comparisons of the Coronary Bypass Operation With Medical Therapy (Section IV)

Task Force Subcommittee Methodology

Publications concerned with time-related freedom from unfavorable events in patients with ischemic heart disease have used a wide variety of methods of analysis and techniques of reporting and displaying information. They have also varied widely in the amount of detail included about the prevalence of the potential risk factors in the groups and subgroups described. A similar variety of methods have been used to compare results of one method of treatment with those of another. This has made troublesome the obtaining of a complete overview of the results of the coronary artery bypass operation compared with those of medical treatment (or coronary

![Figure C1](image)

**Figure C1.** Comparison of survival after randomly assigned surgery (CABG operation) with that after randomly assigned initial medical treatment, according to the results of graded exercise testing (GXT) (25). (See prevalences of risk factors in the accompanying Table E.)

A. Survival in patients with a positive graded exercise test. B. Comparative benefit, in terms of survival, of an initial coronary bypass operation versus initial medical treatment in patients with a positive graded exercise test. C. Format as in A, but in patients with a markedly positive graded exercise test. D. Format similar to B, but in patients with a markedly positive graded exercise test. Note that the surgical benefit is greater in this group.

### Prevalences of Risk Factors in the Overall Group of Patients in the European Randomized Trial (25).

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Surgical</th>
<th>Medical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patients (n)</td>
<td>394</td>
<td>333</td>
</tr>
<tr>
<td>Age (yr)</td>
<td>50 ± 6.6</td>
<td>50 ± 7.1</td>
</tr>
<tr>
<td>Stenosed vessels</td>
<td></td>
<td></td>
</tr>
<tr>
<td>two vessels</td>
<td>37%</td>
<td>41%</td>
</tr>
<tr>
<td>three vessels</td>
<td>56%</td>
<td>50%</td>
</tr>
<tr>
<td>LM &gt;75%</td>
<td>7%</td>
<td>8%</td>
</tr>
<tr>
<td>Prior myocardial infarct</td>
<td>45%</td>
<td>46%</td>
</tr>
<tr>
<td>Ejection fraction</td>
<td>65 ± 10.3%</td>
<td>65 ± 10.0%</td>
</tr>
</tbody>
</table>

Angina

Class I-II                      | 100%     | 100%     |
Class III-IV                    | —        | —        |
Unstable                        | —        | —        |
Noneventrical                   | —        | —        |
Diabetes                        | 6%       | 6%       |
Hypertension                    | 18%      | 15%      |
Revascularization               | 1.9 grafts | 0       |

*The prevalences in the subset with a positive graded exercise test, and in that with a markedly positive graded exercise test, are not available. LM = left main.*
Figure C2. Comparison of survival after randomly assigned surgery (coronary artery bypass operation) with that after randomly assigned initial medical treatment, in patients with unstable angina (31). (See prevalences of risk factors in accompanying Table E). A. Survival of the overall group. B. Comparative benefit, in terms of survival. The inclusion of the zero horizontal line by the 90% confidence intervals indicates that the small comparative advantage of surgery could be due to chance alone. C. Format as in A, but in patients with unstable angina and three vessel coronary artery disease. D. Format as in B, but in patients with unstable angina and three vessel coronary artery disease. The relation of the 90% confidence intervals to the zero horizontal line indicates that the surgical benefit after 2 years is unlikely to be due to chance alone.

For use by the Subcommittee, the data and information in each of the major publications have been reorganized into a common format. (The Subcommittee expresses its appreciation to Dr. David Naftel for performing these computations and reorganizations.) Information about the prevalence of potential risk factors in the patient subgroups presented has been juxtaposed with the graphic presentations of outcome to facilitate interpretation. Only a fraction of the reformatted analyses are presented in this report.

The concept of comparative benefit. This concept, introduced by Califf and colleagues (35), was adopted as a proper method for making comparisons. Four depictions were used to present the comparative benefit in terms of freedom from a specific unfavorable event (see, for example, Appendix D, Fig. D1). In the upper left was
Prevalences of Risk Factors in Two Groups of Patients With Left Main Coronary Artery Disease (29, 81)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>VA Randomized Trial</th>
<th>CASS Registry</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surgical</td>
<td>Medical</td>
</tr>
<tr>
<td>Number of patients (n)</td>
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<td>43</td>
</tr>
<tr>
<td>Age (years)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Stenosed vessels</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>1 vessel</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>2 vessels</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>3 vessels</td>
<td>81%</td>
<td>93%</td>
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<tr>
<td>LM &gt;75%</td>
<td>48%</td>
<td>49%</td>
</tr>
<tr>
<td>Ejection fraction &gt;0.50</td>
<td>17%</td>
<td>28%</td>
</tr>
<tr>
<td>Diabetes</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Hypertension</td>
<td>27%</td>
<td>30%</td>
</tr>
<tr>
<td>Smoking</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Revascularization</td>
<td>2.3 grafts</td>
<td>—</td>
</tr>
</tbody>
</table>

*Mean value, or % of n. †These data are for the overall group, undifferentiated as to surgical versus medical treatment. CASS = Coronary Artery Surgery Study; LM = left main coronary artery; VA = Veterans Affairs.

