ACC/AHA PRACTICE GUIDELINES—FULL TEXT

ACC/AHA Guideline Update on Perioperative Cardiovascular Evaluation for Noncardiac Surgery

A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery)

COMMITTEE MEMBERS

Kim A. Eagle, MD, FACC, *Chair*

Peter B. Berger, MD, FACC
Hugh Calkins, MD, FACC
Bernard R. Chaitman, MD, FACC
Gordon A. Ewy, MD, FACC
Kirsten E. Fleischmann, MD, MPH, FACC
Lee A. Fleisher, MD, FACC

James B. Froehlich, MD, FACC
Richard J. Gusberg, MD, FACS
Jeffrey A. Leppo, MD, FACC
Thomas Ryan, MD, FACC
Robert C. Schlant, MD, FACC
William L. Winters, Jr, MD, MACC

TASK FORCE MEMBERS

Raymond J. Gibbons, MD, FACC, *Chair*
Elliott M. Antman, MD, FACC, *Vice Chair*

Joseph S. Alpert, MD, FACC
David P. Faxon, MD, FACC
Valentin Fuster, MD, PhD, FACC
Gabriel Gregoratos, MD, FACC

Alice K. Jacobs, MD, FACC
Loren F. Hiratzka, MD, FACC
Richard O. Russell, MD, FACC*
Sidney C. Smith, Jr, MD, FACC

TABLE OF CONTENTS

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, and impact 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 1996 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 Ryan, MD; Robert C. Schlant, MD; William H. Spencer III, MD; John A. Spittell, Jr, MD; and Richard D. Twiss, MD. The document update used the 1996 work as its basis. The Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery was chaired by Kim A. Eagle, MD, and included the following members: Peter B. Berger, MD; Hugh Calkins, MD; Bernard R. Chaitman, MD; Gordon A. Ewy, MD; Kirsten E. Fleischmann, MD; Lee A. Fleisher, MD; James B. Froehlich, MD; Richard J. Gusberg, MD; Jeffrey A. Leppo, MD; Thomas J. Ryan, MD; Robert C. Schlant, MD; William L. Winters, Jr, MD.

The ACC/AHA Task Force on Practice Guidelines makes every effort to avoid any actual or potential conflicts of interest that might arise as a result of an outside relationship or personal interest of a member of the writing panel.

Specifically, all members of the writing panel are asked to provide disclosure statements of all such relationships that might be perceived as real or potential conflicts of interest. These statements are reviewed by the parent task force, reported orally to all members of the writing panel at the first meeting, and updated as changes occur.

This document was reviewed by 2 outside reviewers from the AHA and 2 outside reviewers of the ACC, as well as 1 reviewer of the ACC/AHA Task Force on Practice Guidelines. It was approved by the ACC Board of Trustees and the AHA Science Advisory and Coordinating Committee and is being published simultaneously in the *Journal of the American College of Cardiology* and *Circulation* (February 6, 2002 and March 5, 2002, respectively). The document will be reviewed annually after the date of publication and considered current unless the Task Force publishes another update or full revision or withdraws it from publication.

Raymond J. Gibbons, MD, FACC
Chair, ACC/AHA Task Force on Practice Guidelines

I. DEFINITION OF THE PROBLEM

A. *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 strove to incorporate what is currently known about perioperative risk and how this knowledge can be used in the individual patient.

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 evaluation, management, and risk of cardiac problems over the entire perioperative period; and provide a clinical risk profile that the patient, primary physician, anesthesiologist, and surgeon can use in making treatment decisions that may influence short- and long-term cardiac outcomes. *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 and the optimal care of the patient.

B. *Methodology and Evidence*

The ACC/AHA Committee to Update the 1996 Guidelines on Perioperative Cardiovascular Evaluation for Noncardiac Surgery conducted a comprehensive review of the literature

relevant to perioperative cardiac evaluation since the last publication of these guidelines in 1996. Literature searches were conducted in the following databases: PubMed/MEDLINE, EMBASE, the Cochrane Library (including the Cochrane Database of Systematic Reviews and the Cochrane Controlled Trials Register), and Best Evidence. Searches were limited to the English language, 1995 through 2000, and human subjects. In addition, related-article searches were conducted in MEDLINE to find further relevant articles. Finally, committee members recommended applicable articles outside the scope of the formal searches.

Major search topics included perioperative risk, cardiac risk, noncardiac surgery, noncardiac, intraoperative risk, postoperative risk, risk stratification, cardiac complication, cardiac evaluation, perioperative care, preoperative evaluation, preoperative assessment, and intraoperative complications. Additional searches cross-referenced these topics with the following subtopics: troponin, myocardial infarction, myocardial ischemia, Duke activity status index, functional capacity, dobutamine, adenosine, venous thrombosis, thromboembolism, warfarin, PTCA, adrenergic beta-agonists, echocardiography, anticoagulant, beta-blocker, diabetes mellitus, wound infection, blood sugar control, normothermia, body temperature changes, body temperature regulation, hypertension, pulmonary hypertension, anemia, aspirin, arrhythmia, implantable defibrillator, artificial pacemaker, pulmonary artery catheters, Swan Ganz catheter, and platelet aggregation inhibitors.

As a result of these searches, over 400 relevant, new articles were identified and reviewed by the committee for the update of these guidelines. Using evidence-based methodologies developed by the ACC/AHA Task Force on Practice Guidelines, the committee updated the guidelines text and recommendations. New references are numbered 230-390 and are listed together at the end of the reference list. The ACC/AHA classifications of evidence 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 the procedure/therapy is useful and effective.**

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

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

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

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

C. 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 is performed (390). 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 per year, and nearly a fourth of these—major intra-abdominal, thoracic, vascular, and orthopedic procedures—have been associated with significant perioperative cardiovascular morbidity and mortality.

D. 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 or obtained. This is facilitated by communication between anesthesia personnel and physicians responsible for the patient's cardiovascular care.

E. 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. Although 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.

F. 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 whether the patient is in optimal medical condition, given the context of 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 will provide a significant addition to the existing database and will have the potential to affect 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 the nature of the surgical illness. Given an acute surgical emergency, preoperative evaluation might have to be limited to simple and critical tests such as a rapid assessment of cardiovascular vital signs, volume status, hematocrit, electrolytes, renal function, urine analysis, 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 coronary 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 coronary artery disease (CAD) or heart failure (HF) in a patient scheduled for an elective procedure may justify a more extensive workup (4-6).

The consultant must also bear in mind that the perioperative evaluation may be the ideal opportunity to affect 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 impli-

cations for the patient's prognosis. The consultant can also assist in planning for follow-up.

A. 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 myocardial infarction (MI), HF, and symptomatic arrhythmias and also determine whether the patient has a prior history of a pacemaker or implantable cardioverter defibrillator (ICD) or a history of orthostatic intolerance. 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.

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 owing 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). 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 anginal equivalents such as dyspnea or HF may establish or suggest these diagnoses for the first time.

B. Physical Examination

A careful cardiovascular examination should include an assessment of vital signs (including measurement of 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. The presence of an implanted pacemaker or ICD can also be confirmed on physical examination. 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, Cheyne

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

Major
Unstable coronary syndromes
    • Acute or recent MI* with evidence of important ischemic risk by clinical symptoms or noninvasive study
    • Unstable or severe† angina (Canadian class III or IV)‡
Decompensated 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)
Previous MI by history or pathologic Q waves
Compensated or prior heart failure
Diabetes mellitus (particularly insulin-dependent)
Renal insufficiency

Minor
Advanced age
Abnormal ECG (left ventricular hypertrophy, left bundle-branch block, ST-T abnormalities)
Rhythm other than sinus (e.g., atrial fibrillation)
Low functional capacity (e.g., inability to climb one flight of stairs with a bag of groceries)
History of stroke
Uncontrolled systemic hypertension

ECG indicates electrocardiogram; MI, myocardial infarction.
*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); acute MI is within 7 days.
†May include "stable" angina in patients who are unusually sedentary.
‡Campeau L. Grading of angina pectoris. *Circulation*. 1976;54:522-3.

Stokes respiration, poor nutritional status, obesity, skeletal deformities, tremor, and anxiety are just a few of the clues that can be recognized by the skilled physician.

- In patients with acute HF, pulmonary rales and chest X-ray evidence of pulmonary congestion correlate well with elevated pulmonary venous pressure. However, in patients with chronic HF, 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 HF 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 higher risk for noncardiac surgery (12). Significant mitral stenosis or regurgitation increases the risk of HF. Aortic regurgitation and mitral regurgitation may be minimal, yet they predispose the patient to infective endocarditis should bacteremia occur after 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).

C. 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 discussed below:

1. Pulmonary Disease

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 beta-agonists must be considered.

2. 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 CAD and myocardial ischemia are more likely in patients with diabetes and more likely to be silent (230,231). Older patients with diabetes are more likely to develop HF postoperatively than those without diabetes mellitus even after adjustment for treatment with angiotensin converting enzyme (ACE) inhibitors. 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. Historically, it has been acceptable to maintain relatively high glucose levels perioperatively to avoid the attendant risks of hypoglycemic episodes. However, aggressive perioperative glucose control in coronary bypass surgery patients by a continuous, intravenous insulin infusion was superior to intermittent subcutaneous insulin administration in significantly reducing postoperative wound infection (232). Similar benefit may occur surrounding noncardiac surgery (233).

3. Renal Impairment

Azotemia is commonly associated with cardiac disease and is associated with an increased risk of cardiovascular events. Maintenance of adequate intravascular volume for renal perfusion during diuresis of a patient with HF is often challenging. Excessive diuresis in combination with initiation of ACE inhibitors or angiotensin receptor blockers may result in an increase in blood urea nitrogen and serum creatinine concentrations. In patients with known vascular disease, a small increase in blood urea nitrogen and creatinine may suggest the presence of renal artery stenosis. However, small increases in blood urea nitrogen and serum creatinine concentrations are not an indication to discontinue these drugs, because they have been shown to improve survival in patients with HF due to systolic dysfunction. Preoperative evaluation of the patient on dialysis or after renal transplantation should essentially be the same as that for those patients not afflicted with these conditions. Many are elderly and have heart problems similar to the general population. However, a significant number are diabetic, and such patients are quite predisposed to CHD. They should have adequate dialysis preoperatively to prevent pulmonary edema and the consequence of impaired oxygenation or tendency to bleed due to significant azotemia. With the transplant patient, the major issue is management of immunosuppression in the perioperative period. Pre-existing renal disease (preoperative serum creatinine levels between 1.4 and 2.0 mg per dl or above) has been identified as a risk factor for postoperative renal dysfunction and increased long-term

morbidity and mortality compared with patients without renal disease (234). In coronary artery bypass patients who are more than 70 years old, preoperative creatinine levels greater than 2.6 mg per dl place the patient at much greater risk for chronic dialysis postoperatively than those with creatinine levels below 2.6 mg per dl (235). Intuitively, one might extrapolate these findings to those older patients with comparable creatinine levels who undergo major noncardiac surgical procedures. One large study has shown that a preoperative creatinine level greater than 2.0 mg per dl is a significant, independent risk factor for cardiac complications after major noncardiac surgery (236).

4. Hematologic Disorders

Anemia imposes a stress on the cardiovascular system that may exacerbate myocardial ischemia and aggravate HF (14). Preoperative transfusion, when used appropriately in patients with advanced CAD and/or HF, may reduce perioperative cardiac morbidity. However, with current concern about possible transmission of human immunodeficiency virus and hepatitis through the use of blood products, a conservative approach with respect to transfusion is warranted. Hematocrits less than 28% are associated with an increased incidence of perioperative ischemia and postoperative complications in patients undergoing prostate and vascular surgery (237-239).

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.

D. Ancillary Studies

The consultant should review all pertinent 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 X-ray on the basis of history and physical examination. Blood levels of cardiac drugs should be obtained only when there are specific indications, such as changing renal function, recent change in dose, or symptoms suggesting toxicity.

The ECG is frequently obtained as part of a preoperative evaluation in all patients over a specific age or undergoing a specific set of procedures. In fact, an abnormal ECG report is often the reason that consultation is requested. If not, the ECG is almost always indicated as part of a cardiac consultation. 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 ventricular arrhythmias, even in the presence of structural heart disease (240,241). 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. In an attempt to codify those clinical and laboratory factors that influence outcome, numerous investigators have developed risk indices over the past 25 years based on multivariate analyses (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 (15-21,236). For example, Lee et al derived and validated a "simple index" for the prediction of cardiac risk for stable patients undergoing nonurgent major noncardiac surgery (236). Six independent risk correlates were identified: ischemic heart disease (defined as history of MI, history of positive treadmill test, use of nitroglycerin, current complaints of chest pain thought to be secondary to coronary ischemia, or ECG with abnormal Q waves); congestive HF (defined as history of HF, pulmonary edema, paroxysmal nocturnal dyspnea, peripheral edema, bilateral rales, S_3, or X-ray with pulmonary vascular redistribution); cerebral vascular disease (history of transient ischemic attack or stroke); high-risk surgery (abdominal aortic aneurysm, other vascular, thoracic, abdominal, or orthopedic surgery); preoperative insulin treatment for diabetes mellitus; and preoperative creatinine greater than 2 mg per dl. Increasing numbers of risk factors correlated with increased risk, yet the risk was substantially lower than described in many of the original indices. These improvements in outcome most likely reflect selection bias with respect to who presents for elective surgery and advances in surgical technique and anesthesia and in the management of CAD both perioperatively and in general.

Table 1 lists clinical predictors of increased perioperative risk of MI, HF, and death established by multivariate analyses (12,15-24). In clinical practice, more weight should be given to active conditions than to dormant ones, while the degree of deviation from the norm is used as an implicit modifier. Although the scoring systems may assist some practitioners in defining specific risk categories, there was general consensus among committee members that clinical factors could be placed into the following 3 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.

A history of MI or abnormal Q waves by ECG is listed as an intermediate predictor, whereas an acute MI (defined as at least 1 documented MI less than or equal to 7 days before

Table 2. Estimated Energy Requirements for Various Activities*

1 MET	Can you take care of yourself?	4 METs	Climb a flight of stairs or walk up a hill?
	Eat, dress, or use the toilet?		Walk on level ground at 4 mph or 6.4 km per h?
	Walk indoors around the house?		Run a short distance?
	Walk a block or two on level ground at 2 to 3 mph or 3.2 to 4.8 km per h?		Do heavy work around the house like scrubbing floors or lifting or moving heavy furniture?
4 METs	Do light work around the house like dusting or washing dishes?		Participate in moderate recreational activities like golf, bowling, dancing, doubles tennis, or throwing a baseball or football?
		Greater than 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 (7) and AHA Exercise Standards (27).

the examination) or recent MI (greater than 7 days but less than or equal to 1 month before the examination) with evidence of important ischemic risk by clinical symptoms or noninvasive study is a major predictor. This definition reflects the consensus of the ACC Cardiovascular Database Committee. 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 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 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 (i.e., those violating a visceral cavity and those likely to be accompanied by major bleeding or fluid shifts) place patients at highest risk. Vascular procedures are higher risk 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.

E. Stepwise Approach to Perioperative Cardiac Assessment

Fig. 1 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

Table 3. Cardiac Risk* Stratification for Noncardiac Surgical Procedures

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

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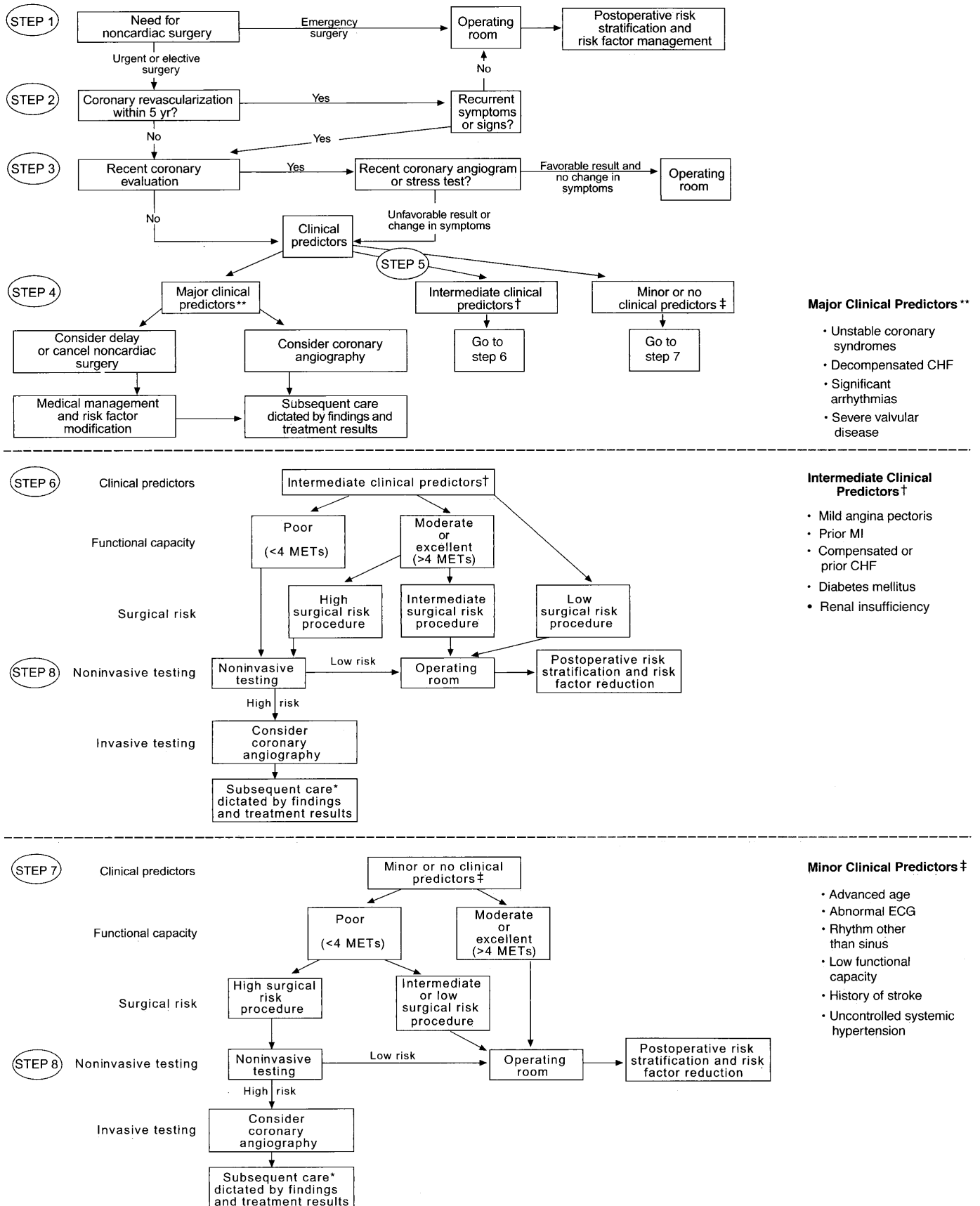†Do not generally require further preoperative cardiac testing.

Figure 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. CHF indicates congestive heart failure; ECG, electrocardiogram; MET, metabolic equivalent; MI, myocardial infarction.

to help define the process. Thus, collected observational data and expert opinion form the basis of the proposed algorithm. However, since publication of the Perioperative Cardiovascular Evaluation Guidelines in 1996 (242), several studies have suggested that this stepwise approach to the assessment of CAD is both efficacious and cost-effective (243-246).

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 (i.e., 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 percutaneous coronary intervention (PCI) from 6 months to 5 years previously, 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 1 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, decompensated HF, hemodynamically significant arrhythmias, 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 previous MI with evidence of important ischemic risk by clinical symptoms or noninvasive study, unstable or severe angina, and new or poorly controlled ischemia-mediated HF. Many patients in these circumstances are referred for coronary angiography to assess further 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 HF, preoperative creatinine greater than 2 mg per dl 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* (Table 3) allows a rational approach to identifying which patients may most benefit from further noninvasive testing.

Functional status has been shown to be reliable for perioperative and long-term prediction of cardiac events (33,34,243,247,248). If the patient has not had a recent exercise test, functional status can usually be estimated from the ability to perform the activities of daily living (247). *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 per kg per minute or 1 MET. For this purpose, functional capacity has been classified as *excellent* (greater than 10 METs), *good* (7 to 10 METs), *moderate* (4 to 7 METs), *poor* (less than 4 METs), or *unknown*. Multiples of the baseline MET value provide a uniform terminology across different exercise protocols to express aerobic demands for specific activities. Maximum and submaximum levels of work differ per unit of time according to the exercise protocol used. Thus, 6 minutes of a Naughton protocol is not equivalent to 6 minutes on a standard Bruce protocol in terms of work performed and energy expended. The predicted MET level for a certain activity is influenced by the degree of conditioning and genetic predisposition. Perioperative cardiac and long-term risks are increased in patients unable to meet a 4-MET demand during most normal daily activities (247). In 1 series of 600 consecutive patients undergoing major noncardiac procedures, perioperative myocardial ischemia and cardiovascular events were more common in patients reporting poor exercise tolerance (inability to walk 4 blocks or climb 2 flights of stairs) even after adjustment for baseline characteristics known to be associated with increased risk (247). The likelihood of a serious complication occurring was inversely related to the number of blocks that could be walked (p=0.006) or flights of stairs that could be climbed (p=0.01). 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). At activity levels less than 4 METs, specific questions to establish risk gradients are less reliable. Furthermore, a clinical questionnaire only *estimates* functional capacity and does not provide as objective a measurement as exercise treadmill testing or arm ergometry. Other activity scales have been advocated, including the Specific Activity Scale (249).

Surgery-Specific Risk (Table 3, Fig. 1). The surgery-specific cardiac risk of noncardiac surgery is related to 2 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 helps 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 surgeries and their surgery-specific risks are given below. *Higher surgery-specific cardiac risk* (e.g., 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 and thorax. *Intermediate-surgical-risk* procedures (combined MI and/or death risk 1% to 5%) include uncomplicated abdominal, head, neck, and thoracic surgery. Urologic and orthopedic surgery would be at the lower end of this risk group. *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. Some require endocarditis prophylaxis.

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 2 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 surgery, anticipated long and complicated thoracic surgery, abdominal surgery, and head and neck surgery) 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 diagnosis and medical management (e.g., use of beta blockers) of the patient with significant cardiac risk 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. At times it is appropriate for the consultant to recommend preventive measures that will decrease the patient's cardiovascular risk for years to come. The overall goal of cardiac assessment should be a consideration of both the impending surgery and 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 in an effort to reduce the risk of noncardiac surgery when they would not otherwise be indicated.*

Step 8 (Fig. 1). 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 to 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 some instances, this approach may be appropriate, however, if it also significantly improves the patient's long-term prognosis.

III. DISEASE-SPECIFIC APPROACHES

A. Coronary Artery Disease

1. Patients With Known CAD

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 obstructions or 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 may present atypically or are functionally limited by severe arthritis or peripheral vascular disease. Such patients may benefit from noninvasive testing (Fig. 1; Table 3) 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, i.e., 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 4). On the other hand, many patients do not require noninvasive testing, particularly if they are not candidates for myocardial revascularization.

2. Patients With Major Risk Factors for CAD

Multiple risk factors have been identified that predispose the patient to the development of CAD and increase periopera-

Table 4. 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† (less than 4 METs or heart rate less than 100 bpm or less than 70% age predicted) manifested by one or more of the following:

- Horizontal or downsloping ST depression greater than 0.1 mV
- ST-segment elevation greater than 0.1 mV in noninfarct lead
- Five or more abnormal leads
- Persistent ischemic response greater than 3 min after exertion
- Typical angina

Intermediate risk

Ischemia induced by moderate-level exercise* (4 to 6 METs or heart rate 100 to 130 bpm [70 to 85% age predicted) manifested by one or more of the following:

- Horizontal or downsloping ST depression greater than 0.1 mV
- Typical angina
- Persistent ischemic response greater than 1 to 3 min after exertion
- Three to four abnormal leads

Low risk

No ischemia or ischemia induced at high-level exercise* (greater than 7 METs or heart rate greater than 130 bpm [greater than 85% age predicted]) manifested by:

- Horizontal or downsloping ST depression greater than 0.1 mV
- Typical angina
- One or 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, the inability to exercise to at least the intermediate-risk level without ischemia should be considered an inadequate test.

ECG indicates electrocardiographically; MET, metabolic equivalent; bpm, beats per minute.
*Based on references 32 and 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 bpm, respectively (32,37-43).

tive 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 CAD and 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. 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 after oophorectomy, are an exception to this rule. Diabetic women have an increased risk, that is equivalent to men of the same age. The

mortality rate after 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.

Vascular disease presents a special problem because of its association 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.

B. Hypertension

Numerous studies (12,15,18,21,51,52) have shown that stage 1 or stage 2 hypertension (systolic blood pressure below 180 mm Hg and diastolic blood pressure below 110 mm Hg) are not independent risks for perioperative cardiovascular complications. However, hypertension is common, and treatment has been shown to be associated with decreased death rates from stroke and CHD in the nonsurgical setting. Unfortunately, all too few patients with hypertension are treated, and fewer yet have their hypertension controlled. Accordingly, the perioperative evaluation is a unique opportunity to identify patients with hypertension and initiate appropriate therapy. 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). Because 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 undergoing 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. 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, whereas hypokalemia in the absence of diuretic therapy raises the possibility of hyperaldosteronism.

If the initial evaluation establishes hypertension as mild or moderate and there are no associated metabolic or cardiovascular abnormalities, there is no evidence that it is beneficial to delay surgery (62). Several investigators have established the value of effective preoperative blood pressure control among patients with established hypertension (56,57,60,63), and antihypertensive medications should be continued during the perioperative period. Particular care should be taken to avoid withdrawal of beta blockers and clonidine because of potential heart rate or blood pressure rebound. In patients unable to take oral medications, parenteral beta blockers and transdermal clonidine may be used. For patients with newly established mild hypertension, institution of therapy may be delayed until after surgery to avoid creation of instability in heart rate or blood pressure.

Stage 3 hypertension (systolic blood pressure greater than or equal to 180 mm Hg and diastolic blood pressure greater than or equal to 110 mm Hg) should be controlled 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. Beta blockers appear to be particularly attractive agents. Several reports have shown that introduction of preoperative beta-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). The preoperative administration of beta-adrenergic blocking drugs has been shown to decrease the incidence of postoperative atrial fibrillation (250), and in patients who have or are at risk for CAD who must undergo noncardiac surgery, treatment with beta blockers during hospitalization can reduce mortality and the incidence of cardiovascular complications (251,252).

Interestingly, patients with preoperative hypertension appear more likely to develop intraoperative hypotension than nonhypertensive persons; this is particularly true for patients taking ACE inhibitors (253). In some patients, this may be related to a decrease in vascular volume. In 1 report, hypotension during anesthesia was associated with a greater incidence of perioperative cardiac and renal complications than intraoperative hypertension, although other studies have not shown this (57).

C. Heart Failure

Heart failure has been identified in several studies as being associated with a poorer outcome when noncardiac surgery is performed. In the study by Goldman et al (12), the presence of a third heart sound or signs of HF were associated with a substantially increased risk during noncardiac surgery. Detsky et al (22) identified alveolar pulmonary edema as a significant risk factor, and in the report by Cooperman et al (24), HF 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 HF, because this may have implications concerning risk of death vs. perioperative HF. For instance, prior HF due to hypertensive heart disease may portend a different risk than prior HF resulting from CAD.

