Cardiac Risk in Noncardiac Surgery: An Update

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The preoperative evaluation and management of the patient potentially at risk for cardiac complications of noncardiac surgery require the collaborative efforts of the surgeon, anesthesiologist, and medical physician. Each brings a somewhat different perspective and expertise to the problem, and ideal decisions are possible only if all work together in a collaborative, mutually respectful manner. Cardiologists and internists should refrain from trite recommendations such as "avoid hypotension" and should not pretend to make recommendations regarding anesthetic routes and techniques except in very unusual circumstances. In the context of the appropriate role for the consulting internist and cardiologist, this review will emphasize important issues in the preoperative and postoperative periods and highlight a probabalistic approach to risk assessment and decision-making, in which additional information is helpful only if it provides incremental assistance.

Understanding Probability

A fundamental principle of risk assessment and medical decision-making is that a group of patients has an "average" probability of a diagnosis or outcome that can then be modified by considering additional individual risk factors or results of diagnostic tests. This principle, which is quantified by Bayes theorem, explains why the same test result has different implications in patients with different *prior probabilities* of disease (1) (Table 1).

Sensitivity and specificity are intrinsic properties of a test—its ability to identify patients with or without the condition of interest, be it a diagnosis or a predicted outcome. Although sensitivity and specificity are independent of the prior or pretest probability of the diagnosis or outcome, they are dependent on the spectrum of patients being studied (1). For example, the sensitivity and specificity of an exercise test will depend on whether it is used on a wide spectrum of consecutive patients with chest pain or whether it is evaluated in a bimodal population of normal medical students and patients with known coronary stenoses. By comparison, predictive value, which is the posttest probability of the diagnosis or outcome, depends critically on the estimated pretest probability as well as on the sensitivity and specificity of the test (1).

This principle has direct applications to the assessment of cardiac risk in noncardiac surgery. For example, in large series of consecutive unselected patients more than 40 yr old undergoing major noncardiac surgical procedures, the risk of perioperative myocardial infarction has been approximately 1.4% (1%–2%) and the risk of perioperative cardiac death has been approximately 1% (0.5%–2%) (2–5). By comparison, in studies of consecutive patients with higher risk characteristics, such as patients undergoing vascular surgery or patients with known or highly suspected coronary heart disease, these risks have been twice as high: approximately 3.1% and 1.7%, respectively (5–11). In more highly selected patients, such as patients who have been referred for dipyridamole thallium scintigraphy in the larger series, the risks are increased yet again by another twofold to approximately 6% and 3%, respectively (12–17). It should not be surprising that the reported value of additional pieces of information or diagnostic tests could be substantially different when applied to patient populations in whom the underlying risks of complications vary by fourfold.

The difficulty in interpreting the relevant literature is further exacerbated by the small size of many individual studies. Factors that have been shown clearly to be important in a series of 1000 or more patients may be present too infrequently to achieve statistical significance in studies with 100–200 patients.

A third issue relates to the way in which additional information and diagnostic tests are assessed. Fortunately, almost all recent analyses have used multivariable approaches to assess the independent impact of various pieces of information. Unfortunately, many studies have not included a careful, comprehensive, prospective clinical evaluation prior to assessing the impact of a diagnostic test. The key issue is the extent

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Table 1. How the Positive and Negative Predictive Values of the Same Test Vary Depending on the Prior Probability of Disease

Interpretation of test result when 10% of patients tested have the disease (prior probability = 10%)					Interpretation of test result when 50% of patients tested have the disease (prior probability = 50%)				
1,000,000 patients					1,000,000 patients				
Prior probability	0.10		0.90		Prior probability	0.50		0.50	
	100,000 with the disease		900,000 without the disease			500,000 with the disease		500,000 without the disease	
Test with sensitivity = 90% specificity = 95%					Test with sensitivity = 90% specificity = 95%				
	90,000 + test result (true positive)	10,000 − test result (false negative)	45,000 + test result (true positive)	855,000 − test result (false negative)		450,000 + test result (true positive)	50,000 − test result (false negative)	25,000 + test result (true positive)	475,000 − test result (false negative)
The probability of disease in a patient with a positive test result (positive predictive value) = 90,000/135,000 = 67%					The probability of disease in a patient with a positive test result (positive predictive value) = 450,000/475,000 = 95%				
The probability of no disease in a patient with a negative test result (negative predictive value) = 855,000/865,000 = 99%					The probability of no disease in a patient with a negative test result (negative predictive value) = 475,000/525,000 = 90%				

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to which such a test will provide incremental information after the most appropriate clinical assessment has already been performed.

