Guidelines for Perioperative Cardiovascular Evaluation for Noncardiac Surgery

Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Perioperative Cardiovascular Evaluation for Noncardiac Surgery)

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Preamble

Clearly it is important that the medical profession play a significant role in critically evaluating the use of diagnostic procedures and therapies in the management or prevention of disease states. Rigorous and expert analysis of the available data documenting relative benefits and risks of those procedures and therapies can produce helpful guidelines that improve the effectiveness of care, optimize patient outcomes, andimpact the overall cost of care favorably by focusing resources on the most effective strategies.

The American College of Cardiology (ACC) and the American Heart Association (AHA) have produced such guidelines in the area of cardiovascular disease jointly since 1980. This report was directed by the ACC/AHA Task Force on Practice Guidelines, which has as its charge to develop and revise practice guidelines for important cardiovascular diseases and procedures. Experts in a given field are selected from both organizations to examine subject-specific data and write guidelines. Additional representatives from other medical practitioner and specialty groups are included in the writing process when appropriate. Each writing group is specifically charged to perform a formal literature review, weigh the strength of evidence for or against a particular treatment or procedure, and include estimates of expected health outcomes where data exist. Patient-specific modifiers, comorbidities, and issues of patient preference that might influence the choice of particular tests or therapies are considered along with frequency of follow-up and cost-effectiveness.

These practice guidelines are intended to assist physicians in clinical decision making by describing a range of generally acceptable approaches for the diagnosis, management, or prevention of specific diseases or conditions. These guidelines attempt to define practices that meet the needs of most patients in most circumstances. The ultimate judgment regarding care of a particular patient must be made by the physician and patient in light of all of the circumstances presented by that patient.

The ACC/AHA classifications I, II, and III are used in this report to summarize indications for a particular therapy or treatment as follows:

Class I: Conditions for which there is evidence for and/or general agreement that a procedure be performed or a treatment is of benefit.

Class II: Conditions for which there is a divergence of evidence and/or opinion about the treatment.

Class III: Conditions for which there is evidence and/or general agreement that the procedure/treatment is not necessary.

The Committee to Develop Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery was chaired by Kim A. Eagle, MD, and included the following members: Bruce H. Brundage, MD, Bernard R. Chaitman, MD, Gordon A. Ewy, MD, Lee A. Fleisher, MD, Norman R. Hertzer, MD, Jeffrey A. Leppo, MD, Thomas J. Ryan, MD, Robert C. Schlant, MD, William H. Spencer III, MD, John A. Spittell, Jr, MD, and Richard D. Twiss, MD. This document was approved by the ACC Board of Trustees and the AHA SACC/Steering Committee and is being published simultaneously in the *Journal of the American College of Cardiology* and *Circulation* in March 1996. The document was also endorsed by the Society for Cardiovascular Anesthesiologists, the Society for Vascular Surgery, and the North American Chapter of the International Society for Cardiovascular Surgery.

This document was reviewed by three outside reviewers nominated by the ACC and by three outside reviewers nominated by the AHA, as well as reviewers nominated by the American Academy of Family Physicians, the Society for Vascular Surgery, the American Society of Anesthesiologists, and the Society of Cardiovascular Anesthesiologists. The document will be reviewed 2 years after the date of publication and yearly thereafter and considered current unless the Task Force publishes a revision or withdrawal.

James L. Ritchie, MD, FACC
Chair, ACC/AHA Task Force on Practice Guidelines

Executive Summary
Purpose of These Guidelines

These guidelines are intended for physicians involved in the preoperative, operative, and postoperative care of patients undergoing noncardiac surgery. They provide a framework for considering cardiac risk of noncardiac surgery in a variety of patient and operative situations. The overriding theme of these guidelines is that intervention is rarely necessary to lower the risk of surgery. The goal of the task force is the rational use of testing in an era of cost containment.

General Approach

Successful perioperative evaluation and treatment of cardiac patients undergoing noncardiac surgery requires careful teamwork and communication between patient, primary care physician, anesthesiologist, and surgeon. In general, indications for further cardiac testing and treatments are the same as those in the nonoperative setting, but their timing is dependent on such factors as the urgency of noncardiac surgery, the patient's risk factors, and specific surgical considerations. Coronary revascularization before noncardiac surgery to enable the patient to “get through” the noncardiac procedure is appropriate only for a small subset of patients at very high risk. Preoperative testing should be limited to circumstances in which the results will affect patient treatment and outcomes. A conservative approach to use of expensive tests and treatments is recommended.

Preoperative Clinical Evaluation

The initial history, physical examination, and electrocardiographic (ECG) assessment should focus on identification of potentially serious cardiac disorders, including coronary artery disease (CAD) (eg, prior myocardial infarction [MI], angina pectoris), congestive heart failure (CHF), and electrical instability (eg, symptomatic arrhythmias).

In addition to identifying the *presence* of preexisting manifested heart disease, it is essential to define disease *severity*, *stability*, and prior *treatment*. Other factors that help determine cardiac risk include

functional capacity, age, comorbid conditions (eg, diabetes mellitus, peripheral vascular disease, renal dysfunction, chronic pulmonary disease), and type of surgery (vascular procedures and prolonged, complicated thoracic, abdominal, and head and neck procedures considered higher risk).

Further Preoperative Testing to Assess Coronary Risk

Which patients are most likely to benefit from preoperative coronary assessment and treatment? The lack of adequately controlled or randomized clinical trials to define the optimal evaluation strategy has led to the proposed algorithm based on collected observational data and expert opinion. A step-wise Bayesian strategy that relies on assessment of clinical markers, prior coronary evaluation and treatment, functional capacity, and surgery-specific risk is outlined below. A framework for determining which patients are candidates for cardiac testing is presented in algorithmic form. Successful use of the algorithm requires an appreciation for different levels of risk attributable to certain clinical circumstances, levels of functional capacity, and types of surgery. These are defined below, after which the step-by-step algorithm is reviewed.

Clinical Markers. The *major clinical predictors* of increased perioperative cardiovascular risk are unstable coronary syndromes such as recent MI with evidence of important ischemic risk and unstable or severe angina; decompensated CHF, significant arrhythmias (high-grade atrioventricular block, symptomatic arrhythmias in the presence of underlying heart disease, supraventricular arrhythmias with uncontrolled ventricular rate), and severe valvular disease.

Intermediate predictors of increased risk are mild angina pectoris, prior MI, compensated or prior CHF, and diabetes mellitus. *Minor predictors* of risk are advanced age, abnormal electrocardiogram, rhythm other than sinus, low functional capacity, history of stroke, and uncontrolled systemic hypertension.

Functional Capacity. This measurement can be expressed in metabolic equivalent (MET) levels. Multiples of the baseline MET value can be used to express aerobic demands for specific activities. Perioperative cardiac and long-term risk is increased in patients unable to meet a 4-MET demand during most normal daily activities. The Duke Activity Status Index and other activity scales provide the clinician with a set of questions to determine a patient's functional capacity. Energy expenditure for activities such as eating, dressing, walking around the house, and dishwashing can range from 1 to 4 METs. Climbing a flight of stairs, walking on level ground at 6.4 km/h, running a short distance, scrubbing floors, or playing a game of golf equals 4 to 10 METs. Strenuous sports such as swimming, singles tennis, and football exceed 10 METS.

Surgery-Specific Risk. Surgery-specific cardiac risk of noncardiac surgery is related to two important factors: the type of surgery itself and the degree of hemodynamic stress associated with surgery-specific procedures. The duration and intensity of coronary and myocardial stressors can be helpful in estimating the likelihood of perioperative cardiac events, particularly for emergency surgery. Surgery-specific risk for noncardiac surgery can be stratified as high, intermediate, and low. *High-risk* surgery includes major emergency surgery, particularly in the elderly; aortic and other major vascular surgery; peripheral vascular surgery; and anticipated prolonged procedures associated with large fluid shifts and/or blood loss. *Intermediate-risk* procedures include carotid endarterectomy, head and neck surgery, intraperitoneal and intrathoracic, orthopedic, and prostate surgery. *Low-risk* procedures include endoscopic and superficial procedures, cataract surgery, and breast surgery.

Indications for Angiography. Indications for coronary angiography are designated as Class I, conditions for which there is evidence for and/or general agreement that a procedure be performed or a treatment is of benefit; Class II, conditions for which there is a divergence of evidence and/or opinion about the treatment; and Class III, conditions for which there is evidence and/or general agreement that the procedure is not necessary.

Class I indications (helpful), for patients with suspected or proven CAD, are high-risk results during

noninvasive testing; angina pectoris unresponsive to medical therapy; unstable angina pectoris in most patients; and nondiagnostic or equivocal noninvasive test in a high-risk patient undergoing a high-risk procedure.

Class II indications (may be helpful) are intermediate-risk results during noninvasive testing; nondiagnostic or equivocal noninvasive test in a patient at lower risk undergoing a higher risk procedure; urgent noncardiac surgery in a patient recovering from acute MI; and perioperative MI.

Class III indications (not necessary) are low-risk noncardiac surgery in patients with known CAD and low-risk results on noninvasive testing; screening for CAD without appropriate noninvasive testing; patients who are asymptomatic after coronary vascularization and have excellent exercise capacity; mild, stable angina in patients with good left ventricular function and low-risk noninvasive test results; patients who are not candidates for revascularization because of concomitant illness; prior technically adequate normal coronary angiogram within 5 years; severe left ventricular dysfunction in patients not considered candidates for revascularization; and patients unwilling to undergo revascularization.

The following steps correspond to the algorithm presented in Fig 1, page 921.

Step 1. What is the urgency of noncardiac surgery? Certain emergencies do not allow time for preoperative cardiac evaluation. Postoperative risk stratification may be appropriate for some patients who have not had such an assessment before.

Step 2. Has the patient undergone coronary revascularization in the past 5 years? If so, and if clinical status has remained stable without recurrent symptoms/signs of ischemia, further cardiac testing is generally not necessary.

Step 3. Has the patient had a coronary evaluation in the past 2 years? If coronary risk was adequately assessed and the findings were favorable, it is usually not necessary to repeat testing unless the patient has experienced a change or new symptoms of coronary ischemia since the previous evaluation.

Step 4. Does the patient have an unstable coronary syndrome or a major clinical predictor of risk? When elective noncardiac surgery is being considered, the presence of unstable coronary disease, decompensated CHF, symptomatic arrhythmias, and/or severe valvular heart disease usually leads to cancellation or delay of surgery until the problem has been identified and treated.

Step 5. Does the patient have *intermediate clinical predictors of risk*? The presence or absence of prior MI by history or ECG, angina pectoris, compensated or prior CHF, and/or diabetes mellitus helps further stratify clinical risk for perioperative coronary events. Consideration of *functional capacity* and level of *surgery-specific risk* allows a rational approach to identifying patients most likely to benefit from further noninvasive testing.

Step 6. Patients without major but with intermediate predictors of clinical risk and moderate or excellent functional capacity can generally undergo intermediate-risk surgery with little likelihood of perioperative death or MI. Conversely, further noninvasive testing is often considered for patients with poor functional capacity or moderate functional capacity but higher-risk surgery and especially for patients with two or more intermediate predictors.

Step 7. Noncardiac surgery is generally safe for patients with neither major nor intermediate predictors of clinical risk and moderate or excellent functional capacity (4 METs or greater). Further testing may be considered on an individual basis for patients without clinical markers but poor functional capacity who are facing higher-risk operations, particularly those with several minor clinical predictors of risk who are to undergo vascular surgery.

Step 8. The results of noninvasive testing can be used to determine further preoperative management.

Alternatively, the results may lead to a recommendation to proceed with surgery. In some patients, the risk of coronary intervention or corrective cardiac surgery may approach or even exceed the risk of the proposed noncardiac surgery. This approach may be appropriate, however, if it also significantly improves the patient's long-term prognosis.

For some patients, a careful consideration of clinical, surgery-specific, and functional status attributes leads to a decision to proceed to coronary angiography.

Management of Specific Preoperative Cardiovascular Conditions

Hypertension: Severe hypertension should be controlled before surgery when possible. The decision to delay surgery because of elevated blood pressure should take into account the urgency of surgery and potential benefit of more intensive medical therapy. Continuation of preoperative antihypertensive treatment through the perioperative period is critical.

Valvular heart disease: Indications for evaluation and treatment of valvular heart disease are identical to those in the nonoperative setting. Symptomatic stenotic lesions are associated with risk of perioperative severe CHF or shock and often require percutaneous valvotomy or valve replacement before noncardiac surgery to lower cardiac risk. Symptomatic regurgitant valve disease is usually better tolerated perioperatively and may be stabilized preoperatively with intensive medical therapy and monitoring. Regurgitant valve disease is then treated definitively with valve repair or replacement after noncardiac surgery. This is appropriate when a wait of several weeks or months before noncardiac surgery may have severe consequences. Exceptions may include severe valvular regurgitation *with* reduced left ventricular function, in which overall hemodynamic reserve is so limited that destabilization during perioperative stresses is very likely.

Myocardial disease: Dilated and hypertrophic cardiomyopathy are associated with increased incidence of perioperative CHF. Management is aimed at maximizing preoperative hemodynamic status and providing intensive postoperative medical therapy and surveillance. An estimate of hemodynamic reserve is useful for anticipating potential complications from intraoperative and/or postoperative stress.

Arrhythmias and conduction abnormalities: The presence of an arrhythmia or cardiac conduction disturbance should provoke a careful evaluation for underlying cardiopulmonary disease, drug toxicity, or metabolic abnormality. Therapy should be initiated for symptomatic or hemodynamically significant arrhythmias, first to reverse an underlying cause and second to treat the arrhythmia. Indications for antiarrhythmic therapy and cardiac pacing are identical to the nonoperative setting.

Supplemental Preoperative Evaluation

No specific recommendations can be made for individual patients. The following should be considered appropriate as indicated in specific situations: resting left ventricular function, exercise stress testing, pharmacological stress testing, ambulatory ECG monitoring and coronary angiography. In most ambulatory patients the test of choice is exercise ECG testing, which can both provide an estimate of functional capacity and detect myocardial ischemia through changes in the ECG and hemodynamic response. In patients with important abnormalities on their resting ECG (left bundle branch block, left ventricular hypertrophy with strain pattern, digitalis effect, etc), other techniques such as exercise echocardiography or exercise myocardial perfusion imaging should be considered.

Implications of Risk Assessment Strategies on Costs

The degree of variation surrounding preoperative testing before noncardiac surgery is substantial. Cost-effectiveness analyses of various methods of preoperative testing and treatments have also yielded highly varied results. It is important for the clinician to consider the cost implications of screening strategies and, when possible, to rely on generally accepted strategies for treating patients in the nonoperative setting.

Preoperative Coronary Revascularization

Coronary artery bypass graft (CABG) surgery: Indications for CABG before noncardiac surgery are identical to those reviewed in the ACC/AHA guidelines for CABG. CABG is rarely indicated to simply "get a patient through." However, when the stress of elective noncardiac surgery is likely to exceed the stress of daily life, it may be reasonable to consider CABG before noncardiac surgery.

Coronary angioplasty: There are no controlled trials comparing perioperative cardiac outcome after noncardiac surgery for patients treated with preoperative PTCA versus medical therapy. Several small observational series have suggested that cardiac death is infrequent in patients who have coronary angioplasty before noncardiac surgery. Several studies have also demonstrated a number of complications from angioplasty, including emergency CABG in some patients. Until further data are available, indications for PTCA in the perioperative setting are similar to those in the ACC/AHA guidelines for use of PTCA in general.

Medical Therapy for Coronary Artery Disease

There are very few randomized trials from which firm conclusions or recommendations can be drawn. However, if patients require β-blockers, calcium channel blockers, and/or nitrates before surgery, continuation of the preoperative medical regimen into the operative and postoperative period may also protect against ischemic tendencies caused by perioperative stresses. The same is true for therapies to control symptoms of CHF. Observational studies also suggest that β-blockers reduce frequency of postoperative ischemia, and in one study reduced incidence of perioperative MIs. Protection against ischemia may also reduce risk of MI.

Anesthetic Considerations and Intraoperative Management

Anesthetic agent: All anesthetic techniques and drugs have known cardiac effects that should be considered in the perioperative plan. There appears to be no one best myocardial protective anesthetic technique. Therefore, the choice of anesthesia and intraoperative monitors is best left to the discretion of the anesthesia care team, which will consider the need for postoperative ventilation; cardiovascular effects, including myocardial depression; sympathetic blockade; and dermatomal level of the procedure. Advocates of monitored anesthesia, in which local anesthesia is supplemented by intravenous sedation/analgesia, have argued that use of this technique avoids the undesirable effects of general or neuraxial techniques, but no studies have established this. Failure to produce complete local anesthesia/analgesia can lead to increased stress response, myocardial ischemia, or depression.

Perioperative pain management: Patient-controlled intravenous and/or epidural analgesia is a popular method for reducing postoperative pain. Several studies suggest that effective pain management leads to a reduction in postoperative catecholamine surges and hypercoagulability.

Intraoperative nitroglycerin: There are insufficient data about the effects of prophylactic intraoperative intravenous nitroglycerin in patients at high risk. Nitroglycerin should be used only when the hemodynamic effects of other agents in use are considered.

Transesophageal echocardiography (TEE): There are few data on the value of TEE-detected transient wall motion abnormalities to predict cardiac morbidity in noncardiac surgical patients. Experience to date suggests that the incremental value of this technique for risk prediction is small. Guidelines for appropriate use of TEE are being developed by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists.

Perioperative Surveillance

Pulmonary artery catheters: Although very few studies that have been reported compare patient

outcomes after treatment with or without pulmonary artery catheters, the following three variables are particularly important in assessing benefit versus risk of pulmonary artery catheter use: disease severity, magnitude of anticipated surgery, and practice setting. The extent of expected fluid shifts is a primary concern. Patients most likely to benefit from perioperative use of a pulmonary artery catheter appear to be those with a recent MI complicated by CHF, those with significant CAD who are undergoing procedures associated with significant hemodynamic stress, and those with systolic or diastolic left ventricular dysfunction, cardiomyopathy, and valvular disease undergoing high-risk operations.

Intraoperative and postoperative ST-segment monitoring: Intraoperative and postoperative ST changes indicating myocardial ischemia are strong predictors of perioperative MI in patients at high risk who undergo noncardiac surgery. Similarly, postoperative ischemia is a significant predictor of long-term MI and cardiac death. Conversely, in patients at low risk who undergo noncardiac surgery, ST depression may occur and often is not associated with regional wall motion abnormalities. Accumulating evidence suggests that proper use of computerized ST-segment analysis in appropriately selected patients at high risk may improve sensitivity for myocardial ischemia detection.

Surveillance for perioperative MI: Few studies have examined the optimal method for diagnosing a perioperative MI. Clinical symptoms, postoperative ECG changes, and elevation of the MB fraction of creatine kinase (CK) have been most extensively studied. Newer myocardial-specific enzyme elevations such as troponin-I, troponin-T, or CK-MB isoforms may also have value. In patients with known or suspected CAD undergoing high-risk procedures, ECGs obtained at baseline, immediately after surgery, and the first 2 days after surgery appear to be cost-effective. Use of cardiac enzymes is best reserved for patients at high risk and those with clinical, ECG, or hemodynamic evidence of cardiovascular dysfunction.