D. 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 cause 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 HF, preoperative assessment of left ventricular function may be recommended to quantify the severity of systolic and diastolic dysfunction. This information is

valuable for both intraoperative and postoperative management. This assessment may include echocardiography.

Hypertrophic obstructive 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 hypertrophied 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 obstructive cardiomyopathy, there were no deaths or serious ventricular arrhythmias during or immediately after general surgical procedures; 1 patient had major vascular surgery. In the 22 patients who underwent catheterization, the mean rest and peak provokable gradients were 30 and 81 mm Hg, respectively. The only patient suffering a perioperative MI had 2-vessel coronary disease. Significant arrhythmias or hypotension requiring vasoconstrictors occurred in 14% and 13% of patients, respectively (64). In another study, 77 patients with hypertrophic obstructive cardiomyopathy who underwent noncardiac surgery were evaluated. There were no deaths, but these patients had a significant incidence of adverse cardiac events, frequently manifested as HF. Independent risk factors for adverse outcome in all patients included major surgery and increasing duration of surgery. Echocardiographic features, including resting outflow tract gradient, were not associated with adverse cardiac events (254).

E. Valvular Heart Disease

Cardiac murmurs are common in patients facing noncardiac surgery. The consultant must be able to distinguish organic from functional murmurs, significant from insignificant murmurs, and the origin of the murmur to determine which patients require prophylaxis for endocarditis and which patients require further quantification 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. On the other hand, in patients with severe aortic stenosis who refuse cardiac surgery or are otherwise not candidates for aortic valve replacement, noncardiac surgery can be performed with a mortality risk of approximately 10% (255,256). 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 perioperative period because the reduction in diastolic filling period that accompanies tachycardia can lead to severe pulmonary congestion. Significant mitral stenosis increases the risk of HF. However, preoperative surgical correction of mitral valve disease is not indicated before noncardiac surgery, unless the valvular condition should be corrected to prolong survival and prevent complications, unrelated to the proposed noncardiac surgery. 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 duration of time in diastole. Tachycardia 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 evidence of mitral valve regurgitation or echocardiographic evidence of thickening and/or redundancy of the valve leaflets (13). Because perioperative volume shifts may cause a patient with an isolated click to develop mitral regurgitation, auscultation in the sitting, standing, squatting, and standing-after-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) may 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 with a catheter to monitor pulmonary artery pressure. It is also important for the consultant to note even mild reduction of the left ventricular ejection fraction (LVEF) in patients with mitral regurgitation. Because the low-pressure left atrium acts as a low-impedance sink 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 they undergo surgery that may result in bacteremia and the need for careful anticoagulation management. The Fifth Consensus Conference on Anticoagulation recommends the following (257):

For patients who require minimally invasive procedures (dental work, superficial biopsies), the recommendation is to briefly reduce the international normalized ratio (INR) to the low or subtherapeutic range and resume the normal dose of oral anticoagulation immediately after the procedure. Perioperative heparin therapy is recommended for patients in whom the risk of bleeding with oral anticoagulation is high

and the risk of thromboembolism without anticoagulation is also high [mechanical valve in the mitral position, Bjork-Shiley valve, recent (i.e., less than 1 year) thrombosis or embolus, or 3 or more of the following risk factors: atrial fibrillation, previous embolus at any time, hypercoagulable condition, mechanical prosthesis and LVEF less than 30% (258)]. For patients between these 2 extremes, physicians must assess the risk and benefit of reduced anticoagulation vs. perioperative heparin therapy.

F. Arrhythmias and Conduction Defects

Cardiac arrhythmias and conduction disturbances are not uncommon findings in the perioperative period (12,16,67), particularly in the elderly. In some studies, both supraventricular and ventricular arrhythmias have been identified as independent risk factors for coronary events in the perioperative period (12,67). More recent detailed studies using continuous ECG monitoring found that asymptomatic ventricular arrhythmias, including couplets and nonsustained ventricular tachycardia, were not associated with an increase in cardiac complications after noncardiac surgery (241). Nevertheless, the presence of an arrhythmia in the preoperative setting should provoke a search for underlying cardiopulmonary disease, ongoing myocardial ischemia or infarction, drug toxicity, or metabolic derangements.

Some 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. Although frequent ventricular premature beats and nonsustained ventricular tachycardia are considered risk factors for the development of intraoperative and postoperative arrhythmias and sustained ventricular arrhythmias during long-term follow-up, they are not associated with an increased risk of nonfatal MI or cardiac death in the perioperative period (240,241). Therefore, aggressive monitoring or treatment in the perioperative period may not be necessary. However, physicians should have a low threshold to institute prophylactic beta-blocker therapy in patients at increased risk of developing a perioperative or postoperative arrhythmia. Several recent studies suggest that beta-blocker therapy can reduce mortality and the incidence of cardiovascular complications (including the development of arrhythmias) during and for up to 2 years after surgery (250-252,259).

High-grade cardiac conduction abnormalities, such as complete atrioventricular block, if unanticipated, can increase operative risk and may necessitate temporary or permanent transvenous pacing. On the other hand, patients with intraventricular conduction delays, even in the presence of a left or right bundle-branch block, 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.

G. Implanted Pacemakers and ICDs

Each year more than 200 000 patients undergo placement of a permanent pacemaker, and more than 60 000 patients undergo placement of an implantable defibrillator. The presence of a pacemaker or ICD has important implications regarding preoperative, intraoperative, and postoperative patient management. The situations in which device malfunction may occur, as well as the techniques that may be used to prevent them, are discussed in Section VII.

H. 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 ventricular dysfunction (74,75). These observations should be kept in mind when such patients are evalutated 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.

Although 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 vascu-

lar resistance. This cycle must be recognized and appropriately treated.

IV. TYPE OF SURGERY

Cardiac complications after noncardiac surgery are a reflection of factors specific to the patient, the operation, and the circumstances under which the operation is undertaken. To the extent that preoperative cardiac evaluation reliably predicts postoperative cardiac outcomes, it may lead to interventions that lower perioperative risk, decrease long-term mortality, or alter the surgical decision-making process. Such alterations might include either choosing a lower-risk, less-invasive procedure or opting for nonoperative management (e.g., recommending an endovascular rather than open operative approach for a particular aneurysm or occlusive lesion, electing to follow-up rather than operate on a moderate-sized (4 to 5 cm) infrarenal aortic aneurysm, or choosing nonoperative treatment for the disabled claudicant who has no limb-threatening ischemia).

To the extent that preoperative cardiac evaluation can identify potentially reducible cardiac risks, interventions directed at reducing those risks might improve both short- and long-term cardiac outcomes. The potential for improvement in long-term outcomes is particularly relevant to operative decision making in patients undergoing surgery directed at long-term goals. When, for example, surgery in asymptomatic individuals is undertaken with the objective of prolonging life (e.g., elective repair of aortic aneurysm) or preventing a future stroke (e.g., carotid endarterectomy), the decision to intervene must be made with the expectation that the patient will live long enough to benefit from the prophylactic intervention.

Although different operations are associated with different cardiac risks, these differences are most often a reflection of the context in which the patient undergoes surgery (stability or opportunity for adequate preoperative preparation), surgery-specific factors (e.g., fluid shifts, stress levels, duration of procedure, or blood loss), or patient-specific factors (the incidence of CAD associated with the condition for which the patient is undergoing surgery).

A. Urgency

Mangano (1) determined that cardiac complications are 2 to 5 times more likely to occur with emergency surgical procedures than with elective operations. This finding is not surprising because 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 replacements 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 (e.g., symptomatic abdominal aortic aneurysms, perforated viscus, or 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.

B. 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 after 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 2 resulted in death 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 rates 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 years. 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 HF 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 (e.g., 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 intravascular fluid volumes, cardiac filling pressures, systemic blood pressure, heart rate, and thrombogenicity (1).

Several 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% vs. 6%) among patients who received infrainguinal bypass grafts. This difference probably is related to the fact that diabetes mellitus (44% vs. 11%) and history of previous MI (43% vs. 28%), angina (36% vs. 15%), or HF (29% vs. 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 after 321 aortic procedures, 177 infrainguinal

bypass grafts, and 49 carotid endarterectomies. Slight differences in the overall incidence of MI among the 3 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, HF, fixed or reversible thallium defects, and 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, and 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 5 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% vs. 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.

In a study based on the 24 959 participants with known CAD in the Coronary Artery Surgery Study (CASS) database, Eagle et al found that the cardiac risk associated with noncardiac operations involving the thorax, abdomen, vasculature, and head and neck was reduced significantly in those patients who had undergone prior coronary artery bypass graft (CABG) (postoperative deaths 1.7% vs. 3.3%, MIs 0.8% vs. 2.7%) (260). In a recent randomized, multicenter trial, Poldermans et al documented the cardioprotective effect of perioperative beta-blockade in substantially and significantly reducing the cardiac morbidity and mortality in high-risk patients undergoing major vascular surgery (252).

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 1985-1987 and found a linear, inverse relation between case volume and mortality rates for surgeons who annually performed 2 or fewer operations (11% mortality), 3 to 9 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 U.S. 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 4 had adjusted mortality rates that clearly could be correlated from 1 condition to another; 3 (carotid endarterectomy, aortic reconstruction, and lower-extremity revascularization) involved vascular surgery, and the fourth (total hip replacement), orthopedic surgery. Thus, if a hospital did well or poorly with 1 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 survival. In the prospectively randomized Veterans Administration trial of carotid endarterectomy vs. nonoperative management for asymptomatic carotid stenosis, for example, more than 20% of both randomized cohorts died of cardiac-related complications within a follow-up period of 4 years (94).

Fleisher et al analyzed a 5% sample of Medicare claims from 1992 to 1993 of patients undergoing major vascular surgery. A total cohort of 2865 individuals underwent aortic surgery with a 7.3% 30-day mortality rate and a 11.3% 1-year mortality rate. A total cohort of 4030 individuals underwent infrainguinal surgery with a 5.8% 30-day mortality rate and 16.3% 1-year mortality rate. This work further confirms that aortic and infrainguinal surgery continues to be associated with high 30-day and 1-year mortality, with aortic surgery being associated with the highest short-term and infrainguinal surgery being associated with the highest long-term mortality rates (261).

Patients undergoing major vascular surgery constitute a particular challenge (i.e., high-risk operations in a patient population with a high prevalence of significant CAD). There are, however, other surgical procedures for which the interaction of patient-specific and surgery-specific factors have been examined. Transplantation surgery generally represents a high-risk procedure in a patient with multiple comorbidities. Significant CAD is common in diabetic patients with end-stage renal disease. In a study of 176 consecutive patients undergoing either kidney or kidney-pancreas transplants, there was a high correlation between adverse postoperative cardiac events and preoperative documentation of reversible defects on intravenous dipyridamole thallium-201 myocardial imaging in combination with sig-

nificant CAD on coronary angiograms: 3 (11.1%) of 27 vs. 1 (0.9%) of 111 patients with a normal dipyridamole thallium-201 scan (262).

Although the prevalence of CAD is relatively low in patients with end-stage liver disease undergoing liver transplantation, 2 studies (263,264) have documented the reliability of dobutamine stress echocardiography in predicting post-transplant cardiac events. Stress echocardiography has also been shown to be useful in predicting cardiac outcomes in patients with advanced obstructive pulmonary disease undergoing lung volume reduction surgery (265,266).

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 vary not only among procedures but also among institutions for the same procedure. Therefore, in assessing the risks and benefits of 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 after a minor noncardiac operation than they are in any other patient situation. 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 CHD has had 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, 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

A. *Shortcut to the Decision to Test*

The preoperative guidelines (ACC/AHA) are fairly straight-forward about recommendations for patients about to undergo emergency surgery, the presence of prior cardiac revascularization, and the occurrence of major cardiac predictors. However, the majority of patients have either intermediate or minor clinical predictors of increased perioperative cardiovascular risk. Table 5 presents a shortcut approach to a large number of patients in whom the decision to recommend testing before surgery can be difficult. Basically, if 2 of the 3 listed factors are true, the guidelines suggest the use of noninvasive cardiac testing as part of the preoperative evaluation. In any patient with an intermediate clinical predictor, the presence of either a low functional capacity or high surgical risk should lead the consulting physician to consider noninvasive testing. In the absence of intermediate clinical predictors, noninvasive testing should be considered when both the surgical risk is high and the functional capacity is low. The guidelines define minor clinical predictors as advanced age, abnormal ECG, rhythm other than sinus, history of stroke, or uncontrolled systemic hypertension. These factors do not by themselves suggest the need for further testing, but when combined with low functional capacity and high-risk surgery, they should lead to consideration of preoperative testing. In making the decision to obtain noninvasive testing, there will occasionally be some practical circumstances when testing will be obtained after surgery, particularly if the results will not affect perioperative care. This test information may also be useful in predicting long-term risk of cardiac events (also see Section X). More specifically, identification of high-risk patients whose long-term outcome would be improved with medical therapy or coronary revascularization procedures is a major goal of preoperative noninvasive testing. Numerous studies using different preoperative noninvasive techniques before noncardiac surgery have demonstrated the ability to detect patients at increased risk of late cardiac events (254,261,265,267-270) (see Fig. 2).

B. *Resting Left Ventricular Function*

1. Summary of Evidence

Resting ventricular function has been evaluated preoperatively before noncardiac surgery by radionuclide angiography, echocardiography, and contrast ventriculography (23,96-105). Of 8 studies that demonstrate a positive relation between decreased preoperative ejection fraction and postoperative mortality or morbidity, 5 were prospective (96,97,100,103,271) and 3 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 HF, 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 HF. (If previous evaluation has documented severe left ventricular dysfunction, repeat preoperative testing may not be necessary.)

Class IIa
   Patients with prior HF and patients with dyspnea of unknown origin.

Class III
   As a routine test of left ventricular function in patients without prior HF.

C. *Assessment of Risk for CAD and Functional Capacity*

1. The 12-Lead ECG

In patients with established or documented coronary disease, the 12-lead rest ECG contains important prognostic information that relates to long-term morbidity and mortality (272-275). The magnitude and extent of Q waves provide a crude

---

Table 5. Shortcut to Noninvasive Testing in Preoperative Patients if Any Two Factors Are Present

---

1. Intermediate clinical predictors are present (Canadian class 1 or 2 angina, prior MI based on history or pathologic Q waves, compensated or prior heart failure, or diabetes)
2. Poor functional capacity (less than 4 METs)
3. High surgical risk procedure (emergency major operations*; aortic repair or peripheral vascular surgery; prolonged surgical procedures with large fluid shifts or blood loss)

HF indicates heart failure; METs, metabolic equivalents; MI, myocardial infarction.

Modified with permission from: Leppo JA, Dahlberg ST. The question: to test or not to test in preoperative cardiac risk evaluation. *J Nucl Cardiol.* 1998;5:332-42. Copyright ©1998 by the American Society of Nuclear Cardiology. This material may not be reproduced, stored in a retrieval system, or transmitted in any form or by any means without the prior permission of the publisher.

*Emergency major operations may require immediately proceeding to surgery without sufficient time for noninvasive testing or preoperative interventions.

Figure 2. Prediction of long-term survival after major vascular surgery. CAD indicates coronary artery disease; LVEF, left ventricular ejection fraction.

estimate of LVEF, and are a predictor of long-term mortality (276,277). Horizontal or downsloping ST-segment depression greater than 0.5 mm, left ventricular hypertrophy with a "strain" pattern, and left bundle-branch block in patients with established coronary disease are all associated with decreased life expectancy (272-280). The resting 12-lead ECG does not identify increased perioperative risk in patients undergoing low-risk surgery (281), but certain ECG abnormalities (above) are clinical predictors of increased perioperative and long-term cardiovascular risk in clinically intermediate- and high-risk patients. In particular, the presence of left ventricular hypertrophy or ST-segment depression on preoperative 12-lead ECG predicts adverse perioperative cardiac events (282).

Recommendations for Preoperative 12-Lead Rest ECG

Class I
  Recent episode of chest pain or ischemic equivalent in clinically intermediate- or high-risk patients scheduled for an intermediate- or high-risk operative procedure.

Class IIa
  Asymptomatic persons with diabetes mellitus.

Class IIb
1. Patients with prior coronary revascularization.
2. Asymptomatic male more than 45 years old or female more than 55 years old with 2 or more atherosclerotic risk factors.

3. Prior hospital admission for cardiac causes.

Class III
  As a routine test in asymptomatic subjects undergoing low-risk operative procedures.

2. 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 are 68% and 77%, respectively (39). The sensitivity and specificity for multivessel dis-

ease are 81% and 66%, and for 3-vessel or left main coronary disease, 86% and 53%, respectively (40).

Weiner et al (32) studied 4083 medically treated patients in CASS and identified a high-risk patient subset (12% of the population) with an annual mortality rate 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 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 rate of less than 1% per year over 4 years of follow-up (32). Similar results have been reported by others (41,42).

a. Summary of Evidence

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, HF, 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 2 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, HF, or ventricular arrhythmia) was 24% (17 patients).

The data 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). Among patients without a cardiac history and with a normal resting ECG, approximately 20% to 50% 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 (107,108,113).

In contrast to the above studies of patients with vascular disease, in a general population of patients of 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 2 patients (1%) had a markedly abnormal (ST-segment depression of 2 mm or more) exercise test. Of the 32 patients with an abnormal exercise test, 5 (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

Table 6. Preoperative Exercise Testing Before Major Noncardiac Surgery

Author	n	Abnormal Test (%)	Criteria For Abnormal Test	Events	Patients With Predictive Value Positive Test	Negative Test	Event	Comments
Peripheral vascular surgery or abdominal aortic aneurysm repair								
McCabe 1981 (106)	314	36	STD, CP, or A	38% (15/39)	81% (13/16)	91% (21/23)	D,M,I,H,A	
Cutler 1981 (107)	130	39	STD	7% (9/130)	16% (8/50)	99% (79/80)	D,M	Less than 75% MPHR increased risk
Arous 1984 (108)	808	17	STD	NR	21% (19/89)	NR	D,M	
Gardine 1985 (109)	86	48	STD	11% (2/19)	11% (1/9)	90% (9/10)	D,M	
von Knorring 1986 (110)	105	25	STD, A, or CP	3% (3/105)	8% (2/26)	99% (78/79)	D,M	
Kopecky 1986 (116)	114	57	Less than 400 kpm	7% (8/110)	13% (8/63)	100% (47/47)	D,M	
Leppo* 1987 (111)	60	28	STD	12% (7/60)	25% (3/12)	92% (44/48)	D,M	Exercise test results used to refer patients for revascularization
Hanson 1988 (112)	74	57	STD	3% (1/37)	5% (1/19)	100% (18/18)	D,M	Arm ergometry
McPhail* 1988 (113)	100	70	Less than 85% MPHR	19% (19/100)	24% (17/70)	93% (28/30)	D,M,A,F	Less than 85% MPHR; p=0.04; STD; NS
Urbinati 1994 (117)	121	23	STD	0	0/28	100% (93/93)	D,M	Carotid endarterectomy patients. STD predicted late death.
Peripheral vascular surgery or major noncardiac surgery								
Carliner 1985 (114)	200	16	STD	32% (16/200)	16% (5/32)	93% (157/168)	D,M	5 METs (NS)

A indicates cardiac arrhythmia; CP, chest pain; D, death; F, failure; H, hypotension; I, myocardial ischemia; M, myocardial infarction; MET, metabolic equivalent; MPHR, maximum predicted heart rate; NR, not reported; NS, not significant; STD, exercise-induced electrocardiographic ischemia.
*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.

general population of patients with CAD (118). The onset of a myocardial ischemic response at low exercise workloads is associated with a significantly increased risk of perioperative and long-term cardiac events. In contrast, the onset of a myocardial ischemic response at high exercise workloads is associated with significantly less risk. The prognostic gradient is also influenced by the age of the patient, the extent of the coronary disease, the degree of left ventricular dysfunction, hemodynamic response to exercise, and presence or absence of chronotropic incompetence. ACC/AHA guidelines concerning the indications for and interpretation of exercise stress testing are available (43).

3. Nonexercise Stress Testing

The 2 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 most common examples presently in use are dobutamine stress echocardiography and intravenous dipyridamole/adenosine myocardial perfusion imaging using both thallium-201 and technetium-99m.

4. Myocardial Perfusion Imaging Methods

a. Summary of Evidence

Publications that report the results of stress myocardial perfusion testing before both vascular and nonvascular surgery are summarized in Table 7. Included were mostly prospectively recruited patient studies, a majority of which involved patients undergoing vascular surgery. Cardiac events in the perioperative period were defined, for the purpose of this table, as 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.

In a meta-analysis of dipyridamole thallium imaging for risk stratification before vascular surgery, Shaw et al (283) reported that a total of 10 studies involving 1994 patients referred for testing before elective vascular surgery demon-

strated significant prognostic utility for this scintigraphic technique. In addition, they noted that the positive predictive value of perfusion imaging was correlated with the pretest cardiac risk of the patients. Overall, a reversible myocardial perfusion defect predicted perioperative events, and a fixed thallium defect predicted long-term cardiac events. Of note, the addition of semiquantitative analysis of perfusion imaging improved the clinical risk stratification based on a relationship of increasing event rates in patients with larger defects.

The need for caution in routine screening with dipyridamole thallium stress test of all patients before vascular surgery has been 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.

This issue of routine testing has been evaluated by 2 studies that prospectively evaluated preoperative cardiac risk assessment with a methodology that generally follows the guidelines outlined in this review. In a report by Vanzetto et al (284), 517 consecutive patients were evaluated before abdominal aortic surgery. If no major or fewer than 2 intermediate clinical cardiac risk factors were present, patients (n=317) went directly to elective surgery. The authors noted a 5.6% incidence of cardiac events (death/MI) in those patients with 1 risk factor and a rate of 2.4% in those with no cardiac risk factors. All high-risk patients (n=134, 2 or more cardiac risk factors) underwent dipyridamole-thallium SPECT imaging, and those with a normal scan (38%) had a cardiac event rate of 2% in contrast to a rate of 23% in 43 patients (36%) demonstrating reversible thallium defects. Bartels et al (243) also reported that patients (n=203) referred for elective vascular surgery who had no clinical intermediate or major clinical risk factors had a 2% incidence of cardiac events. Those patients with either intermediate risk factors and a functional capacity of less than 5 METs or high clinical risk (10 of 23 patients) underwent stress-thallium imaging. The remaining patients had intensified medical therapy before elective surgery. The cardiac event rates were 9% in the intermediate-risk group and 5% in the high-risk group, but the overall cardiac mortality rate was only 1% in the patients who underwent the ACC/AHA guideline workup. Another recent report (285) also used the clinical risk factor parameters to divide vascular surgery patients into low-, intermediate-, and high-cardiac-risk groups. Those authors did not include functional capacity measurements but noted a 0% death or MI rate in the perioperative period among the low-risk patients (n=60). These additional reports support the use of the perioperative risk assessment guidelines, especially in the confirmation that cardiac patients with low clinical risk can typically undergo elective surgery with a low event rate.

In several publications by Hendel et al (128), Lette et al (129), and Brown et al (131), the scoring or quantification of scan abnormalities had a significant impact on improving risk assessment and positive predictive value. The data sug-

Table 7. Myocardial Perfusion Imaging for Preoperative Assessment of Cardiac Risk

Author	n*	Patients With Ischemia (%)	Events: MI/Death (%)	Ischemia Positive Predictive Value	Normal Negative Predictive Value	Comments
Vascular surgery						
Boucher 1985 (119)	48	16 (33)	3 (6)	19% (3/16)	100% (32/32)	First study to define risk of thallium redistribution
Cutler 1987 (120)	116	54 (47)	11 (10)	20% (11/54)	100% (60/60)	Only aortic surgery
Fletcher 1988 (121)	67	15 (22)	3 (4)	20% (3/15)	100% (56/56)	
Sachs 1988 (122)	46	14 (31)	2 (4)	14% (2/14)	100% (24/24)	
Eagle 1989 (21)	200	82 (41)	15 (8)	16% (13/82)	98% (61/62)	Defined clinical risk
McEnroe 1990 (123)	95	34 (36)	7 (7)	9% (3/34)	96% (44/46)	Fixed defects predict events
Younis 1990 (124)	111	40 (36)	8 (7)	15% (6/40)	100% (51/51)	Includes long-term follow-up
Mangano 1991 (125)	60	22 (37)	3 (5)	5% (1/22)	95% (19/20)	Managing physicians blinded to scan result
Strawn 1991 (126)	68	N/A	4 (6)	N/A	100% (21/21)	
Watters 1991 (127)	26	15 (58)	3 (12)	20% (3/15)	100% (11/11)	Includes echocardiographic (TEE) studies
Hendel 1992 (128)	327	167 (51)	28 (9)	14% (23/167)	99% (97/98)	Included long-term follow-up
Lette 1992 (129)	355	161 (45)	30 (8)	17% (28/161)	99% (160/162)	Used quantitative scan index
Madsen 1992 (130)	65	45 (69)	5 (8)	11% (5/45)	100% (20/20)	
Brown 1993 (131)	231	77 (33)	12 (5)	13% (10/77)	99% (120/121)	Prognostic utility enhanced by combined scan and clinical factors
Kresowik 1993 (132)	170	67 (39)	5 (3)	4% (3/67)	98% (64/65)	
Baron 1994 (133)	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 1994 (134)	237	110 (46)	17 (7)	11% (12/110)	100% (97/97)	Cost-effectiveness data included
Koutelou 1995 (378)	106	47 (44)	3 (3)	6% (3/47)	100% (49/49)	Used adenosine/SPECT thallium imaging
Marshall 1995 (387)	117	55 (47)	12 (10)	16% (9/55)	97% (33/34)	Used adenosine thallium and sestamibi. Size of ischemic defect enhanced prognostic utility
Van Damme 1997 (388)	142	48 (34)	3 (2)	N/A	N/A	Used dobutamine SPECT sestamibi and echocardiographic imaging. Echocardiographic and nuclear scan prognostic utility were equivalent
Nonvascular surgery†						
Camp 1990 (135)	40	9 (23)	6 (15)	67% (6/9)	100% (23/23)	Diabetes mellitus, renal transplant
Iqbal 1991 (136)	31	11 (41)	3 (11)	27% (3/11)	100% (20/20)	Exercise 86%, diabetes mellitus, pancreas transplant
Coley 1992 (137)	100	36 (36)	4 (4)	8% (3/36)	98% (63/64)	Define clinical risk factors in patients with known or suspected CAD
Shaw 1992 (138)	60	28 (47)	6 (10)	21% (6/28)	100% (19/19)	Used adenosine
Takase 1993 (139)	53	15 (28)	6 (11)	27% (4/15)	100% (32/32)	Patients with documented or suspected CAD include rest echocardiogram
Younis 1994 (140)	161	50 (31)	15 (9)	18% (9/50)	98% (87/89)	Intermediate- to high-risk CAD
Stratman 1996 (270)	229	67 (29)	10 (4)	6% (4/67)	99% (91/92)	Used dipyridamole sestamibi and noted fixed defect had more prognostic utility than transient defect

CAD indicates coronary artery disease; MI, myocardial infarction; n*, number of patients who underwent surgery: N/A, not available; NFMI, nonfatal myocardial infarction; SPECT, single photon emission computed tomography; TEE, transesophageal echocardiography.