Clinical Factors That Affect Cardiac Risk

Although different studies have used somewhat different methods, several specific factors clearly influence cardiac risk in noncardiac surgery. When the review focuses on the larger *prospective* series, those with 400 or more patients who were evaluated comprehensively prior to surgery, a remarkably consistent picture emerges (2–10). These larger, prospective series should be distinguished from smaller series, which may be of insufficient size to detect important correlations between risk factors and outcomes and that may be overly influenced by the characteristics of a small number of patients. They also differ from studies that used chart review to identify risk factors and outcome. These latter studies relied on the preoperative historical and physical examination data recorded by physicians who cared for the patients, as opposed to the comprehensive evaluation that can be performed and recorded in a prospective study, and on routine postoperative clinical practice rather than a standardized surveillance protocol to detect postoperative outcomes. Among the studies that met these criteria, several included all consecutive, unselected patients more than 40 yr old undergoing major noncardiac surgery (2–5), and others included consecutive *selected* patients who had high risk characteristics such as known coronary artery disease, vascular disease, multiple coronary risk factors, or old age (5–10).

Ischemic Heart Disease

Various measures of coronary artery disease have been associated with cardiac risk in all major studies. The most striking risk factor is a recent myocardial infarction (2,4,18,19). Although data up until the mid-1970s suggested that the risk of perioperative myocardial infarction or cardiac death was approximately 30% in patients who had surgery within 3 mo of a myocardial infarction and approximately 15% in patients who had surgery between 3 and 6 mo after a myocardial infarction (2,18,19), subsequent data suggest far lower risks after elective noncardiac surgery (20–22) (Table 2). In two of these studies (20,21), these lower risks were reported in patients who were selected based on an overall risk assessment and for whom aggressive intraoperative and postoperative monitoring protocols were used. In a series of patients undergoing urgent or emergent vascular surgery within 6 wk after a myocardial infarction between 1980 and 1989, the risks remained high (22).

Table 2. Risk of Reinfarction or Cardiac Death from Surgery in Post-MI Patients

Months after prior MI	Pooled data pre-1976	Rao et al. (20) 1983	Shah et al. (21) 1990	Rivers et al. (22) 1990[a]
0–3	31%	6% (3/52)	4% (1/23)	17% (5/30)
4–6	15%	2% (2/86)	0% (0/18)	
>6	5%	1.5% (9/595)	6% (10/174)	

MI = myocardial infarction.
[a] Vascular surgery patients only.

No data specifically address whether patients who have had reperfusion by thrombolysis or percutaneous transluminal coronary angioplasty (PTCA) face different subsequent risks with noncardiac surgery. However, newer medical and intervention therapies have improved the overall prognosis of the patient after infarction and likely have reduced their risks for subsequent noncardiac surgery as well.

Patients with a recent preoperative myocardial infarction can generally be divided into three groups: 1) those in whom the surgery is emergent and potentially life-saving and in whom it will nearly always be performed regardless of cardiac risk; 2) those in whom it is purely elective and should be delayed for approximately 3 mo, when the infarction is likely to have healed and the patient is back to baseline functional status, or for a full 6 mo for patients who have not fully recovered; and 3) those for whom the surgery is not absolutely emergent but in whom it cannot be delayed for many months without incurring substantial risk that the surgical condition will worsen. In these latter patients, which include those with severe vascular disease or with potentially resectable tumors, the recommended approach is to undergo the usual evaluation and rehabilitation after the infarction. Patients who develop signs or symptoms at low exercise levels will be candidates for coronary angiography and revascularization. Those who are able to rehabilitate without more than mild symptoms can be considered for necessary noncardiac surgery between 6 wk and 3 mo after the infarction, when they normally should be at their baseline functional status if their exercise performance and noninvasive cardiac evaluation permits. This approach, which must be tailored to the needs and risks of the individual patient, appears to balance the competing risks of the cardiac and noncardiac conditions.