Postoperative Therapy and Long-Term Management

When possible, postoperative management should include assessment and management of modifiable risk factors for CAD, heart failure, hypertension, stroke, and other cardiovascular diseases. For many patients, the proposed noncardiac surgery may be the first opportunity for a systematic cardiovascular evaluation. Assessment for hypercholesterolemia, smoking, hypertension, diabetes, physical inactivity, peripheral vascular disease, cardiac murmur(s), arrhythmias, conduction abnormalities, perioperative ischemia, and postoperative MI may lead to further evaluation and treatments that reduce future cardiovascular risk. In particular, patients who sustain a perioperative MI and/or experience repetitive postoperative myocardial ischemia are at substantially high risk for MI or cardiac death during long-term follow-up. These patients should be a particular focus for risk factor interventions and future risk stratification and therapy.

Development of Guidelines

These guidelines are based on a Medline search of the English literature from 1975 through 1994, review of selected journals from 1995, and the expert opinions of 12 committee members representing various disciplines of cardiovascular care, including general cardiology, noninvasive testing, vascular medicine, vascular surgery, anesthesiology, and arrhythmia management. In addition, draft guidelines were submitted for critical review and amendment to physicians representing internal medicine, family practice, nuclear cardiology, general surgery, and anesthesiology as well as executive officers representing the American College of Cardiology and the American Heart Association. The final document represents the eighth iteration over 18 months, which included six drafts in committee and two additional drafts to incorporate key findings from external review.

A large proportion of the data used to develop these guidelines is based on observational or retrospective studies or knowledge of management of cardiovascular disorders in the nonoperative setting. While the collective knowledge surrounding the identification of high- and low-risk patients using perioperative clinical and noninvasive evaluation is substantial, very few prospective or randomized studies have been performed that establish the value of tests or treatments on perioperative outcomes. Therefore, data are

presented in a tabular format, and whenever possible reflect the value of a test or intervention for similar outcomes of a perioperative MI or cardiac death. Because the studies were rarely randomized controlled trials, definitions of a perioperative event varied, investigators were rarely blinded, and many inherent selection biases existed, the task force has chosen not to provide an aggregate synthesis of the data in the form of a point estimate or meta-analysis. On the other hand, presentation of the original data provides substantial support for these recommendations.

Guidelines for Perioperative Cardiovascular Evaluation for Noncardiac Surgery

I. Definition of the Problem

Purpose of These Guidelines

These guidelines are intended for physicians who are involved in the preoperative, operative, and postoperative care of patients undergoing noncardiac surgery. They provide a framework for considering cardiac risk of noncardiac surgery in a variety of patient and surgical situations. The task force that prepared these guidelines strived to incorporate what is currently known about perioperative risk and how this knowledge can be used in the individual patient. Methods used to develop these guidelines are described in Appendix 1.

The tables and algorithms provide quick references for decision making. The overriding theme of this document is that intervention is rarely necessary simply to lower the risk of surgery unless such intervention is indicated irrespective of the preoperative context. The purpose of preoperative evaluation is not to give medical clearance but rather to perform an evaluation of the patient's current medical status, make recommendations concerning the risk of cardiac problems over the entire perioperative period, and provide a clinical risk profile that the patient, his or her primary physician, anesthesiologist, and surgeon can use in making treatment decisions. *No test should be performed unless it is likely to influence patient treatment.* Therefore, the goal of the consultation is the rational use of testing in an era of cost containment.

Epidemiology

The prevalence of cardiovascular disease increases with age, and it is estimated that the number of persons older than 65 years in the United States will increase 25% to 35% over the next 30 years.[1] Coincidentally, this is the same age group in which the largest number of surgical procedures are performed.[2] Thus, it is conceivable that the number of noncardiac surgical procedures performed in older persons will increase from the current 6 million to nearly 12 million procedures performed per year, and nearly a fourth of these—major intra-abdominal, thoracic, vascular, and orthopedic procedures— have been associated with a significant perioperative cardiovascular morbidity and mortality.

Practice Patterns

There are few reliable data available regarding (1) how often a family physician, general internist, subspecialty internist, or surgeon performs a preoperative evaluation on his or her own patient without a formal consultation, and (2) how often a formal preoperative consultation is requested from either a generalist or a subspecialist such as a cardiologist for different types of surgical procedures and different categories of patients. The patterns of practice vary significantly in different locations in the country and vary between patients receiving care under different healthcare provider systems.[3] There is an important need to determine the relative cost-effectiveness of different strategies of perioperative evaluation. In many institutions, patients are evaluated in an anesthesia preoperative evaluation setting. If sufficient information about the patient's cardiovascular status is available, the symptoms are stable, and further evaluation will not influence perioperative management, a formal consultation may not be required nor obtained. This is facilitated by communication between anesthesia personnel and physicians responsible for the patient's cardiovascular care.

Financial Implications

The financial implications of risk stratification cannot be ignored. The need for better methods of objectively measuring cardiovascular risk has led to the development of multiple noninvasive techniques in addition to established invasive procedures. While a variety of strategies to assess and lower cardiac risk have been developed, their aggregate cost has received relatively little attention. Given the striking practice variation and high costs associated with many evaluation strategies, the development of practice guidelines based on currently available knowledge can serve to foster more efficient approaches to perioperative evaluation.

Role of the Consultant

The consultant should review available patient data, obtain a history, and perform a physical examination pertinent to the patient's problem and the proposed surgery. A critical role of the consultant is to communicate the severity and stability of the patient's cardiovascular status and to determine if the patient is in the best reasonable medical condition, given the context of the surgical illness. The consultant may recommend changes in medication and suggest preoperative tests or procedures. In some instances, an additional test is necessary based on the results of the initial preoperative test. In general, preoperative tests are recommended only if the information obtained will result in a change in the surgical procedure performed, a change in medical therapy or monitoring during or after surgery, or a postponement of surgery until the cardiac condition can be corrected or stabilized. Before suggesting an additional test, the consultant should feel confident that the information it provides will provide a significant addition to the existing database and will have the potential to impact treatment. Redundancy should be avoided.

II. General Approach to the Patient

Preoperative cardiac evaluation must be carefully tailored to the circumstances that have prompted the consultation and nature of the surgical illness. Given an acute surgical emergency, preoperative evaluation will be limited to a rapid assessment of cardiovascular vital signs, volume status, and electrocardiogram (ECG). Only the most essential tests and interventions are appropriate until the acute surgical emergency is resolved. A more thorough evaluation can be conducted after surgery. In some circumstances, surgery is not performed as an emergency procedure, but good care dictates prompt surgery. In patients in whom myocardial revascularization is not an option, it is often not necessary to perform a test. Under other, less urgent circumstances, the preoperative cardiac evaluation may lead to a variety of responses. Sometimes this situation may include cancellation of an elective procedure. In this era of managed care and cost-containment, the special needs of patients with comorbid disease who undergo surgery must be considered. “Same day” admission, which has become standard for most operations because of cost-containment issues, may lead to an abbreviated preoperative assessment and could result in greater morbidity and higher cost in high-risk patients. Further study of this question is needed.

The consultant must carefully consider the question that he or she has been asked to answer. A misinterpreted ECG anomaly, atypical chest pain, or a benign arrhythmia in an otherwise healthy patient may require no further workup or special precaution, whereas suspicion of previously unsuspected CAD or CHF in a patient scheduled for an elective procedure may justify a more extensive workup.[4-6]

The cardiac consultant must also bear in mind that the perioperative evaluation may be the ideal opportunity to impact long-term treatment of a patient with significant cardiac disease or risk of such disease. The referring physician and patient should be informed of the results of the evaluation and implications for the patient's prognosis. The consultant can also assist in planning for follow-up.

History

A careful history is crucial to the discovery of cardiac and/or comorbid diseases that would place the patient in a high surgical risk category. The history should seek to identify serious cardiac conditions such as prior angina, recent or past MI, CHF, and symptomatic arrhythmias. Modifiable risk factors for coronary heart disease (CHD) should be recorded along with evidence of associated diseases, such as peripheral vascular disease, cerebrovascular disease, diabetes mellitus, renal impairment, and chronic pulmonary disease. In patients with established cardiac disease, any recent change in symptoms must be ascertained. Accurate recording of current medications and dosages is essential. Use of alcohol and over-the-counter and illicit drugs should be documented.

Table 1. Clinical Predictors of Increased Perioperative Cardiovascular Risk (Myocardial Infarction, Congestive Heart Failure, Death)

Major
Unstable coronary syndromes
● Recent myocardial infarction* with evidence of important ischemic risk by clinical symptoms or noninvasive study
● Unstable or severe† angina (Canadian Class III or IV)‡
Decompensated congestive heart failure
Significant arrhythmias
● High-grade atrioventricular block
● Symptomatic ventricular arrhythmias in the presence of underlying heart disease
● Supraventricular arrhythmias with uncontrolled ventricular rate
Severe valvular disease
Intermediate
Mild angina pectoris (Canadian Class I or II)
Prior myocardial infarction by history or pathological Q waves
Compensated or prior congestive heart failure
Diabetes mellitus
Minor
Advanced age
Abnormal ECG (left ventricular hypertrophy, left bundle branch block, ST-T abnormalities)
Rhythm other than sinus (eg, atrial fibrillation)
Low functional capacity (eg, inability to climb one flight of stairs with a bag of groceries)
History of stroke
Uncontrolled systemic hypertension

ECG indicates electrocardiogram.
*The American College of Cardiology National Database Library defines *recent MI* as greater than 7 days but less than or equal to 1 month (30 days).
†May include “stable” angina in patients who are unusually sedentary.
‡Campeau L. Grading of angina pectoris. *Circulation.* 1976;54:522-523.

The history should also seek to determine the patient's functional capacity (Table 1). An assessment of an individual's capacity to perform a spectrum of common daily tasks has been shown to correlate well with maximum oxygen uptake by treadmill testing.[7] A patient classified as high risk due to age or known CAD but who is asymptomatic and runs for 30 minutes daily may need no further evaluation. In contrast, a sedentary patient without a history of cardiovascular disease but with clinical factors that suggest increased perioperative risk may benefit from a more extensive preoperative evaluation.[5,6,8,9] It is important to emphasize that the preoperative consultation may represent the first careful cardiovascular evaluation for the patient in years, and in some instances, ever. For example, inquiry regarding symptoms suggestive of angina or CHF may establish or suggest these diagnoses for the first time.

Physical Examination

A careful cardiovascular examination should include an assessment of vital signs (including blood pressure in both arms), carotid pulse contour and bruits, jugular venous pressure and pulsations, auscultation of the lungs, precordial palpation and auscultation, abdominal palpation, and examination of the extremities for edema and vascular integrity. More detailed observations will be dictated by specific circumstances.

The following points are worth emphasizing:

● The general appearance provides invaluable evidence regarding the patient's overall status. Cyanosis, pallor, dyspnea during conversation or with minimal activity, poor nutritional status, obesity, skeletal deformities, tremor, and/or anxiety are just a few of the clues that can be recognized by the skilled physician.

● In patients with acute heart failure, pulmonary rales and chest x-ray evidence of pulmonary congestion correlate well with elevated pulmonary venous pressure. In patients with chronic heart failure, however, these findings may be absent. An elevated jugular venous pressure or a positive hepatojugular reflux are more reliable signs of hypervolemia in these patients.[10,11] Peripheral edema is not a reliable indicator of chronic heart failure unless the jugular venous pressure is elevated or the hepatojugular test is positive.

● A careful examination of the carotid and other arterial pulses is essential. The presence of associated vascular disease should heighten suspicion of occult CAD.

● Cardiac auscultation will often provide useful clues to underlying cardiac disease. When present, a third heart sound at the apical area suggests a failing left ventricle, but its absence is not a reliable indicator of good ventricular function.[11]

● If a murmur is present, the clinician will need to decide whether or not it represents significant valvular disease. Detection of significant aortic stenosis is of particular importance because this lesion poses a high risk for noncardiac surgery.[12] Significant mitral stenosis or regurgitation increases risk of CHF. Aortic regurgitation and mitral regurgitation may be minimal, yet predispose the patient to infective endocarditis should bacteremia occur following surgery. In these conditions, especially if mitral regurgitation is rheumatic in origin or due to mitral valve prolapse, consideration must be given to endocarditis prophylaxis.[13]

Comorbid Diseases

The consultant must evaluate the cardiovascular system within the framework of the patient's overall health. Associated conditions often heighten the risk of anesthesia and may complicate cardiac management. The most common of these conditions are:

Pulmonary

The presence of either obstructive or restrictive pulmonary disease places the patient at increased risk of developing perioperative respiratory complications. Hypoxemia, hypercapnia, acidosis, and increased work of breathing can all lead to further deterioration of an already compromised cardiopulmonary system. If significant pulmonary disease is suspected by history or physical examination, determination of functional capacity, response to bronchodilators, and/or evaluation for the presence of carbon dioxide retention through arterial blood gas analysis may be justified. If there is evidence of infection, appropriate antibiotics are critical. Steroids and bronchodilators may be indicated, although the risk of producing arrhythmia or myocardial ischemia by β-agonists must be considered.

Diabetes Mellitus

A variety of metabolic diseases may accompany cardiac disease. Diabetes mellitus is the most common. Its presence should heighten suspicion of CAD, particularly because myocardial ischemia is more likely to be silent in the patient with diabetes mellitus. Management of blood glucose levels in the perioperative period may be difficult. Fragile diabetic patients need careful treatment with adjusted doses or infusions of short-acting insulin based on frequent blood sugar determinations. More stable diabetic patients may be treated with long-acting insulin or oral hypoglycemics. It is acceptable to maintain blood glucose at relatively high levels perioperatively and it is far preferable to tight control with its attendant risks for hypoglycemic episodes.

Renal Impairment

Azotemia is commonly associated with cardiac disease and often complicates its management. Maintenance of adequate intravascular volume for renal perfusion during diuresis of a patient with heart failure is often challenging. Excessive diuresis in combination with initiation of angiotensin converting enzyme (ACE) inhibitors may result in an increase in blood urea nitrogen and plasma creatinine concentrations.

Hematologic Disorders

Anemia imposes a stress on the cardiovascular system that may exacerbate myocardial ischemia and aggravate CHF.[14] Preoperative transfusion, when used appropriately in patients with advanced CAD and/or CHF, may reduce perioperative cardiac morbidity. However, with current concern about possible transmission of HIV and hepatitis through the use of blood products, a conservative approach with respect to transfusion is warranted.

Polycythemia, thrombocytosis, and other conditions that increase blood viscosity may increase the risk of thromboembolism and/or hemorrhage. Appropriate steps to reduce these risks should be considered and tailored to the individual patient's particular circumstances.

Ancillary Studies

The consultant should review all available laboratory data. In this era of cost containment, the laboratory data available may be minimal. Therefore, the consultant may require additional tests such as blood chemistries and a chest radiograph based on history and physical examination. Blood levels of cardiac drugs, including digoxin, should be obtained only when there are specific indications such as changing renal function, recent change in dose, or symptoms suggesting toxicity.

In patients referred for cardiac consultation, an ECG is almost always indicated as part of a preoperative evaluation. In fact, an abnormal ECG report is often the reason that consultation is requested. Metabolic and electrolyte disturbances, medications, intracranial disease, pulmonary disease, etc, can alter the ECG. Conduction disturbances, such as bundle branch block or first-degree atrioventricular block, may lead to concern but usually do not justify further workup. The same is often true of asymptomatic arrhythmias in the absence of significant underlying structural heart disease. On the other hand, subtle ECG clues can point the way to a clinically silent condition of major import.

The basic clinical evaluation obtained by history, physical examination, and review of the ECG usually provides the consultant with sufficient data to estimate cardiac risk. Table 1 lists clinical predictors of increased perioperative risk of MI, CHF, and death established by several authors based on multivariate analysis.[12,15-24] Although some authors have suggested a scoring system that assigns more weight to some factors than others and sums these to arrive at a composite risk,[12,22,24] most recent articles have suggested simpler criteria.[15-21] In clinical practice, more weight is attached to active conditions than dormant ones, while the degree of deviation from the norm is used as an implicit modifier. Table 1 attempts to deal with this practice by placing the predictors in the following three categories:

- *Major* predictors, when present, mandate intensive management, which may result in delay or cancellation of surgery unless it is emergent.

- *Intermediate* predictors are well-validated markers of enhanced risk of perioperative cardiac complications and justify careful assessment of the patient's current status.

- *Minor* predictors are recognized markers for cardiovascular disease that have not been proven to independently increase perioperative risk.

It should be noted that a history of MI or pathological Q waves by ECG is listed as an intermediate predictor, whereas a recent MI* is a major predictor. In this way the separation of MI into the traditional 3- and 6-month intervals has been avoided.[12-25] Current management of MI provides for risk stratification during convalescence.[26] If a recent stress test does not indicate residual myocardium at risk, the likelihood of reinfarction after noncardiac surgery is low. Although there are no adequate clinical trials on which to base firm recommendations, it appears reasonable to wait 4 to 6 weeks after MI to perform elective surgery.

Table 2. Estimated Energy Requirements for Various Activities*

1 MET	Can you take care of yourself? Eat, dress, or use the toilet? Walk indoors around the house? Walk a block or two on level ground at 2-3 mph or 3.2-4.8 km/h? Do light work around the house like dusting or washing dishes?	4 METs	Climb a flight of stairs or walk up a hill? Walk on level ground at 4 mph or 6.4 km/h? Run a short distance? Do heavy work around the house like scrubbing floors or lifting or moving heavy furniture? Participate in moderate recreational activities like golf, bowling, dancing, doubles tennis, or throwing a baseball or football?
4 METs		>10 METs	Participate in strenuous sports like swimming, singles tennis, football, basketball, or skiing?

MET indicates metabolic equivalent.
*Adapted from the Duke Activity Status Index and AHA Exercise Standards.

Table 2 presents a validated method for assessing functional capacity from a carefully obtained history. This method represents an important aspect of evaluating overall cardiac risk and planning appropriate preoperative testing.

Table 3. Cardiac Risk* Stratification for Noncardiac Surgical Procedures

High	(Reported cardiac risk often >5%) ● Emergent major operations, particularly in the elderly ● Aortic and other major vascular ● Peripheral vascular ● Anticipated prolonged surgical procedures associated with large fluid shifts and/or blood loss
Intermediate	(Reported cardiac risk generally <5%) ● Carotid endarterectomy ● Head and neck ● Intraperitoneal and intrathoracic ● Orthopedic ● Prostate
Low†	(Reported cardiac risk generally <1%) ● Endoscopic procedures ● Superficial procedure ● Cataract ● Breast

*****Combined incidence of cardiac death and nonfatal myocardial infarction.
†Do not generally require further preoperative cardiac testing.

Table 3 stratifies the risk of various types of noncardiac surgical procedures. This risk stratification is based on several reported studies.[12,15,21,22,25,28-30] It is clear that major emergent operations in the elderly, ie, those violating a visceral cavity and those likely to be accompanied by major bleeding or fluid shifts, place patients at highest risk. Vascular procedures appear particularly risky, and, primarily because of the likelihood of associated coronary disease, justify careful preoperative screening for myocardial ischemia in many instances. This aspect of decision making is covered more extensively in section IV.