†Studies utilizing pharmacological and/or exercise thallium testing.

All studies except those by Coley (137) and Shaw (138) acquired patient information prospectively. Only in reports by Mangano (125) and Baron (133) were attending physicians blinded to scan results.

Patients with fixed defects were omitted from calculations of positive and negative predictive value.

gest that as the size of the defect increases to a moderate (20% to 25% of left ventricular mass) degree, the cardiac risk significantly increases. The use of techniques to quantify the extent of abnormality and the current routine use of quantitative gated SPECT perfusion imaging to evaluate LVEF will probably improve the positive predictive nature of myocardial perfusion imaging. This would also 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 perfusion imaging are available (141).

5. Dobutamine Stress Echocardiography

a. 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 12 studies, all published since 1991 and identified by a computerized search of the English language literature (Table 8) (105,147-151,263,266,286-289). The populations included predominantly, but not exclusively, patients undergoing peripheral vascular surgical procedures. Only 2 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; i.e., worsening of pre-existing 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" (i.e., arrhythmia, HF, and ischemia) and "hard" (i.e., MI or cardiac death) events.

The data indicate that dobutamine stress echocardiography can be performed safely and with acceptable patient tolerance. The range of positive test results was 9% to 50%. The predictive value of a positive test ranged from 7% to 25% 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 extent of the wall-motion abnormality and/or wall-motion change at low ischemic thresholds is especially important. These findings have been shown to be predictors of long-

term (151,286,290) and short-term (268) outcome. Although hypotension during dobutamine testing is generally not well correlated with the degree of underlying CAD, in 1 recent study, hypotension was an independent predictor of perioperative complications (268). The summary of evidence supports the use of dobutamine echocardiography for assessing preoperative risk in properly selected patients, especially those undergoing peripheral arterial revascularization.

6. 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 are 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 pre-existing 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. Exercise should not be combined with dipyridamole in such patients, and 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 by means of vasodilator stress and myocardial perfusion studies.

Recommendations for Exercise or Pharmacological Stress Testing

Class I
1. **Diagnosis of adult patients with intermediate pretest probability of CAD.**
2. **Prognostic assessment of patients undergoing initial evaluation for suspected or proven CAD; evaluation of subjects with significant change in clinical status.**
3. **Demonstration of proof of myocardial ischemia before coronary revascularization.**
4. **Evaluation of adequacy of medical therapy; prognostic assessment after an acute coronary syndrome (if recent evaluation unavailable).**

Class IIa
   Evaluation of exercise capacity when subjective assessment is unreliable.

Class IIb
1. **Diagnosis of CAD patients with high or low pretest probability; those with resting ST depression less than 1 mm, those undergoing digitalis therapy, and those with ECG criteria for left ventricular hypertrophy.**

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	Positive Predictive Value† for MI or Death	Negative Predictive Value	Comments
Lane 1991 (147)	38	50	3 (8)	New WMA	16% (3/19)	100% (19/19)	Vascular and general surgery
Lalka 1992 (148)	60	50	9 (15)	New or worsening WMA	23% (7/30)	93% (28/30)	Multivariate analysis
Eichelberger 1993 (149)	75	36	2 (3)	New or worsening WMA	7% (2/27)	100% (48/48)	Managing physicians blinded to DSE results
Langan 1993 (150)	74	24	3 (4)	New WMA or ECG changes	17% (3/18)	100% (56/56)	
Poldermans 1993 (105)	131	27	5 (4)	New or worsening WMA	14% (5/35)	100% (96/96)	Multivariate analysis; managing physicians blinded to DSE results
Dávila Román 1993 (151)	88	23	2 (2)	New or worsening WMA	10% (2/20)	100% (68/68)	Included long-term follow-up
Poldermans 1995 (286)	302	24	17 (6)	New or worsening WMA	24% (17/72)	100% (228/228)	Multivariate analysis
Shafritz 1997 (287)	42	0	1 (2)	New or worsening WMA	NA	97% (41/42)	
Plotkin 1998 (263)	80	8	2 (3)	New or worsening WMA, ECG changes, and/or symptoms of chest pain or dyspnea	33% (2/6)	100% (74/74)	Orthotopic liver transplantation
Ballal 1999 (288)	233	17	7 (3)	New or worsening WMA	0% (0/39)‡	96% (187/194)	Included long-term follow-up
Bossone 1999 (266)	46	9	1 (2)	New or worsening WMA	25% (1/4)	100% (42/42)	Lung volume reduction surgery; Included long-term follow-up
Das 2000 (289)	530	40	32 (6)	New or worsening WMA or failure to develop hyper-dynamic function	15% (32/214)	100% (316/316)	Multivariate analysis; Nonvascular surgery

DSE indicates dobutamine stress echocardiogram; ECG, electrocardiogram; MI, myocardial infarction; NA, not available; WMA, wall-motion abnormality.
*Number of patients who underwent surgery.
†Numbers in parentheses refer to number of patients/total in group.
‡Intervening revascularization in 9 (23%) of ischemic patients.

2. Detection of restenosis in high-risk asymptomatic subjects within the initial months after PCI.

Class III
1. **For *exercise* stress testing, diagnosis of patients with resting ECG abnormalities that preclude adequate assessment, e.g., pre-excitation syndrome, electronically paced ventricular rhythm, rest ST depression greater than 1 mm, or left bundle-branch block.**
2. **Severe comorbidity likely to limit life expectancy or candidacy for revascularization.**
3. **Routine screening of asymptomatic men or women without evidence of CAD.**
4. **Investigation of isolated ectopic beats in young patients.**

7. Ambulatory ECG Monitoring

a. Summary of Evidence

The predictive value of preoperative ST changes on 24- to 48-hour ambulatory ECG monitoring for cardiac death or MI in patients undergoing vascular and nonvascular surgery has been reported by several investigators. The frequency of abnormal ST-segment changes observed in 869 patients reported in 7 series was 25% (range, 9% to 39%) (19,158-162). The positive and negative values for perioperative MI and cardiac death are shown in Table 9. In 2 recent studies, it had a predictive value similar to dipyridamole thallium imaging (160,163).

Although the test has been shown to be predictive of cardiac morbidity, there are several limitations. Differences in the study protocols (24 vs. 48 hours, ambulatory vs. in-hospital) may account for the variability in the predictive value of the test. Preoperative ambulatory ECG monitoring 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).

D. Recommendations: When and 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. Treadmill exercise stress testing in patients with abdominal aortic aneurysms greater than 4 cm in diameter is relatively safe. In

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	Negative Value	Event	Comments
Raby 1989 (51)	176	18	A	10% (3/32)	1% (1/144)	D,M	24 to 48 h during ambulation
Pasternack 1989 (162)	200	39	A	9% (7/78)	2% (2/122)	D,M	
Mangano 1990 (19)	144	18	A,B	4% (1/26)	4% (5/118)	D,M	Immediately preoperatively
Fleisher 1992 (158)	67	24	A,B	13% (2/16)	4% (2/51)	D,M	Immediately preoperatively
McPhail 1993 (160)	100	34	A	15% (5/34)	6% (4/66)	D,M	
Kirwin 1993 (159)	96	9	A	11% (1/9)	16% (14/87)	D,M	Definition of MI based on enzymes only
Fleisher 1995 (163)	86	23	A,B	10% (2/20)	3% (2/66)	D,M	Quantitative monitoring not predictive

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

a series of more than 250 patients studied in this circumstance, a single patient developed subacute aneurysm rupture 12 hours after testing and was successfully repaired (291). In patients with important abnormalities on their resting ECG (e.g., left bundle-branch block, left ventricular hypertrophy with "strain" pattern, or digitalis effect), other techniques such as exercise echocardiography or exercise myocardial perfusion imaging should be considered. The sensitivity and specificity of exercise thallium scans in the presence of left bundle-branch block are 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). Exercise should not be combined with dipyridamole in such patients, and synthetic catecholamines can also yield false-positive results (157).

In patients unable to perform adequate exercise, a nonexercise stress test should be used. In this regard, dipyridamole myocardial perfusion imaging testing and dobutamine echocardiography are the most common tests. Intravenous dipyridamole should be avoided in patients with significant bronchospasm, critical carotid disease, or 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 partic-

ular type of test. Fig. 3 illustrates an algorithm to help the clinician choose the most appropriate stress test in those various situations.

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 after recent MI for whom coronary angiography is indicated. In general, indications for preoperative coronary angiography are similar to those identified for the nonoperative setting. The following recommendations provide 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 1999 (292).

Recommendations for Coronary Angiography in Perioperative Evaluation Before (or After) Noncardiac Surgery

Class I: Patients With Suspected or Known CAD
1. **Evidence for high risk of adverse outcome based on noninvasive test results.**
2. **Angina unresponsive to adequate medical therapy.**
3. **Unstable angina, particularly when facing intermediate-risk* or high-risk* noncardiac surgery.**
4. **Equivocal noninvasive test results in patients at high-clinical risk† undergoing high-risk* surgery.**

Class IIa
1. **Multiple markers of intermediate clinical risk† and planned vascular surgery (noninvasive testing should be considered first).**
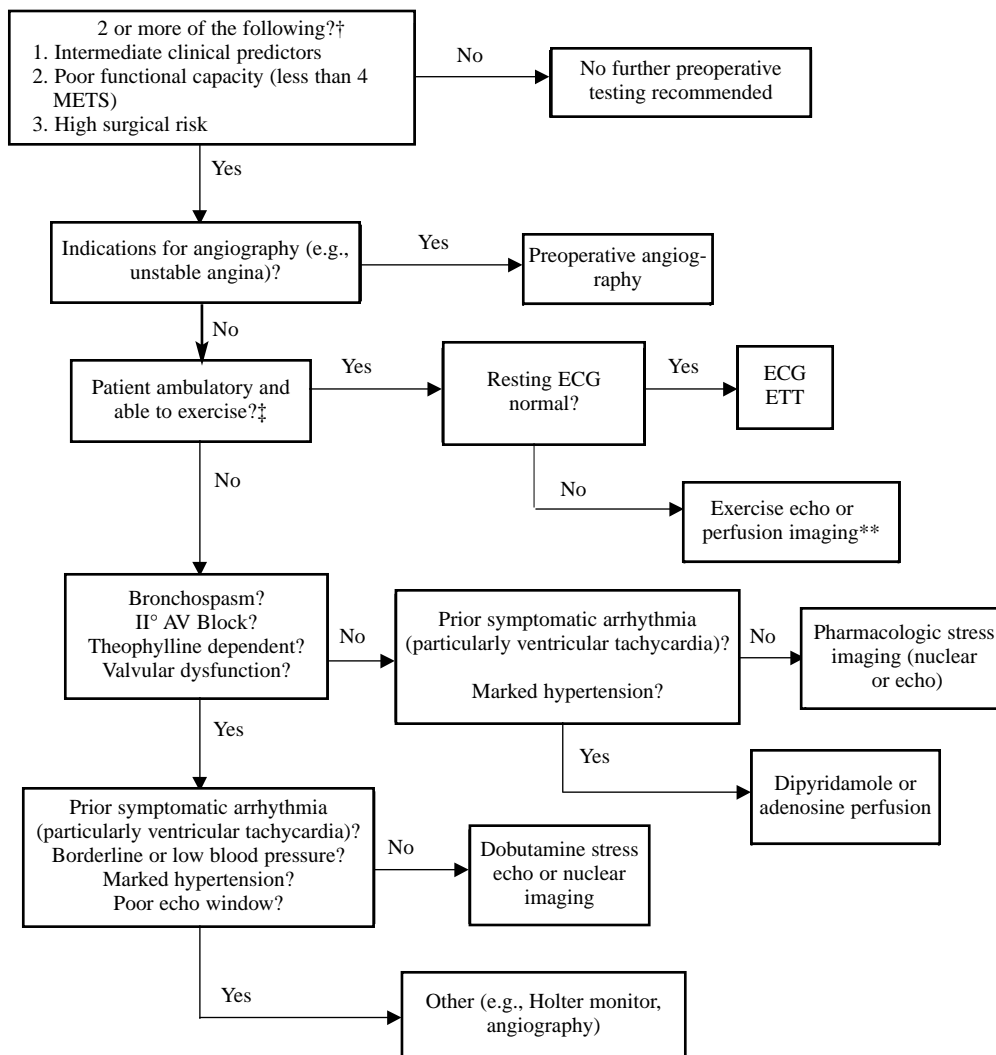
Figure 3. Supplemental Preoperative Evaluation: When and Which Test. Testing is only indicated if the results will impact care.

2. **Moderate to large region of ischemia on noninvasive testing but without high-risk features and without lower LVEF.**
3. **Nondiagnostic noninvasive test results in patients of intermediate clinical risk† undergoing high-risk* noncardiac surgery.**
4. **Urgent noncardiac surgery while convalescing from acute MI.**

Class IIb
1. **Perioperative MI.**
2. **Medically stabilized class III or IV angina and planned low-risk or minor* surgery.**

Class III
1. **Low-risk* noncardiac surgery with known CAD and no high-risk results on noninvasive testing.**
2. **Asymptomatic after coronary revascularization with excellent exercise capacity (greater than or equal to 7 METs).**
3. **Mild stable angina with good left ventricular function and no high-risk noninvasive test results.**

4. **Noncandidate for coronary revascularization owing to concomitant medical illness, severe left ventricular dysfunction (e.g., LVEF less than 0.20), or refusal to consider revascularization.**
5. **Candidate for liver, lung, or renal transplant more than 40 years old as part of evaluation for transplantation, unless noninvasive testing reveals high risk for adverse outcome.**

---

*Cardiac risk according to type of noncardiac surgery. High risk: emergent major operations, aortic and major vascular surgery, peripheral vascular surgery, or anticipated prolonged surgical procedure associated with large fluid shifts and blood loss; intermediate risk: carotid endarterectomy, major head and neck surgery, intraperitoneal and intrathoracic surgery, orthopedic surgery, or prostate surgery; and low risk: endoscopic procedures, superficial procedures, cataract surgery, or breast surgery.

†Cardiac risk according to clinical predictors of perioperative death, MI, or HF. High clinical risk: unstable angina, acute or recent MI with evidence of important residual ischemic risk, decompensated HF, high degree of atrioventricular block, symptomatic ventricular arrhythmias with known structural heart disease, severe symptomatic valvular heart disease, or patient with multiple intermediate-risk markers such as prior MI, HF, and diabetes; intermediate clinical risk: Canadian Cardiovascular Society class I or II angina, prior MI by history or ECG, compensated or prior HF, diabetes mellitus, or renal insufficiency.

VI. IMPLICATIONS OF RISK ASSESSMENT STRATEGIES FOR 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 vs. 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 in the 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. Although physicians should be concerned with improving the clinical outcome of their patients, cost is an appropriate consideration when different evaluation and treatment strategies are available that cannot be distinguished from one another in terms of clinical outcome.

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 in the clinical populations differs so much from center to center, it is difficult to determine the exact risks of aggressive screening and treatments vs. the benefits in terms of risk reduction. Additionally, the models all demonstrate that optimal strategy depends on the mortality rates for both cardiac procedures and noncardiac surgeries in the clinically relevant range. One decision 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.

One report suggested that the cost of a selected coronary screening approach, as described in these guidelines, was as low as $214 per patient (245). Several recent publications have shown a cost per year of life saved for this selected screening strategy of less than $45 000 when applied to patients undergoing vascular surgery (244,246). However, none of these studies included a strategy of selected screening followed by aggressive beta-blocker treatment in high-risk individuals, as recently described by Poldermans and colleagues (252). It is likely that this approach will be preferred over more aggressive coronary assessment/treatment strategies except perhaps among very high-risk subsets of patients (293). Prophylactic beta-blockade represents an excellent strategy in patients for whom coronary revascularization for long-term benefit is not a serious consideration.

VII. PERIOPERATIVE THERAPY

A. Rationale for Surgical Coronary Revascularization and Summary of Evidence

1. Preoperative CABG

To date, no randomized or well-controlled trials have assessed the overall benefit of prophylactic coronary bypass surgery to lower perioperative cardiac risk of noncardiac surgery. Ellis et al analyzed the coronary angiograms of 63 patients undergoing major nonthoracic vascular surgery in a case-control study that indirectly supported benefit from preoperative coronary bypass surgery (294). These investigators found that a coronary occlusion proximal to viable myocardium was associated with a higher rate of perioperative MI and death, raising the question of whether revascularizing coronary occlusions might not reduce the frequency of these adverse events. However, in this study, the number of milder, "nonobstructive" lesions was also associated with MI and death. This is consistent with studies that show that the most severe stenoses may not always be responsible for MI, and that coronary thrombosis frequently occurs at the site of milder stenoses. Thus, preoperative revascularization of severe stenoses may not reduce perioperative ischemic complications.

A study by Fleisher et al of a cohort of Medicare beneficiaries undergoing infrainguinal or abdominal aortic reconstructive surgery found that preoperative stress testing followed by revascularization, when appropriate, was associated with improved short- and long-term survival with the higher-risk aortic surgery (261). However, this association may be confounded by the fact that the cohorts referred for preoperative stress testing were "healthier" patients, as evidenced by the finding that stress testing with or without coronary revascularization was associated with greater short- and long-term survival. 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).

In 1984, 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 less than 0.001). 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.

Eagle et al analyzed 3368 patients in the CASS database who underwent noncardiac surgery during more than 10 years following entry in the CASS study (260). Patients undergoing urologic, orthopedic, breast, and skin operations had a very low mortality rate, less than 1%, regardless of whether they had undergone prior CABG for CAD. However, patients undergoing thoracic, abdominal, vascular, and head and neck surgery had a much higher risk of death and MI in the 30 days after the surgical procedure. When patients undergoing these higher-risk surgical procedures who had undergone prior CABG were compared with those who had not, patients who had undergone prior CABG had a lower risk of death (1.7% vs. 3.3%, p=0.03) and nonfatal MI (0.8% vs. 2.7%, p=0.002) than patients without prior CABG. Prior CABG was most protective among patients with multivessel CAD and those with more severe angina. These data indicate that patients undergoing low-risk procedures are unlikely to derive early benefit from revascularization before low-risk surgery, but suggest that patients with multivessel disease and severe angina undergoing high-risk surgery might well benefit from revascularization before noncardiac surgery.

In attempting to balance the potential risks vs. benefits of 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 2 recent decision models (168,169). If the long-term benefits had been included, the value of preoperative coronary revascularization would have been 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. Although 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% after coronary bypass surgery, compared with 57% for nonsurgical treatment (p=0.02). Rihal and colleagues (166) have reported similar findings in more than 2000 patients enrolled in the CASS study. Compared with coronary bypass surgery in patients with both CHD and peripheral vascular disease, surgically treated patients with 3-vessel disease had significantly better long-term survival than those treated medically after adjustment for all covariates, including clinical measures of disease stability, stress test results, and left ventricular function. In a study at the Cleveland Clinic Foundation, the cumulative 5-year survival

rate for the 216 patients who received coronary bypass was 72% (81% in nondiabetic men) compared with 43% (p=0.001) for 35 patients in whom coronary bypass was indicated but never performed (175,177). Fatal cardiac events occurred within a mean of 4.6 years in 12% and 26% of these 2 subsets, respectively (p=0.033). These latter studies illustrate the importance of both perioperative and long-term cardiac risk when considering whether to recommend coronary bypass surgery before noncardiac surgery. The indications for surgical coronary revascularization in this group, therefore, are 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, 3-vessel CAD in conjunction with left ventricular dysfunction, 2-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 (see Table 3).

2. Preoperative PCI

a. Summary of Evidence

The role of prophylactic preoperative coronary intervention in reducing untoward perioperative cardiac complications remains unclear. No randomized clinical trials have documented whether prophylactic PCI with balloon angioplasty, stents, or other devices before noncardiac surgery reduces perioperative ischemia or MI. There is an ongoing trial designed to determine whether patients who require elective surgery, specifically elective vascular surgery, would benefit from prior preoperative coronary artery revascularization (295). Several retrospective series have been reported (see Table 10). In a 50-patient series reported from Mayo Clinic (179), percutaneous transluminal coronary angioplasty (PTCA) using balloons without stents was performed before noncardiac surgery (52% vascular procedures) in patients at high risk for perioperative complications (62% were classified higher than Canadian 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 PCI, the perioperative MI rate was 5.6%, and the mor-

Table 10. Studies Reporting the Clinical Outcome of Patients Undergoing Noncardiac Surgery After a Percutaneous Coronary Intervention

Study Author	Year Published	No. of Patients who Underwent PCI	Time From PCI to Surgery	Perioperative Mortality, %	Perioperative Infarction Rate, %	Comments
Huber et al (179)	1992	50	9 days (mean)	1.9	5.6	CABG needed after balloon angioplasty in 10% of pts. No control group for comparison.
Elmore et al (180)	1993	14	10 days (mean)	0	0	Very small study. Event rate in pts. treated with CABG or balloon angioplasty less than in control group. Angioplasty pts. had fewer risk factors than pts. undergoing CABG.
Allen et al (181)	1991	148	338 days (mean)	2.7	0.7	No increase in events if surgery performed within 90 days of PTCA.
Gottleib et al (296)	1998	194	11 days (median)	0.5	0.5	Only vascular surgeries included.
Possner et al (298)	1999	686	1 year (median)	2.6	2.2	Pts. who had undergone PCI had a similar frequency of death and MI but half the angina and HF of matched pts. with CAD who had not undergone PCI. Event rates were much higher if PCI had been performed within 90 days.
Kaluza et al (301)	2000	40	13 days (mean)	20	16.8	The only study in which stents were used. Mortality was 32% among pts. operated on less than 12 days after stent placement vs. 0 in pts. operated on 12 to 30 days after PCI.
Hassan et al (303)	2001	251	29 months (median)	0.8	0.8	Among pts. who received PCI in BARI, outcome after noncardiac surgery was equivalent to that of BARI pts. who had received CABG.

BARI indicates Bypass Angioplasty Revascularization Investigation; CABG, coronary artery bypass surgery; CAD, coronary artery disease; HF, heart failure, MI, myocardial infarction; PCI, percutaneous coronary intervention; PTCA, percutaneous transluminal coronary angioplasty; Pts, patients.

tality rate 1.9%. Whether 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 aneurysymorrhaphy. 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 1- and 2-vessel disease and less 3-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 4 operative deaths (1 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.

Gottlieb et al studied 194 patients who underwent PTCA followed by aortic abdominal, carotid endarterectomy, or peripheral vascular surgery. The median interval between PTCA and surgery was 11 days (interquartile ranges 3 and 49 days) (296). Twenty-six (13.4%) of the patients had a cardiac complication, but only 1 patient died, and 1 had a nonfatal MI. The long time interval over which PTCA was performed before surgery and the inability to know whether the clinical outcome of these patients would have been different had a prior PTCA procedure not been performed limit the conclusions that can be drawn from this study. Massie et al performed a case-control study of 140 patients with abnormal dipyridamole thallium scans in 2 or more segments; 70 underwent coronary angiography (of whom 25 were referred for revascularization) and 70 (matched for age, gender, type of vascular surgery, and number of myocardial segments suggesting ischemia on thallium scanning) did not (297). A trend toward late benefit associated with preoperative revascularization was offset by a trend toward an early hazard from the risk of the preoperative invasive cardiac evaluation and treat-

ment. There were no significant differences between the angiography group and matched control subjects with respect to the frequency of perioperative nonfatal MI (13% vs. 9%) or fatal MI (4% vs. 3%) or the frequency of late non-fatal MI (16% vs. 19%) or late cardiac death (10% vs. 13%).

In a retrospective cohort study by Posner et al, adverse events in the 30 days after noncardiac surgery were compared among patients who had undergone preoperative PTCA at any time, patients with coronary disease who had not undergone a percutaneous revascularization procedure, and patients without known coronary disease ("normal controls") (298). Patients with coronary disease had twice the risk of cardiac events as normal controls; however, the risk among patients who had undergone PTCA was half that of patients who had coronary disease but not undergone PTCA. The benefit was limited to a reduction in angina and HF; there was no reduction in early postoperative MI or death associated with prior PTCA. The investigators did not control for the severity of coronary disease, comorbid illness, or the medical management used in the PTCA and no PTCA groups. No benefit was seen in patients undergoing revascularization less than 90 days before noncardiac surgery. The long time frame in which PTCA had been performed preoperatively limits the conclusions that can be drawn from this study.

Given these limited data, 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 (389).

For patients who undergo successful coronary intervention with or without stent placement before planned noncardiac surgery, there is uncertainty regarding how much time should pass before the noncardiac procedure is performed. Delaying noncardiac surgery for more than 6 to 8 weeks increases the chance that restenosis at the angioplasty site will have occurred and thus theoretically increases the chances of perioperative ischemia or MI. However, performing the surgical procedure too soon after the PCI procedure might also be hazardous. Arterial recoil and/or acute thrombosis at the site of balloon angioplasty is most likely to occur within hours to days after coronary angioplasty. Therefore, delaying surgery for at least a week after balloon angioplasty to allow for healing of the vessel injury at the balloon treatment site has theoretical benefits. If a coronary stent is used in the revascularization procedure (as they are currently in the majority of percutaneous revascularization procedures), further delay may be beneficial. Stent thrombosis is most common in the first 2 weeks after stent placement and is exceedingly rare (less than 0.1% of most cases) more than 2 and certainly more than 4 weeks after stent placement (299,300). Given that stent thrombosis remains a very morbid event, resulting in Q-wave MI or death in the majority of patients in whom it occurs, and given that the risk of stent thrombosis diminishes after endothelialization of the stent has occurred (which generally takes 4 to 8 weeks), it appears reasonable to delay elective noncardiac surgery for 2 weeks and ideally 4 weeks to allow for at least partial endothelialization of the stent, but

not for more than 6 weeks or 8 weeks, when restenosis begins to occur (if it is to occur). A retrospective study indicates that the frequency of stent thrombosis when elective noncardiac surgery is performed within 2 weeks of stent placement is very high, as is the frequency of MI and death (301). A thienopyridine (ticlopidine or clopidogrel) is generally administered to stent patients (with aspirin) for 2 to 4 weeks because these drugs reduce stent thrombosis. The thienopyridines (and aspirin as well) inhibit platelet aggregation and therefore increase the risk of bleeding. These medications may increase risk of perioperative surgical bleeding but decrease the risk of stent thrombosis. For this reason, delaying surgery 2 to 4 weeks after stent placement allows their use to reduce coronary thrombosis. Then, after stoppage, the noncardiac surgery can be performed. Consistent with this notion, the ongoing Veterans Administration trial investigating the role of PCI before vascular surgery has stipulated that a minimum of 2 weeks elapse after stent placement before surgery is performed (295). Once the antiplatelet agents are stopped, their effects do not diminish immediately. It is for this reason that some surgical teams request a week's delay before proceeding to surgery.

Similarly, there is little evidence to show how long a more distant PCI (e.g., months to years before noncardiac surgery) protects against perioperative MI or death. Because coronary restenosis is unlikely to occur more than 8 to 12 months after PCI (whether or not a stent is used), it is reasonable to expect ongoing protection against untoward perioperative ischemic complications in asymptomatic, active patients who had been symptomatic prior to complete percutaneous coronary revascularization more than 8 to 12 months previously.