Figure C3. Comparison of survival after surgery (coronary artery bypass operation) with that after initial medical treatment in patients with left main coronary artery disease. See prevalences of risk factors in accompanying table E. A, Survival after randomly assigned treatment (29). B, Comparative benefit, in terms of survival. The surgical advantage is appreciable, and the position of the 90% confidence intervals relative to the zero line indicates that it is unlikely to be due to chance alone. C, Format similar to A but showing data for symptomatic patients with nonrandomly assigned treatment (81). D, Format similar to B but showing data for symptomatic patients with nonrandomly assigned treatment (81). Note the similarity to B.

depicted the time-related probability of freedom from the event after the coronary artery bypass operation, for example, and that after an alternative form of treatment, such as initial medical treatment (or coronary angioplasty). In the lower left was presented the comparative benefit, or the time-related difference in the probability of freedom after the two therapies, "+" resulting from a greater freedom after the coronary bypass operation and indicating a comparative benefit in favor of the operation and "−" resulting from a lesser freedom after the operation and indicating a comparative benefit in favor of the alternative form of treatment. In the upper right was presented time-related hazard functions for the unfavorable outcome event after the two forms of therapy. In the lower right was presented the time-related hazard ratio, depicting again the benefit from the operation or lack thereof. Here no difference was indicated by "1," a benefit from the operation by a ratio <1, and benefit from the alternative form of therapy by a ratio
Typically, in the two upper depictions the 70% confidence intervals around the continuous point estimates of freedom after each of the two treatment strategies were shown. 70% confidence intervals (rather than the wider 95% confidence intervals) were used because of the unreasonableness in clinical medicine of concluding "no benefit" primarily because of a fairly small number of patients in a study. This could happen were the criteria to be nonoverlapping 95% confidence intervals (or a p value <0.05). In the two lower depictions, the "0" and "1" had no confidence intervals, so the lines of comparative benefit were surrounded by their 90% confidence intervals.

When the 70% confidence intervals of the time-related probabilities of freedom for each of the two treatments were widely separated, a p value ≤0.05 was assured, and the inference was that a "near certain difference" existed. When the 70% intervals nearly but not quite touched, a p value ≤0.10 was likely, and the inference was that a "probable difference" existed. These two situations have been classified as treatment class I (Table I). When the 70% confidence intervals touched or overlapped, the inference was that "any difference could be due to chance alone." This situation has been classified as treatment class II.

When the 90% confidence interval of the time-related difference between the probabilities of freedom of the two treatments was widely separated from 0, a p value ≤0.05 was assured, and the inference was that a "near certain benefit" existed. When the 90% interval nearly but not quite touched zero, a p value ≤0.10 was assured, and the inference was that a "probable benefit" existed. These situations again have been classified as treatment class I. When the 90% confidence interval touched or overlapped zero, the inference was that "any benefit could be due to chance alone." This situation has been classified as treatment class II. When the depiction of the two separate probabilities of freedom and the comparative benefit indicated that there was no advantage of the coronary artery bypass operation, the treatment class was considered to be III.

Generating a hazard function equation. The process of converting the depictions in a publication into the Subcommittee format consisted of generating an equation in the hazard function domain, from
Figure C5. Comparison of survival according to the presence or absence of a proximal left anterior descending coronary artery stenosis in patients with multivessel disease. See prevalences of risk factors in the table accompanying Figure C1. A, Survival after randomly assigned initial surgery (coronary artery bypass operation) in such patients without a proximal stenosis in the left anterior descending coronary artery, compared with that after initial medical treatment (25). B, Comparative benefit, in terms of survival, of the coronary bypass operation versus initial medical treatment in the same group of patients. The graph indicates that the small surgical benefit could be due to chance alone. C, Format similar to A, but based on such patients with an important proximal stenosis in the left anterior descending coronary artery (25). The decreased survival with initial medical treatment, compared with that in patients without a proximal stenosis. D, Comparative benefit in the same group of patients. The graph indicates that the considerable surgical benefit is unlikely to be due to chance alone.

which the continuous point estimate and confidence intervals of both the probability of freedom and the hazard function could be generated (24). This was begun by converting the usual life-table depiction of the publication into the cumulative hazard function domain. (When an original data set is being analyzed parametrically, the first informal estimate of the number of hazard phases is made in this domain.) A three phase hazard function was initially assumed to be present (a reasonable assumption from many previous analyses of alternative forms of treatment, including medical treatment, for ischemic heart disease). Then the data were tested for their fit to this assumption. If indicated by this fitting, one or more phases were deleted. Then the data were expressed in an equation, using the techniques of the parametric method in the hazard function domain (24). In the Subcommittee depictions, the actuarial estimates from the paper were also depicted, to provide a validation of the parametric estimate.