Fig 1 (see Executive Summary) presents in algorithmic form a framework for determining which patients are candidates for cardiac testing. For clarity, categories have been established as black and white, but it is recognized that individual patient problems occur in shades of gray. The clinician must consider several interacting variables and give them appropriate weight. Furthermore, there are no adequate controlled or randomized clinical trials to help define the process. Thus, collected observational data and expert opinion form the basis of the proposed algorithm.

Step 1 (Fig 1). The consultant should determine the urgency of noncardiac surgery. In many instances, patient or surgery-specific factors dictate an obvious strategy (ie, immediate surgery) that may not allow for further cardiac assessment or treatment. In such cases, the consultant may function best by providing recommendations for perioperative medical management and surveillance. Selected postoperative risk stratification is often appropriate in patients with elevated risk for long-term coronary events who have never had such an assessment before. This is usually initiated after the patient has recovered from blood loss, deconditioning, and other postoperative complications that might confound interpretation of noninvasive test results.

Step 2 (Fig 1). Has the patient undergone coronary revascularization in the past 5 years? If the patient has had complete surgical revascularization in the past 5 years or coronary angioplasty from 6 months to 5 years ago, and if his or her clinical status has remained stable without recurrent signs or symptoms of ischemia in the interim, the likelihood of perioperative cardiac death or MI is extremely low.[31] Further cardiac testing in this circumstance is generally not necessary.

Step 3 (Fig 1). Has the patient undergone a coronary evaluation in the past 2 years? If an individual has undergone extensive coronary evaluation with either noninvasive or invasive techniques within 2 years and if the findings indicate that coronary risk has been adequately assessed with favorable findings, repeat testing is usually unnecessary. An exception to this rule is the patient who has experienced a definite change or new symptoms of coronary ischemia since the prior coronary evaluation.

Step 4 (Fig 1). Does the patient have one of the unstable coronary syndromes or major clinical predictors of risk (Table 1)? In patients being considered for elective noncardiac surgery, the presence of unstable coronary disease, or decompensated CHF, hemodynamically significant arrhythmias, and/or severe valvular heart disease usually leads to cancellation or delay of surgery until the cardiac problem has been clarified and appropriately treated. Examples of unstable coronary syndromes include recent MI with evidence of ischemic risk by clinical symptoms or noninvasive study, unstable or severe angina, and new or poorly controlled ischemia-mediated CHF. Many patients in these circumstances are referred for coronary angiography to further assess therapeutic options.

Step 5 (Fig 1). Does the patient have *intermediate clinical predictors* of risk (Table 1)? The presence or absence of angina pectoris, prior MI by history or ECG, compensated or prior CHF, or diabetes mellitus helps to further stratify clinical risk for perioperative coronary events. For patients with or without these intermediate clinical risk predictors, consideration of *functional capacity* (as determined by history of daily activities) and level of *surgery-specific risk* allows a rational approach to identifying which patients may most benefit from further noninvasive testing.

Functional status has been shown to be a reliable predictor of future cardiac events.[32] If the patient has not had a recent exercise test, this can usually be estimated from the ability to perform the activities of daily living. *Functional capacity* can be expressed in metabolic equivalent (MET) levels; the oxygen consumption (VO_2) of a 70-kg, 40-year-old man in a resting state is 3.5 mL/kg per minute or 1 MET. For this purpose, functional capacity has been classified as *excellent* (greater than 7 METs), *moderate* (4 to 7 METs), *poor* (less than 4 METs), or *unknown*. Multiples of the baseline MET value can be used to express aerobic demands for specific activities, and the use of the MET level is a more meaningful and useful expression of exercise capacity than attempting to express functional capacity in terms of protocol time and stages reached during an exercise test. The predicted MET level for certain activities is influenced by the degree of conditioning and genetic predisposition. Perioperative cardiac and long-term risk is increased in patients unable to meet a 4-MET demand during most normal daily activities. Examples of leisure activities associated with less than 4 METs are baking, slow ballroom dancing, golfing with a cart, playing a musical instrument, and walking at a speed of approximately 2 to 3 mph. Activities that require more than 4 METs include moderate cycling, climbing hills, ice skating, roller blading, skiing, singles tennis, and jogging. The Duke Activity Status Index (Table 2) contains questions that can be used to estimate the patient's functional capacity.[7,33] Use of the Duke Activity Status Index or other activity scales[34] and knowledge of the MET levels required for physical activities, as listed above, provide the clinician with a relatively easy set of questions to estimate whether a patient's functional capacity will be less than or greater than 4 METs (Table 2). A clinical questionnaire, however, only *estimates* functional capacity and does not provide as objective a measurement as exercise treadmill testing or arm ergometry.

Surgery-Specific Risk (Table 3, Fig 1): The surgery-specific cardiac risk of noncardiac surgery is related to two important factors. First, the type of surgery itself may identify a patient with a greater likelihood of underlying heart disease. Perhaps the best example is vascular surgery, in which underlying CAD is present in a substantial portion of patients. The second aspect is the degree of hemodynamic cardiac stress associated with surgery-specific techniques. Certain operations may be associated with profound alterations in heart rate, blood pressure, vascular volume, pain, bleeding, clotting tendencies, oxygenation, neurohumoral activation, and other perturbations. The intensity of these coronary and myocardial stressors help determine the likelihood of perioperative cardiac events. This is particularly evident in emergency surgery, where the risk of cardiac complications is substantially elevated., Examples of noncardiac surgery and their surgery-specific risk are given below. *Higher surgery-specific cardiac risk* (eg, combined perioperative MI and/or death rate equal to or greater than 5%) is present in patients undergoing aortic surgery, peripheral vascular surgery, and anticipated prolonged surgical procedures associated with large fluid shifts and/or blood loss involving the abdomen, thorax, head, and neck. *Intermediate surgical risk* procedures include urologic, orthopedic, and uncomplicated abdominal, head, neck, and thoracic surgery. *Low-risk procedures* include cataract resection, dermatologic operations, endoscopic procedures, and breast surgery (Table 3). Patients undergoing low-risk procedures do not require further evaluation.

Step 6 (Fig 1): Patients without major but with intermediate predictors of clinical risk (Table 1) and with moderate or excellent functional capacity can generally undergo intermediate-risk surgery with little likelihood of perioperative death or MI. On the other hand, patients with poor functional capacity or those with a combination of only moderate functional capacity and higher-risk surgery are often considered for further noninvasive testing. This is especially true for patients possessing two or more of the above intermediate markers.

Step 7 (Fig 1). Noncardiac surgery is generally safe for patients with minor or no clinical predictors of clinical risk (Fig 1) and with moderate or excellent functional capacity (equal to or greater than 4 METs), regardless of surgical type. Patients with poor functional capacity facing higher-risk operations (vascular, anticipated long and complicated thoracic, abdominal, and head and neck) may be considered for further testing on an individual basis., To reiterate, it is important to emphasize that the concept of “medical clearance” for surgery is short-sighted. The real issue is to perform an evaluation of the patient's current medical status, make recommendations concerning the risk of a cardiac problem over the entire perioperative and postoperative period, and provide a clinical risk profile that the patient, anesthesiologist, and surgeon can use to make management decisions. The overall goal of cardiac assessment should be a consideration of both the impending surgery and, more important, the long-term cardiac risk, independent of the decision to go to surgery.[35] It is almost never appropriate to recommend coronary bypass surgery or other invasive interventions such as coronary

angioplasty that would not otherwise be indicated in an effort to reduce the risk of noncardiac surgery.

Step 8. The results of noninvasive testing can then be used to determine further perioperative management. Such management may include intensified medical therapy or cardiac catheterization, which may lead to coronary revascularization or potentially cancellation or delay of the elective noncardiac operation. Alternatively, results of the noninvasive test may lead to a recommendation to proceed directly with surgery (Fig 1). In some patients, the risk of coronary angioplasty or corrective cardiac surgery may approach or even exceed the risk of the proposed noncardiac surgery. In rare instances, this approach may be appropriate, however, if it also significantly improves the patient's long-term prognosis (Table 4).

Table 4. Indications for Coronary Angiography* in Perioperative Evaluation Before (or After) Noncardiac Surgery

Class I†: Patients with suspected or proven CAD:
- High-risk results during noninvasive testing (Tables 6-9)
- Angina pectoris unresponsive to adequate medical therapy
- Most patients with unstable angina pectoris
- Nondiagnostic or equivocal noninvasive test in a high-risk patient (Table 1) undergoing a high-risk noncardiac surgical procedure (Table 3)

Class II†:
- Intermediate-risk results during noninvasive testing (Tables 6-9)
- Nondiagnostic or equivocal noninvasive test in a lower-risk patient (Table 1) undergoing a high-risk noncardiac surgical procedure (Table 3)
- Urgent noncardiac surgery in a patient convalescing from acute MI
- Perioperative MI

Class III†:
- Low-risk noncardiac surgery (Table 3) in a patient with known CAD and low-risk results on noninvasive testing (Tables 6-9)
- Screening for CAD without appropriate noninvasive testing
- Asymptomatic after coronary revascularization, with excellent exercise capacity (≥7 METs)
- Mild stable angina in patients with good LV function, low-risk noninvasive test results (Tables 6-9)
- Patient is not a candidate for coronary revascularization because of concomitant medical illness
- Prior technically adequate normal coronary angiogram within 5 years
- Severe LV dysfunction (eg, ejection fraction <20%) and patient not considered candidate for revascularization procedure
- Patient unwilling to consider coronary revascularization procedure

*If results will affect management.
†Class I: Conditions for which there is evidence for and/or general agreement that a procedure be performed or a treatment is of benefit. Class II: Conditions for which there is a divergence of evidence and/or opinion about the treatment. Class III: Conditions for which there is evidence and/or general agreement that the procedure is not necessary.
CAD indicates coronary artery disease; MI, myocardial infarction; MET, metabolic equivalent; LV, left ventricular.
Adapted from ACC/AHA Guidelines for Coronary Angiography.

III. Disease-Specific Approaches

Coronary Artery Disease

Patients With Known Coronary Artery Disease

In some patients, the presence of coronary disease may be obvious, such as an acute MI, bypass grafting, coronary angioplasty, or a coronary angiogram showing luminal irregularities. On the other hand, many patients without cardiac symptoms may have severe double- or triple-vessel disease that is not clinically obvious because the patients are functionally limited by severe arthritis or peripheral vascular disease. Such patients may benefit from noninvasive testing (Fig 1; Table 3) for diagnosis if the patient is a candidate for myocardial revascularization. In patients with known CAD, as well as those with previously occult coronary disease, the questions become (1) What is the amount of myocardium in jeopardy? (2) What is the ischemic threshold, ie, the amount of stress required to produce ischemia? and (3) What is the patient's ventricular function? Clarification of these questions is an important goal of the preoperative history, physical examination, and selected noninvasive testing used to determine the patient's prognostic gradient of ischemic response during stress testing (Table 5). On the other hand, many patients do not require noninvasive testing, particularly if they are not candidates for myocardial revascularization.

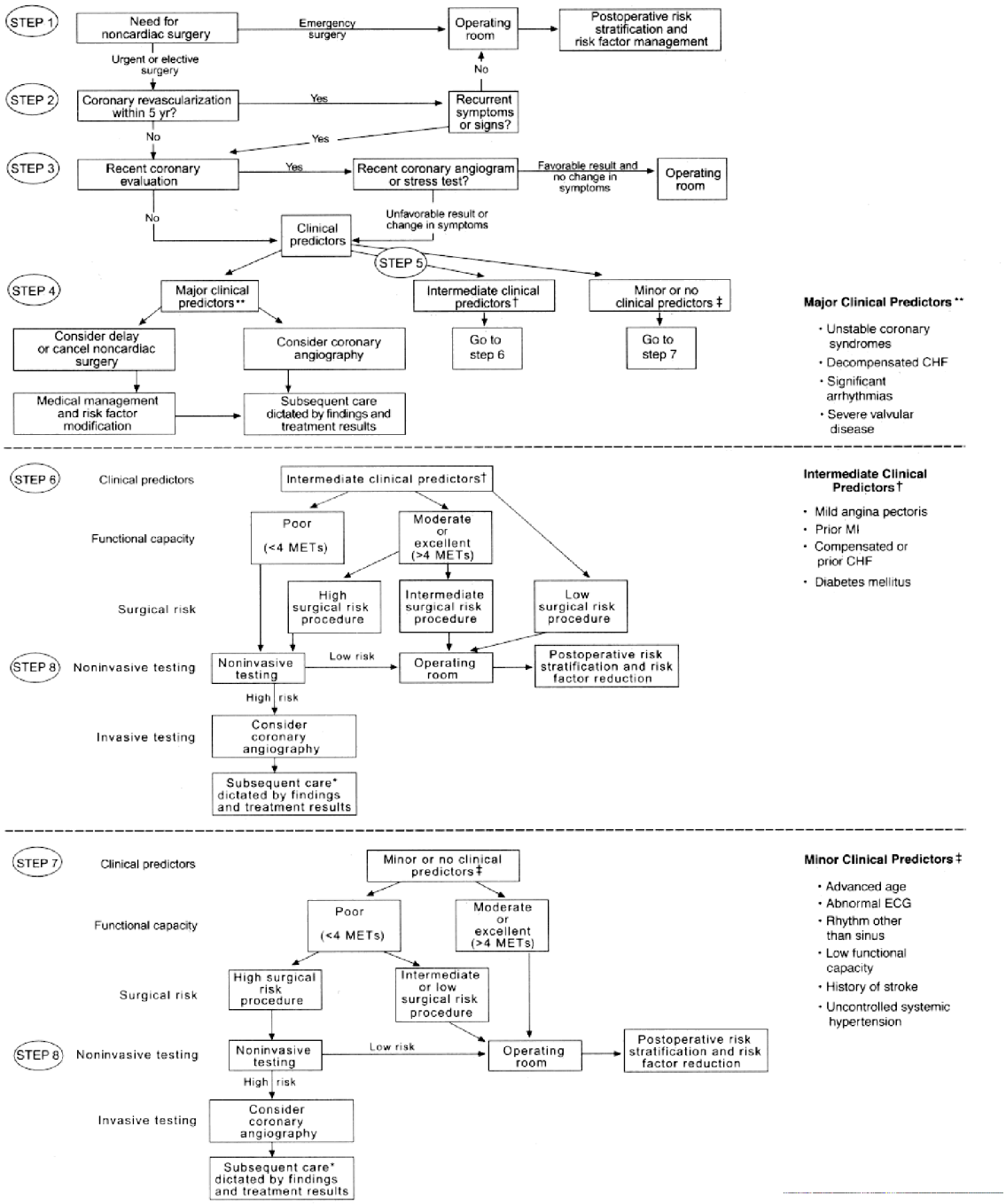

Fig 1. Stepwise approach to preoperative cardiac assessment. Steps are discussed in text. *Subsequent care may include cancellation or delay of surgery, coronary revascularization followed by noncardiac surgery, or intensified care.

Table 5. Prognostic Gradient of Ischemic Responses During an ECG-Monitored Exercise Test*

Patients with suspected or proven CAD
High Risk
Ischemia induced by low-level exercise† (<4 METs or heart rate <100 bpm or <70% age predicted) manifested by one or more of the following: ● Horizontal or downsloping ST depression >0.1 mV ● ST-segment elevation >0.1 mV in noninfarct lead ● Five or more abnormal leads ● Persistent ischemic response >3 min after exertion ● Typical angina
Intermediate Risk
Ischemia induced by moderate-level exercise* (4-6 METs or heart rate 100-130 bpm [70-85% age predicted]) manifested by one or more of the following: ● Horizontal or downsloping ST depression >0.1 mV ● Typical angina ● Persistent ischemic response >1-3 min after exertion ● Three to four abnormal leads
Low Risk
No ischemia or ischemia induced at high-level exercise* (>7 METs or heart rate >130 bpm [>85% age predicted]) manifested by: ● Horizontal or downsloping ST depression >0.1 mV ● Typical angina ● One to two abnormal leads
Inadequate Test
Inability to reach adequate target workload or heart rate response for age without an ischemic response. For patients undergoing noncardiac surgery, ability to exercise to at least the intermediate-risk level without ischemia should be considered at low risk for perioperative ischemic events.

ECG indicates electrocardiographically; MET, metabolic equivalent; bpm, beats per minute.
*Based on references 32, 37-43.
†Workload and heart rate estimates for risk severity require adjustment for patient age. Maximum target heart rates for 40- and 80-year-old subjects on no cardioactive medication are 180 and 140 beats per minute, respectively.

Patients With Major Risk Factors for Coronary Artery Disease

Multiple risk factors have been identified that predispose the patient for CAD and increase perioperative risk. Age, gender, and diabetes mellitus influence the outcome of patients undergoing noncardiac surgery. Some factors, such as diabetes mellitus, not only increase the likelihood and extent of coronary disease but also predispose the patient to complications, such as infection and hyperglycemia or hypoglycemia, which may add to the hemodynamic stress of the operation. Additionally, patients with diabetes mellitus may have a higher incidence of silent myocardial ischemia and infarction than the general population.[44-46]

Advanced age is a special risk, not only because of the increased likelihood of coronary disease, but because of the effects of aging on the myocardium. Heart muscle is terminally differentiated soon after birth, and the number of cardiac myocytes decreases with age.[47] The mortality of acute MI increases dramatically in the aged.[48] This phenomenon may be due in part to the decreased myocardial reserve from a smaller number of residual myocardial cells (presbycardia). Intraoperative or perioperative MI has a higher mortality in the aged.[12,21,22]

Gender is important because premenopausal women have a lower incidence of CAD, and in general CAD occurs 10 or more years later in women than in men.[49] Women who have premature menopause, such that as following oophorectomy, are an exception to this rule. Diabetic women have an increased risk, which is equivalent to men of the same age. The mortality rate following acute MI is greater for women than for men, but older age and diabetes mellitus account for much of this difference.[50] Whether or not other factors such as coronary artery size or different pathophysiology also contribute to the increased risk in women is not yet fully understood.

Peripheral vascular disease presents a special problem because it is associated with a higher incidence of CAD and because the limited activity imposed by claudication may mask coronary disease. A full discussion of the implications of peripheral vascular disease can be found in section IV.

Hypertension

Numerous studies[12,15,18,21,51,52] have shown that moderate hypertension is not an independent risk factor for perioperative cardiovascular complications. On the other hand, as a universally measured variable with a recognized association with CAD, hypertension serves as a useful marker for potential CAD.[53] In addition, several investigators have demonstrated exaggerated intraoperative blood pressure fluctuation with associated ECG evidence of myocardial ischemia in patients with preoperative blood pressure elevation.[54-57] This effect can be modified by treatment.[55-60] Since intraoperative ischemia correlates with postoperative cardiac morbidity,[51,61] it follows that control of blood pressure preoperatively may help reduce the tendency to perioperative ischemia. Although an elevated blood pressure on an initial recording in a patient with previously undiagnosed or untreated hypertension has been shown to correlate with blood pressure lability under anesthesia,[61] the definition of the severity of hypertension rests with subsequent recordings in a nonstressful environment.[53] In patients on therapy for hypertension, a careful review of current medications and dosage, along with known intolerance to previously prescribed drugs, is essential. The physical examination should include a search for target organ damage and evidence of associated cardiovascular pathology. In particular, a funduscopic examination may provide useful data regarding the severity and chronicity of hypertension.