There are data that permit comparison of the protective effects of revascularization with CABG and balloon angioplasty before noncardiac surgery. In the Bypass Angioplasty Revascularization Investigation (BARI), patients with multivessel coronary disease were randomly assigned to undergo balloon angioplasty or CABG (302). In an ancillary study of BARI, the results of 1049 surgeries performed in 501 patients subsequent to their enrollment and revascularization procedure in BARI were analyzed; 250 patients had undergone CABG and 251 had undergone angioplasty (303). The median time from the most recent coronary revascularization procedure to noncardiac surgery was 29 months. The results of the study reveal that the frequency of death or MI was low in patients with multivessel disease who had undergone balloon angioplasty or CABG (1.6% in both groups), and there was no difference in the length of hospitalization or hospital cost. The risk of death or MI was lower when the noncardiac surgery was performed less than 4 years after coronary revascularization (0.8% vs. 3.6% in patients undergoing surgery 4 or more years after coronary revascularization). These data do not provide insight into which patients require preoperative coronary revascularization, but they do suggest that the risk of perioperative infarction or death is approximately equal in patients who have undergone angioplasty or CABG if they had been amenable to either type of coronary revascularization procedure.

B. Perioperative Medical Therapy

1. Summary of Evidence

Several randomized trials have examined the impact of medical therapy begun just before surgery on reducing cardiac events. Most are single-center trials with relatively small numbers of subjects. These studies have evaluated beta blockers, nitroglycerin, the calcium channel blocker diltiazem, as well as alpha agonists (Table 11).

Two recent randomized, double-blinded trials looked at the effect of perioperative beta blockers on cardiac events surrounding surgery. Poldermans et al examined the effect of bisoprolol on patients at high risk for perioperative cardiac complications (252). Of 846 patients with risk factors for cardiac disease and scheduled for vascular surgery, 173 were found to have an abnormal dobutamine stress echocardiogram (DSE). Of these patients, 61 were excluded from further study owing to marked abnormalities on DSE or because they were already taking beta blockers. The remaining 112 patients were randomized to bisoprolol or placebo perioperatively. The rates of cardiac death (3.4% vs. 17%; p=0.02) and nonfatal MI (0% vs. 17%; p less than 0.001) were lower for the bisoprolol vs. placebo groups, respectively. Generalizability of this study is limited by the unblinded design and the exclusion of all but the highest-risk patients. Also, patients began taking bisoprolol a mean of 37 days before surgery, with adjustments made based on heart rate.

Boersma et al subsequently reanalyzed the total cohort of 1351 consecutive patients enrolled in this randomized trial of bisoprolol (304). Forty-five patients had perioperative cardiac death or nonfatal MI. Eighty-three percent of patients had fewer than 3 clinical risk factors. Among this subgroup, patients receiving beta blockers had a lower risk of cardiac complications (0.8% [2/263]) than those not receiving beta blockers (2.3% [20/855]). In patients with 3 or more risk factors (15%), those taking beta blockers who had a DSE demonstrating 4 or fewer segments of new wall-motion abnormalities had a significantly lower incidence of cardiac complications (2.3% [2/86]) compared with those not receiving beta-blocker therapy (10.6% [12/121]). Moreover, among patients with more extensive ischemia on DSE (5 or more segments), there was no difference in the incidence of cardiac events (4 of 11 for those taking beta blockers vs. 5 of 15 for those not taking beta blockers). Therefore, beta-blocker therapy was beneficial in all but the subset of patients with more extensive ischemia.

One must also be cautious about inferring a class effect from this observation about bisoprolol and be mindful of the course of therapy used. The Multicenter Study of Perioperative Ischemia Research Group (251,305) randomized 200 patients undergoing general surgery to a combination of intravenous and oral atenolol vs. placebo for 7 days. Although they found no difference in perioperative MI or death, they reported significantly fewer episodes of ischemia by continuous monitoring (24% vs. 39%; p=0.03) in the atenolol and placebo groups, respectively. They then followed up these patients after discharge and documented fewer deaths in the atenolol group over the subsequent 6 months (1% vs. 10%; p less than 0.001). It is not clear why such a brief course of therapy could exert such delayed effect, and the study did not control for other medications given either before or after surgery. ACE inhibitor and beta-blocker use preoperatively differed significantly between study groups.

More limited studies have also examined the use of perioperative beta blockers. Stone et al (55) gave oral beta 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 et al (186) gave oral metoprolol immediately before surgery, followed by 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 authors reported less intraoperative ischemia in patients treated with oral metoprolol before peripheral vascular surgery (58). Yeager et al (306) reported a case-control analysis of their experience with perioperative MI during vascular surgery, comparing 53 index cases of perioperative MI with 106 matched controls. They found a strong association of beta-blocker use with a decreased likelihood of MI (odds ratio 0.43; p=0.01). Raby et al (307) demonstrated in 26 vascular surgery patients randomized to a protocol of heart rate suppression with intravenous esmolol that the esmolol group had fewer episodes of ischemia than controls (33% vs. 72%; p=0.055).

Several recent studies examined the role of alpha agonists (clonidine and mivazerol) in perioperative cardiac protection. Mivazerol (4 mcg per kg) was given during the first 10 minutes followed by infusion. Oliver et al (308) reported a large, randomized, placebo-controlled, multicenter trial of the alpha2-agonist mivazerol in perioperative use. They randomized 2854 patients with known CAD or significant risk factors who were undergoing noncardiac surgery to a 1.5 mcg per kg per h infusion of mivazerol or placebo (duration of infusion was 72 hours postoperatively). Among patients with an established history of CAD who were undergoing general surgical procedures, the rate of MI was no different between the mivazerol and placebo groups, but the cardiac death rate was reduced (13/946 vs. 25/941; p=0.04). Among patients undergoing vascular procedures, both cardiac death rate (6/454 vs. 18/450; p=0.017) and the combined end point of death or MI (44/454 vs. 64/450; p=0.037) were significantly reduced. The Multicenter Study of Perioperative Ischemia Research Group (309) also reported the results of a placebo-controlled, randomized, double-blind study of perioperative mivazerol. Three hundred patients with known CAD undergoing noncardiac surgery were randomized to high-dose (1.5 mcg per kg per h) or low-dose (0.75 mcg per kg per h) mivazerol or placebo. No differences in perioperative death or MI were observed, but the high-dose group had significantly less myocardial ischemia than the placebo group (20/98 vs. 35/103; p=0.026). Finally, 2 randomized, placebo-

Table 11. Perioperative Prophylactic Anti-Ischemic Medications and Cardiac Morbidity

Author	Procedure	n	Control	Drug	Ischemia* Control	Ischemia* Drug	MI Control	MI Drug	Death Control	Death Drug
Nitroglycerin										
Coriat 1984 (183)	Carotid endarterectomy	45	0.5 mcg per kg per min nitroglycerin	1 mcg per kg per min nitroglycerin intraoperatively	14/22 (64%)	4/23* (17%)	0/22 (0)	0/23 (0)		
Dodds 1993 (184)	Noncardiac	45	Placebo	0.9 mcg per kg per min nitroglycerin intraoperatively	7/22 (32%)	7/23 (30%)	1/22 (5%)	0/23 (0)		
Calcium channel blockers										
Godet 1987 (185)	Vascular	30	Placebo	3 mcg per kg per min diltiazem intraoperatively	11/15 (73%)	6/15 (40%)	0/15 (0)	0/15 (0)		
Beta-adrenergic blockers										
Pasternack 1987 (186)	Abdominal aortic aneurysmorrhaphy	83	Case-control	50 mg PO metoprolol preoperatively			9/51 (17.6%)	1/32† (3.1%)		
Pasternack 1989 (58)	Vascular	200	Unblinded	50 mg PO metoprolol preoperatively	1.8+3.2* episodes	0.8+1.6 episodes				
Stone 1988 (55)	Noncardiac Mild hypertension	128	Placebo	labetalol atenolol olprenolol PO preoperatively	11/39 (28%)	2/89* (2%)	0/39 (0)	0/89 (0)		
Poldermans 1999 (252)	Vascular	112	Unblinded	5 to 10mg PO bisoprolol			9/53 (17%)	0/59 (0)	9/53 (17%)	2/59 (3%)
Raby 1999 (307)	Vascular	26	Placebo	IV esmolol	8/11 (13%)	5/15 (33%)				
Wallace 1998 (305)/ Mangano 1996 (251)	Noncardiac	200	Placebo	10 to 20 mg IV or 50 to 100 mg PO atenolol	39/101 (39%)	24/99 (24%)			(at 6 months) 10/101 (10%)	1/99 (1%)
Alpha agonists										
McSPI Group 1997 (309)	Noncardiac	300	Placebo	0.75 mcg per kg per h 1.5 mcg per kg per h mivazerol	35/103 (34%)	20/98 (20%)	6/103 (6%)	2/98 (2%)		
Ellis 1994 (311)	Noncardiac	61	Placebo	0.2 to 0.3 mcg clonidine	5/24 (21%)	1/28 (4%)				
Oliver 1999 (308)	Noncardiac Vascular	1897 904	Placebo	1.5 mcg per kg per h mivazerol			79/941 (8%) 53/540 (10%)	78/946 (8%) 42/454 (9%)	25/940 (3%) 18/450 (4%)	13/946 (1%) 6/454 (1%)
Stuhmeier 1996 (310)	Vascular	297	Placebo	2 mcg per kg PO clonidine	59/152 (39%)	35/145 (24%)	4/152 (3%)	0/145 (0)	1/152 (1%)	2/145 (1%)

IV indicates intravenous; MI, myocardial infarction; PO, by mouth.
*Myocardial ischemia.
†p less than 0.05 for drug vs. control.

controlled studies of clonidine for perioperative myocardial protection were performed in 297 patients undergoing vascular surgery (310) and 61 patients undergoing general surgery (311). Both demonstrated a significant decrease in the incidence of myocardial ischemia (35/145 vs. 59/152, p less than 0.01, and 1/28 vs. 5/24, p=0.05, respectively). There have been only 2 studies examining the role of calcium channel blockers in this situation. These studies are too small to allow definitive conclusions (Table 11).

The use of nitrates is discussed in the section on intraoperative management (Section VIII).

2. Recommendations

There are still 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. Most are insufficiently powered to address the effect on outcome of MI or cardiac death and rely on the surrogate end point of ECG ischemia to show effect. Current studies, however, suggest that appropriately administered beta blockers reduce perioperative ischemia and may reduce the risk of MI and death in high-risk patients. When possible, beta blockers should be started days or weeks before elective surgery, with the dose titrated to achieve a resting heart rate between 50 and 60 beats per minute. Perioperative treatment with alpha2 agonists may have similar effects on myocardial ischemia, MI, and cardiac death. Clearly, this is an area where further research would be valuable.

Recommendations for Perioperative Medical Therapy

Class I
1. **Beta blockers required in the recent past to control symptoms of angina or patients with symptomatic arrhythmias or hypertension.**
2. **Beta blockers: patients at high cardiac risk owing to the finding of ischemia on preoperative testing who are undergoing vascular surgery.**

Class IIa
    Beta blockers: preoperative assessment identifies untreated hypertension, known coronary disease, or major risk factors for coronary disease.

Class IIb
    Alpha2 agonists: perioperative control of hypertension, or known CAD or major risk factors for CAD.

Class III
1. **Beta blockers: contraindication to beta blockade.**
2. **Alpha2 agonists: contraindication to alpha2 agonists.**

C. 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 care for the patient through pregnancy, labor, and surgical delivery. Excessive changes in intravascular volume should be avoided (see also Section III, "Valvular Heart Disease").

D. Arrhythmia and Conduction Disturbances

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 or symptomatic arrhythmias, electrophysiologic testing and catheter ablation, particularly for supraventricular arrhythmias, may be indicated to prevent arrhythmia recurrence (190,191,312). 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, beta-adrenergic blockers, or calcium channel blockers. Among these 3 types of medications, digitalis is the least effective agent, and beta blockers are the most effective agent for controlling the ventricular response during atrial fibrillation (313). An additional benefit of beta blockers is that they have been shown to accelerate the conversion of postoperative supraventricular arrhythmias to sinus rhythm as compared with diltiazem (314). In patients with atrial fibrillation who are taking 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 tachycardia, usually do not require therapy unless they are associated with hemodynamic compromise or occur in the presence of ongoing or threatened myocardial ischemia or left ventricular dysfunction. Studies have shown that although nearly half of high-risk patients undergoing noncardiac surgery have frequent premature ventricular contractions or asymptomatic nonsustained ventricular tachycardia, the presence of these ventricular arrhythmias is not associated with an increase in nonfatal MI or cardiac death (240,241). Nevertheless, the presence of an arrhythmia in the preoperative setting should provoke a search for underlying cardiopulmonary disease, ongoing myocardial ischemia or infarction, drug toxicity, or metabolic derangements. Physicians should also have a low threshold at which they institute prophylactic beta-blocker therapy in patients at increased risk of developing a perioperative or postoperative arrhythmia (including those in whom arrhythmias are present during the preoperative evaluation). Several recent studies have demonstrated that beta-blocker therapy can reduce the incidence of arrhythmias during the perioperative period (250,259).

Sustained or symptomatic ventricular tachycardia should be suppressed preoperatively with intravenous lidocaine, procainamide, or amiodarone, and a thorough search should be conducted for underlying causes and appropriate short- and long-term therapy. 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).

E. Implanted Pacemakers and ICDs

It is important to be aware of the many potential adverse interactions between electrical/magnetic activity and pacemaker or ICD function that may occur during the operative period (see Section III). These interactions result from electrical current generated by electrocautery or cardioversion, as well as the impact of metabolic derangements, antiarrhythmic agents, and anesthetic agents on pacing and sensing thresholds. The probability of these adverse interactions can be minimized if certain precautions are taken. Although this topic has been analyzed in a number of review articles and book chapters, no formal guidelines have been developed (315-318).

Electrocautery involves the use of radiofrequency current to cut or coagulate tissues. It is usually applied in a unipolar fashion between the cautery device and an indifferent plate attached to the patient's skin. The potential for electrical

magnetic interference with an implanted device is related to the amount of generated current in the vicinity of the pacemaker or ICD device. In general, high current is generated if the cautery device is close to the pacemaker, particularly if the current path of the cautery lies along the axis of the pacemaker or ICD lead. The electrical current generated by electrocautery can cause a variety of responses by the implanted device, including the following: (1) temporary or permanent resetting to a backup, reset, or noise-reversion pacing mode (i.e., a dual-chamber pacemaker may be reset to VVI pacing at a fixed rate); (2) temporary or permanent inhibition of pacemaker output; (3) an increase in pacing rate due to activation of the rate-responsive sensor; (4) ICD firing due to activation by electrical noise; or (5) myocardial injury at the lead tip that may cause failure to sense and/or capture. Cardioversion can have similar effects on pacemaker or ICD function. Although the probability of any of these adverse interactions occurring has fallen owing to the almost universal use of bipolar leads (which reduces the probability of electrical-magnetic interference) and improved pacemaker and ICD design, they still do occur (315-318).

The likelihood and potential clinical impact of adverse interactions occurring in patients with ICDs and pacemaker devices will be influenced by a number of factors, including whether the pacemaker has unipolar or bipolar leads, whether the electrocautery is bipolar or unipolar, the relative distance from and orientation of the electrocautery relative to the pacemaker and pacemaker lead, and whether the patient is pacemaker dependent. These factors, combined with the urgency of surgery and the availability of expertise in pacing and/or ICDs, will ultimately determine the type and extent of evaluation that is performed. However, under optimal circumstances, several general recommendations can be made. Patients with implanted ICDs or pacemakers should have their device evaluated before and after surgical procedures. This evaluation should include determination of the patient's underlying rhythm and interrogation of the device to determine its programmed settings and battery status. If the pacemaker is programmed in a rate-responsive mode, this feature should be inactivated during surgery. If a patient is pacemaker dependent, pacing thresholds should be determined if the patient has not been evaluated recently in a pacemaker clinic. ICD 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. If QRS complexes cannot be seen during electrocautery, other methods of determining heart rate should be monitored to be certain device inhibition is not present. Finally, if emergent cardioversion is required, the paddles should be placed as far from the implanted device as possible and in an orientation likely to be perpendicular to the orientation of the device leads (i.e., anterior-posterior paddle position is preferred).

F. Preoperative Intensive Care

1. 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.

2. Summary of Evidence

Only 2 studies have 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. Berlauk et al randomly assigned 89 patients undergoing infrainguinal arterial bypass procedures to groups that received a pulmonary artery catheter and (1) preoperative hemodynamic optimization overnight in the intensive care unit, (2) hemodynamic optimization 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. Similarly, Ziegler et al found no differences in intraoperative or perioperative cardiac complications between vascular surgery patients randomly assigned to preoperative pulmonary catheter-guided hemodynamic optimization vs. routine care (319).

3. Recommendations

Although no benefit has been shown, some experienced clinicians believe that preoperative preparation in an intensive care unit may benefit certain high-risk patients, particularly those with decompensated HF. Preparation of such patients should occur under close supervision.

G. 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; HF; 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 (320). The choice of prophylactic measure or agent—graded-compression elastic stockings, low-dose subcutaneous heparin, low-molecular-weight heparin, warfarin, or intermittent pneumatic compression—will depend on the risk of venous thromboembolism and the type of surgery planned. Table 12 provides published recommendations for various types of surgical procedures (320).

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). Patients with this condition may be at increased risk of perioperative cardiac complications, even for a given degree of coronary disease (321). This may warrant particular attention to the preoperative evaluation and intraoperative therapy of such patients. 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 monitoring, ventilation, and analgesia. Therefore, a discussion of these issues before the planned surgery will allow for a smooth transition through the perioperative period.

A. Choice of Anesthetic Technique and Agent

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

Table 12. General Guidelines for Perioperative Prophylaxis for Venous Thromboembolism*

Type of Patient/Surgery	Recommendation
Minor surgery in a patient less than 40 years old with no correlates of venous thrombo-embolism risk†	Early ambulation
Moderate-risk surgery in a patient more than 40 to 60 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 less than 40 to 60 years old with clinical conditions associated with venous thromboembolism risk, or older than 60 years old without risk factors	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 thrombo-embolism risk	LDH, LMWH, or dextran combined with IPC. In selected patients, perioperative warfarin (INR 2 to 3) may be used.
Total hip replacement	LMWH (postoperative, subcutaneous twice daily, fixed dose unmonitored) or warfarin (INR 2 to 3, 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 unmoni-tored) or warfarin (INR 2 to 3). IPC may provide additional benefit.
Intracranial neurosurgery	IPC with or without ES. Consider addition of LDH or LMWH in high-risk patients.
Acute spinal cord injury with lower-extremity paralysis	LMWH for prophylaxis. Warfarin may also be effective. ES and IPC may have benefit when used with LMWH.
Patients with multiple trauma	LMWH when feasible; serial surveillance with duplex ultrasonography may be useful. In selected very-high-risk patients, consider prophylactic caval filter. If LMWH not feasible, IPC may be useful.

ES indicates graded-compression elastic stockings; INR, international normalized ratio; IPC, intermittent pneumatic compression; LDH, low-dose subcutaneous heparin; LMWH, low-molecular-weight heparin.
*Developed from Clagett et al. *Chest* 1998;114:531S-60S.
†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; heart failure; myocardial infarction; stroke; fracture(s) of the pelvis, hip, or leg; hypercoagulable states; and possibly high-dose estrogen use.

study of unselected patients, coexisting disease and surgical procedure were the most important determinants of outcome (202). It appears there is no one best myocardium-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. Because 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 most common agents—halothane, enflurane, isoflurane, and sevoflurane—did not influence outcome in randomized trials (206). Desflurane, one of the newer inhalational agents, has been

associated with an increased incidence of myocardial ischemia compared with a narcotic-based anesthetic in patients undergoing CABG, although the incidence of MI was not different (322).

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. A total of 5 stud-

ies have been published (203-207) that evaluate regional vs. general anesthesia for high-risk patients undergoing noncardiac surgery. No difference in outcome was detected in any of these studies.

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 safety margin. 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.

B. 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 differing combinations of general and epidural anesthesia and intravenous and epidural analgesia (323-327). The patients having epidural anesthesia/analgesia have demonstrated lower opiate dosages, better ablation of the catecholamine response, and a less hypercoagulable state (328,329). In 1 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 2 other studies (205,207,327). In a study of 124 patients undergoing aortic surgery, there was no difference in the incidence of myocardial ischemia in patients randomized to postoperative intravenous analgesia vs. epidural analgesia (326). Most important, an effective analgesic (i.e., one that blunts the stress response) regimen must be included in the perioperative plan.

C. Intraoperative Nitroglycerin

1. 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.

2. Summary of Evidence

Four controlled studies have evaluated the value of prophylactic nitroglycerin infusions for high-risk patients, including 2 studies in noncardiac surgery patients (Table 12) (183,184,208,209). Only 1 study, performed in patients with stable angina undergoing carotid endarterectomy, demonstrated a reduced incidence of intraoperative myocardial ischemia in the group receiving 1 mcg per kg per minute of nitroglycerin. Neither of the 2 small studies demonstrated any reduction in the incidence of MI or cardiac death.

Recommendations for Intraoperative Nitroglycerin

Class I
   High-risk patients previously taking nitroglycerin who have active signs of myocardial ischemia without hypotension.

Class IIb
   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.

D. Use of TEE

1. 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 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.

2. 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 2 recent studies from the same group, intraoperative wall-motion abnormalities were poor predictors of cardiac morbidity (210,211). In 1 study involving 322 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).

3. 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.

4. Recommendations

Currently there is insufficient evidence to determine cost-effectiveness of TEE for its use as a diagnostic monitor or to guide therapy during noncardiac surgery; however, the routine use of TEE in noncardiac surgery does not appear warranted. Guidelines for the appropriate use of TEE have been developed by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists (330).

E. Maintenance of Body Temperature

Hypothermia is common during the perioperative period in the absence of active warming of patients. In a retrospective analysis of a prospective randomized trial comparing 2 different anesthetic techniques for infrainguinal revascularization surgery, hypothermia was associated with an increased risk of myocardial ischemia compared with patients who had a core temperature greater than 35.5 degrees C in the postanesthesia care unit (331). Several methods of maintaining normothermia are available in clinical practice, the most widely studied being forced-air warming.

1. Summary of Evidence

One randomized clinical trial has been performed in 300 high-risk patients undergoing noncardiac surgery in which patients were randomized to active warming via forced air (normothermic group) vs. routine care (332). Perioperative morbid cardiac events occurred less frequently in the normothermic group than in the hypothermic group (1.4% vs. 6.3%; p=0.02). Hypothermia was an independent predictor of morbid cardiac events by multivariate analysis (relative risk, 2.2; 95% CI, 1.1 to 4.7; p=0.04), indicating a 55% reduction in risk when normothermia was maintained.

F. 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 have documented its use in patients with unstable coronary syndromes or severe CAD undergoing urgent noncardiac surgery (212,213,333,334). Although the rate of cardiac complications is low compared with other series of patients at similarly high risk, there are no randomized trials to assess its true effectiveness. Additionally, the use of intra-aortic balloon counterpulsation is associated with complications, particularly in patients with peripheral vascular disease.

1. Recommendations

There is currently insufficient evidence to determine the benefits vs. risks 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 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.

A. *Intraoperative and Postoperative Use of Pulmonary Artery Catheters*

1. 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 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 beta-adrenergic sympathetic blockade. In particular, patients with signs and symptoms of HF preoperatively, who have a very high (35%) postoperative incidence of HF, might benefit from invasive hemodynamic monitoring (67).

2. 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, relatively few controlled studies have evaluated pulmonary artery catheterization in relation to clinical outcomes. Randomized trials have evaluated the routine use of pulmonary artery catheters vs. central venous pressure catheters or selective use of monitoring in abdominal aortic surgery and in elective vascular surgery. In studies using appropriate patient selection, no differences in cardiac morbidity (MI, cardiac death) were detected (216,217,319, 335,336). 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). Polanczyk et al performed a prospective cohort study of 4059 patients aged 50 years or older who underwent major elective noncardiac procedures with an expected length of stay of 2 or more days (337). Major cardiac events occurred in 171 patients, and those who underwent perioperative pulmonary artery catheterization had a three-fold increased incidence of major postoperative cardiac events (34 [15.4%] vs. 137 [3.6%]; p less than 0.001). In a case-control analysis of a subset of 215 matched pairs of patients who did and did not undergo pulmonary artery catheterization, adjusted for propensity of pulmonary artery catheterization and type of procedure, patients who underwent perioperative pulmonary artery catheterization also had increased risk of postoperative congestive HF (odds ratio, 2.9; 95% CI, 1.4 to 6.2) and major noncardiac events (odds ratio, 2.2; 95% CI, 1.4 to 4.9) (337). Iberti et al demonstrated in a multicenter survey that physicians' understanding of pulmonary

artery catheterization data is extremely variable, which may account for the higher rate of postoperative congestive HF and greater perioperative net fluid intake (338).

3. Recommendations

Current evidence does not support routine use of a pulmonary artery catheter perioperatively. Although evidence from controlled trials is scant and a large-scale cohort study demonstrated potential harm, the use of pulmonary artery catheters may benefit high-risk patients. This is in keeping with practice parameters for the intraoperative use of a pulmonary artery catheter published by the American Society of Anesthesiologists (218). These parameters approach the decision to place the pulmonary artery catheter as the interrelationship among 3 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. Physician education on the interpretation of the pulmonary artery catheterization data is critical to achieve optimal benefit without harm.

Recommendations for Intraoperative Use of Pulmonary Artery Catheters (218)

Class IIa
   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 (e.g., suprarenal aortic aneurysm repair in a patient with angina).

Class IIb
   Either the patient's condition or the surgical procedure (but not both) places the patient at risk for hemodynamic disturbances (e.g., supraceliac aortic aneurysm repair in a patient with a negative stress test).

Class III
   No risk of hemodynamic disturbances.

B. *Intraoperative and Postoperative Use of ST-Segment Monitoring*

1. General Considerations

Many 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 limited 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 in the identification of ST-segment changes. Because the algorithms

used to measure ST-segment shifts are proprietary, variability in accuracy between the different monitors has been evaluated in several studies compared with off-line analysis of standard Holter recordings (339-341). ST-trending monitors were found to have an average sensitivity and specificity of 74% (range 60% to 78%) and 73% (range 69% to 89%), respectively (340). Several factors have been identified that decreased the accuracy of the monitors, which have been discussed in detail elsewhere. Additionally, the lead system used affects the incidence of ischemia detected, with leads II and V_5 detecting only 80% of all episodes detected by 12-lead ECG (342).

2. 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 an 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 (19,51,219,220). Additionally, postoperative ST-segment changes have been shown to predict worse long-term survival in high-risk patients (214).

In patients at moderate risk for CAD (age less than 45 years without known CAD and only 1 risk factor), the presence of intraoperative and postoperative ST-segment changes was not associated with either ischemia on an exercise stress test or cardiac events within 1 year (343). The total cohort of patients was small, which may limit generalizability of these findings.

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 (221,344). 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.