The confidence intervals from the usual variance-covariance matrix in the parametric method are mainly dependent on the total number of events occurring during the period of study. The raw data necessary for the computation of the variance-covariance matrix were not in the publications from the literature. However, the total number of events was usually stated or could be calculated. The confidence intervals were therefore estimated using this number, recognizing that this was only the best possible estimate under the circumstances.

This method has been validated by comparing the Subcommittee depiction of the time-related probability of survival, with its confidence intervals, after randomly assigned initial medical treatment in the Veterans Administration trial (as seen in Fig. 7) with those obtained by a parametric analysis of the original data. The correspondence was very close. (These data may be obtained from the Subcommittee on request.)
Figure C6. Comparison of survival after nonrandomly assigned surgery (coronary artery bypass operation) with that after initial medical treatment, in patients with three vessel disease and severe angina, according to the severity of left ventricular dysfunction (33). See prevalences of risk factors in Figure 3E (table) under "Angina III–IV."). A, Survival in patients with mild left ventricular dysfunction. B, Comparative benefit. The graph indicates that the important surgical benefit is unlikely to be due to chance alone. C, Format similar to A, but showing data for patients with severe left ventricular dysfunction. Note that the surgical survival at 1 month and 5 years is less than that when left ventricular dysfunction is mild. D, Format similar to B but showing data for patients with severe left ventricular dysfunction. The data emphasize that the surgical benefit is greater when left ventricular dysfunction is severe than when it is mild, even though the 1 month and 5 year surgical survival rates are lower than when dysfunction is mild.
Appendix D

Comparison of the Coronary Artery Bypass Operation With Coronary Angioplasty (Section V)

Figure D1. Comparison of survival after nonrandomly assigned initial coronary artery bypass surgery with that after initial coronary angioplasty in heterogeneous groups of patients (70). See prevalences of risk factors in accompanying Table E. A, Survival (without risk adjustment). B, Comparative benefits. There appears to be a small benefit of angioplasty, but this was not confirmed by multivariable Cox regression analysis for risk factor adjustment. C, Hazard functions (each with two phases) for death. The constant phase of hazard is higher after the coronary bypass operation (surgical treatment). D, The hazard ratio. This indicates that in the heterogeneous groups the improved comparative benefit of coronary angioplasty is unlikely to be due to chance alone, but Cox multivariable regression analysis did not confirm this.

Prevalences of Risk Factors in Patients Undergoing the Coronary Artery Bypass Operation (CABG) or Angioplasty (PTCA)

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>CABG</th>
<th>PTCA</th>
</tr>
</thead>
<tbody>
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<td>Number of patients (n)</td>
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<td>389</td>
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<tr>
<td>Age (yr)</td>
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<td>55</td>
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<tr>
<td>Stenosed vessels</td>
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<tr>
<td>1 vessel</td>
<td>4%</td>
<td>60%</td>
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<tr>
<td>2 vessels</td>
<td>22%</td>
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<td>3 vessels</td>
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<td>6%</td>
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<td>Left main stenosis</td>
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<td>1%</td>
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<td>Prior myocardial infarction</td>
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<td>Ejection fraction</td>
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</tr>
<tr>
<td>Unstable Angina</td>
<td>20%</td>
<td>40%</td>
</tr>
</tbody>
</table>

*Data for both groups are for 1981 to 1986 (70). Note the increased prevalence of most risk factors in the patients undergoing the coronary bypass operation.
Figure D2. Comparison of predicted survival and hazard functions after the coronary artery bypass operation with that after coronary angioplasty in elderly patients (>70 years of age) with three vessel coronary artery disease and mild left ventricular dysfunction. Both depictions are nomograms of patient-specific (risk factor-adjusted) solutions of multivariable risk factor equations (6,73). A, Survival. B, Comparative benefit. The comparative benefit of the coronary bypass operation is unlikely to be due to chance alone. C, Hazard function. D, Hazard ratio, showing a comparative benefit of the coronary bypass operation that is unlikely to be due to chance alone.
Figure D3. Comparison of freedom from angina after nonrandomly assigned coronary bypass surgery with that after coronary angioplasty (69). (See prevalences of risk factors in accompanying Table E). A, Freedom from return of angina. Although the treatments were nonrandomly assigned, the method of the study assured that all patients were suitable for both treatments, and resulted in well-matched populations. B, Comparative benefit. The comparative benefit in terms of the coronary bypass operation is unlikely to be due to chance alone. C, Hazard functions for return of angina. D, Hazard ratio. The benefit of the coronary bypass operation is unlikely to be due to chance alone.

Appendix E

Indications for the Coronary Bypass Operation (Section VI)

Definitions
A. Severity of Angina (Canadian Cardiovascular Society) (129)

Class I angina occurs only with strenuous or prolonged exertion at work or recreation and does not occur with ordinary physical activity.

Class II angina occurs with walking rapidly on level ground or a grade and with rapidly walking up stairs. Ordinary walking for <2 blocks on the level or climbing one flight of stairs does not cause angina except during the first few hours after awakening, after meals, under emotional stress, in the wind or in cold weather. This implies slight limitation of ordinary activity.