The physical examination and simple laboratory tests can rule out some of the rare but important causes of hypertension. Further evaluation to exclude secondary hypertension is rarely warranted before necessary surgery, but in patients with severe hypertension, particularly of recent onset, it may be appropriate to delay elective surgery while the patient is evaluated for curable causes of hypertension. If pheochromocytoma is a serious possibility, surgery should be delayed to permit its exclusion. A long abdominal bruit may suggest renal artery stenosis. A radial to femoral artery pulse delay suggests coarctation of the aorta; hypokalemia in the absence of diuretic therapy raises the possibility of aldosteronism.

If the initial evaluation establishes hypertension as mild or moderate and there are no associated metabolic or cardiovascular abnormalities, there is no need to delay surgery.[62] Several investigators have established the value of effective preoperative blood pressure control,[56,57,60,63] and antihypertensive medications should be continued during the perioperative period. Particular care should be taken to avoid withdrawal of β-blockers and clonidine because of potential heart rate and/or blood pressure rebound. In patients unable to take oral medications, parenteral β-blockers and transdermal clonidine may be used.

If more severe hypertension (eg, diastolic blood pressure greater than or equal to 110 mm Hg) exists before elective noncardiac surgery, it is prudent to control it before surgery. In many such instances, establishment of an effective regimen can be achieved over several days to weeks of preoperative outpatient treatment. If surgery is more urgent, rapid-acting agents can be administered that allow effective control in a matter of minutes or hours. β-blockers appear to be particularly attractive agents. Several reports have shown that introduction of preoperative β-adrenergic blockers leads to effective modulation of severe blood pressure fluctuations and a reduction in the number and duration of perioperative coronary ischemic episodes.[55-60]

Interestingly, patients with preoperative hypertension appear more likely to develop intraoperative hypotension than nonhypertensive persons. In some patients this may be related to a decrease in vascular volume. In one report, hypotension during anesthesia correlated better with perioperative cardiac and renal complications than intraoperative hypertension, although other studies have not shown this.[57]

Congestive Heart Failure

Congestive heart failure has been identified in several studies as being associated with a poorer outcome when noncardiac surgery is performed. In Goldman's study,[12] the presence of a third heart sound or signs of CHF were associated with a substantially increased risk during noncardiac surgery. Detsky[22]

identified alveolar pulmonary edema as a significant risk factor, and in Cooperman's report,[24] CHF also bestowed a significant risk. Every effort must be made to detect unsuspected heart failure by a careful history and physical examination. If possible, it is important to identify the etiology of CHF, because this may have implications concerning risk of death versus perioperative CHF. For instance, prior CHF due to hypertensive heart disease may portend a different risk compared with prior heart failure resulting from CAD.

Cardiomyopathy

There is little information on the preoperative evaluation of patients with cardiomyopathy before noncardiac surgery. At this time, preoperative recommendations must be based on a thorough understanding of the pathophysiology of the myopathic process. Every reasonable effort should be made before surgery to determine the etiology of the primary myocardial disease. For example, infiltrative diseases such as amyloidosis may produce either systolic or diastolic dysfunction. Knowledge of this fact may alter intraoperative and postoperative management of intravenous fluids. In patients with a history or signs of CHF, preoperative assessment of left ventricular function may be recommended to quantify the severity of systolic as well as diastolic dysfunction. This information is valuable for both intraoperative and postoperative management. This assessment may include echocardiography unless it has been previously performed.

Hypertrophic cardiomyopathy poses special problems. Reduction of blood volume, decreased systemic vascular resistance, and increased venous capacitance may cause a reduction in left ventricular volume and thereby potentially increase a tendency to outflow obstruction with potentially untoward results. Furthermore, reduced filling pressures may result in a significant fall in stroke volume because of the decreased compliance of the hypertrophic ventricle. Catecholamines should be avoided because they may increase the degree of dynamic obstruction and decrease diastolic filling. In a relatively small series of 35 patients with hypertrophic cardiomyopathy with obstruction, there were no deaths or serious ventricular arrhythmias during or immediately after general surgical procedures; one patient had major vascular surgery. In the 22 patients who underwent catheterization, the mean rest and peak provokable gradients were 30 mm Hg and 81 mm Hg, respectively. The only patient suffering a perioperative MI had two-vessel coronary disease. Significant arrhythmias or hypotension requiring vasoconstrictors occurred in 14% and 13% of patients, respectively.[64] Patients with hypertrophic cardiomyopathy are also at an increased risk for perioperative CHF.

Valvular Heart Disease

Cardiac murmurs are common in patients facing noncardiac surgery. The consultant must be able to distinguish organic from functional, significant from insignificant, and the etiology of the murmur in order to determine which patients require prophylaxis for endocarditis and which patients require further quantitation of the severity of the valvular lesion.

Severe aortic stenosis poses the greatest risk for noncardiac surgery.[12] If the aortic stenosis is severe and symptomatic, elective noncardiac surgery should generally be postponed or canceled. Such patients require aortic valve replacement before elective but necessary noncardiac surgery. In rare instances, percutaneous balloon aortic valvuloplasty may be justified when the patient is not a candidate for valve replacement.

Mitral stenosis, although increasingly rare, is important to recognize. When stenosis is mild or moderate, the consultant must ensure control of heart rate during the operative and perioperative period because the reduction in diastolic filling period that accompanies tachycardia can lead to severe pulmonary congestion. When the stenosis is severe, the patient may benefit from balloon mitral valvuloplasty or open surgical repair before high-risk surgery.[65]

Aortic regurgitation needs to be identified, not only for appropriate prophylaxis for bacterial

endocarditis, but also to ensure appropriate medical treatment. Careful attention to volume control and afterload reduction is recommended. In contrast to mitral stenosis, severe aortic regurgitation is not benefited by unusually slow heart rates which can increase the volume of regurgitation by increasing the amount of time in diastole. Tachycardia predominantly affects diastole and thus reduces the time of regurgitation in severe aortic regurgitation.

Mitral regurgitation has many causes, the most common being papillary muscle dysfunction and mitral valve prolapse. Perioperative antibiotic prophylaxis is recommended for patients with mitral valve prolapse who have clinical or echocardiographic evidence of mitral valve regurgitation or thickening and/or redundancy of the valve leaflets.[13] Since perioperative volume shifts may cause a patient with an isolated click to develop mitral regurgitation, auscultation in the sitting, standing, squatting, and standing-post-squatting positions may identify a tendency to volume or stress-related regurgitation.

Patients with severe mitral regurgitation (often manifested clinically by an apical holosystolic murmur, a third heart sound, and a diastolic flow rumble) benefit from afterload reduction and administration of diuretics to produce maximal hemodynamic stabilization before high-risk surgery. Occasionally this therapy can best be accomplished by treatment in an intensive care unit using a catheter to monitor pulmonary artery pressure. It is also important for the consultant to note even mild reduction of left ventricular ejection fraction (LVEF) in patients with mitral regurgitation. Because the low-pressure left atrium acts as a pressure runoff in patients with severe mitral regurgitation, LVEF may overestimate true left ventricular performance. In such patients, even a mildly reduced LVEF may be a sign of reduced ventricular reserve.

Patients with a mechanical prosthetic valve are of concern because of the need for endocarditis prophylaxis[13] when undergoing surgery that may result in bacteremia and the need for careful anticoagulation management. The Fourth Consensus Conference on Anticoagulation recommends the following[66]:

> For patients who require minimal invasive procedures (dental work, superficial biopsies), we recommend briefly reducing the INR to the low or subtherapeutic range, and resuming the normal dose of oral anticoagulation immediately following the procedure. Perioperative heparin therapy is recommended for patients in whom the risk of bleeding on oral anticoagulation is high and the risk of thromboembolism off anticoagulation is also high (major surgery in the setting of mitral valve prosthesis). For patients between these two extremes, physicians must assess the risk and benefit of reduced anticoagulation versus perioperative heparin therapy.

Arrhythmias and Conduction Defects

Cardiac arrhythmias and conduction disturbances are common findings in the perioperative period,[12,16,67] particularly in the elderly. Although both supraventricular and ventricular arrhythmias have been identified as independent risk factors for coronary events in the perioperative period,[12,67] they are probably significant only in that they either reflect or occur in the presence of underlying serious cardiopulmonary disease which, by itself, increases the risk of surgery.[68] The presence of an arrhythmia in the perioperative setting should provoke a thorough search for underlying cardiopulmonary disease, drug toxicity, or metabolic derangements.

Many cardiac arrhythmias, although relatively benign, may unmask underlying cardiac problems; for example, supraventricular arrhythmia can produce ischemia by increasing myocardial oxygen demand in patients with coronary disease. Rarely, arrhythmias, because of the hemodynamic or metabolic derangements they cause, may deteriorate into more life-threatening rhythm disturbances; for example, atrial fibrillation with a rapid ventricular response in a patient with an accessory bypass pathway may degenerate into ventricular fibrillation. Ventricular arrhythmias, whether single premature ventricular contractions, complex ventricular ectopy, or nonsustained ventricular tachycardia usually do not require therapy except in the presence of ongoing or threatened myocardial ischemia or moderate to severe left

ventricular dysfunction when such arrhythmias represent a significant risk factor. Conversely, in the absence of cardiopulmonary disease, it is likely that such arrhythmias have the same benign prognosis perioperatively as that demonstrated in population studies.[69,70]

High-grade cardiac conduction abnormalities, such as complete atrioventricular block, if unanticipated, can increase operative risk and necessitate temporary or permanent transvenous pacing. On the other hand, patients with intraventricular conduction delays and no history of advanced heart block or symptoms rarely progress to complete heart block perioperatively.[71] The availability of transthoracic pacing units makes the decision for temporary transvenous pacing less critical.

Pulmonary Vascular Disease

There are no reported studies that specifically assess the perioperative risk associated with pulmonary vascular disease in patients having noncardiac surgery. In fact, there are no systematic studies of the risk of noncardiac surgery for patients with congenital heart disease, corrected or uncorrected.[72] A number of reports have evaluated cardiovascular function many years after surgery for congenital heart disease. Five years after surgery for ventricular septal defect or patent ductus arteriosus, pulmonary vasoreactivity often remains abnormal, increasing to high levels during hypoxia. Such patients may not tolerate intraoperative or postoperative hypoxia as well as normal individuals.

Patients with congenital heart disease have also demonstrated a reduced cardiac reserve during exercise.[73] Postoperative studies of patients with coarctation of the aorta or tetralogy of Fallot have demonstrated findings consistent with underlying impairment of ventricular function.[74,75] These observations should be kept in mind when evaluating such patients before noncardiac surgery. Patients receiving primary cardiac repair at a younger age in the present era may be less prone to postoperative ventricular dysfunction because of improved surgical techniques.

While most experts agree that pulmonary hypertension poses an increased risk for noncardiac surgery, no organized study of the problem has been performed. The only analogous situation is labor and delivery for women with Eisenmenger syndrome due to a congenital intracardiac shunt. Peripartum mortality was reported to be between 30% and 70% in 1971, but no recent data exist to clarify whether or not this has fallen with improvements in care.[76] In patients with severe pulmonary hypertension and a cardiac shunt, systemic hypotension results in increased right to left shunting and predisposes the patient to development of acidosis, which can lead to further decreases in systemic vascular resistance. This cycle must be recognized and appropriately treated.

IV. Type of Surgery

Urgency

In a recent review, Mangano[1] determined that cardiac complications are two to five times more likely to occur with emergency surgical procedures than with elective operations. This finding is not surprising, since the necessity for immediate surgical intervention may make it impossible to evaluate and treat such patients optimally. For instance, collected data have confirmed that the composite mortality rate for elective repair of patients with asymptomatic abdominal aortic aneurysms is significantly lower (3.5%) than that for ruptured aneurysms (42%).[77] The mortality rate for graft replacement of symptomatic but intact abdominal aortic aneurysms remains relatively high (19%) despite the fact that, like elective cases, they are not associated with antecedent blood loss or hypotension. Unfortunately, most true surgical emergencies (eg, symptomatic abdominal aortic aneurysms, perforated viscus, major trauma) do not permit more than a cursory cardiac evaluation.

In addition, some situations do not lend themselves to comprehensive cardiac evaluation, although surgical care may qualify as semielective. In some patients, the impending danger of the disease is greater than the anticipated perioperative risk. Examples include patients who require arterial bypass

procedures for limb salvage or mesenteric revascularization to prevent intestinal gangrene. Patients with malignant neoplasms also pose a diagnostic and therapeutic dilemma with respect to preoperative cardiac evaluation, especially when it is difficult to determine whether the malignancy is curable before surgical exploration. Each of these situations illustrates the importance of close communication among consultant, surgeon, and anesthesiologist to plan an approach for cardiac assessment that is appropriate for the individual patient and the underlying disease.

Surgical Risk

For elective surgery, cardiac risk can be stratified according to a number of factors, including the magnitude of the surgical procedure. Some operations are simply more dangerous than others. Backer et al[78] encountered no cardiac complications following 288 ophthalmologic procedures in 195 patients with a prior history of MI compared with a reinfarction rate of 6.1% for a number of nonophthalmologic surgeries at the same center. A recent large-scale study supported the low morbidity and mortality rates in superficial procedures performed on an ambulatory basis. Warner et al[79] determined the perioperative (30-day) incidence of MI and cardiac death in 38 500 patients who underwent 45 090 consecutive anesthesias. Fourteen (0.03% anesthesia) perioperative MIs occurred, of which two patients died on postoperative day 7 after the infarction. Two MIs occurred either intraoperatively or within the first 8 hours, one of which was fatal. Using age- and gender-adjusted annual incidence rate for MIs and sudden death, the authors predicted that 17.8 MIs should have occurred among this population during the study period, suggesting that these events may have occurred independent of the procedure. Several large surveys have demonstrated that perioperative cardiac morbidity is particularly concentrated among patients who undergo major thoracic, abdominal, or vascular surgery, especially when they are 70 years or older.[1,78,80-82] Ashton et al,[15] prospectively studied the incidence of perioperative MI associated with thoracic, abdominal, urologic, orthopedic, and vascular surgery in a cohort of 1487 men older than 40. The highest infarction rate (4.1%) (odds ratio, 10.39; 95% confidence interval [CI], 2.3 to 47.5) occurred in the subset of patients with an established diagnosis of CAD. Nevertheless, independent significant risk factors for infarction also included age greater than 75 years (odds ratio, 4.77; 95% CI, 1.17 to 19.41), and the need for elective vascular surgery even in the absence of suspected CAD (adjusted odds ratio, 3.72; 95% CI, 1.12 to 12.37).

Few procedure-specific data are available regarding perioperative cardiac morbidity in most surgical specialties, perhaps because advanced age and serious, incidental CAD are assumed to be distributed randomly within groups of patients who undergo noncardiac operations in such fields as general surgery, thoracic surgery, orthopedics, urology, gynecology, and neurosurgery. Pedersen et al[83] found by logistic regression that age greater than or equal to 70 years, MI within the preceding 12 months, and CHF were associated with an increased incidence of postoperative cardiac complications in a series of 7300 patients who underwent a mix of both “major” and “minor” gastrointestinal, urologic, gynecologic, and orthopedic procedures. Marsch et al[84] reached similar conclusions in a much smaller series of 52 patients who required elective hip arthroplasty; the 11 patients in this study who had previous clinical indications of CAD sustained significantly higher rates of monitored ischemia or MI during the perioperative period (adjusted odds ratio, 1.9; 95% CI, 0.7 to 5.2) and late cardiac events during 4 years of follow-up (adjusted odds ratio 3.5; 95% CI, 1.3 to 9.2) than did the remaining 41 patients.

As shown by Ashton et al[15] and many others, however, patients who require vascular surgery appear to have an increased risk for cardiac complications because:

- Many of the risk factors contributing to peripheral vascular disease (eg, diabetes mellitus, tobacco use, hyperlipidemia) are also risk factors for CAD.

- The usual symptomatic presentation for CAD in these patients may be obscured by exercise limitations imposed by advanced age or intermittent claudication, or both.

- Major arterial operations often are time-consuming and may be associated with substantial

fluctuations in intra-extravascular fluid volumes, cardiac filling pressures, systemic blood pressure, heart rate, and thrombogenicity.[1]

Two recent studies have attempted to stratify the incidence of perioperative and intermediate-term MI according to the original type of vascular surgery performed. In a prospective series of 53 aortic procedures and 87 infrainguinal bypass grafts for which operative mortality rates were nearly identical (9% and 7%, respectively), Krupski et al[85] found that the risk for fatal/nonfatal MI within a 2-year follow-up period was 3.5 times higher (21% versus 6%) among patients who received infrainguinal bypass grafts. This difference probably is related to the fact that diabetes mellitus (44% versus 11%) and a history of previous MI (43% versus 28%), angina (36% versus 15%), or CHF (29% versus 9%) also were significantly more prevalent in the infrainguinal bypass group. L'Italien et al[86] have presented comparable data regarding the perioperative incidence of fatal/nonfatal MI and the 4-year event-free survival rate following 321 aortic procedures, 177 infrainguinal bypass grafts, and 49 carotid endarterectomies. Slight differences in the overall incidence of MI among the three surgical groups, which may have been related to the prevalence of diabetes mellitus, were exceeded almost entirely in significance by the influence of discrete cardiac risk factors (previous MI, angina, CHF, fixed or reversible thallium defects, ST-T depression during stress testing).[86] These and other studies[5] suggest that the clinical evidence of CAD in a patient who has peripheral vascular disease appears to be a better predictor of subsequent cardiac events than the particular type of peripheral vascular operation to be performed.

In a selective review of several thousand vascular surgical procedures (carotid endarterectomy, aortic aneurysm resection, lower extremity revascularization) reported in the English literature from 1970 to 1987, Hertzer[6] found that cardiac complications were responsible for about half of all perioperative deaths, and that fatal events were nearly five times more likely to occur in the presence of standard preoperative indications of CAD. Furthermore, the late (5-year) mortality rate for patients who were suspected to have CAD was twice that for patients who were not (approximately 40% versus 20%). It is noteworthy that both the perioperative and 5-year mortality rates for the small groups of patients who previously had coronary bypass surgery were similar to the results reported for larger series of patients who had no clinical indications of CAD at the time of peripheral vascular surgery.