Thus, although there are data to support the contention that ST-segment monitoring detects ischemia, no studies have addressed the issue of the effect on outcome when therapy is based on the results of ST-segment monitoring.

Recommendations for Perioperative ST-Segment Monitoring

Class IIa

When available, proper use of computerized ST-segment analysis in patients with known CAD or undergoing vascular surgery may provide increased sensitivity to detect myocardial ischemia during the perioperative period and may identify patients who would
benefit from further postoperative and long-term interventions.

Class IIb
Patients with single or multiple risk factors for CAD.

Class III
Patients at low risk for CAD.

C. Surveillance for Perioperative MI

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.

1. General Considerations

Perioperative MI can be documented by assessing clinical symptoms, serial electrocardiography, cardiac-specific biomarkers, comparative ventriculographic studies before and after surgery, radioisotopic studies specific for myocardial necrosis, and autopsy studies. The criteria used to diagnose infarction in various studies differ not only in the level of cardiac biomarkers that determine abnormality but also the frequency with which they are sampled following noncardiac surgery. The cardiac biomarker profile after infarction exhibits a typical rise and fall that differs among different biomarkers. Daily sampling may miss detection of a cardiac biomarker rise (such as MB isoenzyme of creatine kinase [CK-MB], thus underestimating the incidence of perioperative infarction. The ECG criteria used to define infarction may also differ not only in the definition of a Q wave but also with respect to the magnitude of ST-T wave shifts that determine an abnormal response. In the analysis of cardiac biomarker criteria, numerous assays are available to measure CK-MB, cardiac troponin I, and to a lesser extent, cardiac troponin T. CK-MB may be released from noncardiac sources in patients with ischemic limbs or those undergoing aortic surgery, the group at highest risk for a perioperative MI. The use of cardiac troponin I or T offers the potential of enhanced specificity (223,345-350).

2. Summary of Evidence

Very few studies have examined long-term outcome using protocol-specific criteria for perioperative MI after noncardiac surgery. Charlson et al (224) reported on 232 mostly hypertensive or diabetic patients undergoing elective noncardiac surgery. Serial ECGs and 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 et al (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 1,561 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.

The use of cardiac troponin I to examine the diagnosis of perioperative MI was assessed in a series of 96 subjects undergoing vascular surgery and 12 undergoing spinal surgery. Blood samples were obtained every 6 hours for 36 hours postoperatively, and ECGs were acquired daily. The appearance of a new segmental wall-motion abnormality on a postoperative day 3 echocardiogram was used to diagnose perioperative infarction. All 8 patients who underwent vascular surgery and had segmental wall-motion abnormalities had elevated cardiac troponin I levels; 6 had elevated CK-MB. Of 100 patients without new segmental wall-motion abnormalities, 19 had CK-MB elevations; 1 had cardiac troponin I elevation (222). Several studies have examined cardiac troponin T as a marker for perioperative necrosis after noncardiac surgery. Of 772 patients who underwent major noncardiac procedures without major cardiovascular complications during the index hospital admission, 12% and 27%, respectively, had elevated cardiac troponin T and CK-MB values. During 6-month follow-up, 19 subjects had major cardiac complications (14 cardiac deaths, 3 nonfatal MIs, and 2 admissions for unstable angina). The relative risk of cardiac events was 5.4 when cardiac troponin T was elevated, whereas CK-MB did not predict late postdischarge cardiac events (349). In another report (346), the diagnosis of perioperative MI was defined prospectively as total CK-MB greater than 174 units per liter and 2 of the following: (1) CK-2/CK (mass or activity) greater than 5%, (2) Q waves greater than 40 ms and 1 mm deep in 2 contiguous leads, (3) troponin T greater than 0.2 mcg per liter, or (4) a positive pyrophosphate scan. Of 323 patients undergoing noncardiac surgery (13.6% vascular), 18 (5.6%) had a perioperative MI. The incident rate of perioperative MI was 5.3% when the diagnosis included autopsy data, new Q waves, or CK-2 elevation greater than 5% of total CK associated with new ECG changes. The incidence increased to 11.2% when the definition included autopsy data, new Q waves, cardiac troponin T greater than 0.2 mcg per liter, and ECG changes. The MI rate increased to 20.7% when the definition of perioperative MI included autopsy data, new Q waves, or cardiac troponin T greater than 0.2 mcg per liter.

3. Recommendations

Further evaluation regarding the optimal strategy for surveillance and diagnosis of perioperative MI is required. On the basis of current evidence, in patients without documented CAD, surveillance should be restricted to patients who develop perioperative signs of cardiovascular dysfunction. In patients with high or intermediate clinical risk who have known or suspected CAD and who are undergoing high- or intermediate-risk surgical procedures, the procurement of ECGs at baseline, immediately after the surgical procedure, and daily on the first 2 days after surgery appears to be the most cost-effective strategy. Cardiac troponin measurements 24 hours postoperatively and on day 4 or hospital discharge (whichever comes first) should be part of the diagnostic strategy for perioperative MI detection (350). The majority of perioperative MI events will be non-Q wave. Additional research is needed to correlate long-term outcome results to magnitude of isolated cardiac troponin elevations. The diagnosis of MI should be entertained when the typical cardiac biomarker profile is manifest in the immediate postoperative phase. A risk gradient can be based on the magnitude of biomarker elevation and presence or absence of concomitant new ECG abnormalities, hemodynamic instability, and quality and intensity of chest pain syndrome, if present. The ACC and the European Society of Cardiology have provided a redefinition of acute MI based on studies examining cardiac troponins and clinical presentation/outcomes (351). Patients who sustain a perioperative MI should have evaluation of left ventricular function performed before hospital discharge, and standard postinfarction therapeutic medical therapy should be prescribed as defined in the ACC/AHA Acute Myocardial Infarction guidelines (370). Perioperative surveillance for acute coronary syndromes using routine ECG and cardiac serum biomarkers is unnecessary in clinically low-risk patients undergoing low-risk operative procedures.

D. Arrhythmia/Conduction Disease Disorders

Postoperative arrhythmias are often due to remedial noncardiac problems such as infection, hypotension, metabolic derangements, and hypoxia. The approach taken to the acute management of postoperative tachycardias varies depending on the likely mechanism. If the patient develops a sustained regular narrow-complex tachycardia, which is likely due to atrioventricular nodal re-entrant tachycardia or atrioventricular reciprocating tachycardia, the tachycardia can almost always be terminated with vagal maneuvers (Valsalva maneuver or carotid sinus massage) or with intravenous adenosine. Most antiarrhythmic agents (especially beta blockers, calcium channel blockers, and type 1a or 1c antiarrhythmic agents) can be used to prevent further recurrences in the postoperative setting. A somewhat different approach is generally recommended for atrial fibrillation and atrial flutter. The initial approach to management generally involves the use of intravenous digoxin, diltiazem or a beta blocker in an attempt to slow the ventricular response. Among these 3 types of medications, digitalis is least effective and beta blockers most effective for controlling the ventricular response during atrial fibrillation (313). An additional benefit of beta blockers is that they have been shown to accelerate the conversion of postoperative supraventricular

arrhythmias to sinus compared with diltiazem (314). Cardioversion of atrial fibrillation/flutter is generally not recommended for asymptomatic or minimally symptomatic arrhythmias 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 (226-228,352). Unifocal or multifocal premature ventricular contractions do not merit therapy. Very frequent ventricular ectopy or prolonged runs of nonsustained ventricular tachycardia may require antiarrhythmic therapy if they are symptomatic or result in hemodynamic compromise. Patients with an ischemic cardiomyopathy who have nonsustained ventricular tachycardia in the perioperative period may benefit from referral for electrophysiologic testing to determine the need for an ICD (353,354). Ventricular arrhythmias may respond to intravenous beta blockers, lidocaine, procainamide, or amiodarone (186,355-357). Electrical cardioversion should be used for sustained supraventricular or ventricular arrhythmias that cause hemodynamic compromise.

Bradyarrhythmias that occur in the postoperative period are usually secondary to some other cause, such as certain medications, 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. 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. The indications are the same as those for elective permanent pacemaker implantations.

X. POSTOPERATIVE AND LONG-TERM MANAGEMENT

It has been recognized since the early 1980s that cardiac events are a frequent outcome in postoperative vascular surgery patients (358). Over the course of the last decade, advances in preoperative, intraoperative, and postoperative management have resulted in better patient outcomes in noncardiac (especially vascular) surgery (359,360). This is due to a number of factors that involve better detection of underlying CAD in preoperative patients, as well as greater skill and experience in the perioperative care of such patients. The combination of improved medical therapy, which typically includes beta blockers, aspirin, and lipid-lowering agents, and coronary revascularization in appropriate cases should result in improved event-free survival.

Despite optimal perioperative management, some patients will experience perioperative MI, which is associated with a 40% to 70% mortality (361). The reason for the high mortality is undoubtedly multifactorial and related in part to signif-icant comorbidity in such patients. However, the inability to administer reperfusion therapy undoubtedly contributes to the high mortality associated with MI early after noncardiac surgery.

Many perioperative MIs are a result of a sudden thrombotic coronary occlusion, as is the case with MI that occurs in the nonoperative setting (362,363). Among eligible patients, rapid reperfusion therapy is the cornerstone of therapy (364). Thrombolytic therapy markedly reduces mortality when administered to patients who have MI unrelated to a surgical procedure. However, because of the substantial risk of bleeding at the surgical site, patients who have recently undergone surgery have been excluded from all trials of thrombolytic therapy, and recent surgery is generally considered a strong contraindication to thrombolytic therapy. Although thrombolytic therapy has been administered to patients for life-threatening pulmonary embolus shortly after noncardiac surgery, the thrombolytic dosage has generally been less and has been administered over a longer time interval than is standard for the treatment of acute MI (365,366). Immediate coronary angioplasty has been favorably compared with thrombolytic therapy in the treatment of acute MI (367), but of greater importance is that the risk of bleeding at the surgical site is believed to be less with direct angioplasty than with thrombolytic therapy. Only a single small study (368) has evaluated the role of immediate angiography and angioplasty among 48 patients who were believed able to take aspirin and intravenous heparin, and to undergo immediate angiography and PCI. This study suggested that such a strategy is feasible and may be beneficial. However, time to reperfusion is a critical determinant of outcome in acute MI, and any hope of benefiting patients who have a perioperative acute MI due to an acute coronary occlusion requires that angiography and revascularization be rapidly performed (i.e., within 12 hours of symptom onset) (368,369). In addition, these reperfusion procedures should not be performed routinely on an emergency basis in postoperative patients in whom MI is not related to an acute coronary occlusion. For instance, in cases of increased myocardial demand in a patient with postoperative tachycardia or hypertension, lowering the heart rate or blood pressure is likely to be of greater benefit, and certainly less risk. There is also no evidence to support immediate angiography in patients found to have an elevated cardiac marker, such as CK-MB band or cardiac troponin, who are otherwise clinically stable.

Although reperfusion therapy is an important therapy in acute ST-segment–elevation MI, the emphasis on reperfusion therapy should not detract from pharmacological therapy, which is also very important and has been shown to reduce adverse events in such patients, as well as in patients with non–ST-elevation acute coronary syndromes. Therapy with aspirin, a beta blocker, and an ACE inhibitor, particularly for patients with low ejection fractions or anterior infarctions, may be beneficial, whether or not the patients are rapidly taken to the catheterization laboratory (370). An extensive evidence-based review of therapy for acute MI can be found in the ACC/AHA guidelines for the management of patients with acute MI (370). Although not intended specifically for

patients who have a postoperative MI, they are nonetheless appropriate for these high-risk patients. Similarly, the ACC/AHA guidelines for unstable angina represent an important template for management of this condition in the postoperative setting (371).

In the approach to the long-term postoperative management of noncardiac surgery patients, one should first appreciate that the occurrence of an intraoperative nonfatal MI carries a high risk for future cardiac events that are often dominated by cardiovascular death (214,372). Therefore, patients who sustain acute myocardial injury in the perioperative or postoperative period should receive careful medical evaluation for residual ischemia and overall left ventricular function. The ACC/AHA guidelines for post-MI evaluation in these types of patients should be followed as soon as possible after surgical recovery. The use of pharmacological stress (26) or dynamic exercise (if feasible) for risk stratification should also be a priority in patients to help determine who would benefit from coronary revascularization. In all cases, the appropriate evaluation and management of complications and risk factors such as angina, HF, hypertension, hyperlipidemia, cigarette smoking, diabetes (hyperglycemia), and other cardiac abnormalities should commence before hospital discharge. It is also important to communicate these new observations and determinations of cardiac status and risk to the physician who will be responsible for arranging subsequent medical care and follow-up.

It is also appropriate to recommend secondary risk reduction in the relatively large number of elective-surgery patients in whom cardiovascular abnormalities are detected during preoperative evaluations. Although the occasion of surgery is often taken as a specifically high-risk time, most of the patients who have known or newly detected CAD during their preoperative evaluations will not have any events during elective noncardiac surgery. A recent review (261) of a national Medicare population sample identified a cohort of patients (n=6895) who underwent elective vascular surgery during a 17-month period in 1991 and 1992. The authors noted a relatively high mortality rate (15%) at 1 year of follow-up among patients who did not undergo preoperative stress testing. However, in those patients (19%) undergoing preoperative stress testing with or without coronary bypass surgery, the mortality rate was lower (less than 6%). In other follow-up studies (372,373) of vascular surgery patients who were followed up for a mean of 40 to 48 months, cardiac events were significantly more frequent in those who had a reduced LVEF of less than 35% or 40% and who demonstrated ischemia of at least moderate size on dipyridamole-thallium imaging. Therefore, it is important to consider which preoperative clinical risk factors and noninvasive testing parameters can be used to help predict long-term cardiac risk.

Most of the long-term follow-up studies in postoperative patients involve vascular surgery. Fig. 2 summarizes some large follow-up studies in patients undergoing major vascular surgery who were followed up over the next 2 to 5 years for subsequent cardiac death or MI. It is clear that preopera-

tive clinical risk assessment as determined by the Goldman criteria, LVEF, coronary angiography, dipyridamole-thallium imaging, and dobutamine echocardiography can also be used to evaluate long-term cardiac risk. Cardiac mortality in the postoperative period increases with higher clinical risk, lower LVEF (less than 35%), multivessel CAD, abnormal thallium scans, or multiple ischemic segments on dobutamine echocardiography studies. Other studies (374-376) also confirm the value of semiquantitative analysis of myocardial perfusion imaging when using these types of perioperative tests to predict future cardiac events. All these studies have the ability to combine an assessment of myocardial ischemia and left ventricular function into a more useful clinical index.

It is clear from these and other imaging studies (377-379) that the extent of ischemia or reduced ventricular function achieves the best level of prognostic utility for future cardiac events. Overall, a normal or near-normal stress imaging study suggests a relatively small risk, but the positive predictive accuracy of abnormal studies is greatly enhanced by the establishment of a progressive gradient for that abnormality.

Although the perioperative cardiac event rate for renal and liver transplantation is fairly low, the long-term risk for MI or cardiovascular death associated with such transplants often results in referrals for preoperative cardiac consultation and testing. Compared with the data for long-term follow-up in vascular surgery patients, the results in renal and liver transplants are somewhat less compelling. Not all publications support the routine use of cardiac screening to help stratify renal patients according to risk (380), but more recent publications (262,381) have shown significant prognostic value for preoperative stress testing in these patients. This is especially true if there are cardiac risk factors and for patients with diabetes (382). There are only a few reports (264,383) dealing with the evaluation of cardiac risk in liver transplant patients, and the data are not compelling for routine testing. This is most likely because of the very low incidence of cardiac events in these studies. However, until more data are available, it may be prudent to consider preoperative testing in those liver transplant patients who have clinical cardiac risk factors.

These types of observations should encourage us to pay closer attention to the medical outcome of patients seen for perioperative evaluations, especially in the context of vascular surgery. After the preoperative cardiac risk has been determined by clinical or noninvasive testing, most patients will benefit from pharmacological agents to lower low-density lipoprotein cholesterol levels, increase high-density lipoprotein levels, or both. On the basis of expert opinion, the goal should be to lower the low-density lipoprotein level to less than 100 mg per dl (2.6 mmol per dl) (229,384,385).

In general, the indications for additional screening or testing in postoperative patients depend on individual patient characteristics. A recent decision-tree model (244) was constructed to compare cost-effectiveness of various preoperative screening protocols in postoperative vascular surgery patients for up to 5 years after discharge. The best event-free survival and cost-effectiveness ratio were noted for selective

preoperative stress testing (using dipyridamole-thallium imaging) in patients with intermediate clinical risk, whereas high-risk patients were referred to coronary angiography and low-risk patients were sent to elective surgery without further workup. This is the general approach suggested in these guidelines. In addition, another recent report (386) showed that the clinical risk factors used in these guidelines were more sensitive than surgical factors for predicting perioperative cardiac events. These recent studies confirm the importance of clinical evaluations for both the perioperative and long-term follow-up periods. The performance of prospective clinical trials would be an important addition to this overall clinical analysis. Finally, as noted for patients having a perioperative MI, it is important that the physician(s) responsible for the long-term care of the patient be provided with complete 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 opportunity 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. Future research should be directed at determining the value of routine prophylactic medical therapy vs. more extensive diagnostic testing and interventions.

XII. CARDIAC RISK OF NONCARDIAC SURGERY: AREAS IN NEED OF FURTHER RESEARCH

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

- 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

STAFF

American College of Cardiology
Christine W. McEntee, Chief Executive Officer

Paula M. Thompson, MPH, Senior Research Analyst

Sharyn L. Vitrano, Project Manager

Dawn R. Phoubandith, MSW, Project/Publication Manager

Gwen C. Pigman, MLS, Librarian

American Heart Association
M. Cass Wheeler, Chief Executive Officer

Sidney C. Smith, Jr, MD, Chief Science Officer

Kathryn A. Taubert, PhD, Vice President
  Science and Medicine

APPENDIX 1. DEFINITION OF TERMINOLOGY

Acute coronary syndrome – Any constellation of clinical signs or symptoms suggestive of acute myocardial infarction (MI) or unstable angina. This syndrome includes patients with acute MI, ST-segment elevation MI, non–ST-segment elevation MI, enzyme-diagnosed MI, biomarker-diagnosed MI, late ECG-diagnosed MI, and unstable angina. This term is useful to generically refer to patients who ultimately prove to have one of these diagnoses to describe management alternatives at a time before the diagnosis is ultimately confirmed. This term is also used prospectively to identify those patients at a time of initial presentation who should be considered for treatment of acute MI or unstable angina.

Acute myocardial infarction – an acute process of myocardial ischemia with sufficient severity and duration to result in permanent myocardial damage. Clinically, the diagnosis of permanent myocardial damage is typically made when there is a characteristic rise and fall in cardiac biomarkers indicative of myocardial necrosis that may or may not be accompanied by the development of Q waves on the ECG. Permanent myocardial damage may also be diagnosed when histologic evidence of myocardial necrosis is observed on pathologic examination.

Angina pectoris – a clinical syndrome typically characterized by a deep, poorly localized chest, arm, or jaw discomfort that is reproducible and associated with physical exertion or emotional stress and relieved promptly (i.e., less than 5 minutes) by rest or sublingual nitroglycerin. The discomfort of angina is often hard for patients to describe, and many patients do not consider it to be "pain." Patients with unstable angina may have discomfort with all the qualities of typ-

ical angina except that episodes are more severe and prolonged and may occur at rest with an unknown relationship to exertion or stress. In most, but not all, patients these symptoms reflect myocardial ischemia resulting from significant underlying coronary artery disease.

Arrhythmias – irregularity of the heartbeat caused by damage to or defect in the heart tissue and its electrical system. Arrhythmias considered major predictors of increased perioperative cardiovascular risk include high-grade atrioventricular block, symptomatic ventricular arrhythmias in the presence of underlying heart disease, and supraventricular arrhythmias with uncontrolled ventricular rate.

Atypical chest pain – pain, pressure, or discomfort in the chest, neck, or arms not clearly exertional or not otherwise consistent with pain or discomfort of myocardial ischemic origin.

Cardiomyopathy – disease or disorder of the heart muscle that results in weakening and/or stiffness of the heart muscle, heart enlargement, and left ventricular wall changes. Dilated and hypertrophic cardiomyopathy are associated with an increased incidence of perioperative heart failure.

Cerebrovascular disease – a general classification determined by one or more of the following: (1) cerebrovascular accident (stroke), as documented by loss of neurologic function caused by an ischemic event with residual symptoms at least 24 h after onset; (2) reversible ischemic neurologic deficit, as documented by a loss of neurologic function caused by ischemia with symptoms at least 24 h after onset but with complete return of function within 72 h; (3) transient ischemic attack, as documented by a loss of neurologic function caused by ischemia that was abrupt in onset but with complete return of function within 24 h; (4) unresponsive coma greater than 24 h; or 5) noninvasive carotid test with greater than 75% occlusion.

Coronary artery disease – the atherosclerotic narrowing of the major epicardial coronary arteries *(see also "myocardial ischemia")*

Coronary revascularization – includes percutaneous coronary intervention of any type (balloon angioplasty, atherectomy, stent, or other) and/or coronary artery bypass graft.

Functional capacity/functional status – determined by patient's ability to perform activities of daily living, quantified in metabolic equivalents (METs). Perioperative cardiac and long-term risk are increased in patients unable to meet a 4-MET demand during most normal daily activities. 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.

Heart failure – a clinical syndrome characterized in most patients by dyspnea and fatigue at rest and/or with exertion

caused by underlying structural and/or functional heart disease. Manifestations include neuroendocrine activation, sodium and water retention, edema, reflex control abnormalities, vascular and endothelial dysfunction, and skeletal muscle dysfunction.

Hypercholesterolemia – total cholesterol greater than 200 mg per dl, low-density lipoprotein greater than or equal to 130 mg per dl, high-density lipoprotein less than 30 mg per dl, or admission cholesterol greater than 200 mg per dl. Also includes patients with a history of hypercholesterolemia diagnosed and/or treated by a physician.

Hypertension – blood pressure greater than 140 mm Hg systolic or 90 mm Hg diastolic on at least 2 occasions. Also, documented by history of treatment for hypertension with medication, diet, and/or exercise, or current use of antihypertensive pharmacologic therapy.

Ischemic heart disease – a form of heart disease in which the primary manifestations result from myocardial ischemia due to atherosclerotic coronary artery disease. This term encompasses a spectrum of patients ranging from the asymptomatic preclinical phase to acute myocardial infarction and sudden cardiac death.

Likelihood – used in these guidelines to refer to the probability of an underlying diagnosis or outcome.

Myocardial ischemia – inadequate circulation of blood to the heart muscle due to obstructions of heart arteries *(see also "coronary artery disease")*.

Orthostatic hypotension – low blood pressure precipitated by moving from a lying or sitting position to standing up straight. **Postural orthostatic tachycardia syndrome**, a 28 beats-per-minute or greater increase in heart rate on standing, is a type of mild orthostatic intolerance.

Perioperative cardiac evaluation – consideration of cardiac risk due to noncardiac surgery in a variety of patients in preoperative, operative, and postoperative care. The purpose of perioperative cardiac evaluation is to assess the patient's current medical status; make recommendations concerning the evaluation, management, and risk of cardiac problems over the entire perioperative period; and provide a clinical risk profile that can be used in making treatment decisions.

Peripheral vascular disease – a disorder that occurs when arteries are blocked by atherosclerotic plaque. Patients most frequently present with claudication, aching that occurs with walking and subsides with rest.

Previous myocardial infarction – indicates that a patient has had at least 1 documented myocardial infarction 8 or more days before examination. Documented evidence of previous myocardial infarction is defined as at least 2 of the following: (1) prolonged (greater than 20 min) typical chest pain not relieved by rest or nitrates; (2) biochemical evidence of myocardial necrosis (this can be manifested as creatine

kinase-MB greater than upper limit of normal, total creatine kinase greater than 2 times the upper limit of normal, or troponin greater than the upper diagnostic limit); (3) new wall-motion abnormalities; or (4) at least 2 serial ECGs with (a) elevation in ST-T segments documented in 2 or more contiguous leads and/or (b) Q waves that are 0.03 seconds in width or greater than one third of the total QRS complex documented in 2 or more contiguous leads.

Pulmonary hypertension – systolic pulmonary artery pressure greater than 60 mm Hg or pulmonary vascular resistance greater than 260 dyne per sec per cm[5].

Renal failure – renal insufficiency resulting in an increase in serum creatinine to more than 2 mg per dl (or a 50% or greater increase over an abnormal baseline level) measured before the procedure or that requires dialysis.

Risk – high, intermediate, and low risk in these guidelines refer to the probability of future adverse cardiac events, particularly death or myocardial infarction.

Stable angina – angina without a change in frequency or pattern for at least the past 6 weeks. Angina is controlled by rest and/or oral or transcutaneous medications.

Tamponade – fluid in the pericardial space documented by echocardiography or other methods that result in systemic hypotension requiring intervention.

Unstable angina – An acute process of myocardial ischemia that is not of sufficient severity and duration to result in permanent myocardial damage. Patients with unstable angina typically do not present with ST-segment elevation on the ECG and do not release biomarkers indicative of myocardial necrosis into the blood.

Unstable coronary disease – general classification of risk, including recent myocardial infarction with evidence of ischemic risk by clinical symptoms or noninvasive study, unstable or severe angina, or new or poorly controlled ischemia-mediated heart failure.