Class III angina occurs when walking <2 blocks on level ground.
at a normal pace, under normal conditions, or when climbing one flight of stairs. This implies marked limitation of ordinary physical activity.

Class IV angina occurs with even mild activity, and may occur at rest but must be of brief (<15 min) duration. (If the angina is of longer duration, it is called unstable angina.) This implies inability to carry out even mild physical activity.

B. Unstable Angina

Unstable angina has been variously defined by practitioners (130) by the randomized trials of unstable angina (30,31,131) and more recently in a summarizing paper by Braunwald (132). For the purposes of this report, establishing subgroups of unstable angina seemed unwise, since no clear relation of subgroups to outcome has been established. In any event, unstable angina is taken as clear evidence of important reversible myocardial ischemia.

In this report, unstable angina implies one of several syndromes. It applies to patients with severe and persisting angina on presentation to the physician or hospital, with electrocardiographic (ECG) evidence of ischemia and only minor creatine kinase MB isoenzyme evidence (available only later) of myocardial infarction. The syndrome is considered more ominous if it occurs in the absence of stimuli to increased total body oxygen consumption or catecholamine release (unusual emotional stress, fever, infection, hypotension or uncontrolled hypertension, tachyarrhythmia or hypovolemia). It also applies to patients who have new onset angina (Canadian class IV) within 2 months of presentation, or recurring or prolonged (>15 min) severe angina within 10 days of presentation, whether or not it is new. The phrase is also appropriate to patients who develop (or continue with) severe angina within 2 weeks of an acute myocardial infarction. In all subsets, there will usually be ECG evidence of myocardial ischemia during the severe pain, and no evidence of more than minimal myocardial necrosis.

C. Moderate or Severe Myocardial Ischemia With Noninvasive Stress Testing

This report uses only two categorizations of the results of noninvasive stress testing: 1) no or mild myocardial ischemia, and 2) moderate or severe myocardial ischemia (positive results). For the purposes of this report, evidence of moderate or severe myocardial ischemia in patients with coronary artery disease includes

1. On exercise electrographic testing with a low level of exercise (≤stage 2 Bruce protocol, or ≤6.5 metabolic equivalents (MET) (approximately 3.5 ml oxygen uptake·kg·min⁻¹), or maximal work load <100 W): a) ≥1 mm ischemic (horizontal or downsloping) ST segment depression in multiple leads; b) ECG changes lasting >6 min after cessation of exercise; c) sustained decrease >10 mm Hg in systolic blood pressure, or a lower than usual systolic blood pressure (≤130 mm Hg) in response to the exercise; di ventricular tachycardia: ei angina.

2. On thallium scintigraphy: a) reversible thallium defects in more than one area at risk, or in a very large single area; b) increased thallium uptake by the lungs during exercise (reflecting pulmonary edema).

3. On radionuclide testing: a) exercise-induced reduction in ejection fraction ≥0.10; b) development of segmental wall motion abnormalities; c) exercise-induced left ventricular cavity dilation. This general area has been well reviewed in three previous Task Force reports (101,133,134).

D. Distribution and Severity of Coronary Artery Disease

A stenosis is, for the purposes of this report, considered important in the coronary arteries when it produces ≥70% reduction in the luminal diameter of the vessel. However, some multivariable risk factor analyses have found stenoses ≥50% to be risk factors for an unfavorable outcome event.1 An exception is the left main coronary artery, in which a ≥50% reduction in luminal diameter is considered to be an important stenosis.

The phrases one vessel, two vessel, or three vessel coronary artery disease consider as "a vessel" the left anterior descending coronary artery, the right coronary artery or the posterior descending coronary artery, and the left circumflex coronary artery and/or one or more large marginal branches. The circulation should always be labeled "right dominant," "left dominant," or "co-dominant," according to the origin of the posterior descending coronary artery.

E. Left Ventricular Dysfunction

For the purposes of this report, left ventricular dysfunction at rest has been termed "absent, grade 0," or "present, and mild, moderate or severe in degree," on the basis of ejection fraction or Coronary Artery Surgery Study (CASS) score (Table E1), or an interpretation of the functional significance of other quantitative measurements of left ventricular function, such as radionuclide techniques. In some multivariable analyses, other arbitrary criteria have been used, including four grades of left ventricular dysfunction. In one randomized trial, a simple yes or no indication of the presence of dysfunction was used.

Table E1. Interrelations Between "Left Ventricular Dysfunction" at Rest, Ejection Fraction and Coronary Artery Surgery Study (CASS) Score

<table>
<thead>
<tr>
<th>Left Ventricular Dysfunction</th>
<th>Ejection Fraction</th>
<th>CASS Score (26.80)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>0.60</td>
<td>5 (is normal)</td>
</tr>
<tr>
<td>Mild</td>
<td>0.50-0.60</td>
<td>5-9</td>
</tr>
<tr>
<td>Moderate</td>
<td>0.35-0.50</td>
<td>9-15</td>
</tr>
<tr>
<td>Severe</td>
<td>0.35</td>
<td>15</td>
</tr>
</tbody>
</table>

*These interrelations are for the purposes of this report, and are somewhat arbitrary, although in general agreement with the interrelations described in other reports.