Published mortality rates from large referral centers may not reflect the results at thousands of other hospitals throughout the United States in which, collectively, most vascular surgeries are performed on an individual, low-volume basis. Hsia et al[87] have calculated that fewer than 10 carotid endarterectomies were performed annually at 45% of all hospitals in which Medicare beneficiaries received this procedure from 1985 to 1989, and Fisher et al[88] demonstrated that the perioperative mortality rate (1.1% to 3.2%) had an inverse relation to the low volume of carotid endarterectomies in 2089 Medicare patients at 139 New England hospitals. Similar trends (high volume/low risk, low volume/high risk) have been confirmed by statewide audits of aortic aneurysm resection in Vermont, Kentucky, and New York.[89-91] In New York, for example, Hannan et al[91] reviewed 3570 elective aneurysm resections from 1985 to 1987 and found a linear, inverse relation between case volume and mortality rates for surgeons who annually performed two or fewer operations (11% mortality), three to nine operations (7.3% mortality), or 10 or more operations (5.6% mortality). No comparable data are available for lower extremity bypass procedures, but according to the National Center for Health Statistics, the potential magnitude of this problem is illustrated by the fact that each year approximately 100 000 patients are discharged from US hospitals after lower extremity revascularization.[92]

Chassin et al[93] collected 1984 data for the 30 most common diagnosis-related groups for which charges were submitted from nearly 5 000 000 admissions to over 5000 hospitals. Of 48 homogeneous medical and surgical conditions developed from a statistical model, only four had adjusted mortality rates that clearly could be correlated from one condition to another; three (carotid endarterectomy, aortic reconstruction, lower extremity revascularization) involved vascular surgery, and the fourth (total hip replacement), orthopedic surgery. Thus, if a hospital did well or poorly with one of these operations, it tended to do equally well or poorly with the rest of them. Considering the fact that the prevalence of CAD contributes substantially to the perioperative risk of vascular surgery, at least some of the

differences in surgical outcome from one hospital to another may be accounted for by variations in the degree to which it is recognized and appropriately treated. The level of this awareness also has implications regarding late survival. In the prospectively randomized Veterans Administration trial of carotid endarterectomy versus nonoperative management for asymptomatic carotid stenosis, for example, more than 20% of both randomized cohorts died from cardiac-related complications within a follow-up period of 4 years.[94]

As Fleisher and Barash[95] have emphasized, the specific surgical setting must be considered within any algorithm regarding preoperative cardiac evaluation. The term *noncardiac operation* is exceedingly broad in its definition; it embraces aging patients with complex technical problems as well as younger patients scheduled for straightforward surgical procedures. As described above, cardiovascular morbidity and mortality not only vary among procedures but among institutions for the same procedure. Therefore, in assessing the risks and benefits of a perioperative intervention strategy, risks associated with noncardiac surgery must be individualized. It is important to remember, however, that the indications for coronary intervention should not be redefined simply because a patient who has CAD of marginal significance also happens to require a major noncardiac procedure. Conversely, the long-term implications of severe left main or triple-vessel disease and diminished left ventricular function are no less ominous following a minor noncardiac operation than they are in any other patient. In the final analysis, one of the ultimate objectives of the preoperative cardiac assessment is to exclude the presence of such serious CAD that some form of direct intervention would be warranted even if no noncardiac operation were necessary. In this regard, the presentation for noncardiac surgery may simply represent the first time that a patient with overt or suspected coronary heart disease has an opportunity for cardiovascular assessment.

In summary, the surgical procedures have been classified as low, intermediate, and high risk as shown in Table 3. Although coronary disease is the overwhelming risk factor for perioperative morbidity, procedures of different levels of stress are associated with different levels of morbidity and mortality. Superficial and ophthalmologic procedures represent the lowest risk and are rarely associated with excess morbidity and mortality. Major vascular procedures represent the highest-risk procedures. Within the intermediate-risk category, morbidity and mortality vary, depending on the surgical location and extent of the procedure. Some procedures may be short, with minimal fluid shifts, while others may be associated with prolonged duration and large fluid shifts and greater potential for postoperative myocardial ischemia and respiratory depression. Therefore, the physician must exercise judgment to correctly assess perioperative surgical risks and the need for further evaluation.

V. Supplemental Preoperative Evaluation

Resting Left Ventricular Function

Summary of Evidence

Resting ventricular function has been evaluated preoperatively before noncardiac surgery by radionuclide angiography, echocardiography, and contrast ventriculography.[23,96-105] Of seven studies that demonstrate a positive relation between decreased preoperative ejection fraction and postoperative mortality or morbidity, four were prospective[96,97,100,103] and three retrospective.[98,99,103] The greatest risk of complications was observed in patients with an LVEF at rest of less than 35%. In the perioperative phase, poor left ventricular systolic or diastolic function is mainly predictive of postoperative CHF, and in critically ill patients, death. It is noteworthy, however, that resting left ventricular function was not found to be a *consistent* predictor of perioperative ischemic events.

Recommendations for Preoperative Noninvasive Evaluation of Left Ventricular Function

Class I. Patients with current or poorly controlled CHF. (If previous evaluation has documented severe left ventricular dysfunction, repeat preoperative testing may not be necessary.)

Class II. Patients with prior CHF and patients with dyspnea of unknown etiology.
Class III. As a routine test of left ventricular function in patients without prior CHF.

Assessment of Risk for Coronary Artery Disease and Functional Capacity

Exercise Stress Testing for Myocardial Ischemia and, Functional Capacity

The aim of supplemental preoperative testing is to provide an objective measure of functional capacity, to identify the presence of important preoperative myocardial ischemia or cardiac arrhythmias, and to estimate perioperative cardiac risk and long-term prognosis. Poor functional capacity in patients with chronic CAD or those convalescing after an acute cardiac event is associated with an increased risk of subsequent cardiac morbidity and mortality.[37] Decreased functional capacity may be caused by several factors, including inadequate cardiac reserve, advanced age, transient myocardial dysfunction from myocardial ischemia, deconditioning, and poor pulmonary reserve.

In evaluating the role of exercise testing to assess patients undergoing noncardiac procedures, it is useful to summarize what is known about ECG exercise testing in general. The sensitivity gradient for detecting obstructive coronary disease is dependent on severity of stenosis and extent of disease as well as criteria used for a positive test. As many as 50% of patients with single-vessel coronary disease and adequate levels of exercise can have a normal exercise ECG.[38] The mean sensitivity and specificity of exercise testing for obstructive coronary disease is 68% and 77%, respectively.[39] The sensitivity and specificity for multivessel disease is 81% and 66%, and for three-vessel or left main coronary disease, 86% and 53%, respectively.[40]

Weiner et al[32] studied 4083 medically treated patients in the Coronary Artery Surgery Study (CASS) and identified a high-risk patient subset (12% of the population) with an annual mortality greater than or equal to 5% per year when the exercise workload was less than Bruce stage I and the exercise ECG showed ST-segment depression greater than or equal to 1 mm. A low-risk patient subset (34% of the population) who were able to complete or do more than Bruce stage III with a normal exercise ECG had an annual mortality of less than 1% per year over 4 years of follow-up.[32] Similar results have been reported by others.[41,42]

Summary of evidence. The use of preoperative exercise ECG testing to estimate coronary disease presence and risk of perioperative events in patients undergoing major noncardiac surgery was reviewed through a Medline search of the English literature on exercise and peripheral vascular disease from 1975 to September 1994.[106-116] Table 6 lists publications in which exercise test results and perioperative events were reported. In most series, very high-risk patients (recent MI, unstable angina, CHF, and serious ventricular arrhythmias) were excluded. McPhail et al[113] reported on preoperative exercise treadmill testing and supplemental arm ergometry in 100 patients undergoing surgery for peripheral vascular disease or abdominal aortic aneurysm. Of the 100 patients, 30 were able to reach 85% of age-predicted heart rate maximum, and only two had cardiac complications (6%). In contrast, 70% of the population were unable to reach 85% of age-predicted heart rate or had an abnormal exercise ECG. In this group the cardiac complication rate (MI, death, heart failure, or ventricular arrhythmia) was 24% (17 patients).

Table 6. Preoperative Exercise Testing Before Major Noncardiac Surgery

Author	n	Patients With Abnormal Test (%)	Criteria for Abnormal Test	Events	Predictive Value: Positive Test	Predictive Value: Negative Test	Event	Co
Peripheral vascular surgery or abdominal aortic aneurysm repair								
McCabe '81	314	36	STD, CP, or A	38% (15/39)	81% (13/16)	91% (21/23)	D,M,I,H,A	
Cutler '81	130	39	STD	7% (9/130)	16% (8/50)	99% (79/80)	D,M	<75% MPHR in
Arous '84	808	17	STD	NR	21% (19/89)	NR	D,M	
Gardine '85	86	48	STD	11% (2/19)	11% (1/9)	90% (9/10)	D,M	

von Knorring '86	105	25	STD, A, or CP	3% (3/105)	8% (2/26)	99% (78/79)	D,M	
Kopecky '86	114	57	<400 kpm	7% (8/110)	13% (8/63)	100% (47/47)	D,M	
Leppo* '87	60	28	STD	12% (7/60)	25% (3/12)	92% (44/48)	D,M	Exercise test res patients for reva
Hanson '88	74	57	STD	3% (1/37)	5% (1/19)	100% (18/18)	D,M	Arm ergometry
McPhail* '88	100	70	<85% MPHR	19% (19/100)	24% (17/70)	93% (28/30)	D,M,A,F	<85% MPHR; *P*
Urbinati '94	121	23	STD	0	0/28	100% (93/93)	D,M	Carotid endarect predicted late de
Peripheral vascular surgery or major noncardiac surgery								
Carliner '85	200	16	STD	32% (16/200)	16% (5/32)	93% (157/168)	D,M	5 METs (NS)

STD indicates exercise-induced electrocardiographic ishemia; CP, chest pain; A, cardiac arrhythmia; D, death; M, myocardial infarction; I, myocardial ischemia; H, hypotension; MPHR, maximum predicted heart rate; NR, not reported; F, failure; NS, not significant; MET, metabolic equivalent.
*Studies with prospective collection of postoperative electrocardiogram and cardiac enzymes.
In references 106, 108, 109, 112, and 116, the total number of patients undergoing peripheral vascular surgery was less than the total number tested.

The data summarized in Table 6 indicate a peak exercise heart rate greater than 75% of age-predicted maximum can be expected in approximately half of patients who undergo treadmill exercise, with supplemental arm ergometry when necessary for patients limited by claudication.[107] The frequency of an abnormal exercise ECG response is dependent on prior clinical history.[107,110] In patients without a cardiac history and a normal resting ECG, approximately 20% to 25% of patients will have an abnormal exercise ECG. The frequency is greater (35% to 50%) in patients with a prior history of MI or an abnormal rest ECG. The risk of perioperative cardiac events and long-term risk is significantly increased in patients with an abnormal exercise ECG at low workloads.

In contrast to the above studies of patients with vascular disease, in a general population of patients in whom only 20% to 35% had peripheral vascular disease and were undergoing noncardiac surgery, Carliner et al[114] reported exercise-induced ST-segment depression greater than or equal to 1 mm in 16% of 200 patients older than 40 years (mean age, 59 years) being considered for elective surgery. Only two patients (1%) had a markedly abnormal exercise test. Of the 32 patients with an abnormal exercise test, five (16%) died or had a nonfatal MI. Of 168 patients with a negative test, 157 (93%) did not die or have an MI. In this series, however, the results of preoperative exercise testing were not statistically significant independent predictors of cardiac risk.

Table 5 provides a prognostic gradient of ischemic responses during an ECG-monitored exercise test as developed for a general population of patients with CAD.[118] The prognostic gradient is also influenced by the age of the patient, the extent of the coronary disease, and the degree of left ventricular dysfunction. ACC/AHA guidelines concerning the indications for and interpretation of exercise stress testing are available.[43]

Nonexercise Stress Testing

The two main techniques used in preoperative evaluation of patients undergoing noncardiac surgery who cannot exercise are to increase myocardial oxygen demand (pacing, intravenous dobutamine) and to induce hyperemic responses by pharmacological vasodilators such as intravenous dipyridamole or adenosine. The two most common methodologies presently in use are dobutamine stress echocardiography and intravenous dipyridamole myocardial perfusion imaging. Adenosine can also be used as an alternative to dipyridamole in these types of studies.

Myocardial perfusion imaging methods

Summary of evidence. A computerized search (Medline) of the English literature from 1975 to 1994

identified 23 publications describing the use of dipyridamole thallium stress testing in the preoperative evaluation of patients before both vascular and nonvascular surgery. These publications are summarized in Table 7 and were chosen from a total of 397 articles identified using key words.* Included were mostly prospectively recruited patient studies that predominantly involved patients undergoing vascular surgery. Cardiac events in the perioperative period were defined, for the purpose of this table, as only MI or death from cardiac causes, and information about events and scan results had to be available. The percentage of patients with evidence of ischemic risk as judged by thallium redistribution ranged from 23% to 69%. The positive predictive value of thallium redistribution ranged from 4% to 20% in reports that included more than 100 patients. In more recent publications, the positive predictive value of thallium imaging has been significantly decreased. This is probably related to the fact that in recent years scintigraphic information obtained is actively used to select patients for therapeutic interventions such as coronary revascularization as well as to adjust perioperative medical treatment and monitoring and to select different surgical procedures. The negative predictive value of a normal scan remains uniformly high at approximately 99% for MI and/or cardiac death. Although the risk of a perioperative cardiac event in patients with fixed defects is higher than in patients with a normal scan, it is still significantly lower than the risk in patients with thallium redistribution.

Table 7. Dipyridamole-Thallium Imaging for Preoperative Assessment of Cardiac Risk

Author	n*	Patients With Ischemia by TI-Rd (%)	Events MI/Death (%)	Perioperative Events: RD Scan Positive Predictive Value	Perioperative Events: Normal Scan Negative Predictive Value	Comments
Vascular surgery						
Boucher '85	48	16 (33)	3 (6)	19% (3/16)	100% (32/32)	First study to define risk of thallium redistribution
Cutler '87	116	54 (47)	11 (10)	20% (11/54)	100% (60/60)	Only aortic surgery
Fletcher '88	67	15 (22)	3 (4)	20% (3/15)	100% (56/56)	
Sachs '88	46	14 (31)	2 (4)	14% (2/14)	100% (24/24)	
Eagle '89	200	82 (41)	15 (8)	16% (13/82)	98% (61/62)	Defined clinical risk
McEnroe '90	95	34 (36)	7 (7)	9% (3/34)	96% (44/46)	Fixed defects predict events
Younis '90	111	40 (36)	8 (7)	15% (6/40)	100% (51/51)	Includes long-term follow-up
Mangano '91	60	22 (37)	3 (5)	5% (1/22)	95% (19/20)	Managing physicians blinded to scan result
Strawn '91	68	n/a	4 (6)	n/a	100% (21/21)	
Watters '91	26	15 (58)	3 (12)	20% (3/15)	100% (11/11)	Includes echo (TEE) studies
Hendel '92	327	167 (51)	28 (9)	14% (23/167)	99% (97/98)	Included long-term follow-up
Lette '92	355	161 (45)	30 (8)	17% (28/161)	99% (160/162)	Used quantitative scan index
Madsen '92	65	45 (69)	5 (8)	11% (5/45)	100% (20/20)	
Brown '93	231	77 (33)	12 (5)	13% (10/77)	99% (120/121)	Prognostic utility enhanced by combined scan and clinical factors
Kresowik '93	170	67 (39)	5 (3)	4% (3/67)	98% (64/65)	
Baron '94	457	160 (35)	22 (5)	4% (7/160)	96% (195/203) NFMI only	Did not analyze for cardiac deaths; no independent value of scan
Bry '94	237	110 (46)	17 (7)	11% (12/110)	100% (97/97)	Cost-effectiveness data included
Nonvascular surgery†						
Camp '90	40	9 (23)	6 (15)	67% (6/9)	100% (23/23)	Diabetes mellitus, renal transplant
Iqbal '91	31	11 (41)	3 (11)	27% (3/11)	100% (20/20)	Exercise 86%, diabetes mellitus, pancreas transplant
Coley '92	100	36 (36)	4 (4)	8% (3/36)	98% (63/64)	Define clinical risk factors in patients with known or suspected CAD

Shaw '92	60	28 (47)	6 (10)	21% (6/28)	100% (19/19)	Used adenosine
Takase '93	53	15 (28)	6 (11)	27% (4/15)	100% (32/32)	Patients with documented or suspected CAD include rest echocardiogram
Younis '94	161	50 (31)	15 (9)	18% (9/50)	98% (87/89)	Intermediate- to high-risk CAD

Rd indicates redistribution; n*, number of patients who underwent surgery; MI, myocardial infarction; TEE, transesophageal echocardiography; NFMI, nonfatal myocardial infarction; †, studies utilizing pharmacologic and/or exercise thallium testing.
All studies except those by Coley and Shaw acquired patient information prospectively. Only in reports by Mangano and Baron were scan results blinded from attending physicians.
Patients with fixed defects were omitted from calculations of positive and negative predictive value.

The need for caution in routine screening with a dipyridamole thallium stress test of all patients before vascular surgery has been recently raised by Baron et al.[133] In this review of 457 patients undergoing elective abdominal aortic surgery, the presence of definite CAD and age greater than 65 years were better predictors of cardiac complications than perfusion imaging.

In several publications by Hendel et al,[128] Lette et al,[129] and Brown et al,[131] the scoring or quantitation of scan abnormalities had a significant impact on improving risk assessment and positive predictive value. The data suggest that as the size of the defect increases, cardiac risk significantly increases. The use of techniques to quantitate the extent of abnormality will probably improve the positive predictive nature of myocardial perfusion imaging and impact the potential role of interventions such as cardiac catheterization and revascularization. Although there are few published reports using adenosine myocardial perfusion imaging in the preoperative risk assessment of patients before noncardiac surgery, its usefulness appears to be equivalent to that of dipyridamole. ACC/AHA guidelines concerning indications for and interpretation of stress testing with myocardial perfusing imaging are available.[141]

Dobutamine stress echocardiography

Summary of evidence. Several reports have documented the accuracy of dobutamine stress echocardiography to identify patients with significant angiographic coronary disease.[141-146] The use of dobutamine stress echocardiography in preoperative risk assessment was evaluated in six studies, all published since 1991 and identified by a computerized search of the English language literature (Table 8).[105,147-151] The populations included predominantly, but not exclusively, patients undergoing peripheral vascular surgical procedures. Only two studies blinded the physicians and surgeons who treated the patients to the dobutamine stress echocardiographic results.[105, 149] In the remaining studies the results were used to influence preoperative management, particularly the decision whether or not to proceed with coronary angiography or coronary revascularization before elective surgery. Each study used similar, but not identical, protocols. The definition of a positive and negative test result differed considerably, based on subjective analysis of regional wall motion; ie, worsening of preexisting wall motion abnormalities was considered by some investigators as a positive and by others as a negative finding. The end points used to define clinical outcome varied and included both “soft” (ie, arrhythmia, heart failure, and ischemia) and “hard” (ie, MI or cardiac death) events.