Few data are available to assess risk in patients with unstable or accelerated angina or with very advanced and disabling angina. In general, such patients routinely undergo coronary angiography and attempted revascularization for their coronary disease independent of their noncoronary conditions. The availability of PTCA (23,24) has provided an attractive option for these patients without requiring an inordinate delay of the noncardiac surgery or heroic attempts to perform two major operations under the same anesthesia.

A more difficult issue is the evaluation of the patient with suspected or known coronary disease that is not obviously unstable or disabling. Patients with a prior myocardial infarction or stable, Class I-II angina (Table 3) are at higher risk of cardiac complications with perhaps a 10-fold relative increase in risk as compared with patients who do not have coronary disease (4,6,8,11,25). However, the 10-fold relative increase in risk corresponds to a rather low absolute risk: approximately a 4% risk of myocardial infarction and approximately a 1%–2% risk of cardiac death (6,8,11,25). These risks tend not to exceed the very similar risks for both myocardial infarction and cardiac death that would be associated with an aggressive strategy of coronary angiography and revascularization followed by the noncardiac surgery (11), so a routinely aggressive approach to these patients does not appear to be warranted. Strategies for attempting to identify the subset of patients with suspected or known coronary disease who are at sufficiently increased risk to warrant more aggressive approaches are described later.

Left Ventricular Dysfunction and Congestive Heart Failure

Although the precise factors vary from study to study, large series have consistently noted that patients with substantially depressed left ventricular function or evidence of advanced congestive heart failure have an increase in cardiac risk (2,4,11). To the extent that the left ventricular dysfunction is a manifestation of prior large or multiple myocardial infarctions, the dysfunction also serves as a marker of the severity of coronary artery disease. Even in the absence of known coronary disease, patients with left ventricular dysfunction or heart failure based on hypertension, valvular heart disease, or cardiomyopathy are less able to handle the fluid shifts and volume changes that are often associated with major surgery. Patients more than 40 yr old who have persistent evidence of congestive heart failure at the time of major surgery are at highest risk for pulmonary edema (15% or so), whereas those with well controlled congestive heart failure have risks that are lower (approximately 5%) than those with persistent heart failure but clearly higher than those who have never had heart failure (approximately 2%) (4,25).

Table 3. Assessment of Cardiac Functional Class Using Two Different Systems

Class	Canadian Cardiovascular Society[a]	Specific activity scale[b]
I	Ordinary physical activity, such as walking and climbing stairs, does not cause angina. Angina occurs with strenuous or rapid or prolonged exertion at work or recreation.	Can carry at least 24 lb up eight steps, carry objects that are at least 80 lb, shovel snow, spade soil, jog/walk 5 mph, ski, or play basketball, football, squash, or handball.
II	Slight limitation of ordinary activity. Angina occurs with walking or climbing stairs rapidly, walking uphill, walking or stair climbing after meals, or in cold, or in wind, or under emotional stress, or only during the few hours after awakening. Angina occurs when walking more than two blocks on the level or climbing more than one flight of ordinary stairs at a normal pace and in normal conditions.	Can carry anything up a flight of eight steps without stopping, have sexual intercourse without stopping, garden, rake, weed, roller skate, dance, foxtrot, or walk at a 4-mph rate on level ground.
III	Marked limitation of ordinary physical activity. Angina occurs with walking one to two blocks on the level and climbing one flight of stairs in normal conditions and at a normal pace.	Can shower without stopping, strip and make bed, mop floors, hang washed clothes, clean windows, walk 2.5 mph, bowl, play golf (walk and carry clubs), push power lawn mower, or dress without stopping because of symptoms.
IV	Inability to carry on any physical activity without discomfort—angina *may be* present at rest.	Can do none of the above or have symptoms at rest.

[a] Campeau L. Grading of angina pectoris [letter]. Circulation 1975;54:522.
[b] 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.

Valvular Heart Disease

Most series had insufficient numbers of patients with significant valvular heart disease to reach definitive conclusions regarding risks. Patients with severe aortic stenosis appear to be at highest risk (2), although data suggest that a majority of these patients can tolerate surgery under careful perioperative management (26). Nevertheless, patients with symptomatic aortic stenosis who are candidates for valve replacement surgery should generally have the surgery performed prior to nonemergent noncardiac surgery. If the noncardiac surgery is urgent or the patient may not be a candidate for valve replacement, balloon aortic valvuloplasty can provide several months of hemodynamic and symptomatic relief and provide a window of opportunity for safer general surgery (27). Patients who have significant aortic valve gradients but who are asymptomatic and have a good exercise tolerance generally do well with noncardiac surgery (26).