Appendix F

Patient-Specific Guidelines and Indications for the Coronary Bypass Operation (Section X)

Methodology

The methodology for patient-specific predicting and comparing is simple, and in essence has been described in Section X and alluded to in other parts of the report. The bases of the methodology are multivariable risk factor equations, preferably in the hazard function domain.

The equations currently available for patient-specific predicting and comparing, along with coefficients and p values, are depicted on the following pages. The confidence intervals are determined by the variance-covariance matrix, which is more complex than can conveniently be printed. The equations and the variance-covariance matrix (for confidence intervals) are available as computer software from the Subcommittee. These can be used in a personal computer for generating patient-specific predictions and comparisons.

The Subcommittee deeply appreciates the privilege of using the
multivariable risk factor equations in the hazard function domain for probability of freedom from unfavorable outcome events after the coronary bypass operation, derived in collaboration with and from the data base of Dr. Paul Sergeant and his colleagues in cardiology at the Katholieke Universiteit in Leuven, Belgium (KUL) (5) (Sergeant PJ. Blackstone EH, Lesaffre E, Flameng W, Kirklin JW. Unpublished study, 1990). The Subcommittee also expresses its deep appreciation to Drs. Timothy Takaro, Herbert Hultgren, Peter Peduzzi, Katherine Dete and the Department of Veterans Affairs for providing the data base of patients with stable angina randomized to initial medical treatment in the Veterans Affairs randomized trial (28-29). The Subcommittee is also deeply grateful for the very helpful collaboration of Drs. Stewart Scott, Robert Luchi and RH Deupree, and the Department of Veterans Affairs in providing the data base of patients with unstable angina randomized to initial medical treatment in the Veterans Affairs trial (30-31). These data bases were subjected to multivariable risk factor analysis in the hazard function domain by Dr. EH Blackstone, for the Subcommittee. The other equations have been previously published.

Confidence intervals when predicting for an individual

There is a tendency to believe that the confidence intervals are wider when predicting time-related probability of freedom from an unfavorable outcome event for an individual, than when predicting it for a group. To some extent this is based on a misunderstanding of what is being predicted, and to some extent it reflects the fact that this matter remains one of opinion and not one of proof.

The Equations

The form of the risk factor equations is the log-linear one (24). The definitions and units of variables appearing more than once in a...

1. Multivariable risk factor equation for death after the coronary bypass operation (UAB, 1977–1981). This equation is given in the original publication (34).

2. Multivariable risk factor equation for death after the coronary bypass operation (KUL). For the three hazard phases, shaping parameter estimates and incremental risk factors, their coefficients, standard deviations and p values were:

   **Early:** \( \delta = 0, \rho = 0.1113, \gamma = 1.443, m = 0, \) intercept = -5.901, age (years) = 0.05760 ± 0.0138 (p < 0.0001), left main disease (0 = no, ≥90% stenosis = 1) = 0.6730 ± 0.31 (p = 0.03), ejection fraction = -2.082 ± 0.77 (p = 0.007), left ventricular hypertrophy (0 = no, 1 = yes) = 0.8049 ± 0.29 (p = 0.006), severity of angina (0 = none, 1 = mild stable angina, 2 = moderate or severe stable angina, 3 = severe nonexertional angina, 4 = unstable angina) = 0.6126 ± 0.111 (p < 0.0001), mean quality of distal coronary vessels (0 = no, 1 = yes) = 0.6849 ± 0.122 (p = 0.004), sequential grafting (ratio of number of distal anastomoses to number of conduits) = 0.3538 ± 0.122 (p = 0.004).

   **Constant:** intercept = -4.709, ejection fraction = -3.806 ± 0.77 (p < 0.0001), ischemic mitral incompetence (0 = no, 1 = yes) = 0.7834 ± 0.26 (p = 0.002), no anginal symptoms (0 = no, 1 = yes) = 0.6196 ± 0.23 (p = 0.007), unstable angina (0 = no, 1 = yes) = 0.7944 ± 0.20 (p < 0.0001), peripheral vascular disease (0 = yes) = 0.24 ± 0.6609 (p = 0.002), number of distal anastomoses to number of conduits) = 0.3538 ± 0.122 (p = 0.004).