Table 8. Summary Of Studies Examining The Value Of Dobutamine Stress Echocardiography For Preoperative Risk Assessment

Author	N*	Patients With Ischemia (%)	Events MI/Death (%)	Criteria For Abnormal Test	Predictive Value† Positive/MI Or Death	Negative	Comments
Lane '91	38	50	3 (8%)	New WMA	16% (3/19)	100% (19/19)	Vascular and general surger
Lalka '92	60	50	9 (15%)	New or worsening WMA	23% (7/30)	93% (28/30)	Multivariate analysis
Eichelberger '93	75	36	2 (3%)	New or worsening WMA -*	7% (2/27)	100% (48/48)	Managing physicians blinde DSE results
Langan '93	74	24	3 (4%)	New WMA or ECG changes	17% (3/18)	100% (56/56)	
Poldermans '93	131	27	5 (4%)	New or worsening WMA	14% (5/35)	100% (96/96)	Multivariate analysis; manag physicians blinded to DSE r
Dávila Román '93	88	23	2 (2%)	New or worsening WMA	10% (2/20)	100% (68/68)	Included long-term follow-u

MI indicates myocardial infarction; WMA, wall motion abnormality; DSE, dobutamine stress echocardiogram.

*Number of patients who underwent surgery.
†Numbers in parentheses refer to number of patients/total in group.

The data indicate that dobutamine stress echocardiography can be performed safely and with acceptable patient tolerance. The range of positive test results was 23% to 50%. The predictive value of a positive test ranged from 17% to 43% for all events and 7% to 23% for hard events (MI or death). The negative predictive value ranged from 93% to 100%. In the series by Poldermans et al,[105] the presence of a new wall motion abnormality was a powerful determinant of an increased risk for perioperative events after multivariable adjustment for different clinical and echocardiographic variables. Several studies suggest that the degree of wall motion abnormalities and/or wall motion change at low infusion rates of dobutamine is especially important. The published experience of dobutamine stress echocardiography to assess perioperative risk before vascular and nonvascular surgery is relatively small compared with the published literature on exercise testing or intravenous dipyridamole myocardial perfusion imaging. Updated ACC/AHA guidelines concerning the indications for and interpretation of echocardiography (including stress echocardiography) will be published shortly.

Stress testing in the presence of left bundle branch block. The sensitivity and specificity of exercise thallium scans in the presence of left bundle branch block is reported to be 78% and 33%, respectively, and overall diagnostic accuracy varies from 36% to 60%.[152,153] In contrast, the use of vasodilators in such patients has a sensitivity of 98%, a specificity of 84%, and a diagnostic accuracy of 88% to 92%.[154-156] Pharmacological stress testing with adenosine or dipyridamole is preferable to dobutamine or exercise imaging in patients with preexisting left bundle branch block. The tachycardia induced during exercise and conceivably also during dobutamine infusion may result in reversible septal defects even in the absence of left anterior descending artery disease in some patients. This response is unusual with either dipyridamole or adenosine stress testing. It should also be noted that exercise should not be combined with dipyridamole in such patients and that synthetic catecholamines will also yield false-positive results.[157] Therefore, the preoperative evaluation of CAD in patients with left bundle branch block should be performed using vasodilator stress and myocardial perfusion studies.

Ambulatory Electrocardiographic Monitoring

Summary of evidence. The use of preoperative ambulatory ECG monitoring to estimate coronary disease presence and risk of perioperative events in patients undergoing major noncardiac surgery was reviewed through a Medline search of the English literature on preoperative and myocardial ischemia and surgery from 1976 to September 1994. The predictive value of preoperative ST changes on 24- to 48-hour ambulatory electrocardiography for cardiac death or MI in patients undergoing vascular and nonvascular noncardiac surgery has been reported by several investigators. The frequency of abnormal ST-segment changes observed in 869 patients reported in seven series was 25% (range, 9% to 39%).[19,158-162] The positive and negative predictive values for perioperative MI and cardiac death are shown in Table 9. In two recent studies it had a predictive value similar to dipyridamole thallium imaging.[160,163]

Table 9. Predictive Value of Preoperative ST-Segment Changes Detected by Ambulatory Monitoring for Perioperative Myocardial Infarction and Cardiac Death After Major Vascular Surgery

Author	n	Patients With Abnormal Test (%)	Criteria for Abnormal Test	Perioperative Events: Positive* Test	Perioperative Events: Negative Test	Event	Comments
Raby '89	176	18	A	10% (3/32)	1% (1/144)	D,M	24-48 h during ambulation
Pasternack '89	200	39	A	9% (7/78)	2% (2/122)	D,M	
Mangano '90	144	18	A,B	4% (1/26)	4% (5/118)	D,M	Immediately preop
Fleisher '92	67	24	A,B	13% (2/16)	4% (2/51)	D,M	Immediately preop
McPhail '93	100	34	A	15% (5/34)	6% (4/66)	D,M	
Kirwin '93	96	9	A	11% (1/9)	16% (14/87)	D,M	Definition of MI based on enzymes only

Fleisher '95	86	23	A,B	10% (2/20)	3% (2/66)	D,M	Quantitative monitoring not predictive

A indicates ≥1 mm ST-segment depression; D, death; MI, myocardial infarction; B, ≥2 mm ST-segment elevation.
*Positive predictive value for postoperative cardiac events.

Although the test has been shown to be predictive of cardiac morbidity, there are several limitations. Differences in the study protocols (24 versus 48 hours, ambulatory versus in-hospital) may account for the variability in the predictive value of the test. Preoperative ambulatory electrocardiography for ST-segment changes cannot be performed in a significant percentage of patients because of baseline ECG changes. The test, as currently used, only provides a binary outcome and therefore cannot further stratify the high-risk group in order to identify the subset for whom coronary angiography should be considered.[163]

Recommendations: which test? In most ambulatory patients, the test of choice is exercise ECG testing, which can both provide an estimate of functional capacity and detect myocardial ischemia through changes in the ECG and hemodynamic response. In patients with important abnormalities on their resting ECG (left bundle branch block, left ventricular hypertrophy with strain pattern, digitalis effect, etc), other techniques such as exercise echocardiography or exercise myocardial perfusion imaging should be considered. [163]

In patients unable to perform adequate exercise, a nonexercise stress test should be used. In this regard, dipyridamole thallium testing and dobutamine echocardiography are the most common. Intravenous dipyridamole should be avoided in patients with significant bronchospasm, critical carotid disease, or patients with a condition that prevents their being withdrawn from theophylline preparations. Dobutamine should not be used as a stressor in patients with serious arrhythmias or severe hypertension or hypotension. For patients in whom echocardiographic image quality is likely to be poor, a myocardial perfusion study is more appropriate. Soft tissue attenuation can also be a problem with myocardial perfusion imaging. If there is an additional question about valvular dysfunction, the echocardiographic stress test is favored. In many instances, either stress perfusion or stress echocardiography is appropriate. In a meta-analysis of dobutamine stress echocardiography, ambulatory electrocardiography, radionuclide ventriculography, and dipyridamole thallium scanning in predicting adverse cardiac outcome after vascular surgery, all tests had a similar predictive value, with overlapping confidence intervals.[164] The expertise of the local laboratory in identifying advanced coronary disease is probably more important than the particular type of test.

Currently the use of ambulatory electrocardiography as a preoperative test should be restricted to identifying patients for whom additional surveillance or medical intervention might be beneficial. The current evidence does not support the use of ambulatory electrocardiography as the only diagnostic test to refer patients for coronary angiography.

For certain patients at high risk, it may be appropriate to proceed with coronary angiography rather than perform a noninvasive test. For example, preoperative consultation may identify patients with unstable angina or evidence for residual ischemia following recent MI for whom coronary angiography is indicated. In general, indications for preoperative coronary angiography are similar to those identified for the nonoperative setting. Table 4 provides a summary of indications for preoperative coronary angiography in patients being evaluated before noncardiac surgery. These are adapted from the ACC/AHA guidelines for coronary angiography published in 1987.[36]

VI. Implications of Risk Assessment Strategies on Costs

The decision to recommend further noninvasive or invasive testing for the individual patient being considered for noncardiac surgery ultimately becomes a balancing act between the estimated probabilities of effectiveness versus risk. The proposed benefit, of course, is the possibility of identifying advanced but relatively unsuspected CAD that might result in significant cardiac morbidity or mortality either perioperatively or long term. In the process of further screening and treatment, the risks from the

tests and treatments themselves may offset or even exceed the potential benefit of evaluation. Furthermore, the cost of screening and treatment strategies must be considered.

The medical literature is helpful in defining the risk versus effectiveness in patients being considered for surgery. As noted above, patients who have had coronary revascularization within the previous 5 years and no recurrent ischemic symptoms are at such low risk for perioperative complications that further screening is unnecessary. Furthermore, absence of certain clinical markers defines a low-risk group that is unlikely to require further screening. This fact is true for patients who have an absence of prior angina, MI, CHF, pathological Q waves on ECG, or diabetes mellitus, particularly with excellent or normal functional capacity (Table 1, Fig 1). In the remaining patients who have some increased markers of coronary artery risk, particularly when coupled with poor or unknown functional capacity, the issue of screening is especially relevant and difficult. Depending on referral patterns, the percentage of patients being considered for noncardiac surgery who fit this particular clinical category can vary greatly.

Cambria et al[165] have reported their experience using a selected clinical algorithm as discussed above. The cost assessment of this strategy in 201 consecutive patients being considered for aortic surgery is presented in Fig. 2. In this series, only 58 (29%) of patients considered for aortic repair underwent further noninvasive testing with exercise and/or dipyridamole thallium study. Sixteen patients (8%) were referred for cardiac catheterization, with preoperative coronary revascularization performed in 13 (6.5%). This selected use of noninvasive testing and very selected use of revascularization resulted in an overall perioperative cardiac mortality of just 0.5%.

To illustrate the cost implications of noninvasive testing and its potential cost-effectiveness, information from the Medicare databases was applied to the series by Cambria et al in Fig 2. If a cost of $567 per nuclear stress test is assumed, the accumulated costs of the selective screening of 58 patients is $32 886. In contrast, the cost of screening all 201 patients would have been $113 967, a net increase of $81 081 over selective screening. Based on an annual incidence of 500 000 major vascular surgical procedures in the United States, selective testing could result in a savings of more than $200 million, compared with a policy of routine testing. If the accumulated costs of the tests and coronary interventions are taken into account, the overall cost of using this particular selected screening strategy in the 201 patients was approximately $590 206, or $2936 per patient.

As described previously, there are no randomized trials demonstrating the efficacy of screening and coronary interventions versus vascular surgery only. However, the low mortality reported by Cambria et al and others in patients who had undergone coronary revascularization suggests that such strategies improve survival. Using the Cambria data set as an example and assuming only one life was saved as a result of this strategy, the strategy would be at the expensive end of medical cost-effectiveness. If long-term benefits are considered and this patient lived 10 years, this strategy would have cost $59 020 per year of life saved (ignoring other subsequent costs). If the screening strategy was more successful, perhaps resulting in two lives saved, the cost per year of life saved would have been $29 510, a figure that is much more consistent with other currently accepted medical therapies. Importantly, many of these costs would likely be incurred at some point regardless of consideration for vascular surgery. In addition, Rihal et al[166] demonstrated a long-term survival benefit of coronary artery bypass grafting in patients with the combination of peripheral vascular disease and triple-vessel CAD. Therefore, by including both short- and long-term benefits, such a strategy might prove to be cost-effective.

Formal decision and cost-effectiveness analyses of this particular question have been done and have yielded highly varied results.[134,167-169] Because the exact amount of risk reduction from coronary revascularization and the clinical populations differs so much from center to center, it is difficult to determine the exact risks of aggressive screening and treatments versus the benefits in terms of risk reduction. Additionally, the models all demonstrate that optimal strategy depends on the mortality rates for both cardiac and noncardiac surgeries in the clinically relevant range. One recent model, which did not support a strategy incorporating coronary angiography and revascularization, used lower mortality rates than those used or reported in the other studies.[91,168,169] Therefore, use of any decision and cost-effectiveness model in a specific situation depends on the comparability of local mortality rates to those

of the model.

Progression of Clinical Care	Cost per Test or per Procedure at Each Step	Accumulated Costs for Each Algorithm Step in Total for Screening/Treating 201 Patients
201 consecutive patients ↓		
Exercise and/or dipyridamole stress test (CPT codes 78465 and 93015) 58 patients (29%) ↓	Nuclear stress testing $457 + 110 = $567[1]	$32 886
Cardiac catheterization and coronary angiography 16 patients (8%) ↓	Cardiac catheterization without angioplasty or bypass surgery $9 200[2]	$27 600
Coronary revascularization PTCA: 2 patients CABG: 11 patients (6.5%) ↓	Cardiac catheterization with PTCA $21760[3] Cardiac catheterization with CABG $44 200[4]	$43 520 $486 200
Total perioperative cardiac death 1 patient (0.5%)		$590 206

Fig 2. Cost assessment of a screening strategy for major vascular surgery patients. [1]1993 medicare average allowed charges, global fees. [2]Metlife. 1992 claims data from insurance pool. *Statistical Bulletin.*
January -March 1994;23. [3]Metlife. 1992 claims data from insurance pool. *Statistical Bulletin.*
January -March 1994;10. [4]Metlife. 1992 claims data from insurance pool. *Statistical Bulletin.*
January -March 1994;15. CPT indicates Current Procedural Terminology; PTCA, percutaneous translumminal coronary angioplasty; CABG, coronary artery bypass surgery.

Fig 2 is meant to illustrate the potential costs versus effectiveness of one such screening strategy. It is vitally important for the clinician to consider the cost implications of screening strategies, particularly in a field in which there are no randomized clinical trials evaluating the impact of therapies on outcomes.

VII. Preoperative Therapy

Rationale for Surgical Coronary Revascularization and Summary of Evidence

Preoperative Coronary Artery Bypass Surgery

As noted, no good randomized or controlled trials have assessed the overall benefit of prophylactic coronary bypass surgery to lower perioperative cardiac risk of noncardiac surgery. On the other hand, a number of retrospective studies have demonstrated that patients who previously have successfully undergone coronary bypass have a low perioperative mortality rate in association with noncardiac procedures and that their mortality rate is comparable to the surgical risk for other patients who have no clinical indications of CAD.[170-173]

Foster et al[23] reviewed 1600 patients who had been enrolled in the CASS registry from 1978 to 1981 and eventually underwent major noncardiac operations, 113 (7%) of which were vascular procedures. The study group included 399 patients without angiographic evidence of advanced CAD (group 1), 743 patients who had prior coronary bypass grafting before noncardiac procedures (group 2), and 458 patients who had significant angiographic CAD (70% luminal stenosis) but no prior bypass surgery (group 3). The operative mortality rates for noncardiac procedures in these three groups were 0.5%, 0.9%, and

2.4%, respectively, and no group differences were noted in the incidence of perioperative MI or cardiac arrhythmias. The operative mortality rate in group 3 was significantly higher (*P*=.009) than in either of the other two groups, but this report does not include any angiographic stratification of coronary risk within group 3 itself. Therefore, the perioperative mortality of 2.4% probably underestimates subsequent surgical risk in patients who had multiple-vessel or surgically incorrectable CAD while overestimating it in other patients who did not yet meet standard criteria for coronary bypass grafting. In 1984 the results of preoperative coronary angiography were reported in a larger series of 1001 patients under consideration for elective vascular surgical procedures at the Cleveland Clinic.[174] Severe CAD that met contemporary indications for coronary bypass surgery at that time was identified by routine coronary angiography in 251 patients, including 188 (34%) of 554 patients with clinical evidence of CAD and 63 (14%) of 446 patients without clinical manifestations of CAD (*P*<.001). Of these, 216 underwent coronary bypass surgery (before vascular surgery) with a related mortality rate of 5.3% followed by a mortality rate of 1.5% for vascular surgery. Operative deaths with vascular surgery occurred in 1 (1.4%) of 74 patients with normal coronary arteries, in 5 (1.8%) of 278 with mild to moderate CAD, in 9 (3.6%) of 250 with advanced but compensated CAD, and in 6 (14%) of 44 with severe, uncorrected, or inoperable CAD.[175] Studies such as these have generated interest in the possible protective influence of coronary bypass surgery on subsequent surgical risk, even though interpretation of most retrospective studies is limited by failure to define the criteria for nonfatal MIs and to indicate whether or not serial ECGs and cardiac enzymes were obtained perioperatively.

In attempting to balance the potential risks versus benefits of coronary artery bypass grafting (CABG) before noncardiac surgery, the additional short-term risks and long-term benefits should be understood. Long-term benefits of such strategies were not incorporated into two recent decision models.[168,169] If the long-term benefits were included, the value of preoperative coronary revascularization would be increased. For instance, the European Coronary Surgery Study Group[176] has reported interesting findings in a small subset of 58 patients with peripheral vascular disease within a much larger series of 768 men who were randomly assigned to receive either coronary bypass surgery or medical management for angina pectoris. While the presence of incidental peripheral vascular disease was associated with reductions in the 8-year survival rates for either surgical or medical management of CAD, its influence was especially unfavorable in patients who received medical therapy alone. That is, the long-term survival rate was 85% following coronary bypass surgery, compared with 57% for nonsurgical treatment (*P*=.02). Rihal and colleagues[166] have recently reported similar findings in more than 2000 patients enrolled in the CASS study. If medical therapy is compared with coronary bypass surgery in patients with both coronary heart disease and peripheral vascular disease, surgically treated patients with three-vessel disease had significantly better long-term survival than those treated medically after adjusting for all covariates, including clinical measures of disease stability, stress test results, and left ventricular function. In the study at the Cleveland Clinic Foundation, the cumulative 5-year survival rate for the 216 patients receiving coronary bypass was 72% (81% in nondiabetic men), compared with 43% (*P*=.001) for 35 patients in whom coronary bypass also was indicated but never performed.[175,177] Fatal cardiac events occurred within a mean of 4.6 years in 12% and in 26% of these two subsets, respectively (*P*=.033). These later studies illustrate the importance of both perioperative and long-term cardiac risk when considering whether or not to recommend coronary bypass surgery before noncardiac surgery. The indications for surgical coronary revascularization in this group are therefore essentially identical to those recommended by the ACC/AHA Task Force and the accumulated data on which those conclusions were based.[178] Examples include patients with the following conditions: acceptable coronary revascularization risk and suitable viable myocardium with left main stenosis, three-vessel CAD in conjunction with left ventricular dysfunction, two-vessel disease involving severe proximal left anterior descending artery obstruction, and intractable coronary ischemia despite maximal medical therapy.

In patients in whom coronary revascularization is indicated, timing of the procedure depends on the urgency of the noncardiac surgical procedure balanced against stability of the underlying CAD. The decision to perform revascularization on a patient before noncardiac surgery to “get them through” the noncardiac procedure is appropriate only in a small subset of very high-risk patients. Patients undergoing elective noncardiac procedures who are found to have prognostic high-risk coronary anatomy and in whom long-term outcome would likely be improved by coronary bypass grafting,[178] should generally

undergo revascularization before a noncardiac elective surgical procedure of high or intermediate risk (Table 3).

Preoperative Coronary Angioplasty

Summary of evidence. At present no randomized clinical trials have documented whether or not prophylactic coronary revascularization with angioplasty before noncardiac surgery reduces the incidence of perioperative cardiac events. Several retrospective series, however, have been reported. In a 50-patient series reported from Mayo Clinic,[179] coronary angioplasty was performed before noncardiac surgery (52% vascular procedures) in patients at high risk for perioperative complications (62% were classified higher than Canadian Heart Class III, 76% had multivessel disease, and all had abnormal noninvasive tests). Ten percent required urgent coronary bypass surgery after angioplasty. The noncardiac procedure was performed a median of 9 days after percutaneous transluminal coronary angioplasty (PTCA), the perioperative MI rate was 5.6%, and the mortality rate 1.9%. Whether or not this result differs from what might have occurred without PTCA is uncertain.