Hypertension

Patients with hypertension are at increased risk for coronary artery disease and congestive heart failure, and they tend to have more silent myocardial ischemia with surgery, whether or not they have clinical coronary disease (28,29). However, hypertension itself does not appear to be a major independent risk factor for the development of clinically detectable myocardial infarction or of cardiac death with noncardiac surgery (2,4). Although aggressive approaches can reduce blood pressure lability and perhaps evidence of silent myocardial ischemia during surgery (30,31), epidemiologic data suggest that patients with untreated or persistent mild to moderate hypertension can undergo anesthesia and surgery without increasing the risks of major morbid events (32).

Arrhythmias

Both atrial and ventricular arrhythmias are often markers of the severity of underlying coronary disease and left ventricular dysfunction. In an era when noninvasive cardiac tests were generally unavailable or infrequently used to assess the severity of coronary disease or depressed left ventricular function, the presence of preoperative arrhythmias was an alternative way to assess which patients had relatively more severe effects from these underlying cardiac conditions (2).

Since these arrhythmias appear to be markers of underlying heart disease, they tend to correlate with both ischemic and heart failure complications (2). In contrast, if patients have these arrhythmias but no underlying heart disease, the arrhythmias themselves add rather little to the absolute risk of a major cardiac event (33,34); by extrapolation, their risks for such an event in the perioperative period are probably also low. There is no evidence that the institution of new, prophylactic medications in the perioperative period will alter risk, or that asymptomatic arrhythmias need to be suppressed (35), although patients with other indications for the treatment of these arrhythmias should receive such treatment.

Age

Studies have consistently shown that older patients have higher risk of cardiac complications, and in most studies age has been an independent predictive factor, even after controlling for the severity of cardiac disease and comorbid conditions (2,8,11). Although chronologic age is not a perfect predictor of frailty, older patients clearly have less physiologic reserve and more cardiac disease, the severity of which may be masked by their diminished exercise levels.

Type of Surgery

Operations that are associated with more difficult postoperative recuperation, including major abdominal and thoracic operations, tend to carry higher risk than those surgeries that are not as likely to be associated with postoperative hypoxemia, major fluid shifts, bleeding, and other major noncardiac problems (2,4). Patients undergoing major vascular surgery are more likely to have atherosclerotic coronary disease as well and have increased risk because of the prevalence of this underlying problem. The highest risk noncardiac operation is aortic aneurysm repair (2,4,36), presumably because these patients have both a high risk of noncardiac postoperative complications and a high prevalence of underlying coronary disease (2,4).

The higher incidence of postoperative complications in patients undergoing these types of operations is not related primarily to the length of anesthesia, since there appears to be little if any correlation between the length of an operation and the probability of postoperative complications after controlling for the type of surgery (2,24). In fact, studies of perioperative ischemia suggest that although intraoperative myocardial ischemia is somewhat predictive of postoperative cardiac events, it is less predictive than either asymptomatic preoperative ischemia or asymptomatic postoperative ischemia (37,38). More sophisticated intraoperative monitoring with transesophageal echocardiography can provide interesting hemodynamic information but there are no data to indicate that it is critical for clinical care or decision-making, or for affecting important patient outcomes (39).

General Medical and Surgical Status

Patients who undergo emergency operations are at higher risk than similar patients undergoing elective surgery (2,4,8), presumably because they are more likely to suffer noncardiac complications that, all other things being equal, are then more likely to put stress on the cardiovascular system and cause secondary cardiac complications. Patients with other evidence for important comorbid problems, such as hypoxemia, hypercapnia, hypokalemia, acidosis, renal failure, or serious liver or other diseases also have higher risk of cardiac complications, again presumably because their unstable condition puts added stress on the cardiovascular system (2,4,8).