   **Late (rising):** \( \tau = 1, \gamma = 1, \alpha = 1, \eta = 3.526, \) intercept = 9.827, age (years) = 0.2620 ± 0.080 (p = 0.001), age (natural logarithm transformation) = -11.18 ± 4.1 (p = 0.006), number of diseased vessels (1 to 3, ≥70% stenosis) = 0.3219 ± 0.140 (p = 0.02), ejection fraction = -2.287 ± 1.10 (p = 0.04), peripheral vascular disease (0 = yes) = 0.630 ± 0.23 (p = 0.005), small coronary arteries (0 = yes) = 1.229 ± 0.40 (p = 0.002), insulin-treated diabetes = 1.756 ± 0.41 (p < 0.0001), 1-second expiratory rate = -0.01493 ± 0.0056 (p = 0.008), triglyceride level (mg/dl^-1, natural logarithm transformation) = 0.4884 ± 0.169 (p = 0.004), nonuse of internal mammary (thoracic) artery as a conduit (0 = no, 1 = yes) = 1.234 ± 0.29 (p < 0.0001).

3. Multivariable risk factor equation for death after the coronary bypass operation (UAB, 1986–1988) (6). For the single hazard phase (2-year followup), shaping parameter estimates and incremental risk factors, their coefficients, standard deviations and p values were:

   \( \alpha = 0.002157, \gamma = 1, \alpha = 3.048, \eta = 1, \) intercept = -10.2, age (years) = 0.06234 ± 0.0088 (p < 0.0001), left main disease (0 = no, ≥50% stenosis = 1) = 0.3374 ± 0.192 (p = 0.08), number of prior myocardial infaracts = 0.3127 ± 0.118 (p = 0.008), myoccardial infarction within 30 days of operation (0 = no, 1 = yes) = 0.4017 ± 0.194 (p = 0.04), CASS left ventricular wall motion score (score minus 5) = 0.04746 ± 0.020 (p = 0.02), hemodynamic instability without shock (0 = no, 1 = yes) = 1.359 ± 0.28 (p < 0.0001), cardiogenic shock (0 = no, 1 = yes) = 1.919 ± 0.30 (p < 0.0001), nonuse of internal mammary (thoracic) artery as a conduit = 0.5498 ± 0.163 (p = 0.0007).

4. Multivariable risk factor equation for return of angina after the coronary bypass operation (KUL). For the three hazard phases, shaping parameters and incremental risk factors, their coefficients, standard deviations, and p values were: Early: \( \delta = 0, \rho = 3.405, \gamma = 1, m = 0, \) intercept = -3.471, age (years) = -0.03833 ± 0.0114 (p = 0.0008), severity of angina (0 = none, 1 = mild stable angina, 2 = moderate or severe stable angina, 3 = severe nonexertional angina, 4 = unstable angina) = 0.2986 ± 0.096 (p = 0.002), peripheral vascular disease (0 = no, 1 = yes) = 1.074 ± 0.22 (p < 0.0001), mean quality of distal coronary vessels (0 = normal, 1 = diffuse but nonstenosing disease, 2 = diffuse stenosing disease, 3 = diffuse stenotic disease requiring endarterectomy) = 0.3912 ± 0.143 (p = 0.006), nonuse of internal mammary (thoracic) artery as a conduit to the left anterior coronary artery (0 = no, 1 = yes) = 0.623 ± 0.25 (p = 0.01), incomplete revascularization (0 = no, 1 = yes) = 0.6849 ± 0.23 (p = 0.003), peripheral vascular disease (0 = yes) = 0.24 ± 0.6609 (p = 0.007), sequential grafting (ratio of number of distal anastomoses to number of conduits) = 0.3538 ± 0.122 (p = 0.004).
quality of distal coronary vessels = 0.2475 ± 0.074 (p = 0.0008), small coronary arteries (ratio of number of 1 mm or smaller
distal coronary anastomoses to number of distal anastomoses) = 0.9316 ± 0.23 (p < 0.0001), ascending aortic disease (0 = no, 1 = yes) =
0.5289 ± 0.26 (p = 0.04), systemic hypertension (0 = no, 1 = systolic
pressure ≥160 mm Hg or diastolic pressure ≥100 mm Hg) = 0.3586 ±
0.101 (p = 0.0004). Late: \( \tau = 1, \gamma = 1, \alpha = 1, \eta = 3.355, \) intercept =
-21.74, duration of angina symptoms = 0.006292 ± 0.0021 (p = 0.002),
triglyceride level (mg dl\(^{-1}\), logarithmic transformation) = 0.6123 ± 0.193 (p = 0.002), sequential grafting (the ratio of number of
distal anastomoses to number of conduits + 0.5, natural logarithm
transformation) = 1.409 ± 0.36 (p < 0.0001).