APPENDIX 2. ABBREVIATIONS

ACC = American College of Cardiology
ACE = angiotensin converting enzyme
AHA = American Heart Association
BARI = Bypass Angioplasty Revascularization Investigation
CABG = coronary artery bypass graft
CAD = coronary artery disease
CASS = Coronary Artery Surgery Study
CHD = coronary heart disease
CI = confidence interval
CK-MB = creatine kinase-MB
DSE = dobutamine stress echocardiogram
ECG = electrocardiogram
HF = heart failure
ICD = implantable cardioverter defibrillator
LVEF = left ventricular ejection fraction
MET = metabolic equivalent
MI = myocardial infarction
PCI = percutaneous coronary intervention
PTCA = percutaneous transluminal coronary angioplasty
TEE = transesophageal echocardiography

REFERENCES

1. Mangano DT. Perioperative cardiac morbidity. Anesthesiology. 1990;72:153-84.
2. Deleted during update.
3. Fleisher LA, Beattie C. Current practice in the preoperative evaluation of patients undergoing major vascular surgery: a survey of cardiovascular anesthesiologists. J Cardiothorac Vasc Anesth. 1993;7:650-4.
4. Wells PH, Kaplan JA. Optimal management of patients with ischemic heart disease for noncardiac surgery by complementary anesthesiologist and cardiologist interaction. Am Heart J. 1981; 102:1029-37.
5. Roger VL, Ballard DJ, Hallett JW Jr, Osmundson PJ, Puetz PA, Gersh BJ. Influence of coronary artery disease on morbidity and mortality after abdominal aortic aneurysmectomy: a population-based study, 1971-1987. J Am Coll Cardiol. 1989;14:1245-52.
6. Hertzer NR. Basic data concerning associated coronary disease in peripheral vascular patients. Ann Vasc Surg. 1987;1:616-20.
7. Hlatky MA, Boineau RE, Higginbotham MB, et al. A brief self-administered questionnaire to determine functional capacity (the Duke Activity Status Index). Am J Cardiol. 1989;64:651-4.
8. Gersh BJ, Rihal CS, Rooke TW, Ballard DJ. Evaluation and management of patients with both peripheral vascular and coronary artery disease. J Am Coll Cardiol. 1991;18:203-14.
9. Jamieson WRE, Janusz MT, Miyagishima RT, Gerein AN. Influence of ischemic heart disease on early and late mortality after surgery for peripheral occlusive vascular disease. Circulation. 1982;66(suppl 1):I-92-7.
10. Ewy GA. The abdominojugular test: technique and hemodynamic correlates. Ann Intern Med. 1988;109:456-60.
11. Butman SM, Ewy GA, Standen JR, Kern KB, Hahn E. Bedside cardiovascular examination in patients with severe chronic heart failure: importance of rest or inducible jugular venous distension. J Am Coll Cardiol. 1993;22:968-74.
12. Goldman L, Caldera DL, Nussbaum SR, et al. Multifactorial index of cardiac risk in noncardiac surgical procedures. N Engl J Med. 1977;297:845-50.
13. Dajani AS, Bisno AL, Chung KJ, et al. Prevention of bacterial endocarditis: recommendations by the American Heart Association. JAMA. 1990;264:2919-22.
14. Nelson AH, Fleisher LA, Rosenbaum SH. Relationship between postoperative anemia and cardiac morbidity in high-risk vascular patients in the intensive care unit. Crit Care Med. 1993;21:860-6.
15. Ashton CM, Petersen NJ, Wray NP, et al. The incidence of perioperative myocardial infarction in men undergoing noncardiac surgery. Ann Intern Med. 1993;118:504-10.
16. Hollenberg M, Mangano DT, Browner WS, London MJ, Tubau JF, Tateo IM. Predictors of postoperative myocardial ischemia in patients undergoing noncardiac surgery: The Study of Peri-

operative Ischemia Research Group. JAMA. 1992;268:205-9.

17. Hubbard BL, Gibbons RJ, Lapeyre AC III, Zinsmeister AR, Clements IP. Identification of severe coronary artery disease using simple clinical parameters. Arch Intern Med. 1992;152:309-12.

18. Lette J, Waters D, Bernier H, et al. Preoperative and long-term cardiac risk assessment: predictive value of 23 clinical descriptors, 7 multivariate scoring systems, and quantitative dipyridamole imaging in 360 patients. Ann Surg. 1992;216:192-204.

19. Mangano DT, Browner WS, Hollenberg M, London MJ, Tubau JF, Tateo IM. Association of perioperative myocardial ischemia with cardiac morbidity and mortality in men undergoing noncardiac surgery: The Study of Perioperative Ischemia Research Group. N Engl J Med. 1990;323:1781-8.

20. Michel LA, Jamart J, Bradpiece HA, Malt RA. Prediction of risk in noncardiac operations after cardiac operations. J Thorac Cardiovasc Surg. 1990;100:595-605.

21. Eagle KA, Coley CM, Newell JB, et al. Combining clinical and thallium data optimizes preoperative assessment of cardiac risk before major vascular surgery. Ann Intern Med. 1989;110:859-66.

22. Detsky AS, Abrams HB, McLaughlin JR, et al. Predicting cardiac complications in patients undergoing non-cardiac surgery. J Gen Intern Med. 1986;1:211-9.

23. Foster ED, Davis KB, Carpenter JA, Abele S, Fray D. Risk of noncardiac operation in patients with defined coronary disease: The Coronary Artery Surgery Study (CASS) registry experience. Ann Thorac Surg. 1986;41:42-50.

24. Cooperman M, Pflug B, Martin EW Jr, Evans WE. Cardiovascular risk factors in patients with peripheral vascular disease. Surgery. 1978;84:505-9.

25. Tarhan S, Moffitt EA, Taylor WF, Giuliani ER. Myocardial infarction after general anesthesia. JAMA. 1972;220:1451-4.

26. Gunnar RM, Passamani ER, Bourdillon PD, et al. Guidelines for the early management of patients with acute myocardial infarction: a report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Subcommittee to Develop Guidelines for the Early Management of Patients with Acute Myocardial Infarction). J Am Coll Cardiol. 1990;16:249-92.

27. Fletcher GF, Balady G, Froelicher VF, Hartley LH, Haskell WL, Pollock ML. Exercise standards: a statement for healthcare professionals from the American Heart Association: Writing Group. Circulation. 1995;91:580-615.

28. Steen PA, Tinker JH, Tarhan S. Myocardial reinfarction after anesthesia and surgery. JAMA. 1978;239:2566-70.

29. Rao TL, Jacobs KH, El-Etr AA. Reinfarction following anesthesia in patients with myocardial infarction. Anesthesiology. 1983;59:499-505.

30. Hertzer NR. Fatal myocardial infarction following peripheral vascular operations: a study of 951 patients followed 6 to 11 years postoperatively. Cleve Clin Q. 1982;49:1-11.

31. Mahar LJ, Steen PA, Tinker JH, Vlietstra RE, Smith HC, Pluth JR. Perioperative myocardial infarction in patients with coronary artery disease with and without aorta/-coronary artery bypass grafts. J Thorac Cardiovasc Surg. 1978;76:533-7.

32. Weiner DA, Ryan TJ, McCabe CH, et al. Prognostic importance of a clinical profile and exercise test in medically treated patients with coronary artery disease. J Am Coll Cardiol. 1984;3:772-9.

33. Nelson CL, Herndon JE, Mark DB, Pryor DB, Califf RM, Hlatky MA. Relation of clinical and angiographic factors to functional capacity as measured by the Duke Activity Status Index. Am J Cardiol. 1991;68:973-5.

34. Myers J, Do D, Herbert W, Ribisl P, Froelicher VF. A nomogram to predict exercise capacity from a specific activity questionnaire and clinical data. Am J Cardiol. 1994;73:591-6.

35. Eagle KA, Rihal CS, Foster ED, Mickel MC, Gersh BJ. Long-term survival in patients with coronary artery disease: importance of peripheral vascular disease. The Coronary Artery Surgery Study (CASS) Investigators. J Am Coll Cardiol. 1994;23:1091-5.

36. Guidelines for coronary angiography: a report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Subcommittee on Coronary Angiography). J Am Coll Cardiol. 1987;10:935-50.

37. Morris CK, Ueshima K, Kawaguchi T, Hideg A, Froelicher VF. The prognostic value of exercise capacity: a review of the literature. Am Heart J. 1991;122:1423-31.

38. Chaitman BR. The changing role of the exercise electrocardiogram as a diagnostic and prognostic test for chronic ischemic heart disease. J Am Coll Cardiol. 1986;8:1195-210.

39. Gianrossi R, Detrano R, Mulvihill D, et al. Exercise-induced ST depression in the diagnosis of coronary artery disease: a meta-analysis. Circulation. 1989;80:87-98.

40. Detrano R, Gianrossi R, Mulvihill D, et al. Exercise-induced ST segment depression in the diagnosis of multivessel coronary disease: a meta analysis. J Am Coll Cardiol. 1989;14:1501-8.

41. Mark DB, Hlatky MA, Harrell FE Jr, Lee KL, Califf RM, Pryor DB. Exercise treadmill score for predicting prognosis in coronary artery disease. Ann Intern Med. 1987;106:793-800.

42. Mark DB, Shaw L, Harrell FE Jr, et al. Prognostic value of a treadmill exercise score in outpatients with suspected coronary artery disease. N Engl J Med. 1991;325:849-53.

43. Guidelines for exercise testing: a report of the American College of Cardiology/American Heart Association Task Force on Assessment of Cardiovascular Procedures (Subcommittee on Exercise Testing). J Am Coll Cardiol. 1986;8:725-38.

44. Alpert JS, Chipkin SR, Aronin N. Diabetes mellitus and silent myocardial ischemia. Adv Cardiol. 1990;37:279-303.

45. Shindo T, Nosaka H, Kimura T, et al. Angiography of silent myocardial ischemia. J Cardiol. 1991;21:761-9.

46. Titus BG, Sherman CT. Asymptomatic myocardial ischemia during percutaneous transluminal coronary angioplasty and importance of prior Q-wave infarction and diabetes mellitus. Am J Cardiol. 1991;68:735-9.

47. Olivetti G, Melissari M, Capasso JM, Anversa P. Cardiomyopathy of the aging human heart: myocyte loss and reactive cellular hypertrophy. Circ Res. 1991;68:1560-8.

48. GISSI-3: effects of lisinopril and transdermal glyceryl trinitrate singly and together on 6-week mortality and ventricular function after acute myocardial infarction. Gruppo Italiano per lo Studio della Sopravvivenza nell'infarto Miocardico. Lancet. 1994;343:1115-22.

49. Castelli WP. Epidemiology of coronary heart disease: the Framingham study. Am J Med. 1984;76:4-12.

50. Becker RC, Terrin M, Ross R, Knatterud GL, Desvigne-Nickens P, Gore JM, Braunwald E, and the Thrombolysis in Myocardial Infarction Investigators. Comparison of clinical outcomes for women and men after acute myocardial infarction. Ann Intern Med. 1994;120:638-45.

51. Raby KE, Barry J, Creager MA, Cook EF, Weisberg MC, Goldman L. Detection and significance of intraoperative and postoperative myocardial ischemia in peripheral vascular surgery. JAMA. 1992;268:222-7.

52. Detsky AS, Abrams HB, Forbath N, Scott JG, Hilliard JR.

Cardiac assessment for patients undergoing noncardiac surgery: a multifactorial clinical risk index. Arch Intern Med. 1986;146: 2131-4.

53. The fifth report of the Joint National Committee on Detection, Evaluation, and Treatment of High Blood Pressure (JNC V). Arch Intern Med. 1993;153:154-83.

54. Charlson ME, MacKenzie CR, Gold JP, Ales KL, Topkins M, Shires GT. Preoperative characteristics predicting intraoperative hypotension and hypertension among hypertensives and diabetics undergoing noncardiac surgery. Ann Surg. 1990;212:66-81.

55. Stone JG, Foex P, Sear JW, Johnson LL, Khambatta HJ, Triner L. Myocardial ischemia in untreated hypertensive patients: effect of a single small oral dose of a beta-adrenergic blocking agent. Anesthesiology. 1988;68:495-500.

56. Stone JG, Foex P, Sear JW, Johnson LL, Khambatta HJ, Triner L. Risk of myocardial ischaemia during anaesthesia in treated and untreated hypertensive patients. Br J Anaesth. 1988;61:675-9.

57. Prys-Roberts C, Meloche R, Foex P. Studies of anaesthesia in relation to hypertension, I: cardiovascular responses of treated and untreated patients. Br J Anaesth. 1971;43:122-37.

58. Pasternack PF, Grossi EA, Baumann FG, et al. Beta-blockade to decrease silent myocardial ischemia during peripheral vascular surgery. Am J Surg. 1989;158:113-6.

59. Cucchiara RF, Benefiel DJ, Matteo RS, DeWood M, Albin MS. Evaluation of esmolol in controlling increases in heart rate and blood pressure during endotracheal intubation in patients undergoing carotid endarterectomy. Anesthesiology. 1986;65:528-31.

60. Magnusson J, Thulin T, Werner O, Jarhult J, Thomson D. Haemodynamic effects of pretreatment with metoprolol in hypertensive patients undergoing surgery. Br J Anaesth. 1986;58:251-60.

61. Slogoff S, Keats AS. Does perioperative myocardial ischemia lead to postoperative myocardial infarction? Anesthesiology. 1985;62:107-14.

62. Bedford RF, Feinstein B. Hospital admission blood pressure: a predictor for hypertension following endotracheal intubation. Anesth Analg. 1980;59:367-70.

63. Goldman L, Caldera DL. Risks of general anesthesia and elective operation in the hypertensive patient. Anesthesiology. 1979;50:285-92.

64. Thompson RC, Liberthson RR, Lowenstein E. Perioperative anesthetic risk of noncardiac surgery in hypertrophic obstructive cardiomyopathy. JAMA. 1985;254:2419-21.

65. Reyes VP, Raju BS, Wynne J, et al. Percutaneous balloon valvuloplasty compared with open surgical commissurotomy for mitral stenosis. N Engl J Med. 1994;331:961-7.

66. Stein PD, Alpert JS, Copeland J, Dalen JE, Goldman S, Turpie AGG. Antithrombotic therapy in patients with mechanical and biological prosthetic heart valves. Chest. 1992;102(suppl):445S-55S.

67. Goldman L, Caldera DL, Southwick FS, et al. Cardiac risk factors and complications in non-cardiac surgery. Medicine (Baltimore). 1978;57:357-70.

68. Deleted during update.

69. Deleted during update.

70. Deleted during update.

71. Pastore JO, Yurchak PM, Janis KM, Murphy JD, Zir LM. The risk of advanced heart block in surgical patients with right bundle branch block and left axis deviation. Circulation. 1978;57:677-80.

72. Webb GD, Burrows FA. The risks of noncardiac surgery. J Am Coll Cardiol. 1991;18:323-5.

73. Lueker RD, Vogel JH, Blount SG Jr. Cardiovascular abnormalities

74. Maron BJ, Humphries JO, Rowe RD, Mellits ED. Prognosis of surgically corrected coarctation of the aorta: a 20-year postoperative appraisal. Circulation. 1973;47:119-26.

75. James FW, Kaplan S, Schwartz DC, Chou TC, Sandker MJ, Naylor V. Response to exercise in patients after total surgical correction of tetralogy of Fallot. Circulation. 1976;54:671-9.

76. Neilson G, Galea EG, Blunt A. Eisenmenger's syndrome and pregnancy. Med J Aust. 1971;1:431-4.

77. Taylor LM Jr, Porter JM. Basic data related to clinical decision-making in abdominal aortic aneurysms. Ann Vasc Surg. 1987;1:502-4.

78. Backer CL, Tinker JH, Robertson DM, Vlietstra RE. Myocardial reinfarction following local anesthesia for ophthalmic surgery. Anesth Analg. 1980;59:257-62.

79. Warner MA, Shields SE, Chute CG. Major morbidity and mortality within 1 month of ambulatory surgery and anesthesia. JAMA. 1993;270:1437-41.

80. Greenburg AG, Saik RP, Pridham D. Influence of age on mortality of colon surgery. Am J Surg. 1985;150:65-70.

81. Plecha FR, Bertin VJ, Plecha EJ, et al. The early results of vascular surgery in patients 75 years of age and older: an analysis of 3259 cases. J Vasc Surg. 1985;2:769-74.

82. Goldman L. Cardiac risks and complications of noncardiac surgery. Ann Intern Med. 1983;98:504-13.

83. Pedersen T, Eliasen K, Henriksen E. A prospective study of risk factors and cardiopulmonary complications associated with anaesthesia and surgery: risk indicators of cardiopulmonary morbidity. Acta Anaesthesiol Scand. 1990;34:144-55.

84. Marsch SC, Schaefer HG, Skarvan K, Castelli I, Scheidegger D. Perioperative myocardial ischemia in patients undergoing elective hip arthroplasty during lumbar regional anesthesia. Anesthesiology. 1992;76:518-27.

85. Krupski WC, Layug EL, Reilly LM, Rapp JH, Mangano DT. Comparison of cardiac morbidity rates between aortic and infrainguinal operations: two-year follow-up. Study of Perioperative Ischemia Research Group. J Vasc Surg. 1993;18:609-15.

86. L'Italien GJ, Cambria RP, Cutler BS, et al. Comparative early and late cardiac morbidity among patients requiring different vascular surgery procedures. J Vasc Surg. 1995;21:935-44.

87. Hsia DC, Krushat WM, Moscoe LM. Epidemiology of carotid endarterectomies among Medicare beneficiaries. J Vasc Surg. 1992;16:201-8.

88. Fisher ES, Malenka DJ, Solomon NA, Bubolz TA, Whaley FS, Wennberg JE. Risk of carotid endarterectomy in the elderly. Am J Public Health. 1989;79:1617-20.

89. Pilcher DB, Davis JH, Ashikaga T, et al. Treatment of abdominal aortic aneurysm in an entire state over 7 1/2 years. Am J Surg. 1980;139:487-94.

90. Richardson JD, Main KA. Repair of abdominal aortic aneurysms: a statewide experience. Arch Surg. 1991;126:614-6.

91. Hannan EL, Kilburn H Jr, O'Donnell JF, et al. A longitudinal analysis of the relationship between in-hospital mortality in New York State and the volume of abdominal aortic aneurysm surgeries performed. Health Serv Res. 1992;27:17-42.

92. Gillum RF. Peripheral arterial occlusive disease of the extremities in the United States: hospitalization and mortality. Am Heart J. 1990;120(pt 1):1414-8.

93. Chassin MR, Park RE, Lohr KN, Keesey J, Brook RH.

Differences among hospitals in Medicare patient mortality. Health Serv Res. 1989;24:1-31.

94. Hobson RW II, Weiss DG, Fields WS, et al. Efficacy of carotid endarterectomy for asymptomatic carotid stenosis: The Veterans Affairs Cooperative Study Group. N Engl J Med. 1993;328:221-7.

95. Fleisher LA, Barash PG. Preoperative cardiac evaluation for noncardiac surgery: a functional approach. Anesth Analg. 1992;74: 586-98.

96. Fletcher JP, Antico VF, Gruenewald S, Kershaw LZ. Risk of aortic aneurysm surgery as assessed by preoperative gated heart pool scan. Br J Surg. 1989;76:26-8.

97. Pedersen T, Kelbaek H, Munck O. Cardiopulmonary complications in high-risk surgical patients: the value of preoperative radionuclide cardiography. Acta Anaesthesiol Scand. 1990;34:183-9.

98. Lazor L, Russell JC, DaSilva J, Radford M. Use of the multiple uptake gated acquisition scan for the preoperative assessment of cardiac risk. Surg Gynecol Obstet. 1988;167:234-8.

99. Pasternack PF, Imparato AM, Bear G, et al. The value of radionuclide angiography as a predictor of perioperative myocardial infarction in patients undergoing abdominal aortic aneurysm resection. J Vasc Surg. 1984;1:320-5.

100. Mosley JG, Clarke JM, Ell PJ, Marston A. Assessment of myocardial function before aortic surgery by radionuclide angiocardiography. Br J Surg. 1985;72:886-7.

101. Pasternack PF, Imparato AM, Riles TS, et al. The value of the radionuclide angiogram in the prediction of perioperative myocardial infarction in patients undergoing lower extremity revascularization procedures. Circulation. 1985;72(suppl 2, pt 2):II-13-7.

102. Kazmers A, Cerqueira MD, Zierler RE. The role of preoperative radionuclide ejection fraction in direct abdominal aortic aneurysm repair. J Vasc Surg. 1988;8:128-36.

103. Fiser WP, Thompson BW, Thompson AR, Eason C, Read RC. Nuclear cardiac ejection fraction and cardiac index in abdominal aortic surgery. Surgery. 1983;94:736-9.

104. Hostetler MD, Dunn MI. Perioperative evaluation of a patient with abdominal aortic aneurysm. JAMA. 1993;269:95.

105. Poldermans D, Fioretti PM, Forster T, et al. Dobutamine stress echocardiography for assessment of perioperative cardiac risk in patients undergoing major vascular surgery. Circulation. 1993;87:1506-12.

106. McCabe CJ, Reidy NC, Abbott WM, Fulchino DM, Brewster DC. The value of electrocardiogram monitoring during treadmill testing for peripheral vascular disease. Surgery. 1981;89:183-6.

107. Cutler BS, Wheeler HB, Paraskos JA, Cardullo PA. Applicability and interpretation of electrocardiographic stress testing in patients with peripheral vascular disease. Am J Surg. 1981;141:501-6.

108. Arous EJ, Baum PL, Cutler BS. The ischemic exercise test in patients with peripheral vascular disease: implications for management. Arch Surg. 1984;119:780-3.

109. Gardine RL, McBride K, Greenberg H, Mulcare RJ. The value of cardiac monitoring during peripheral arterial stress testing in the surgical management of peripheral vascular disease. J Cardiovasc Surg (Torino). 1985;26:258-61.

110. von Knorring J, Lepantalo M. Prediction of perioperative cardiac complications by electrocardiographic monitoring during treadmill exercise testing before peripheral vascular surgery. Surgery. 1986;99:610-3.

111. Leppo J, Plaja J, Gionet M, Tumolo J, Paraskos JA, Cutler BS. Noninvasive evaluation of cardiac risk before elective vascular surgery. J Am Coll Cardiol. 1987;9:269-76.

112. Hanson P, Pease M, Berkoff H, Turnipseed W, Detmer D. Arm exercise testing for coronary artery disease in patients with peripheral vascular disease. Clin Cardiol. 1988;11:70-4.

113. McPhail N, Calvin JE, Shariatmadar A, Barber GG, Scobie TK. The use of preoperative exercise testing to predict cardiac complications after arterial reconstruction. J Vasc Surg. 1988;7:60-8.

114. Carliner NH, Fisher ML, Plotnick GD, et al. Routine preoperative exercise testing in patients undergoing major noncardiac surgery. Am J Cardiol. 1985;56:51-8.

115. Gerson MC, Hurst JM, Hertzberg VS, Baughman R, Rouan GW, Ellis K. Prediction of cardiac and pulmonary complications related to elective abdominal and noncardiac thoracic surgery in geriatric patients. Am J Med. 1990;88:101-7.

116. Kopecky SL, Gibbons RJ, Hollier LH. Preoperative supine exercise radionuclide angiogram predicts perioperative cardiovascular events in vascular surgery [abstr]. J Am Coll Cardiol. 1986;7: 226A.

117. Urbinati S, Di Pasquale G, Andreoli A, et al. Preoperative noninvasive coronary risk stratification in candidates for carotid endarterectomy. Stroke. 1994;25:2022-7.

118. Chaitman BR. Exercise stress testing. In: Braunwald E, ed. Heart Disease: A Textbook of Cardiovascular Medicine. 4th ed. Philadelphia, Pa: WB Saunders Co; 1992:168.

119. Boucher CA, Brewster DC, Darling RC, Okada RD, Strauss HW. Determination of cardiac risk by dipyridamole-thallium imaging before peripheral vascular surgery. N Engl J Med. 1985;312:389-94.

120. Cutler BS, Leppo JA. Dipyridamole thallium 201 scintigraphy to detect coronary artery disease before abdominal aortic surgery. J Vasc Surg. 1987;5:91-100.

121. Fletcher JP, Antico VF, Gruenewald S, Kershaw LZ. Dipyridamole-thallium scan for screening of coronary artery disease prior to vascular surgery. J Cardiovasc Surg (Torino). 1988;29:666-9.

122. Sachs RN, Tellier P, Larmignat P, et al. Assessment by dipyridamole-thallium-201 myocardial scintigraphy of coronary risk before peripheral vascular surgery. Surgery. 1988;103:584-7.

123. McEnroe CS, O'Donnell RF Jr, Yeager A, Konstam M, Mackey WC. Comparison of ejection fraction and Goldman risk factor analysis of dipyridamole-thallium 201 studies in the evaluation of cardiac morbidity after aortic aneurysm surgery. J Vasc Surg. 1990;11:497-504.

124. Younis LT, Aguirre F, Byers S, et al. Perioperative and long-term prognostic value of intravenous dipyridamole thallium scintigraphy in patients with peripheral vascular disease. Am Heart J. 1990;119:1287-92.

125. Mangano DT, London MJ, Tubau JF, et al. Dipyridamole thallium-201 scintigraphy as a preoperative screening test: a reexamination of its predictive potential. Study of Perioperative Ischemia Research Group. Circulation. 1991;84:493-502.

126. Strawn DJ, Guernsey JM. Dipyridamole thallium scanning in the evaluation of coronary artery disease in elective abdominal aortic surgery. Arch Surg. 1991;126:880-4.

127. Watters TA, Botvinick EH, Dae MW, et al. Comparison of the findings on preoperative dipyridamole perfusion scintigraphy and intraoperative transesophageal echocardiography: implications regarding the identification of myocardium at ischemic risk. J Am Coll Cardiol. 1991;18:93-100.

128. Hendel RC, Whitfield SS, Villegas BJ, Cutler BS, Leppo JA. Prediction of late cardiac events by dipyridamole thallium imag-

ing in patients undergoing elective vascular surgery. Am J Cardiol. 1992;70:1243-9.

129. Lette J, Waters D, Cerino M, Picard M, Champagne P, Lapointe J. Preoperative coronary artery disease risk stratification based on dipyridamole imaging and a simple three-step, three-segment model for patients undergoing noncardiac vascular surgery or major general surgery. Am J Cardiol. 1992;69:1553-8.

130. Madsen PV, Vissing M, Munck O, Kelbaek H. A comparison of dipyridamole thallium 201 scintigraphy and clinical examination in the determination of cardiac risk before arterial reconstruction. Angiology. 1992;43:306-11.

131. Brown KA, Rowen M. Extent of jeopardized viable myocardium determined by myocardial perfusion imaging best predicts perioperative cardiac events in patients undergoing noncardiac surgery. J Am Coll Cardiol. 1993;21:325-30.

132. Kresowik TF, Bower TR, Garner SA, et al. Dipyridamole thallium imaging in patients being considered for vascular procedures. Arch Surg. 1993;128:299-302.

133. Baron JF, Mundler O, Bertrand M, et al. Dipyridamole-thallium scintigraphy and gated radionuclide angiography to assess cardiac risk before abdominal aortic surgery. N Engl J Med. 1994;330:663-9.

134. Bry JD, Belkin M, O'Donnell TF Jr, et al. An assessment of the positive predictive value and cost-effectiveness of dipyridamole myocardial scintigraphy in patients undergoing vascular surgery. J Vasc Surg. 1994;19:112-21.

135. Camp AD, Garvin PJ, Hoff J, Marsh J, Byers SL, Chaitman BR. Prognostic value of intravenous dipyridamole thallium imaging in patients with diabetes mellitus considered for renal transplantation. Am J Cardiol. 1990;65:1459-63.

136. Iqbal A, Gibbons RJ, McGoon MD, Steiroff S, Frohnert PT, Velosa JA. Noninvasive assessment of cardiac risk in insulin-dependent diabetic patients being evaluated for pancreatic transplantation using thallium-201 myocardial perfusion scintigraphy. Transplant Proc. 1991;23(pt 2):1690-1.

137. Coley CM, Field TS, Abraham SA, Boucher CA, Eagle KA. Usefulness of dipyridamole-thallium scanning for preoperative evaluation of cardiac risk for nonvascular surgery. Am J Cardiol. 1992;69:1280-5.

138. Shaw L, Miller DD, Kong BA, et al. Determination of perioperative cardiac risk by adenosine thallium-201 myocardial imaging. Am Heart J. 1992;124:861-9.

139. Takase B, Younis LT, Byers SL, et al. Comparative prognostic value of clinical risk indexes, resting two-dimensional echocardiography, and dipyridamole stress thallium-201 myocardial imaging for perioperative cardiac events in major nonvascular surgery patients. Am Heart J. 1993;126:1099-106.

140. Younis L, Stratmann H, Takase B, Byers S, Chaitman BR, Miller DD. Preoperative clinical assessment and dipyridamole thallium-201 scintigraphy for prediction and prevention of cardiac events in patients having major noncardiovascular surgery and known or suspected coronary artery disease. Am J Cardiol. 1994;74:311-7.