Elmore et al[180] compared the results of preoperative coronary angioplasty and coronary bypass surgery in patients identified for elective abdominal aortic aneurysmorrhaphy. This study retrospectively analyzed the records of 2452 patients who underwent abdominal aortic surgery between 1980 and 1990. Only 100 (4.1%) had revascularization before aortic surgery, and 95% of these had symptomatic CAD. Eighty-six had coronary bypass surgery and 14 had angioplasty. There were no perioperative deaths in this group at the time of aortic surgery, compared with 2.9% perioperative mortality for the entire group (n=2452). The patients having angioplasty had significantly more one- and two-vessel disease and less three-vessel disease than did the bypass group. Late cardiac events were more frequent in the angioplasty group. The small numbers in the angioplasty group and the retrospective analysis over a long period of time make interpretation of the results of this study difficult. It appears, however, that candidates for elective abdominal aortic aneurysmorrhaphy with symptomatic disease (CAD) have a low operative mortality when revascularization is performed before surgery by either angioplasty or bypass surgery.

Allen et al[181] performed a retrospective analysis of 148 patients who underwent angioplasty before noncardiac surgery (abdominal 35%, vascular 33%, and orthopedic 13%). Surgery occurred within 90 days after angioplasty in 72. There were four operative deaths (one cardiac), and 16 patients experienced cardiac complications during the noncardiac surgery. Cardiac complications were more common in patients older than 60 years. Little information can be gleaned from this small retrospective study except to note the low incidence of cardiac death in patients who had coronary angioplasty sometime before their noncardiac surgery.

Given these limited data, the role of prophylactic preoperative coronary angioplasty in reducing untoward perioperative cardiac complications remains incompletely defined. Until further data are available, the indications for PTCA in the perioperative setting are identical to those developed by the joint ACC/AHA Task Force providing guidelines for the use of PTCA in general.[182]

For patients who have undergone successful coronary angioplasty just before proposed noncardiac surgery, there is uncertainty regarding how much time should pass before the noncardiac procedure is performed. Delaying noncardiac surgery for more than 1 to 2 months would lead to a greater chance of coronary restenosis at the angioplasty site and thus theoretically increase the chances of perioperative ischemia or MI. At the other extreme, arterial recoil and/or acute thrombosis at the site of PTCA is most likely to occur within hours to 1 to 2 days after coronary angioplasty, and arterial remodeling takes place for several weeks after the procedure. It would theoretically be reasonable to delay elective noncardiac surgery for at least several days to allow for coronary plaque and/or myocardial stabilization. Unfortunately, there have been no prospective studies to determine what the optimal period of delay should be. Similarly, there is little evidence to show how long more distant PTCA (eg, months to years before noncardiac surgery) protects against perioperative MI or death. Since coronary restenosis is unlikely to occur more than 6 months after PTCA, it is reasonable to expect ongoing protection against untoward perioperative ischemic complications in asymptomatic, active patients who had prior complete

percutaneous coronary revascularization 6 months to 5 years previously.

Medical Therapy

Summary of Evidence

Few randomized trials have examined the impact of medical therapy given just before surgery on reducing cardiac events, and all are single-center trials with relatively small numbers. These few studies have evaluated β-blockers, nitroglycerin, and the calcium channel blocker diltiazem (Table 10).

Table 10. Perioperative Prophylactic Anti-Ischemic Medications and Cardiac Morbidity

Author	Procedure	n	Control	Drug	Ischemia* Control	Ischemia* Drug	MI Control	MI Drug
Nitroglycerin								
Coriat '86	Carotid endarterectomy	45	0.5 µg/kg/min Nitroglycerin	1.0 µg/kg/min Nitroglycerin intraoperatively	14/22	4/23*	0/22	0/23
Dodds '93	Noncardiac	45	Placebo	0.9 µg/kg/min Nitroglycerin intraoperatively	7/22	7/23	1/22	0/23
Calcium channel blockers								
Godet '87	Vascular	30	Placebo	3 µg/kg/min Diltiazem intraoperatively	11/15	6/15	0/15	0/15
β-adrenergic blockers								
Pasternack '87	Abdominal aortic aneurysmorrhaphy	83	Case-control	50 mg PO Metoprolol preoperatively			9/51 (17.6%)	1/32† (3.1%)
Pasternack '89	Vascular	200	Unblinded	50 mg PO Metoprolol preoperatively	0.8+1.6 episodes	1.8+3.2* episodes		
Stone '88	Noncardiac Mild hypertension	128	Placebo	Labetalol Atenolol Olprenolol PO Preoperatively	11/39 (28%)	2/89* (2%)	0/39	0/89

MI indicates myocardial infarction.
*Myocardial ischemia.
†P<.05 for drug versus control.

Three limited studies have examined the use of perioperative β-blockers. Stone et al[55] gave oral β-blockers 2 hours before surgery to a randomized group of patients with mild hypertension who had predominantly (58%) vascular surgery. Control subjects had a higher frequency (28%) of ST-segment depression than treated patients (2%). In a nonrandomized study, Pasternack[186] gave oral metoprolol immediately before surgery and followed with intravenous drug during abdominal aortic aneurysm repair. Only 3% suffered an acute MI, compared with 18% for matched controls. In a later report the same author reported less intraoperative ischemia in patients treated with oral metoprolol before peripheral vascular surgery.[58]

There has been only one study examining the role of calcium channel blockers in this situation. The study was too small to allow definitive conclusions (Table 10).

The use of nitrates is discussed in the section on intraoperative management.

Recommendations

There are very few randomized trials of medical therapy before noncardiac surgery to prevent perioperative cardiac complications, and they do not provide enough data from which to draw firm conclusions or recommendations. Preliminary studies, however, suggest that appropriately administered β-blockers reduce perioperative ischemia and may ultimately be shown to reduce risk of MI and death. Clearly, this is an area where further research would be valuable.

Perioperative Therapy With β-Blockers

Class I. β-blockers required in the recent past to control symptoms of angina or patients with

symptomatic arrhythmias or hypertension.
Class II. Preoperative assessment identifies untreated hypertension, known coronary disease, or major factors for coronary disease.
Class III. Contraindication to β-blockade.

Valve Surgery

There is little information about the appropriateness of valvular repair or replacement before a noncardiac surgical procedure is undertaken. Clinical experience indicates that patients with valvular heart disease severe enough to warrant surgical treatment should have valve surgery before elective noncardiac surgery. Recently it has been suggested that patients with severe mitral or aortic stenosis who require urgent noncardiac surgery, such as intestinal resection for lesions causing serious gastrointestinal bleeding, may benefit from catheter balloon valvuloplasty at least as a temporizing step to reduce the operative risk of noncardiac surgery.[187,188] Unfortunately, there are no controlled studies, and the risks of balloon aortic valvuloplasty in older patients are significant.[187]

Experience with managing valvular heart disease during labor and delivery provides insights into the approach to management of the patient for noncardiac surgery. The vast majority of women with regurgitant valvular heart disease can be managed medically during the course of pregnancy, including labor and delivery, because the decrease in peripheral vascular resistance that occurs with pregnancy tends to decrease regurgitant lesions.[189] Increased arterial impedance is not well tolerated in patients with aortic and mitral regurgitation. Therefore, increases in blood pressure should be prevented, and left ventricular afterload should be optimized with vasodilators. In contrast, patients with significant aortic or mitral stenosis often do not do well with the increased hemodynamic burden of pregnancy. If the stenosis is severe, percutaneous catheter balloon valvotomy should be considered as definitive therapy or as a bridge to carry the patient through pregnancy, labor, and surgical delivery. Excessive changes in intravascular volume should be avoided (see also section III, “Valvular Heart Disease”).

Arrhythmia/Conduction/Device

In the perioperative setting, cardiac arrhythmias or conduction disturbances often reflect the presence of underlying cardiopulmonary disease, drug toxicity, or metabolic derangements. In patients with documented hemodynamically significant and/or symptomatic arrhythmias, ambulatory ECG monitoring or specialized electrophysiological studies of the heart with guided drug therapy may be indicated to reduce recurrences of arrhythmias.[190,191] Supraventricular arrhythmias may require either electrical or pharmacological cardioversion if they produce symptoms or hemodynamic compromise. If cardioversion is not possible, satisfactory heart rate control should be accomplished with oral or intravenous digitalis, β-adrenergic blockers, or calcium channel blockers. In patients with atrial fibrillation who are on oral anticoagulation therapy, it may be necessary to discontinue the anticoagulant several days before surgery. If time does not allow and it is important that the patient not be on anticoagulants, the effect of warfarin can be reversed by parenteral vitamin K or fresh frozen plasma.[66] Ventricular arrhythmias, whether simple premature ventricular contractions, complex ventricular ectopy, or nonsustained ventricular tachycardia, usually do not require therapy except in the presence of ongoing or threatened myocardial ischemia or moderate to severe left ventricular dysfunction in which such arrhythmias represent a significant risk factor. Sustained or symptomatic ventricular tachycardia should be suppressed preoperatively with intravenous lidocaine or procainamide. The indications for temporary pacemakers are almost identical to those previously stated for long-term permanent cardiac pacing.[192] Patients with intraventricular conduction delays, bifascicular block (right bundle branch block with left anterior or posterior hemiblock), or left bundle branch block with or without first degree atrioventricular block do not require temporary pacemaker implantation in the absence of a history of syncope or more advanced atrioventricular block.[71] Permanent pacemakers may need to be checked for end-of-life indicators and programmed to verify normal function and the patient's level of pacemaker dependency. In patients who are totally pacemaker dependent, electrocautery poses a special problem and should be used only briefly, with the indifferent pole placed as far away from the pacemaker and heart as possible. In

pacemaker-dependent patients, use of bipolar pacing will minimize the risk of use of electrocautery. Also, converting the pacemaker to an uninhibited mode such as AOO, VOO, or DOO with programming or a magnet prevents unwanted inhibition of pacing. Implanted defibrillators or antitachycardia devices should be programmed *Off* immediately before surgery and then *On* again postoperatively to prevent unwanted discharge due to spurious signals that the device might interpret as ventricular tachycardia or fibrillation.

Preoperative Intensive Care

General Considerations

Preoperative invasive monitoring in an intensive care setting can be used to optimize and even augment oxygen delivery in patients at high risk. It has been proposed that indexes derived from the pulmonary artery catheter and invasive blood pressure monitoring can be used to maximize oxygen delivery, which will lead to a reduction in organ dysfunction.

Summary of Evidence

Only one study has prospectively evaluated the efficacy of preoperative pulmonary artery catheter utilization and optimization of hemodynamics in a randomized trial with cardiac complications as a major outcome. Eighty-nine patients undergoing infrainguinal arterial bypass procedures were randomly assigned to groups that received a pulmonary artery catheter and (1) preoperative optimization overnight in the intensive care unit, (2) for 3 hours preoperatively by the anesthesia care team, or (3) intraoperative monitoring based solely on clinical indications.[193] When MI or nonarrhythmogenic cardiac death was used as the outcome, no significant differences were demonstrated.

Recommendations

Based on the scant evidence, preoperative preparation in an intensive care unit may benefit certain high-risk patients, particularly those with decompensated CHF. Preparation of such patients should occur under close supervision.

Venothromboembolism/Peripheral Arterial Disease

Two peripheral vascular disorders that merit attention preoperatively are venous thromboembolism and, in the elderly, chronic occlusive peripheral arterial disease.

Prophylactic measures need to be planned and in some cases started preoperatively for persons with clinical circumstances associated with postoperative venous thromboembolism. These correlates of thromboembolic risk include advanced age, prolonged immobility, or paralysis; prior venous thromboembolism; malignancy; major surgery (particularly operations involving the abdomen, pelvis, or lower extremities); obesity; varicose veins; CHF; MI; stroke; fractures of the pelvis, hip or leg; congenital or acquired aberrations in hemostatic mechanisms (hypercoagulable states), and, possibly, high-dose estrogen use as determined by the recent consensus conference of the American College of Chest Physicians.[194] The choice of prophylactic measure or agent—graded compression elastic stockings, low-dose subcutaneous heparin, low molecular weight heparin, low-dose warfarin, or intermittent pneumatic compression—will depend on the risk of venous thromboembolism and the type of surgery planned. Table 11 provides recently published recommendations for various types of surgical procedures.[194-196]

TABLE 11. General Guidelines for Perioperative Prophylaxis for Venous Thromboembolism*

Type of Patient/Surgery	Recommendation
Minor surgery in a patient <40 years old with no correlates of venous thromboembolism risk†	Early ambulation.

Moderate-risk surgery in a patient >40 years old with no correlates of thromboembolism risk	ES; LDH (2 h preoperatively and every 12 h after), or IPC (intraoperatively and postoperatively).
Major surgery in a patient >40 years old with clinical conditions associated with venous thromboembolism risk	LDH (every 8 h) or LMWH. IPC if prone to wound bleeding.
Very high-risk surgery in a patient with multiple clinical conditions associated with thromboembolism risk	LDH, LMWH, or dextran combined with IPC. In selected patients, perioperative warfarin (INR 2.0- 3.0) may be used.
Total hip replacement	LMWH (postoperative, subcutaneous twice daily, fixed dose unmonitored) or warfarin (INR 2.0-3.0, started preoperatively or immediately after surgery) or adjusted dose unfractionated heparin (started preoperatively). ES or IPC may provide additional efficacy.
Total knee replacement	LMWH (postoperative, subcutaneous, twice daily, fixed dose unmonitored) or IPC.
Hip fracture surgery	LMWH (preoperative, subcutaneous, fixed dose unmonitored) or warfarin (INR 2.0-3.0). IPC may provide additional benefit.
Intracranial neurosurgery	IPC with or without ES. Consider addition of LDH in high-risk patients.
Acute spinal cord injury with lower-extremity paralysis	Adjusted dose heparin or LMWH for prophylaxis. Warfarin may also be effective. LDH, ES, and IPC may have benefit when used together.
Patients with multiple trauma	IPC, warfarin, or LMWH when feasible, serial surveillance with duplex ultrasonography may be useful. In selected very high-risk patients, consider prophylactic caval filter.

ES indicates graded compression elastic stockings; LDH, low-dose subcutaneous heparin; IPC, intermittent pneumatic compression; LMWH, low molecular weight heparin.
*Developed from Clagett et al.
†Clinical conditions associated with increased risk of venous thromboembolism: advanced age; prolonged immobility or paralysis; previous venous thromboembolism; malignancy; major surgery of abdomen, pelvis, or lower extremity; obesity; varicose veins; congestive heart failure; myocardial infarction; stroke; fracture(s) of the pelvis, hip or leg; hypercoagulable states; and possibly high-dose estrogen use.

The noninvasive techniques—impedance plethysmography and real-time compression ultrasonography—are effective objective tests to exclude clinically suspected deep venous thrombosis and are best used for this purpose.[197,198] Routine screening of all postoperative patients with a noninvasive technique is not as cost-effective or efficient as appropriate antithrombotic prophylaxis for moderate- and high-risk patients.[195-199]

The prevalence of chronic occlusive peripheral arterial disease rises with increasing age, affecting more than 10% of the general population older than 65 years[200] and as many as half of persons with CAD.[201] Protection of the limbs from trauma during and after surgery is as important for those with asymptomatic arterial disease as for those with claudication.

VIII. Anesthetic Considerations and Intraoperative Management

The pathophysiological events that occur with the trauma of surgery and the perioperative administration of anesthetic and pain-relieving drugs often affect the physiology of cardiac function and dysfunction to great degrees. Specific integration of these changes with the consultative evaluation is a field unto itself and beyond the scope of these guidelines. The information provided by the cardiovascular consultant needs to be integrated by the anesthesiologist, surgeon, and postoperative caregivers in preparing an individualized perioperative management plan.

There are many different approaches to the details of the anesthetic care of the cardiac patient. Each has implications regarding anesthetic and intraoperative monitoring. In addition, no study has clearly demonstrated a change in outcome from the use of the following techniques: a pulmonary artery catheter, ST-segment monitor, transesophageal echocardiography (TEE), or intravenous nitroglycerin. Therefore, the choice of anesthetic and intraoperative monitors is best left to the discretion of the anesthesia care team. Intraoperative management may be influenced by the perioperative plan, including need for postoperative monitors, ventilation, and postoperative analgesia. Therefore, a discussion of these issues before the planned surgery will allow for a smooth transition through the perioperative period.

Choice of Anesthetic Technique and Agent

Multiple studies have examined the influence of anesthetic drugs and techniques on cardiac morbidity. In

large-scale studies of unselected patients, coexisting disease and surgical procedure are the most important determinants of outcome.[202] It appears there is no one best myocardial protective anesthetic technique.[203-207] All anesthetic techniques and drugs are associated with known effects that should be considered in the perioperative plan. Opioid-based anesthetics have become popular because of the cardiovascular stability associated with their use. The use of high doses, however, is associated with the need for postoperative ventilation. Since weaning from the ventilator in an intensive care setting has been associated with myocardial ischemia, this feature is important in the overall risk-benefit equation.

All inhalational agents have cardiovascular effects, including depression of myocardial contractility and afterload reduction, their similarities being greater than their differences. The choice of agent among the three most common agents—halothane, enflurane, and isoflurane—did not influence outcome in randomized trials.[206] The cardiovascular safety of the newer agents, desflurane and sevoflurane, is not as well established.

Neuraxial anesthetic techniques include spinal and epidural approaches. Both techniques can result in sympathetic blockade, resulting in decreases in both preload and afterload. The decision to use neuraxial anesthesia for the high-risk cardiac patient may be influenced by the dermatomal level of the surgical procedure. Infrainguinal procedures can be performed under spinal or epidural anesthesia with minimal hemodynamic changes if neuraxial blockade is limited to those dermatomes. Abdominal procedures can also be performed using neuraxial techniques; however, high dermatomal levels of anesthesia may be required and may be associated with significant hemodynamic effects. High dermatomal levels can potentially result in hypotension and reflex tachycardia if preload becomes compromised or blockade of the cardioaccelerators occurs.

Monitored anesthesia care by an anesthesia caregiver includes the use of local anesthesia supplemented with intravenous sedation/analgesia and is believed by some to be associated with the greatest marginal safety. In a large-scale study, however, monitored anesthesia care was associated with the highest incidence of 30-day mortality.[202] This finding may reflect a strong selection bias in which the patients with significant coexisting disease were selected for surgery with monitored anesthesia care rather than other anesthetic techniques. Although this technique can eliminate some of the undesirable effects of general or neuraxial anesthesia, it provides poor blockade of the stress response unless the local anesthetic provides profound anesthesia of the affected area. If the local anesthetic block is less than satisfactory or cannot be used at all, monitored anesthesia care could result in an increased incidence of myocardial ischemia and cardiac dysfunction compared with general or regional anesthesia. To achieve the desired effect, excess sedation can occur. Therefore, there may be no significant difference in overall safety with monitored anesthesia care, and general or regional anesthesia may be preferable.