5. Incremental risk factor equation for acute myocardial infarction
after the coronary bypass operation (KUL). For the two hazard phases,
shaping parameter estimates and incremental risk factors, their coefficients,
standard deviations and p values were: Early: \( \delta = 0, \rho = 38.80, \nu =
2.685, m = 0, \) intercept = -2.152, unstable angina (0 = no, 1 = yes) =
0.6085 ± 0.26 (p = 0.02), number of conduits used = -0.4578 ± 0.143 (p = 0.001), incomplete revascularization (0 = no, 1 = ≥70% stenosis
remaining unhealed) = 0.6243 ± 0.26 (p = 0.02), surgeon C (0 = no, 1 = yes) = -0.5678 ± 0.28 (p = 0.04). Late: \( \tau = 1, \gamma = 1, \alpha =
1, \eta = 2.697, \) intercept = -47.16, age (years, natural logarithmic transformation) = 6.161 ± 2.9 (p = 0.03), age
(100/years transformation) = 3.263 ± 1.30 (p = 0.01), unstable angina
(0 = no, 1 = yes) = 0.4048 ± 0.176 (p = 0.02), diabetes (0 =
no, 1 = glucose intolerance, 2 = oral hypoglycemic-treated, 3 =
insulin-treated) = 0.3624 ± 0.108 (p = 0.0008), family history
of coronary artery disease (0 = no, 1 = yes) = 0.3276 ± 0.146 (p = 0.02),
high density lipoprotein level (mg dl\(^{-1}\), logarithmic transformation)
= 0.3456 ± 0.149 (p = 0.02), nonuse of internal mammary (thoracic)
artery as the conduit to the left anterior descending coronary artery
= 0.4388 ± 0.174 (p = 0.01).

6. Multivariable risk factor equation for sudden death after the
coronary bypass operation (KUL). For the two hazard phases,
shaping parameters, incremental risk factors and their coefficients,
standard deviations and p values were: Constant: intercept =
-9.188, absence of left main disease (≥50% stenosis = 0, <50%
stenosis = 1) = 1.590 ± 0.77 (p = 0.04), three vessel disease (0 =
no, 1 = ≥70% stenosis of three vessels) = 1.240 ± 0.50 (p = 0.01),
shaping parameter estimates and incremental risk factors, their coefficients,
standard deviations and p values were: Early: \( \delta = 0, \rho = 107.7, \nu =
1, m = 1, \) intercept = -1.470, left main disease (<50% stenosis = 0, ≥50%
stenosis = 1) = 0.9894 ± 0.45 (p = 0.03), number of diseased vessels (1 to 3, ≥50% stenosis) = 0.2937 ± 0.144 (p = 0.04), number of previous acute myocardial infarctions =
0.2874 ± 0.110 (p = 0.009), history of hypertension (0 = no, 1 = yes) =
0.6793 ± 0.193 (p = 0.0004).

7. Multivariable risk factor equation for a subsequent coronary
bypass operation after initial medical treatment for stable angina
(VA). Data from Blackstone EH, Kirklin JW. Peduzzi P, Takaro T,
Hultgren HN. Outcome after randomization to initial medical
therapy in the VA randomized trial of chronic stable angina
(unpublished study, 1990). For the single hazard phase, incremental risk
factors, their coefficients, standard deviations and p values were: Constant: intercept = -7.233, left main disease (<50% stenosis = 0,
≥50% stenosis = 1) = 1.325 ± 0.33 (p = 0.0001), two or three vessel
disease (<50% stenosis = 0, ≥50% stenosis = 1) = 0.5161 ± 0.26
(p = 0.04), no impairment of left ventricular contractility (0 =
impairment, 1 = no impairment) = 0.3830 ± 0.166 (p = 0.02), VA
angina score (1 to 18) = 0.1109 ± 0.035 (p = 0.002), duration of
pretreatment anginal symptoms (months) = 0.002941 ± 0.00148
(p = 0.05).

8. Multivariable risk factor equation for death after initial medical
therapy for unstable angina (VA). (Data from Blackstone EH,
Kirklin JW. Scott SM, Luchi R, Deupree RH. Outcome after randomization to initial medical treatment in the VA
randomized trial of unstable angina (unpublished study, 1990). These equations are available on computer software.

9. Multivariable risk factor equation for acute myocardial infarction
(fatal and nonfatal) after initial medical treatment for stable
angina (VA). For the single hazard phase, incremental risk factors,
their coefficients, standard deviations, and p values were: Early: \( \delta =
0, \rho = 107.7, \nu = 1, m = 1, \) intercept = -1.470, left main disease
(<50% stenosis = 0, ≥50% stenosis = 1) = 0.9894 ± 0.45 (p = 0.03),
number of previous acute myocardial infarctions = 0.2937 ± 0.144
(p = 0.04), number of previous acute myocardial infarctions =
0.2874 ± 0.110 (p = 0.009), history of hypertension (0 = no, 1 = yes) =
0.6793 ± 0.193 (p = 0.0004).

10. Multivariable risk factor equation for a subsequent coronary
bypass operation after initial medical treatment for stable angina
(VA). For the two hazard phases, shaping parameter estimates and incremental risk factors, their coefficients, standard deviations, and p values were: Early: \( \delta = 0, \rho = 107.7, \nu =
1, m = 1, \) intercept = -1.470, left main disease (<50% stenosis = 0,
≥50% stenosis = 1) = 0.9894 ± 0.45 (p = 0.03), two or three vessel
disease (<50% stenosis = 0, ≥50% stenosis = 1) = 0.5161 ± 0.26
(p = 0.04), no impairment of left ventricular contractility (0 =
impairment, 1 = no impairment) = 0.3830 ± 0.166 (p = 0.02), VA
angina score (1 to 18) = 0.1109 ± 0.035 (p = 0.002), duration of
pretreatment anginal symptoms (months) = 0.002941 ± 0.00148
(p = 0.05).