Multifactorial Indices

Multifactorial indices, which combine many important characteristics of the patient, are preferable to reliance on any single clinical factor when assessing perioperative risk. Three different large studies (2,4,5) have proposed slightly different multifactorial indices (Table 4), each of which has substantial overlap in terms of the factors that are included. Of these three, the only one to have been evaluated in other large prospective series is the original multifactorial index (2). In consecutive, unselected patients, this index has performed nearly equivalently in two large prospective validations in Canada and Europe (3,4) as in its original set of patients in the United States (Figure 1). It also performed extremely well in a consecutive series of patients with prior coronary or valvular surgery who then underwent noncardiac surgery (40). In other selected patients, such as those who had medical consultations or underwent abdominal aortic aneurysm surgery, the original index performed significantly better than chance but not as well as in the original series (36,41). Ongoing work by my colleagues and me, and by others, should help update the factors that remain important in the current era.

Since a fundamental principle of clinical reasoning is that new information, such as from a diagnostic test or multifactorial index, must be integrated with prior information to estimate an updated probability, it is not surprising that risk indices derived on more general patient populations would not be perfectly applicable to more selected patient samples (41,42). Therefore, in the context of probabilistic reasoning, the result of a risk index can be considered in the same way that one would interpret the result of a diagnostic test. By integrating a patient's score on a risk index with the prior probability of major complications in a large population of reasonably similar patients, the resulting risk estimate, like a positive predictive value described in Table 1, will be better than either the prior probability or the risk index score alone (Table 5).

The Special Case of Patients with Ischemic Heart Disease

Patients with known ischemic heart disease or who are at very high risk for it represent a special type of

Table 4. Three Cardiac Risk Indices

Factor	Points
Original index[a] (2)	
Age >70 yr	5
MI in previous 6 mo	10
S_3 gallop or jugular venous distention	11
Important aortic stenosis	3
Rhythm other than sinus or PACs on last preoperative ECG	7
>5 PVCs/min documented at any time before operation	7
Po_2 <60 or Pco_2 >50 mm Hg; K <3.0 or HCO_3 <20 mEq/L; BUN >50 or Cr >3.0 mg/dL; abnormal AST, signs of chronic liver disease, or bedridden from noncardiac causes	3
Intraperitoneal, intrathoracic, or aortic operation	
Emergency operation	4
Detsky et al.[b] (5)	
MI within 6 mo	10
MI more than 6 mo	5
Canadian Cardiovascular Society angina	
Class III	10
Class IV	20
Unstable angina within 6 mo	10
Alveolar pulmonary edema	
Within 1 wk	10
Ever	5
Suspected critical aortic stenosis	20
Rhythm other than sinus or sinus plus PACs on last preoperative ECG	5
More than five PVCs/min at any time prior to surgery	5
Poor general medical status	5
Age >70 yr	5
Emergency operation	10
Larsen et al.[c] (4)	
Congestive heart failure	
Persistent pulmonary congestion	12
No, but previous pulmonary edema	8
Neither, but previous heart failure	4
Ischemic heart disease	
MI within 3 mo	11
No, but older infarction and/or angina pectoris	3
Diabetes mellitus	3
Serum creatinine >0.13 mmol/L	2
Emergency operation	3
Major surgical procedure	
Aortic operation	5
Other intraperitoneal/pleural operation	3

MI = myocardial infarction; PAC = premature atrial contraction; ECG = electrocardiogram; PVC = premature ventricular contraction; K = potassium; BUN = blood urea nitrogen; Cr = creatinine; AST = aspartate aminotransferase.

[a] Derived from 1001 consecutive unselected patients more than 40 yr old undergoing major noncardiac surgery using multivariable analysis.

[b] Modification of original index based on the clinical judgments of the authors.

[c] Derived from 2609 patients more than 40 yr old undergoing nonminor noncardiac surgery using multivariable analysis.