Perioperative Pain Management

From the cardiac perspective, pain management may be a crucial aspect of perioperative care. Because the majority of cardiac events in noncardiac surgical patients occur postoperatively, the postoperative period may be the time during which ablation of stress, adverse hemodynamics, and hypercoagulable responses is most critical. Although no randomized, controlled study specifically addressing analgesic regimens has demonstrated improvement in outcome, patient-controlled analgesia techniques are associated with greater patient satisfaction and lower pain scores. Epidural or spinal opiates are becoming more popular and have several theoretic advantages. Several studies have evaluated general anesthesia/intravenous analgesia compared with epidural or epidural combined with general anesthesia/epidural analgesia. The patients having epidural anesthesia/analgesia have demonstrated lower opiate dosages, better ablation of the catecholamine response, and a less hypercoagulable state. In one study of patients undergoing lower extremity vascular bypass procedures, the use of epidural anesthesia/analgesia was associated with a lower incidence of cardiac morbidity; however, this finding was not confirmed in another study.[205,207] Most important, an effective analgesic (ie, one that blunts the stress response) regimen must be included in the perioperative plan.

Intraoperative Nitroglycerin

General Considerations

Nitroglycerin has been shown to reverse myocardial ischemia intraoperatively. Intraoperative prophylactic use of nitroglycerin in patients at high risk may have no effects, however, or may actually lead to cardiovascular decompensation through decreases in preload. Additionally, nitroglycerin paste or patch may have uneven absorption intraoperatively. Accordingly nitroglycerin should usually be administered in the intravenous formulation, if required.

The venodilating and arterial dilating effects of nitroglycerin are mimicked by some anesthetic agents, so that the combination of agents may lead to significant hypotension and myocardial ischemia. Therefore, nitroglycerin should be used only when the hemodynamic effects of other agents being used are considered.

Summary of Evidence

Four controlled studies have evaluated the value of prophylactic nitroglycerin infusions for high-risk patients, including two studies in noncardiac surgery patients (Table 11).[183,184,208,209] Only one study, performed in patients with stable angina undergoing carotid endarterectomy, demonstrated a reduced incidence of intraoperative myocardial ischemia in the group receiving 1.0 µg/kg per minute of nitroglycerin. Neither of the two small studies demonstrated any reduction in the incidence of MI or cardiac death.

Recommendations for Intraoperative Nitroglycerin

Class I. High-risk patients previously on nitroglycerin who have active signs of myocardial ischemia without hypotension.
Class II. As a prophylactic agent for high-risk patients to prevent myocardial ischemia and cardiac morbidity, particularly in those who have required nitrate therapy to control angina. The recommendation for prophylactic use of nitroglycerin must take into account the anesthetic plan and patient hemodynamics and must recognize that vasodilation and hypovolemia can readily occur during anesthesia and surgery.
Class III. Patients with signs of hypovolemia or hypotension.

Use of Transesophageal Echocardiography

General Considerations

The use of TEE has become increasingly common in the operating room for cardiac surgery but is less frequently used in noncardiac surgery. Multiple investigations have documented the improved sensitivity and specificity of TEE for detection of myocardial ischemia, compared with electrocardiography or pulmonary capillary wedge pressure measurements. Most studies have used off-line analysis of the TEE images, however, and automated, on-line detection may increase its value.

Summary of Evidence

There are few data regarding the value of TEE-detected wall motion abnormalities to predict cardiac morbidity in noncardiac surgical patients. In two recent studies from the same group, intraoperative wall motion abnormalities were poor predictors of cardiac morbidity.[210,211] In one study involving 332 men undergoing noncardiac surgeries, TEE demonstrated an odds ratio of 2.6 (95% CI, 1.2 to 5.7) for predicting perioperative cardiac events.[210]

Analysis and Interpretation

Interpretation of TEE requires additional training. At present there are no commercially available real-time monitors of quantitative wall motion. Although regional wall motion abnormalities in a high-risk patient suggest myocardial ischemia, resolution of myocardial ischemia may not result in improvement of wall motion.

Recommendations

Currently there is insufficient evidence to determine the cost-effectiveness of TEE for its use as a diagnostic monitor or to guide therapy during noncardiac surgery. Guidelines for the appropriate use of TEE are being developed by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists.

Intra-aortic Balloon Counterpulsation Device

Placement of an intra-aortic balloon counterpulsation device has been suggested as a means of reducing perioperative cardiac risk in noncardiac surgery. Several case reports, comprising a total of 21 patients, have documented its use in patients with unstable coronary syndromes or severe CAD undergoing urgent noncardiac surgery.[212,213] Although cardiac complications did not occur while the device was in place, they did occur during the perioperative period after its removal. Its use is also limited for technical reasons in the group at highest risk, ie, vascular surgery.

Recommendations

There is currently insufficient evidence to determine the value of prophylactic placement of an intra-aortic balloon counterpulsation device for high-risk noncardiac surgery.

IX. Perioperative Surveillance

Although much attention has been focused on the preoperative preparation of the high-risk patient, intraoperative and postoperative surveillance for myocardial ischemia and infarction, arrhythmias, and venous thrombosis should also lead to reductions in morbidity. Postoperative myocardial ischemia has been shown to be the strongest predictor of perioperative cardiac morbidity and is rarely accompanied by pain.[1] Therefore, it may go untreated until overt symptoms of cardiac failure develop.

The diagnosis of a perioperative MI has both short- and long-term prognostic value. Traditionally, a perioperative MI has been associated with a 30% to 50% perioperative mortality and has recently been associated with reduced long-term survival.[19,29,214,215] Therefore, it is important to identify patients who sustain a perioperative MI and to treat them aggressively since it may reduce both short- and long-term risk.

Intraoperative and Postoperative Use of Pulmonary Artery Catheters

General Considerations

The pulmonary artery catheter can provide significant information critical to the care of the cardiac patient. Its use, however, must be balanced against the cost and risk of complications from insertion and use of the catheter, which are low when the operators are experienced. Several studies have evaluated the benefit of pulmonary artery catheters in both randomized trials and those using historical controls. In patients with a prior MI, when perioperative care included pulmonary artery and intensive care monitoring for 3 days postoperatively, there was a lower incidence of reinfarction than in historical controls.[29] Other changes in management occurred during the period under study, however, including the increased use of β-adrenergic sympathetic blockade. In particular, patients with signs and symptoms of heart failure preoperatively, who have a very high (35%) postoperative incidence of heart failure, might benefit from invasive hemodynamic monitoring.[67]

Summary of Evidence

Although a great deal of literature has evaluated the utility of a pulmonary artery catheter during the perioperative period in noncardiac surgery, only six controlled studies evaluated pulmonary artery catheterization in relation to clinical outcomes. Three recent randomized trials have evaluated the routine use of pulmonary artery catheters versus central venous pressure catheters or selective use of monitoring. In studies using appropriate patient selection, no differences in cardiac morbidity (MI, cardiac death) were detected.[216,217] An additional study demonstrated no difference in cardiac morbidity in infrainguinal surgery patients when monitored by a pulmonary artery catheter either from the evening before surgery, 3 hours before surgery, or only if clinically indicated; however, the groups with the pulmonary artery catheter had fewer intraoperative hemodynamic disorders.[193]

Recommendations

Practice parameters for the intraoperative use of a pulmonary artery catheter have recently been published by the American Society of Anesthesiologists.[218] These parameters approach the decision to place the pulmonary artery catheter as the interrelationship between three variables: patient disease, surgical procedure, and practice setting. With regard to the surgical procedure, the extent of intraoperative and postoperative fluid shifts is a dominant factor.

Intraoperative Use of Pulmonary Artery Catheters[218]

Class I. Patients at risk for major hemodynamic disturbances that are most easily detected by a pulmonary artery catheter who are undergoing a procedure that is likely to cause these hemodynamic changes in a setting with experience in interpreting the results (eg, suprarenal aortic aneurysm repair in a patient with angina).
Class II. Either the patient's condition or the surgical procedure (but not both) places the patient at risk for hemodynamic disturbances (eg, total hip replacement in a patient with chronic renal insufficiency).
Class III. No risk of hemodynamic disturbances.

Intraoperative and Postoperative Use of ST-Segment Monitoring

General Considerations

Some contemporary operating rooms and intensive care unit monitors incorporate algorithms that perform real-time analysis of the ST segment. In addition, real-time ST-segment monitoring via telemetry or ambulatory ECG (Holter) monitors with alarms is being developed. Numerous studies have demonstrated the poor ability of physicians to detect significant ST-segment changes compared with computerized or off-line analysis. If available, computerized ST-segment trending is superior to visual interpretation. Although proprietary, many of these algorithms have been validated for their ability to accurately detect ST-segment shifts.

Summary of Evidence

Virtually all studies examining the predictive value of intraoperative and postoperative ST-segment changes have been performed using ambulatory ECG recorders. Using retrospective analysis, investigators have found postoperative ST-segment changes indicative of myocardial ischemia to be the strongest independent predictor of perioperative cardiac events in high-risk noncardiac surgery patients in multiple studies, with changes of prolonged duration being particularly associated with increased risk.[19,219,220] Additionally, postoperative ST-segment changes have been shown to predict worse long-term survival in high-risk patients.[214]

Intraoperative ST-segment changes may also occur in low risk populations. ST-segment depression has been shown to occur during elective Cesarean sections in healthy patients.[221] Because these changes

were not associated with regional wall motion abnormalities on precordial echocardiography, in this low-risk population such ST-segment changes may not be indicative of myocardial ischemia and CAD.

Recommendations

Proper use of computerized ST-segment analysis in appropriate high-risk patients may provide increased sensitivity to detect myocardial ischemia during the perioperative period and may identify patients who might benefit from further postoperative and long-term interventions. Therefore, computerized monitoring of the ST segment can provide useful information in appropriate high-risk patients, if available. The cost-effectiveness of computerized ST-segment analysis for reducing perioperative morbidity, however, has not been documented. Further research is required.

Surveillance for Perioperative Myocardial Infarction

Multiple studies have evaluated predictive factors for a perioperative MI. The presence of clinical evidence of coronary artery or peripheral vascular disease has been associated with an increased incidence of perioperative MI. Factors that increase the risk of a perioperative MI have been discussed previously. Because of the increased risk of both short- and long-term mortality from a perioperative MI, accurate diagnosis is important.

General Considerations

Perioperative MI can be documented by serial electrocardiography, cardiac-specific enzyme analyses, comparative ventriculographic studies before and after surgery, and radioisotopic studies specific for myocardial necrosis. Published ECG reporting criteria for MI vary, however, with some authors requiring Minnesota code criteria, others simply reporting new Q waves, and others not specifying the ECG criteria. Nonspecific ST and T wave changes are common in the immediate postoperative period but have not been associated with increased morbidity.[222] In the analysis of cardiac enzyme criteria, numerous techniques are available to measure CK-MB, and the threshold at which an enzyme rise is considered abnormal is variable. In addition, CK-MB has been shown to be released from noncardiac sources in patients with ischemic limbs or undergoing aortic surgery, the group at highest risk for a perioperative MI. Finally, new myocardial-specific enzymes that are currently being developed and evaluated in the perioperative patient, such as cardiac troponin-I or troponin-T or CK-MB isoforms, require further study before determining their usefulness in this setting.[223]

Summary of Evidence

Very few studies have examined the optimal protocol for diagnosing a perioperative MI. Charlson et al[224] reported on 232 mostly hypertensive or diabetic patients undergoing elective noncardiac surgery. Serial ECGs and creatine kinase isoenzymes (CK-MB) were collected for 6 days postoperatively. The incidence of perioperative MI varied greatly, depending on the diagnostic criteria used. A strategy using an ECG immediately after the surgical procedure and on the first and second days postoperatively had the highest sensitivity. Strategies including the serial measurement of CK-MB had higher false-positive rates without higher sensitivities. In contrast, Rettke[225] reported that overall survival was associated with the degree of CK-MB elevation in 348 patients undergoing abdominal aortic aneurysm repair, with higher levels associated with worse survival. Yeager et al[215] evaluated the prognostic implications of a perioperative MI in a series of 1561 major vascular procedures. These authors found that the incidence of subsequent MI and coronary artery revascularization was significantly higher in patients who suffered a perioperative MI, except in the subset who only demonstrated an elevated CK-MB without ECG changes or cardiovascular symptoms.

Recommendations

Further evaluation regarding the optimal strategy for surveillance and diagnosis of perioperative MI is

required before one method is advocated. In patients without evidence of CAD, surveillance should be restricted to patients who develop perioperative signs of cardiovascular dysfunction. In patients with known or suspected CAD undergoing surgical procedures associated with a high incidence of cardiovascular morbidity, ECGs at baseline, immediately after the surgical procedure, and daily on the first 2 days postoperatively appears to be the most cost-effective strategy. Measurements of cardiac enzymes are best reserved for patients at high risk or those who demonstrate ECG or hemodynamic evidence of cardiovascular dysfunction.

Arrhythmia/Conduction Disease

Postoperative arrhythmias are often due to remedial noncardiac problems such as infection, hypotension, metabolic derangements, and hypoxia. Cardioversion of supraventricular arrhythmias is generally not recommended until correction of the underlying problems has occurred, which frequently leads to a return to normal sinus rhythm. Also, cardioversion is unlikely to result in long-term normal sinus rhythm if the underlying problem is not corrected. The avoidance of an electrolyte abnormality, especially hypokalemia and hypomagnesemia, may reduce the perioperative incidence and risk of arrhythmias, although acute preoperative repletion of potassium in an asymptomatic individual may be associated with greater risk than benefits.[226-228] Bradyarrhythmias occurring in the postoperative period are usually secondary to some other cause, such as an electrolyte disturbance, hypoxemia, or ischemia. On an acute basis, many will respond to intravenous medication such as atropine, and some will respond to intravenous aminophylline. Those bradyarrhythmias due to sinus node dysfunction and advanced conduction abnormalities such as complete heart block will respond to temporary or permanent transvenous pacing or permanent pacing with indications the same as those for elective pacemaker implantations.

Supraventricular arrhythmias may respond to digitalis, calcium channel blockers, or β-blockers with slowing of heart rate and cardioversion. Unifocal or multifocal premature ventricular contractions do not merit vigorous therapy. Complex ventricular ectopy such as nonsustained or sustained ventricular tachycardia requires more vigorous therapy, especially in the presence of ongoing or threatened myocardial ischemia, left ventricular dysfunction, or valvular heart disease. Ventricular arrhythmias may respond to intravenous β-blockers, lidocaine, procainamide, or amiodarone.[186] Electrical cardioversion should be used for supraventricular or ventricular arrhythmias causing hemodynamic compromise.

X. Postoperative Therapy/Future Management

Whenever feasible, postoperative management should include the assessment and management of any risk factors for CAD, heart failure, hypertension, stroke, or other cardiovascular disease that may have been identified in the preoperative period. Such factors include hypercholesterolemia, smoking, labile or sustained systemic arterial hypertension, borderline hyperglycemia or diabetes mellitus, obesity, physical inactivity, excess alcohol consumption, carotid bruit, peripheral vascular disease, heart murmurs, abnormal ECG, cardiac arrhythmia or conduction abnormality, perioperative ischemia, postoperative MI, abnormal pulmonary function tests, or a positive family history of premature cardiovascular disease. Appropriate plans should be made for the postoperative evaluation of any of these findings and the institution of appropriate diagnostic tests and management plans. In particular, patients who sustain a perioperative MI or develop evidence of myocardial ischemia should be carefully evaluated. These patients have a substantial risk of MI and/or cardiac death over the subsequent 5 to 10 years. Accordingly, these patients should be carefully evaluated by noninvasive testing to determine left ventricular function and whether or not they have evidence of myocardial ischemia on exertion or during pharmacological stress.[26] Some patients may benefit from coronary revascularization by CABG or PTCA.

Most patients who have documented arteriosclerosis will benefit from pharmacological agents to lower low density lipoprotein (LDL) cholesterol levels, increase high density lipoprotein (HDL) levels, or both. The goal should be to lower the LDL level to less than 100 mg/dL (2.6 mmol/dL).[229]

In general, the indications for additional screening or testing are dependent on individual patient characteristics. It is important that the physician(s) responsible for the long-term care of the patient be sent full information about any cardiovascular abnormalities or risk factors for CAD identified during the perioperative period.

XI. Conclusions

Successful perioperative evaluation and management of high-risk cardiac patients undergoing noncardiac surgery requires careful teamwork and communication between surgeon, anesthesiologist, the patient's primary care physician, and the consultant. In general, indications for further cardiac testing and treatments are the same as in the nonoperative setting, but their timing is dependent on several factors, including the urgency of noncardiac surgery, patient-specific risk factors, and surgery-specific considerations. The use of both noninvasive and invasive preoperative testing should be limited to those circumstances in which the results of such tests will clearly affect patient management. Finally, for many patients, noncardiac surgery represents their first chance to receive an appropriate assessment of both short- and long-term cardiac risk. Thus, the consultant best serves the patient by making recommendations aimed at lowering the immediate perioperative cardiac risk as well as assessing the need for subsequent postoperative risk stratification and interventions directed to modify coronary risk factors.

XII. Cardiac Risk of Noncardiac Surgery: Areas in Need of Further Research

- Role of prophylactic revascularization in reducing perioperative and long-term MI and death and its cost-effectiveness

- Cost-effectiveness of the various methods of noninvasive testing for reducing cardiac complications

- Establishment of efficacy and cost-effectiveness of various medical therapies for high-risk patients

- Establishment of optimal guidelines for selected patient subgroups, particularly the elderly and women

- Establishment of the efficacy of monitoring patients for myocardial ischemia and infarction, particularly the role of monitoring in affecting treatment decisions and outcomes.

Appendix 1

Methods

These guidelines are based on a Medline search of the English literature from 1975 through 1994, review of selected journals from 1995, and the expert opinions of 12 committee members representing various disciplines of cardiovascular care, including general cardiology, noninvasive testing, vascular medicine, vascular surgery, anesthesiology, and arrhythmia management. In addition, draft guidelines were submitted for critical review and amendment to physicians representing internal medicine, family practice, nuclear cardiology, general surgery, and anesthesiology as well as executive officers representing the American College of Cardiology and the American Heart Association. The final document represents the eighth iteration over 18 months, which included six drafts in committee and two additional drafts to incorporate key findings from external review.

A large proportion of the data used to develop these guidelines is based on observational or retrospective studies or knowledge of management of cardiovascular disorders in the nonoperative setting. While the collective knowledge surrounding the identification of high- and low-risk patients using perioperative clinical and noninvasive evaluation is substantial, very few prospective or randomized studies have been performed that establish the value of tests or treatments on perioperative outcomes. Therefore, data are presented in a tabular format, and whenever possible reflect the value of a test or intervention for similar outcomes of a perioperative MI or cardiac death. Because the studies were rarely randomized controlled

trials, definitions of a perioperative event varied, investigators were rarely blinded, and many inherent selection biases existed, the task force has chosen not to provide an aggregate synthesis of the data in the form of a point estimate or meta-analysis. On the other hand, presentation of the original data provides substantial support for these recommendations.

Appendix 2

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