11. Multivariable risk factor equation for death, acute myocardial
infarction and a subsequent coronary artery bypass operation after
initial medical treatment for unstable angina (VA). (Data from
Blackstone EH. Kirklin JW. Scott SM. Luchi R. Deupree RH. Outcome after randomization to initial medical treatment in the VA
randomized trial of unstable angina (unpublished study, 1990). These equations are available on computer software.

12. Multivariable risk factor equation for death after coronary
angioplasty (UAB) (73). For the two hazard phases, shaping parameters and incremental risk factors, their coefficients, standard deviations, and p values were: Early: \( \delta = 0, \rho = 0.002388, \nu = 1, m = 1, \) intercept = -5.958, number of previous myocardial infarctions =
1.500 ± 0.64 (p = 0.02), cardiacogenic shock (0 = no, 1 = yes) = 2.780 ±
1.16 (p = 0.02). Constant: intercept = -7.645, number of diseased vessels (1 to 3, ≥70% stenosis) = 1.039 ± 0.26 (p < 0.0001), cardiacogenic
shock = 4.412 ± 0.59 (p < 0.0001), ethnicity (0 = white, 1 =
black) = 1.380 ± 0.43 (p = 0.001), diabetes (0 = no, 1 = yes) = 1.234 ±
0.39 (p = 0.002).

13. Multivariable risk factor equation for angina after coronary
angioplasty (UAB) (73). For the single hazard phases, shaping parameters and incremental risk factors, their coefficients, standard deviations, and p values were: \( \kappa = 0.008162, \gamma = 1, \alpha = 2.521, \eta =
1, \) intercept = -4.197, number of diseased vessels (1 to 3, ≥50%
stenosis) = 0.4092 ± 0.136 (p = 0.003), important hyperlipidemia
1. Multivariable risk factor equation for acute myocardial infarction (excluding infarctions in immediate proximity to the angioplasty site and considering only preangioplasty variables) after coronary angioplasty (UAB) (73). For the two hazard phases, shaping parameters and incremental risk factors, their coefficients, standard deviations, and p values were: Early: \( \delta = 0, \rho = 1.399, \nu = -0.2293, m = 0, \) intercept = \(-4.761 \) (no risk factors). Constant: intercept = \(-8.790, \) number of previous myocardial infarcts = \( 0.069, \) incomplete revascularization (no vessel disease \( \geq 50\% \) stenosis = 0, remaining postangioplasty vessel disease \( \geq 50\% \) stenosis = 1) = 2.061 \( \pm 1.03 \) (p = 0.05), angioplasty (0 = no, 1 = yes) = 1.125 \( \pm 0.45 \) (p = 0.01). Later (peaking): \( \delta = 0, \rho = 2.616, \nu = 0.2480, m = 0, \) intercept = \(-2.532, number of \) vessels (1 to 3 \( \geq 50\% \) stenosis, natural exponential transformation) = 0.1229 \( \pm 0.036 \) (p = 0.0006), no previous myocardial infarcts (0 = previous infarcts, 1 = no infarcts) = 1.812 \( \pm 0.71 \) (p = 0.01). number of lesions dilated = \(-1.650 \pm 0.84 \) (p = 0.05).

2. Multivariable risk factor equation for the coronary bypass operation (preangioplasty variables only) after angioplasty (UAB) (73). For the two hazard phases, shaping parameters and incremental risk factors, their coefficients, standard deviations and p values were: Early: \( \delta = 0, \rho = 0.03392, \nu = -0.08466, m = 4.206, \) intercept = \(-8.193, ratio of weight to height (kg\cdot cm^{-1}) = 10.92 \( \pm 6.0 \) (p = 0.07). Late: \( \delta = 1, \gamma = 1, \alpha = 1, \eta = 0.5006, \) intercept = \(-12.45, ratio of weight to height = 12.66 \( \pm 3.3 \) (p = 0.0002), number of vessels (1 to 3 \( \geq 50\% \) stenosis, natural exponential transformation) = 0.1323 \( \pm 0.041 \) (p = 0.001), proximal left anterior descending coronary artery disease (0 = <50\% stenosis, 1 = \( \geq 50\% \) stenosis) = 1.213 \( \pm 0.39 \) (p = 0.002), proximal right coronary artery disease (0 = <70\% stenosis, 1 = \( \geq 70\% \) stenosis) = 0.9517 \( \pm 0.45 \) (p = 0.03), ejection fraction = 2.799 \( \pm 1.50 \) (p = 0.06), hemodynamic instability (0 = no, 1 = yes) = 1.339 \( \pm 0.47 \) (p = 0.004).

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