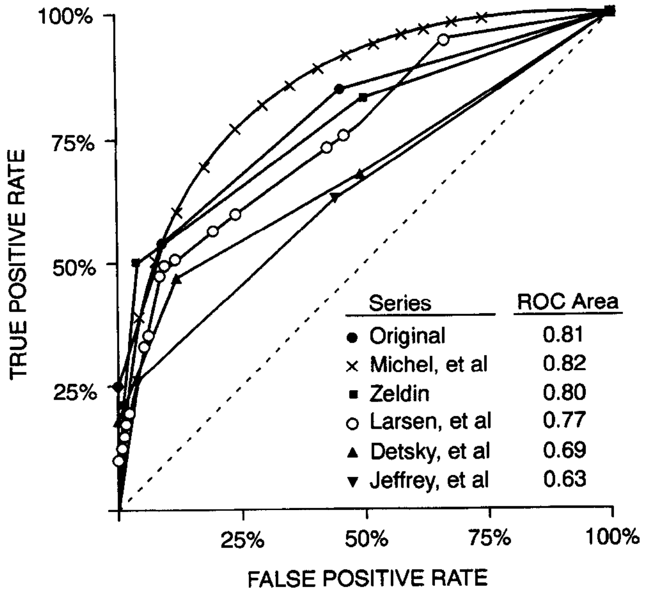

Figure 1. Comparative accuracy of the original multifactorial index in various large studies. Receiver operating characteristics curve (ROC) plot of the true-positive rate (sensitivity) on the ordinates against the false-positive rate (1-specificity) on the abscissae of the ability of the original multifactorial index to discriminate patients with and without major cardiac complications. Steeper curves in the upper left quadrant represent better tests. In all studies, the index performed significantly better than chance by formal statistical testing, and in the two largest studies of consecutive, unselected patients, its performance was very similar to the original report. [Please see reference list: Original (2), Michel et al. (40), Zeldin (3), Larsen et al. (4), Detsky et al. (5,41), and Jeffrey et al. (36).]

patient. Even if they are thought to be at low risk on any of several cardiac risk indices, specific attention must be given to the status of their coronary disease before deciding that surgery is low risk.

Perhaps the most important indicator of risk in the patient with coronary artery disease or multiple risk factors for it is the patient's functional status. In the largest experience of patients with well defined coronary disease, patients with significant coronary artery disease who had Class I or Class II angina or who were asymptomatic after myocardial infarction had a 2.4% mortality rate after a subsequent noncardiac surgery if their coronary disease was managed medically (11). However, only 6 of the 11 deaths were directly related to cardiac causes, thus yielding a 1.3% cardiac mortality rate. Although the rates of total death (0.9%) and cardiac death (0.4%) were lower among patients with similar degrees of coronary disease who had undergone coronary artery bypass grafting prior to noncardiac surgery, the absolute differences were small (11). Furthermore, since the average expected mortality rate from elective coronary artery bypass grafting is about 1.5%, the strategy of prophylactic coronary bypass surgery prior to noncardiac surgery would be expected to yield an overall mortality rate

Table 5. Potential Use of the Original Multifactorial Cardiac Risk Index to Estimate the Probability of Cardiac Complications in Different Types of Patients

Type of patient	Approximate baseline risk of major cardiac complications (%)	Approximate risk of major cardiac complications as adjusted using multifactorial index (%)[a]			
		Class I, 0–5 points	Class II, 6–12 points	Class III, 13–25 points	Class IV, ≥26 points
Minor surgery	1	0.3	1	3	19
Unselected consecutive patients more than 40 yr old who have major noncardiac surgery	3	1	3.5	10	45
Patients with known high risk characteristics, such as patients undergoing abdominal aortic aneurysm surgery	10	3	10	30	75

Updated from Goldman L. J Cardiothoracic Anesth 1987;1:237–44 (42).
[a] Calculated using data from five studies (2–5,36) and more than 4300 patients using the original multifactorial cardiac risk index on various types of patients.

that would be essentially identical to the strategy of noncardiac surgery under good medical management. Enthusiasm for routine preoperative coronary revascularization must be further tempered by the realization that there was no difference in the risk of perioperative myocardial infarction between the two groups in this study (11).

An alternative approach for patients with known coronary artery disease would be preoperative PTCA. In a relatively large series of preoperative PTCA (24), 50 patients with advanced coronary disease were treated with PTCA before 54 operations, 49 of which were major. An average of 1.5 stenoses were dilated per patient, and PTCA was successful in 50 of the patients. In the five in whom it was unsuccessful, one had a myocardial infarction. Four additional myocardial infarctions occurred in patients who were able to undergo their operations: one with the PTCA itself and three postoperative myocardial infarctions, one of which was fatal, despite the PTCA. Based on substantial data regarding the relative risks and benefits of PTCA as compared with coronary artery bypass grafting (43), it should not be expected that PTCA will be sufficiently less risky than coronary artery bypass grafting to become a routine preoperative strategy for patients with known mild, stable angina.