141. Ritchie JL, Bateman TM, Bonow RO, et al. Guidelines for clinical use of cardiac radionuclide imaging: a report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Committee on Radionuclide Imaging), developed in collaboration with the American Society of Nuclear Cardiology. J Am Coll Cardiol. 1995;25:521-47.

142. Berthe C, Pierard LA, Hiernaux M, et al. Predicting the extent and location of coronary artery disease in acute myocardial infarction

by echocardiography during dobutamine infusion. Am J Cardiol. 1986;58:1167-72.

143. Cohen JL, Greene TO, Ottenweller J, Binenbaum SZ, Wilchfort SD, Kim CS. Dobutamine digital echocardiography for detecting coronary artery disease. Am J Cardiol. 1991;67:1311-8.

144. Sawada SG, Segar DS, Ryan T, et al. Echocardiographic detection of coronary artery disease during dobutamine infusion. Circulation. 1991;83:1605-14.

145. Martin TW, Seaworth JF, Johns JP, Pupa LE, Condos WR. Comparison of adenosine, dipyridamole, and dobutamine in stress echocardiography. Ann Intern Med. 1992;116:190-6.

146. Marwick T, Willemart B, D'Hondt AM, et al. Selection of the optimal nonexercise stress for the evaluation of ischemic regional myocardial dysfunction and malperfusion: comparison of dobutamine and adenosine using echocardiography and 99mTc-MIBI single photon emission computed tomography. Circulation. 1993;87:345-54.

147. Lane RT, Sawada SG, Segar DS, et al. Dobutamine stress echocardiography for assessment of cardiac risk before noncardiac surgery. Am J Cardiol. 1991;68:976-7.

148. Lalka SG, Sawada SG, Dalsing MC, et al. Dobutamine stress echocardiography as a predictor of cardiac events associated with aortic surgery. J Vasc Surg. 1992;15:831-40.

149. Eichelberger JP, Schwarz KQ, Black ER, Green RM, Ouriel K. Predictive value of dobutamine echocardiography just before noncardiac vascular surgery. Am J Cardiol. 1993;72:602-7.

150. Langan EM III, Youkey JR, Franklin DP, Elmore JR, Costello JM, Nassef LA. Dobutamine stress echocardiography for cardiac risk assessment before aortic surgery. J Vasc Surg. 1993;18:905-11.

151. Dávila-Román VG, Waggoner AD, Sicard GA, Geltman EM, Schechtman KB, Perez JE. Dobutamine stress echocardiography predicts surgical outcome in patients with an aortic aneurysm and peripheral vascular disease. J Am Coll Cardiol. 1993;21:957-63.

152. DePuey EG, Guertler-Krawczynska E, Robbins WL. Thallium-201 SPECT in coronary artery disease patients with left bundle branch block. J Nucl Med. 1988;29:1479-85.

153. Larcos G, Gibbons RJ, Brown ML. Diagnostic accuracy of exercise thallium-201 single-photon emission computed tomography in patients with left bundle branch block. Am J Cardiol. 1991;68:756-60.

154. Rockett JF, Wood WC, Moinuddin M, Loveless V, Parrish B. Intravenous dipyridamole thallium-201 SPECT imaging in patients with left bundle branch block. Clin Nucl Med. 1990;15:401-7.

155. O'Keefe JH Jr, Bateman TM, Barnhart CS. Adenosine thallium-201 is superior to exercise thallium-201 for detecting coronary artery disease in patients with left bundle branch block. J Am Coll Cardiol. 1993;21:1332-8.

156. Hirzel HO, Senn M, Nuesch K, et al. Thallium-201 scintigraphy in complete left bundle branch block. Am J Cardiol. 1984;53:764-9.

157. Tighe DA, Hutchinson HG, Park CH, Chung EK, Fischman DL, Raichlen JS. False-positive reversible perfusion defect during dobutamine-thallium imaging in left bundle branch block. J Nucl Med. 1994;35:1989-91.

158. Fleisher LA, Rosenbaum SH, Nelson AH, Barash PG. The predictive value of preoperative silent ischemia for postoperative ischemic cardiac events in vascular and nonvascular surgery patients. Am Heart J. 1991;122(pt 1):980-6.

159. Kirwin JD, Ascer E, Gennaro M, et al. Silent myocardial ischemia is not predictive of myocardial infarction in peripheral vascular surgery patients. Ann Vasc Surg. 1993;7:27-32.

160. McPhail NV, Ruddy TD, Barber GG, Cole CW, Marois LJ, Gulenchyn KY. Cardiac risk stratification using dipyridamole myocardial perfusion imaging and ambulatory ECG monitoring prior to vascular surgery. Eur J Vasc Surg. 1993;7:151-5.

161. Raby KE, Goldman L, Creager MA, et al. Correlation between preoperative ischemia and major cardiac events after peripheral vascular surgery. N Engl J Med. 1989;321:1296-300.

162. Pasternack PF, Grossi EA, Baumann FG, et al. The value of silent myocardial ischemia monitoring in the prediction of perioperative myocardial infarction in patients undergoing peripheral vascular surgery. J Vasc Surg. 1989;10:617-25.

163. Fleisher LA, Rosenbaum SH, Nelson, Jain D, Wackers FJT, Zaret BL. Preoperative dipyridamole thallium imaging and Holter monitoring as a predictor of perioperative cardiac events and long term outcome. Anesthesiology. In press.

164. Mantha S, Roizen MF, Barnard J, Thisted RA, Ellis JE, Foss J. Relative effectiveness of four preoperative tests for predicting adverse cardiac outcomes after vascular surgery: a meta-analysis. Anesth Analg. 1994;79:422-33.

165. Deleted during update.

166. Rihal CS, Eagle KA, Mickel MC, Foster ED, Sopko G, Gersh BJ. Surgical therapy for coronary artery disease among patients with combined coronary artery and peripheral vascular disease. Circulation. 1995;91:46-53.

167. Coley CM, Eagle KA, Singer DE, et al. Decision analysis for preoperative cardiac risk evaluation before vascular surgery [abstr]. Clin Res. 1987;35:342A.

168. Fleisher LA, Skolnick ED, Holroyd KJ, Lehmann HP. Coronary artery revascularization before abdominal aortic aneurysm surgery: a decision analytic approach. Anesth Analg. 1994;79:661-9.

169. Mason JJ, Owens DK, Harris RA, Cooke JP, Hlatky MA. The role of coronary angiography and coronary revascularization before noncardiac vascular surgery. JAMA. 1995;273:1919-25.

170. Diehl JT, Cali RF, Hertzer NR, Beven EG. Complications of abdominal aortic reconstruction: an analysis of perioperative risk factors in 557 patients. Ann Surg. 1983;197:49-56.

171. Crawford ES, Morris GC Jr, Howell JF, Flynn WF, Moorhead DT. Operative risk in patients with previous coronary artery bypass. Ann Thorac Surg. 1978;26:215-21.

172. Reul GJ Jr, Cooley DA, Duncan JM, et al. The effect of coronary bypass on the outcome of peripheral vascular operations in 1093 patients. J Vasc Surg. 1986;3:788-98.

173. Nielsen JL, Page CP, Mann C, Schwesinger WH, Fountain RL, Grover FL. Risk of major elective operation after myocardial revascularization. Am J Surg. 1992;164:423-6.

174. Hertzer NR, Beven EG, Young JR, et al. Coronary artery disease in peripheral vascular patients: a classification of 1000 coronary angiograms and results of surgical management. Ann Surg. 1984;199:223-33.

175. Hertzer NR, Young JR, Beven EG, et al. Late results of coronary bypass in patients with peripheral vascular disease, I: five-year survival according to age and clinical cardiac status. Cleve Clin Q. 1986;53:133-143.

176. European Coronary Surgery Study Group. Long-term results of prospective randomised study of coronary artery bypass surgery in stable angina pectoris. Lancet. 1982;2:1173-80.

177. Hertzer NR, Young JR, Beven EG, et al. Late results of coronary bypass in patients with peripheral vascular disease, II: five-year survival according to sex, hypertension, and diabetes. Cleve Clin J Med. 1987;54:15-23.

178. Guidelines and indications for coronary artery bypass graft surgery: a report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Subcommittee on Coronary Artery Bypass Graft Surgery). J Am Coll Cardiol. 1991;17:543-89.

179. Huber KC, Evans MA, Bresnahan JF, Gibbons RJ, Holmes DR Jr. Outcome of noncardiac operations in patients with severe coronary artery disease successfully treated preoperatively with coronary angioplasty. Mayo Clin Proc. 1992;67:15-21.

180. Elmore JR, Hallett JW Jr, Gibbons RJ, et al. Myocardial revascularization before abdominal aortic aneurysmorrhaphy: effect of coronary angioplasty. Mayo Clin Proc. 1993;68:637-41.

181. Allen JR, Helling TS, Hartzler GO. Operative procedures not involving the heart after percutaneous transluminal coronary angioplasty. Surg Gynecol Obstet. 1991;173:285-8.

182. Deleted during update.

183. Coriat P, Daloz M, Bousseau D, Fusciardi J, Echter E, Viars P. Prevention of intraoperative myocardial ischemia during noncardiac surgery with intravenous nitroglycerin. Anesthesiology. 1984;61:193-6.

184. Dodds TM, Stone JG, Coromilas J, Weinberger M, Levy DG. Prophylactic nitroglycerin infusion during noncardiac surgery does not reduce perioperative ischemia. Anesth Analg. 1993;76:705-13.

185. Godet G, Coriat P, Baron JF, et al. Prevention of intraoperative myocardial ischemia during noncardiac surgery with intravenous diltiazem: a randomized trial versus placebo. Anesthesiology. 1987;66:241-5.

186. Pasternack PF, Imparato AM, Baumann FG, et al. The hemodynamics of beta-blockade in patients undergoing abdominal aortic aneurysm repair. Circulation. 1987;76(suppl 3, pt 2):III-1-7.

187. Hayes SN, Holmes DR Jr, Nishimura RA, Reeder GS. Palliative percutaneous aortic balloon valvuloplasty before noncardiac operations and invasive diagnostic procedures. Mayo Clin Proc. 1989;64:753-7.

188. Rahimtoola SH. Catheter balloon valvuloplasty of aortic and mitral stenosis in adults. Circulation. 1987;75:895-901.

189. Marcus FI, Ewy GA, O'Rourke RA, Walsh B, Bleich AC. The effect of pregnancy on the murmurs of mitral and aortic regurgitation. Circulation. 1970;41:795-805.

190. Waller TJ, Kay HR, Spielman SR, Kutalek SP, Greenspan AM, Horowitz LN. Reduction in sudden death and total mortality by antiarrhythmic therapy evaluated by electrophysiologic drug testing: criteria of efficacy in patients with sustained ventricular tachyarrhythmia. J Am Coll Cardiol. 1987;10:83-9.

191. Swerdlow CD, Winkle RA, Mason JW. Prognostic significance of the number of induced ventricular complexes during assessment of therapy for ventricular tachyarrhythmias. Circulation. 1983;68:400-5.

192. Guidelines for implantation of cardiac pacemakers and antiarrhythmia devices: a report of the American College of Cardiology/American Heart Association Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures (Committee on Pacemaker Implantation). J Am Coll Cardiol. 1991;18:1-13.

193. Berlauk JF, Abrams JH, Gilmour IJ, O'Connor SR, Knighton DR, Cerra FB. Preoperative optimization of cardiovascular hemodynamics improves outcome in peripheral vascular surgery: a prospective, randomized clinical trial. Ann Surg. 1991;214:289-97.

194. Deleted during update.

195. Verstraete M. The diagnosis and treatment of deep-vein thrombosis [editorial]. N Engl J Med. 1993;329:1418-20.

196. Deleted during update.

197. Heijboer H, Cogo A, Buller HR, Prandoni P, ten Cate JW. Detection of deep vein thrombosis with impedance plethysmography and real-time compression ultrasonography in hospitalized patients. Arch Intern Med. 1992;152:1901-3.

198. Moser KM, Fedullo PF. The diagnosis of deep vein thrombosis [letter]. N Engl J Med. 1994;330:863-864.

199. Bergqvist D, Jendteg S, Lindgren B, Matzsch T, Persson U. The economics of general thromboembolic prophylaxis. World J Surg. 1988;12:349-55.

200. Criqui MH, Fronek A, Barrett-Connor E, Klauber MR, Gabriel S, Goodman D. The prevalence of peripheral arterial disease in a defined population. Circulation. 1985;71:510-5.

201. Friedman SA, Pandya M, Greif E. Peripheral arterial occlusion in patients with acute coronary heart disease. Am Heart J. 1973; 86:415-9.

202. Cohen MM, Duncan PG, Tate RB. Does anesthesia contribute to operative mortality? JAMA. 1988;260:2859-63.

203. Leung JM, Goehner P, O'Kelly BF, et al. Isoflurane anesthesia and myocardial ischemia: comparative risk versus sufentanil anesthesia in patients undergoing coronary artery bypass graft surgery. The SPI (Study of Perioperative Ischemia) Research Group. Anesthesiology. 1991;74:838-47.

204. Baron JF, Bertrand M, Barre E, et al. Combined epidural and general anesthesia versus general anesthesia for abdominal aortic surgery. Anesthesiology. 1991;75:611-8.

205. Christopherson R, Beattie C, Frank SM, et al. Perioperative morbidity in patients randomized to epidural or general anesthesia for lower extremity vascular surgery: Perioperative Ischemia Randomized Anesthesia Trial Study Group. Anesthesiology. 1993;79:422-34.

206. Slogoff S, Keats AS. Randomized trial of primary anesthetic agents on outcome of coronary artery bypass operations. Anesthesiology. 1989;70:179-88.

207. Tuman KJ, McCarthy RJ, Spiess BD. Epidural anaesthesia and analgesia decreases postoperative hypercoagulability in high-risk vascular patients. Anesth Analg. 1990;70:S414.

208. Gallagher JD, Moore RA, Jose AB, Botros SB, Clark DL. Prophylactic nitroglycerin infusions during coronary artery bypass surgery. Anesthesiology. 1986;64:785-9.

209. Thomson IR, Mutch WA, Culligan JD. Failure of intravenous nitroglycerin to prevent intraoperative myocardial ischemia during fentanyl-pancuronium anesthesia. Anesthesiology. 1984;61:385-93.

210. Eisenberg MJ, London MJ, Leung JM, et al. Monitoring for myocardial ischemia during noncardiac surgery: a technology assessment of transesophageal echocardiography and 12-lead electrocardiography. The Study of Perioperative Ischemia Research Group. JAMA. 1992;268:210-6.

211. London MJ, Tubau JF, Wong MG, et al. The natural history of segmental wall motion abnormalities in patients undergoing noncardiac surgery: SPI Research Group. Anesthesiology. 1990;73:644-55.

212. Siu SC, Kowalchuk GJ, Welty FK, Benotti PN, Lewis SM. Intra-aortic balloon counterpulsation support in the high-risk cardiac patient undergoing urgent noncardiac surgery. Chest. 1991;99:1342-5.

213. Grotz RL, Yeston NS. Intra-aortic balloon counterpulsation in high-risk cardiac patients undergoing noncardiac surgery. Surgery. 1989;106:1-5.

214. Mangano DT, Browner WS, Hollenberg M, Li J, Tateo IM. Long-term cardiac prognosis following noncardiac surgery: The Study of Perioperative Ischemia Research Group. JAMA. 1992;268:233-9.

215. Yeager RA, Moneta GL, Edwards JM, Taylor LM Jr, McConnell DB, Porter JM. Late survival after perioperative myocardial infarction complicating vascular surgery. J Vasc Surg. 1994;20:598-606.

216. Isaacson IJ, Lowdon JD, Berry AJ, et al. The value of pulmonary artery and central venous monitoring in patients undergoing abdominal aortic reconstructive surgery: a comparative study of two selected, randomized groups. J Vasc Surg. 1990;12:754-60.

217. Joyce WP, Provan JL, Ameli FM, McEwan MM, Jelenich S, Jones DP. The role of central haemodynamic monitoring in abdominal aortic surgery: a prospective randomised study. Eur J Vasc Surg. 1990;4:633-6.

218. Practice guidelines for pulmonary artery catheterization: a report by the American Society of Anesthesiologists Task Force on Pulmonary Artery Catheterization. Anesthesiology. 1993;78:380-94.

219. Landesberg G, Luria MH, Cotev S, et al. Importance of long-duration postoperative ST-segment depression in cardiac morbidity after vascular surgery. Lancet. 1993;341:715-9.

220. Fleisher LA, Nelson AH, Rosenbaum SH. Postoperative myocardial ischemia: etiology of cardiac morbidity or manifestation of underlying disease? J Clin Anesth. 1995;7:97-102.

221. Mathew JP, Fleisher LA, Rinehouse JA, et al. ST segment depression during labor and delivery. Anesthesiology. 1992;77:635-41.

222. Breslow MJ, Miller CF, Parker SD, Walman AT, Rogers MC. Changes in T-wave morphology following anesthesia and surgery: a common recovery-room phenomenon. Anesthesiology. 1986;64:398-402.

223. Adams JE III, Sicard GA, Allen BT, et al. Diagnosis of perioperative myocardial infarction with measurement of cardiac troponin I. N Engl J Med. 1994;330:670-4.

224. Charlson ME, MacKenzie CR, Ales K, Gold JP, Fairclough G Jr, Shires GT. Surveillance for postoperative myocardial infarction after noncardiac operations. Surg Gynecol Obstet. 1988;167:404-14.

225. Rettke SR, Shub C, Naessens JM, Marsh HM, O'Brien JF. Significance of mildly elevated creatine kinase (myocardial band) activity after elective abdominal aortic aneurysmectomy. J Cardio-thorac Vasc Anesth. 1991;5:425-30.

226. Nordrehaug JE. Malignant arrhythmia in relation to serum potassium in acute myocardial infarction. Am J Cardiol. 1985;56:20D-3D.

227. Hollifield JW. Thiazide treatment of systemic hypertension: effects on serum magnesium and ventricular ectopic activity. Am J Cardiol. 1989;63:22G-5G.

228. Wong KC, Schafer PG, Schultz JR. Hypokalemia and anesthetic implications. Anesth Analg. 1993;77:1238-60.

229. Deleted during update.

230. Aronow WS, Ahn C. Incidence of heart failure in 2,737 older persons with and without diabetes mellitus. Chest. 1999;115:867-8.

231. Shindler DM, Kostis JB, Yusuf S, et al. Diabetes mellitus, a predictor of morbidity and mortality in the Studies of Left Ventricular Dysfunction (SOLVD) Trials and Registry. Am J Cardiol. 1996;77:1017-20.

232. Furnary AP, Zerr KJ, Grunkemeier GL, Starr A. Continuous intravenous insulin infusion reduces the incidence of deep sternal wound infection in diabetic patients after cardiac surgical procedures. Ann Thorac Surg. 1999;67:352-60.

233. Pomposelli JJ, Baxter JK III, Babineau TJ, et al. Early postoperative glucose control predicts nosocomial infection rate in diabetic

patients. JPEN J Parenter Enteral Nutr. 1998;22:77-81.

234. Samuels LE, Sharma S, Morris RJ, et al. Coronary artery bypass grafting in patients with chronic renal failure: a reappraisal. J Card Surg. 1996;11:128-33.

235. Corwin HL, Sprague SM, DeLaria GA, Norusis MJ. Acute renal failure associated with cardiac operations: a case-control study. J Thorac Cardiovasc Surg. 1989;98:1107-12.

236. Lee TH, Marcantonio ER, Mangione CM, et al. Derivation and prospective validation of a simple index for prediction of cardiac risk of major noncardiac surgery. Circulation. 1999;100:1043-49.

237. Hogue CW Jr, Goodnough LT, Monk TG. Perioperative myocardial ischemic episodes are related to hematocrit level in patients undergoing radical prostatectomy. Transfusion. 1998;38:924-31.

238. Hahn RG, Nilsson A, Farahmand BY, Persson PG. Blood haemoglobin and the long-term incidence of acute myocardial infarction after transurethral resection of the prostate. Eur Urol. 1997;31:199-203.

239. Nelson AH, Fleisher LA, Rosenbaum SH. Relationship between postoperative anemia and cardiac morbidity in high-risk vascular patients in the intensive care unit. Crit Care Med. 1993;21:860-6.

240. O'Kelly B, Browner WS, Massie B, Tubau J, Ngo L, Mangano DT. Ventricular arrhythmias in patients undergoing noncardiac surgery: the Study of Perioperative Ischemia Research Group. JAMA. 1992;268:217-21.

241. Mahla E, Rotman B, Rehak P, et al. Perioperative ventricular dysrhythmias in patients with structural heart disease undergoing noncardiac surgery. Anesth Analg. 1998;86:16-21.

242. Eagle KA, Brundage BH, Chaitman BR, et al. 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). J Am Coll Cardiol. 1996;27:910-48.

243. Bartels C, Bechtel JF, Hossmann V, Horsch S. Cardiac risk stratification for high-risk vascular surgery. Circulation. 1997;95:2473-5.

244. Glance LG. Selective preoperative cardiac screening improves five-year survival in patients undergoing major vascular surgery: a cost-effectiveness analysis. J Cardiothorac Vasc Anesth. 1999;13:265-71.

245. Rubin DN, Ballal RS, Marwick TH. Outcomes and cost implications of a clinical-based algorithm to guide the discriminate use of stress imaging before noncardiac surgery. Am Heart J. 1997;134:83-92.

246. Shaw LJ, Hachamovitch R, Cohen M, et al. Cost implications of selective preoperative risk screening in the care of candidates for peripheral vascular operations. Am J Managed Care. 1997;3:1817-27.

247. Reilly DF, McNeely MJ, Doerner D, et al. Self-reported exercise tolerance and the risk of serious perioperative complications. Arch Intern Med. 1999;159:2185-92.

248. Older P, Hall A, Hader R. Cardiopulmonary exercise testing as a screening test for perioperative management of major surgery in the elderly. Chest. 1999;116:355-62.

249. Goldman L, Hashimoto B, Cook EF, Loscalzo A. Comparative reproducibility and validity of systems for assessing cardiovascular functional class: advantages of a new specific activity scale. Circulation. 1981;64:1227-34.

250. Jakobsen CJ, Bille S, Ahlburg P, Rybro L, Hjortholm K, Andresen EB. Perioperative metoprolol reduces the frequency of atrial fibrillation after thoracotomy for lung resection. J Cardiothorac Vasc Anesth. 1997;11:746-51.

251. Mangano DT, Layug EL, Wallace A, Tateo I. Effect of atenolol on mortality and cardiovascular morbidity after noncardiac surgery. Multicenter Study of Perioperative Ischemia Research Group [published erratum appears in N Engl J Med 1997;336:1039]. N Engl J Med. 1996;335:1713-20.

252. Poldermans D, Boersma E, Bax JJ, et al, for the Dutch Echocardiographic Cardiac Risk Evaluation Applying Stress Echocardiography Study Group. The effect of bisoprolol on perioperative mortality and myocardial infarction in high-risk patients undergoing vascular surgery. N Engl J Med. 1999;341:1789-94.

253. Brabant SM, Bertrand M, Eyraud D, Darmon PL, Coriat P. The hemodynamic effects of anesthetic induction in vascular surgical patients chronically treated with angiotensin II receptor antagonists. Anesth Analg. 1999;89:1388-92.

254. Haering JM, Comunale ME, Parker RA, et al. Cardiac risk of noncardiac surgery in patients with asymmetric septal hypertrophy. Anesthesiology. 1996;85:254-9.

255. Raymer K, Yang H. Patients with aortic stenosis: cardiac complications in non-cardiac surgery. Can J Anaesth. 1998;45:855-9.

256. Torsher LC, Shub C, Rettke SR, Brown DL. Risk of patients with severe aortic stenosis undergoing noncardiac surgery. Am J Cardiol. 1998;81:448-52.

257. Proceedings of the American College of Chest Physicians 5th Consensus on Antithrombotic Therapy. 1998. Chest. 1998;114:439S-769S.

258. ACC/AHA guidelines for the management of patients with valvular heart disease: a report of the American College of Cardiology/American Heart Association. Task Force on Practice Guidelines (Committee on Management of Patients with Valvular Heart Disease). J Am Coll Cardiol. 1998;32:1486-588.

259. Bayliff CD, Massel DR, Inculet RI, et al. Propranolol for the prevention of postoperative arrhythmias in general thoracic surgery. Ann Thorac Surg. 1999;67:182-6.

260. Eagle KA, Rihal CS, Mickel MC, Holmes DR, Foster ED, Gersh BJ. Cardiac risk of noncardiac surgery: influence of coronary disease and type of surgery in 3368 operations. CASS Investigators and University of Michigan Heart Care Program. Coronary Artery Surgery Study. Circulation. 1997;96:1882-7.

261. Fleisher LA, Eagle KA, Shaffer T, Anderson GF. Perioperative and long-term mortality rates after major vascular surgery: the relationship to preoperative testing in the Medicare population. Anesth Analg. 1999;89:849-55.

262. Mistry BM, Bastani B, Solomon H, et al. Prognostic value of dipyridamole thallium-201 screening to minimize perioperative cardiac complications in diabetics undergoing kidney or kidney-pancreas transplantation. Clin Transplant. 1998;12:130-5.

263. Plotkin JS, Benitez RM, Kuo PC, et al. Dobutamine stress echocardiography for preoperative cardiac risk stratification in patients undergoing orthotopic liver transplantation. Liver Transpl Surg. 1998;4:253-7.

264. Donovan CL, Marcovitz PA, Punch JD, et al. Two-dimensional and dobutamine stress echocardiography in the preoperative assessment of patients with end-stage liver disease prior to orthotopic liver transplantation. Transplantation. 1996;61:1180-8.

265. Bach DS, Curtis JL, Christensen PJ, et al. Preoperative echocardiographic evaluation of patients referred for lung volume reduction surgery. Chest. 1998;114:972-80.

266. Bossone E, Martinez FJ, Whyte RI, Iannettoni MD, Armstrong WF, Bach DS. Dobutamine stress echocardiography for the preoperative evaluation of patients undergoing lung volume reduction surgery. J Thorac Cardiovasc Surg. 1999;118:542-6.

267. Poldermans D, Arnese M, Fioretti PM, et al. Sustained prognos-

tic value of dobutamine stress echocardiography for late cardiac events after major noncardiac vascular surgery. Circulation. 1997;95:53-8.

268. Bigatel DA, Franklin DP, Elmore JR, Nassef LA, Youkey JR. Dobutamine stress echocardiography prior to aortic surgery: long-term cardiac outcome. Ann Vasc Surg. 1999;13:17-22.

269. Landesberg G, Wolf Y, Schechter D, et al. Preoperative thallium scanning, selective coronary revascularization, and long-term survival after carotid endarterectomy. Stroke. 1998;29:2541-8.

270. Stratmann HG, Younis LT, Wittry MD, Amato M, Miller DD. Dipyridamole technetium-99m sestamibi myocardial tomography in patients evaluated for elective vascular surgery: prognostic value for perioperative and late cardiac events. Am Heart J. 1996;131:923-9.

271. Halm EA, Browner WS, Tubau JF, Tateo IM, Mangano DT for the Study of Perioperative Ischemia Research Group. Echocardiography for assessing cardiac risk in patients having noncardiac surgery. [published erratum appears in Ann Intern Med 1997;126:494]. Ann Intern Med. 1996;125:433-41.

272. Sutherland SE, Gazes PC, Keil JE, Gilbert GE, Knapp RG. Electrocardiographic abnormalities and 30-year mortality among white and black men of the Charleston Heart Study. Circulation. 1993;88:2685-92.

273. Kannel WB, Gordon T, Offutt D. Left ventricular hypertrophy by electrocardiogram: prevalence, incidence, and mortality in the Framingham study. Ann Intern Med. 1969;71:89-105.

274. Tervahauta M, Pekkanen J, Punsar S, Nissinen A. Resting electrocardiographic abnormalities as predictors of coronary events and total mortality among elderly men. Am J Med. 1996;100:641-5.

275. Kreger BE, Cupples LA, Kannel WB. The electrocardiogram in prediction of sudden death: Framingham Study experience. Am Heart J. 1987;113:377-82.

276. Kannel WB, Abbott RD. Incidence and prognosis of unrecognized myocardial infarction: an update on the Framingham study. N Engl J Med. 1984;311:1144-7.

277. Crow RS, Prineas RJ, Hannan PJ, Grandits G, Blackburn H. Prognostic associations of Minnesota Code serial electrocardiographic change classification with coronary heart disease mortality in the Multiple Risk Factor Intervention Trial. Am J Cardiol. 1997;80:138-44.

278. Kannel WB, Cobb J. Left ventricular hypertrophy and mortality: results from the Framingham Study. Cardiology. 1992;81:291-8.

279. Schneider JF, Thomas HE Jr, Kreger BE, McNamara PM, Kannel WB. Newly acquired left bundle-branch block: the Framingham study. Ann Intern Med. 1979;90:303-10.

280. Rabkin SW, Mathewson FA, Tate RB. Natural history of left bundle-branch block. Br Heart J. 1980;43:164-9.

281. Schein OD, Katz J, Bass EB, et al. The value of routine preoperative medical testing before cataract surgery. Study of Medical Testing for Cataract Surgery. N Engl J Med. 2000;342:168-75.

282. Landesberg G, Einav S, Christopherson R, et al. Perioperative ischemia and cardiac complications in major vascular surgery: importance of the preoperative twelve-lead electrocardiogram. J Vasc Surg. 1997;26:570-8.

283. Shaw LJ, Eagle KA, Gersh BJ, Miller DD. Meta-analysis of intravenous dipyridamole-thallium-201 imaging (1985 to 1994) and dobutamine echocardiography (1991 to 1994) for risk stratification before vascular surgery. J Am Coll Cardiol. 1996;27:787-98.

284. Vanzetto G, Machecourt J, Blendea D, et al. Additive value of thallium single-photon emission computed tomography myocardial imaging for prediction of perioperative events in clinically selected high cardiac risk patients having abdominal aortic surgery. Am J Cardiol. 1996;77:143-8.

285. Roghi A, Palmieri B, Crivellaro W, Sara R, Puttini M, Faletra F. Preoperative assessment of cardiac risk in noncardiac major vascular surgery. Am J Cardiol. 1999;83:169-74.

286. Poldermans D, Arnese M, Fioretti PM, et al. Improved cardiac risk stratification in major vascular surgery with dobutamine-atropine stress echocardiography. J Am Coll Cardiol. 1995;26:648-53.

287. Shafritz R, Ciocca RG, Gosin JS, Shindler DM, Doshi M, Graham AM. The utility of dobutamine echocardiography in preoperative evaluation for elective aortic surgery. Am J Surg. 1997;174:121-5.

288. Ballal RS, Kapadia S, Secknus MA, Rubin D, Arheart K, Marwick TH. Prognosis of patients with vascular disease after clinical evaluation and dobutamine stress echocardiography. Am Heart J. 1999;137:469-75.

289. Das MK, Pellikka PA, Mahoney DW, et al. Assessment of cardiac risk before nonvascular surgery: dobutamine stress echocardiography in 530 patients. J Am Coll Cardiol. 2000;35:1647-53.

290. Day SM, Younger JG, Karavite D, Bach DS, Armstrong WF, Eagle KA. Usefulness of hypotension during dobutamine echocardiography in predicting perioperative cardiac events. Am J Cardiol. 2000;85:478-83.

291. Best PJ, Tajik AJ, Gibbons RJ, Pellikka PA. The safety of treadmill exercise stress testing in patients with abdominal aortic aneurysms. Ann Intern Med. 1998;129:628-31.

292. Scanlon PJ, Faxon DP, Audet AM, et al. ACC/AHA guidelines for coronary angiography: a report of the American College of Cardiology/American Heart Association Task Force on practice guidelines (Committee on Coronary Angiography). Developed in collaboration with the Society for Cardiac Angiography and Interventions. J Am Coll Cardiol. 1999;33:1756-824.

293. Lee TH. Reducing cardiac risk in noncardiac surgery [editorial]. N Engl J Med. 1999;341:1838-40.

294. Ellis SG, Hertzer NR, Young JR, Brener S. Angiographic correlates of cardiac death and myocardial infarction complicating major nonthoracic vascular surgery. Am J Cardiol. 1996;77:1126-8.

295. McFalls EO, Ward HB, Krupski WC, et al, for the Veterans Affairs Cooperative Study Group on Coronary Artery Revascularization Prophylaxis for Elective Vascular Surgery. Prophylactic coronary artery revascularization for elective vascular surgery: study design. Control Clin Trials. 1999;20:297-308.

296. Gottlieb A, Banoub M, Sprung J, Levy PJ, Beven M, Mascha EJ. Perioperative cardiovascular morbidity in patients with coronary artery disease undergoing vascular surgery after percutaneous transluminal coronary angioplasty. Cardiothorac Vasc Anesth. 1998;12:501-6.

297. Massie MT, Rohrer MJ, Leppo JA, Cutler BS. Is coronary angiography necessary for vascular surgery patients who have positive results of dipyridamole thallium scans? J Vasc Surg. 1997;25:975-82.

298. Posner KL, Van Norman GA, Chan V. Adverse cardiac outcomes after noncardiac surgery in patients with prior percutaneous transluminal coronary angioplasty. Anesth Analg. 1999;89:553-60.

299. Wilson SH, Rihal CS, Bell MR, Velianou JL, Holmes DR Jr, Berger PB. Timing of coronary stent thrombosis in patients treated with ticlopidine and aspirin. Am J Cardiol. 1999;83:1006-11.

300. Berger PB, Bell MR, Hasdai D, Grill DE, Melby S, Holmes DR, Jr. Safety and efficacy of ticlopidine for only 2 weeks after suc-

cessful intracoronary stent placement. Circulation. 1999;99:248-53.

301. Kaluza GL, Joseph J, Lee JR, Raizner ME, Raizner AE. Catastrophic outcomes of noncardiac surgery soon after coronary stenting. J Am Coll Cardiol. 2000;35:1288-94.

302. Comparison of coronary bypass surgery with angioplasty in patients with multivessel disease. The Bypass Angioplasty Revascularization Investigation (BARI) Investigators [published erratum appears in N Engl J Med 1997;336:147]. N Engl J Med. 1996;335:217-25.

303. Hassan SA, Hlatky MA, Boothroyd D, et al. Outcomes of noncardiac surgery after coronary bypass surgery or coronary angioplasty in the Bypass Angioplasty Revascularization Investigation (BARI). Am J Med 2001;110:260-6.

304. Boersma E, Poldermans D, Bax JJ, et al. Predictors of cardiac events after major vascular surgery: role of clinical characteristics, dobutamine echocardiography, and beta-blocker therapy. JAMA. 2001;285:1865-73.

305. Wallace A, Layug B, Tateo I, et al, for the McSPI Research Group. Prophylactic atenolol reduces postoperative myocardial ischemia. Anesthesiology. 1998;88:7-17.

306. Yeager RA, Moneta GL, Edwards JM, Taylor LM Jr, McConnell DB, Porter JM. Reducing perioperative myocardial infarction following vascular surgery: the potential role of beta-blockade. Arch Surg. 1995;130:869-72.

307. Raby KE, Brull SJ, Timimi F, et al. The effect of heart rate control on myocardial ischemia among high-risk patients after vascular surgery. Anesth Analg. 1999;88:477-82.

308. Oliver MF, Goldman L, Julian DG, Holme I. Effect of mivazerol on perioperative cardiac complications during non-cardiac surgery in patients with coronary heart disease: the European Mivazerol Trial (EMIT). Anesthesiology. 1999;91:951-61.

309. Mangano DT, Martin E, Motsch J, et al. Perioperative sympatholysis: beneficial effects of the alpha-2-adrenoceptor agonist mivazerol on hemodynamic stability and myocardial ischemia. Anesthesiology. 1997;86:346-63.

310. Stuhmeier KD, Mainzer B, Cierpka J, Sandmann W, Tarnow J. Small, oral dose of clonidine reduces the incidence of intraoperative myocardial ischemia in patients having vascular surgery. Anesthesiology. 1996;85:706-12.

311. Ellis JE, Drijvers G, Pedlow S, et al. Premedication with oral and transdermal clonidine provides safe and efficacious postoperative sympatholysis. Anesth Analg. 1994;79:1133-40.

312. Zipes DP, DiMarco JP, Gillette PC, et al. Guidelines for clinical intracardiac electrophysiological and catheter ablation procedures: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Clinical Intracardiac Electrophysiologic and Catheter Ablation Procedures), developed in collaboration with the North American Society of Pacing and Electrophysiology. J Am Coll Cardiol. 1995;26:555-73.

313. Farshi R, Kistner D, Sarma JS, Longmate JA, Singh BN. Ventricular rate control in chronic atrial fibrillation during daily activity and programmed exercise: a crossover open-label study of five drug regimens. J Am Coll Cardiol. 1999;33:304-10.

314. Balser JR, Martinez EA, Winters BD, et al. Beta-adrenergic blockade accelerates conversion of postoperative supraventricular tachyarrhythmias. Anesthesiology. 1998;89:1052-9.

315. Levine PA, Balady GJ, Lazar HL, Belott PH, Roberts AJ. Electrocautery and pacemakers: management of the paced patient subject to electrocautery. Ann Thorac Surg. 1986;41:313-7.

316. Bourke ME. The patient with a pacemaker or related device. Can J Anaesth. 1996;43:R24-41.

317. Madigan JD, Choudhri AF, Chen J, Spotnitz HM, Oz MC, Edwards N. Surgical management of the patient with an implanted cardiac device: implications of electromagnetic interference. Ann Surg. 1999;230:639-47.

318. Pinski SL, Trohman RG. Interference with cardiac pacing. Cardiol Clin. 2000;18:219-39.

319. Ziegler DW, Wright JG, Choban PS, Flancbaum L. A prospective randomized trial of preoperative "optimization" of cardiac function in patients undergoing elective peripheral vascular surgery. Surgery. 1997;122:584-92.

320. Clagett GP, Anderson FA Jr, Geerts W, et al. Prevention of venous thromboembolism. Chest. 1998;114:531S-60S.

321. Rihal CS, Sutton-Tyrrell K, Guo P, et al. Increased incidence of periprocedural complications among patients with peripheral vascular disease undergoing myocardial revascularization in the Bypass Angioplasty Revascularization Investigation. Circulation. 1999;100:171-7.

322. Helman JD, Leung JM, Bellows WH, et al, for the SPI Research Group. The risk of myocardial ischemia in patients receiving desflurane versus sufentanil anesthesia for coronary artery bypass graft surgery. Anesthesiology. 1992;77:47-62.

323. Christopherson R, Beattie C, Frank SM, et al, for the Perioperative Ischemia Randomized Anesthesia Trial Study Group. Perioperative morbidity in patients randomized to epidural or general anesthesia for lower extremity vascular surgery. Anesthesiology. 1993;79:422-34.

324. Baron JF, Bertrand M, Barre E, et al. Combined epidural and general anesthesia versus general anesthesia for abdominal aortic surgery. Anesthesiology. 1991;75:611-8.

325. Tuman KJ, McCarthy RJ, March RJ, DeLaria GA, Patel RV, Ivankovich AD. Effects of epidural anesthesia and analgesia on coagulation and outcome after major vascular surgery. Anesth Analg. 1991;73:696-704.

326. Bois S, Couture P, Boudreault D, et al. Epidural analgesia and intravenous patient-controlled analgesia result in similar rates of postoperative myocardial ischemia after aortic surgery. Anesth Analg. 1997;85:1233-39.

327. Bode RH Jr, Lewis KP, Zarich SW, et al. Cardiac outcome after peripheral vascular surgery: comparison of general and regional anesthesia. Anesthesiology. 1996;84:3-13.

328. Parker SD, Breslow MJ, Frank SM, et al, for the Perioperative Ischemia Randomized Anesthesia Trial Study Group. Catecholamine and cortisol responses to lower extremity revascularization: correlation with outcome variables. Crit Care Med. 1995;23:1954-61.

329. Rosenfeld BA, Beattie C, Christopherson R, et al, for the Perioperative Ischemia Randomized Anesthesia Trial Study Group. The effects of different anesthetic regimens on fibrinolysis and the development of postoperative arterial thrombosis. Anesthesiology. 1993;79:435-43.

330. Practice guidelines for perioperative transesophageal echocardiography: a report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Anesthesiology. 1996;84: 986-1006.

331. Frank SM, Beattie C, Christopherson R, et al, for the Perioperative Ischemia Randomized Anesthesia Trial Study Group. Unintentional hypothermia is associated with postoperative myocardial ischemia. Anesthesiology. 1993;78:468-76.

332. Frank SM, Fleisher LA, Breslow MJ, et al. Perioperative maintenance of normothermia reduces the incidence of morbid cardiac

events: a randomized clinical trial. JAMA. 1997;277:1127-34.

333. Shayani V, Watson WC, Mansour MA, Thomas N, Pickleman J. Intra-aortic balloon counterpulsation in patients with severe cardiac dysfunction undergoing abdominal operations. Arch Surg. 1998;133:632-35.

334. Masaki E, Takinami M, Kurata Y, Kagaya S, Ahmed A. Anesthetic management of high-risk cardiac patients undergoing noncardiac surgery under the support of intraaortic balloon pump. J Clin Anesth. 1999;11:342-5.

335. Bender JS, Smith-Meek MA, Jones CE. Routine pulmonary artery catheterization does not reduce morbidity and mortality of elective vascular surgery: results of a prospective, randomized trial. Ann Surg. 1997;226:229-36.

336. Valentine RJ, Duke ML, Inman MH, et al. Effectiveness of pulmonary artery catheters in aortic surgery: a randomized trial. J Vasc Surg. 1998;27:203-11.

337. Polanczyk CA, Marcantonio E, Goldman L, et al. Impact of age on perioperative complications and length of stay in patients undergoing noncardiac surgery. Ann Intern Med. 2001;134:637-43.

338. Iberti TJ, Fischer EP, Leibowitz AB, Panacek EA, Silverstein JH, Albertson TE, for the Pulmonary Artery Catheter Study Group. A multicenter study of physicians' knowledge of the pulmonary artery catheter. JAMA. 1990;264:2928-32.

339. Ellis JE, Shah MN, Briller JE, Roizen MF, Aronson S, Feinstein SB. A comparison of methods for the detection of myocardial ischemia during noncardiac surgery: automated ST-segment analysis systems, electrocardiography, and transesophageal echocardiography. Anesth Analg. 1992;75:764-72.

340. Leung JM, Voskanian A, Bellows WH, Pastor D. Automated electrocardiograph ST segment trending monitors: accuracy in detecting myocardial ischemia. Anesth Analg. 1998;87:4-10.

341. Slogoff S, Keats AS, David Y, Igo SR. Incidence of perioperative myocardial ischemia detected by different electrocardiographic systems. Anesthesiology. 1990;73:1074-81.

342. London MJ, Hollenberg M, Wong MG, et al. Intraoperative myocardial ischemia: localization by continuous 12-lead electrocardiography. Anesthesiology. 1988;69:232-41.

343. Fleisher LA, Zielski MM, Schulman SP. Perioperative ST-segment depression is rare and may not indicate myocardial ischemia in moderate-risk patients undergoing noncardiac surgery. J Cardiothorac Vasc Anesth. 1997;11:155-9.

344. Palmer CM, Norris MC, Giudici MC, Leighton BL, DeSimone CA. Incidence of electrocardiographic changes during cesarean delivery under regional anesthesia. Anesth Analg. 1990;70:36-43.

345. Adams JE III, Sicard GA, Allen BT, et al. Diagnosis of perioperative myocardial infarction with measurement of cardiac troponin I. N Engl J Med. 1994;330:670-4.

346. Badner NH, Knill RL, Brown JE, Novick TV, Gelb AW. Myocardial infarction after noncardiac surgery. Anesthesiology. 1998;88:572-8.

347. Godet G, Ben Ayed S, Bernard M, et al. Cardiac troponin I cutoff values to predict postoperative cardiac complications after circulatory arrest and profound hypothermia. J Cardiothorac Vasc Anesth. 1999;13:272-5.

348. Lee TH, Thomas EJ, Ludwig LE, et al. Troponin T as a marker for myocardial ischemia in patients undergoing major noncardiac surgery. Am J Cardiol. 1996;77:1031-6.

349. Lopez-Jimenez F, Goldman L, Sacks DB, et al. Prognostic value of cardiac troponin T after noncardiac surgery: 6-month follow-up data. J Am Coll Cardiol. 1997;29:1241-5.

350. Metzler H, Gries M, Rehak P, Lang T, Fruhwald S, Toller W. Perioperative myocardial cell injury: the role of troponins. Br J Anaesth. 1997;78:386-90.

351. Myocardial infarction redefined: a consensus document of The Joint European Society of Cardiology/American College of Cardiology Committee for the redefinition of myocardial infarction. J Am Coll Cardiol. 2000;36:959-69.

352. Terzi A, Furlan G, Chiavacci P, Dal Corso B, Luzzani A, Dalla VS. Prevention of atrial tachyarrhythmias after non-cardiac thoracic surgery by infusion of magnesium sulfate. Thorac Cardiovasc Surg. 1996;44:300-3.

353. Buxton AE, Lee KL, Fisher JD, Josephson ME, Prystowsky EN, Hafley G for the . Multicenter Unsustained Tachycardia Trial Investigators. A randomized study of the prevention of sudden death in patients with coronary artery disease [published erratum appears in N Engl J Med 2000;342:1300]. N Engl J Med. 1999;341:1882-90.

354. Moss AJ, Hall WJ, Cannom DS, et al, for the Multicenter Automatic Defibrillator Implantation Trial Investigators. Improved survival with an implanted defibrillator in patients with coronary disease at high risk for ventricular arrhythmia. N Engl J Med. 1996;335:1933-40.

355. Kowey PR, Marinchak RA, Rials SJ, Filart RA. Intravenous amiodarone. J Am Coll Cardiol. 1997;29:1190-8.

356. Scheinman MM, Levine JH, Cannom DS, et al, for the Intravenous Amiodarone Multicenter Investigators Group. Dose-ranging study of intravenous amiodarone in patients with life-threatening ventricular tachyarrhythmias. Circulation. 1995;92:3264-72.

357. Kowey PR, Levine JH, Herre JM, et al, for the Intravenous Amiodarone Multicenter Investigators Group. Randomized, double-blind comparison of intravenous amiodarone and bretylium in the treatment of patients with recurrent, hemodynamically destabilizing ventricular tachycardia or fibrillation. Circulation. 1995;92:3255-63.

358. Jamieson WR, Janusz MT, Miyagishima RT, Gerein AN. Influence of ischemic heart disease on early and late mortality after surgery for peripheral occlusive vascular disease. Circulation. 1982;66:I92-7.

359. Killen DA, Reed WA, Gorton ME, Borkon AM, Piehler JM, Wathanacharoen S. 25-Year trends in resection of abdominal aortic aneurysms. Ann Vasc Surg. 1998;12:436-44.

360. Won A, Acosta JA, Browner D, Hye RJ. Validation of selective cardiac evaluation prior to aortic aneurysm repair. Arch Surg. 1998;133:833-8.

361. Mangano DT, Goldman L. Preoperative assessment of patients with known or suspected coronary disease. N Engl J Med. 1995;333:1750-6.

362. Dawood MM, Gutpa DK, Southern J, Walia A, Atkinson JB, Eagle KA. Pathology of fatal perioperative myocardial infarction: implications regarding pathophysiology and prevention. Int J Cardiol. 1996;57:37-44.

363. Berger PB, Wolf CM, Bell MR, et al. Characteristics and outcome of patients referred to emergency coronary angiography and PTCA for acute myocardial infarction early after noncardiac surgery [abstr]. J Am Coll Cardiol 1999;33:367A.

364. Indications for fibrinolytic therapy in suspected acute myocardial infarction: collaborative overview of early mortality and major morbidity results from all randomised trials of more than 1000 patients. Fibrinolytic Therapy Trialists' (FTT) Collaborative Group [published erratum appears in Lancet 1994;343:742]. Lancet. 1994;343:311-22.

365. Goldhaber SZ. Pulmonary embolism thrombolysis: broadening

the paradigm for its administration [editorial]. Circulation. 1997;96:716-8.

366. Kasper W, Konstantinides S, Geibel A, et al. Management strategies and determinants of outcome in acute major pulmonary embolism: results of a multicenter registry. J Am Coll Cardiol. 1997;30:1165-71.

367. Weaver WD, Simes RJ, Betriu A, et al. Comparison of primary coronary angioplasty and intravenous thrombolytic therapy for acute myocardial infarction: a quantitative review [published erratum appears in JAMA 1998 Jun 17;279(23):1876]. JAMA. 1997;278:2093-8.

368. Berger PB, Holmes DR Jr, Stebbins AL, Bates ER, Califf RM, Topol EJ. Impact of an aggressive invasive catheterization and revascularization strategy on mortality in patients with cardiogenic shock in the Global Utilization of Streptokinase and Tissue Plasminogen Activator for Occluded Coronary Arteries (GUSTO-I) trial: an observational study. Circulation. 1997;96:122-7.

369. Cannon CP, Gibson M, Lambrew CT, et al. Relationship of time to treatment and door-to-balloon time to mortality in 27,080 patients with acute myocardial infarction treated with primary angioplasty [abstr]. Circulation. 1999;100(suppl I):360.

370. Ryan TJ, Antman EM, Brooks NH, et al. 1999 update: ACC/AHA guidelines for the management of patients with acute myocardial infarction: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Management of Acute Myocardial Infarction). J Am Coll Cardiol. 1999;34:890-911.

371. Braunwald E, Antman EM, Beasley JW, et al. ACC/AHA guidelines for the management of patients with unstable angina and non-ST-segment elevation myocardial infarction: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on the Management of Patients With Unstable Angina). J Am Coll Cardiol. 2000;36:970-1062.

372. McFalls EO, Ward HB, Santilli S, Scheftel M, Chesler E, Doliszny KM. The influence of perioperative myocardial infarction on long-term prognosis following elective vascular surgery. Chest. 1998;113:681-6.

373. Schueppert MT, Kresowik TF, Corry DC, et al. Selection of patients for cardiac evaluation before peripheral vascular operations. J Vasc Surg. 1996;23:802-8.

374. Lette J, Waters D, Bernier H, et al. Preoperative and long-term cardiac risk assessment: predictive value of 23 clinical descriptors, 7 multivariate scoring systems, and quantitative dipyridamole imaging in 360 patients. Ann Surg. 1992;216:192-204.

375. Fleisher LA, Rosenbaum SH, Nelson AH, Jain D, Wackers FJ, Zaret BL. Preoperative dipyridamole thallium imaging and ambulatory electrocardiographic monitoring as a predictor of perioperative cardiac events and long-term outcome. Anesthesiology. 1995;83:906-17.

376. Emlein G, Villegas B, Dahlberg S, Leppo J. Left ventricular cavity size determined by preoperative dipyridamole thallium scintigraphy as a predictor of late cardiac events in vascular surgery patients. Am Heart J. 1996;131:907-14.

377. Klonaris CN, Bastounis EA, Xiromeritis NC, Balas PE. The predictive value of dipyridamole-thallium scintigraphy for cardiac risk assessment before major vascular surgery. Int Angiol. 1998; 17:171-8.

378. Koutelou MG, Asimacopoulos PJ, Mahmarian JJ, Kimball KT, Verani MS. Preoperative risk stratification by adenosine thallium 201 single-photon emission computed tomography in patients undergoing vascular surgery. J Nucl Cardiol. 1995;2:389-94.

379. Pasquet A, D'Hondt AM, Verhelst R, Vanoverschelde JL, Melin J, Marwick TH. Comparison of dipyridamole stress echocardiography and perfusion scintigraphy for cardiac risk stratification in vascular surgery patients. Am J Cardiol. 1998;82:1468-74.

380. Holley JL, Fenton RA, Arthur RS. Thallium stress testing does not predict cardiovascular risk in diabetic patients with end-stage renal disease undergoing cadaveric renal transplantation. Am J Med. 1991;90:563-70.

381. Le A, Wilson R, Douek K, et al. Prospective risk stratification in renal transplant candidates for cardiac death. Am J Kidney Dis. 1994;24:65-71.

382. Bates JR, Sawada SG, Segar DS, et al. Evaluation using dobutamine stress echocardiography in patients with insulin-dependent diabetes mellitus before kidney and/or pancreas transplantation. Am J Cardiol. 1996;77:175-9.

383. Kryzhanovski VA, Beller GA. Usefulness of preoperative noninvasive radionuclide testing for detecting coronary artery disease in candidates for liver transplantation. Am J Cardiol. 1997;79:986-8.

384. Gibbons RJ, Chatterjee K, Daley J, et al. ACC/AHA/ACP-ASIM guidelines for the management of patients with chronic stable angina: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee on Management of Patients With Chronic Stable Angina). J Am Coll Cardiol. 1999;33:2092-197.

385. Smith SC, Blair SN, Criqui MH, et al. Preventing heart attack and death in patients with coronary disease. Circulation. 1995;92:2-4.

386. Ali MJ, Davison P, Pickett W, Ali NS. ACC/AHA guidelines as predictors of postoperative cardiac outcomes. Can J Anaesth. 2000;47:10-19.

387. Marshall ES, Raichlen JS, Forman S, Heyrich GP, Keen WD, Weitz HH. Adenosine radionuclide perfusion imaging in the preoperative evaluation of patients undergoing peripheral vascular surgery. Am J Cardiol. 1995:76:817-21.

388. Van Damme H, Pierard L, Gillain D, Benoit T, Rigo P, Limet R. Cardiac risk assessment before vascular surgery: a prospective study comparing clinical evaluation, dobutamine stress echocardiography, and dobutamine Tc-99m sestamibi tomoscintigraphy. Cardiovasc Surg. 1997;5:54-64.

389. Smith SC Jr, Dove JT, Jacobs AK, et al. ACC/AHA guidelines for percutaneous coronary intervention: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Revise the 1993 Guidelines for Percutaneous Transluminal Coronary Angioplasty). J Am Coll Cardiol 2001;37:2215-38.

390. Fleisher LA, Eagle KA. Lowering cardiac risk in noncardiac surgery. N Engl J Med 2001;345:1677-82.