If patients with stable and relatively mild (Class I or early Class II) angina have risks that, although up to 10 times or more higher than patients without coronary disease, are still not sufficiently high to warrant routine preoperative coronary arteriography and revascularization, how can such patients be identified reasonably reliably? Perhaps the easiest approach is to know or learn the patient's functional status. In two different studies of patients more than 65 yr old undergoing major abdominal or thoracic noncardiac surgery, the ability to reach a heart rate of 100 bpm or more with supine bicycle exercise was a better predictor of perioperative complications than the rest or exercise electrocardiogram or radionuclide ejection fraction (44,45). In a study of vascular surgery patients (46), complication rates were substantially lower in patients who could reach 85% of their maximal predicted heart rate than in patients who could not; exercise capacity appeared to be more important than the amount of ST-segment depression at peak exercise. In another study, the complication rate was 1% in vascular surgery patients with a negative exercise test as compared with a 16% rate in patients with a positive test (47).

The weight of evidence indicates that patients who are known to be Class I or early Class II functional status or who can be shown to have such a functional status by exercise testing are at sufficiently low risk for major complications that there currently is no rationale for routine coronary angiography and revascularization. In patients who cannot exercise, however, because of conditions such as orthopedic problems or peripheral vascular disease, the assessment of functional capacity and of cardiac risk for noncardiac surgery is more difficult (48–50). The frequency of anginal symptoms cannot be used as a proxy for functional capacity, because inactive patients may have infrequent symptoms that would be unmasked if their noncardiac conditions permitted them to attempt to be more active. It is in such patients that a variety of newer diagnostic tests have been proposed and are used frequently but with great variation among different physicians (51).

Assessment based on functional status may miss patients with silent ischemia. However, silent ischemia is most often found in patients who also have symptomatic ischemia. Searches for silent ischemia are most likely to be fruitful in patients who either already have anginal symptoms or who are at very high risk for coronary disease and are unable to exercise because of noncardiac conditions.

Preoperative Cardiac Testing in Patients Who Cannot Exercise

Several investigators have reported that preoperative dipyridamole thallium scintigraphy can effectively stratify cardiac risk in patients undergoing peripheral vascular surgery (12,14–17,52–55). In many of these studies, the thallium scintigram result was the single most important predictive factor. Eagle et al. (14), however, demonstrated that the dipyridamole thallium scintiscan is most helpful in patients who are at neither very high nor very low risk based on a simple clinical assessment. Regardless of whether a clinical assessment is based on their factors (age >70 yr, history of angina, history of ventricular arrhythmias requiring treatment, diabetes requiring treatment, or a Q-wave on the electrocardiogram) (14) or on the factors reported in Table 4, patients with none of their factors or who are Class I on a multifactorial index and have no prior history of known coronary heart disease are at low risk for complications regardless of the thallium scintiscan result. At the other extreme, patients with three or more of the factors reported by Eagle et al. (14) or who are known to be Class III or Class IV by other approaches (Table 4) are at high risk regardless of the thallium scintiscan result. The thallium scintiscan was helpful primarily with the middle risk patients: those with one or two factors and a positive thallium scintiscan had a 30% complication rate, which was similar to the rate in patients with three or more factors, while patients with one or two factors and a negative thallium scintiscan had just a 3% complication rate, similar to patients with no clinical factors (14).

In the large series of patients who were referred for dipyridamole thallium scintigraphy, the risks of major cardiac complications tended to average 6% or more and the risk of perioperative death averaged about 3% (12–17). In this selected group of patients, virtually all studies have shown dipyridamole thallium scintigraphy to add important incremental prognostic information.

By comparison, unselected patients undergoing abdominal aneurysm repair or vascular surgery have risks only approximately half as high as in these selected patients. In both one large (9) and one smaller (56) series of dipyridamole thallium scintigraphy in this less selected patient population, the scintiscan did not add significant predictive information. It therefore appears that dipyridamole thallium scintigraphy can be a very useful test in selected, high-risk patients who are referred for the test and who are known to have coronary disease or be at any high risk for it, but the test is not as useful and perhaps not useful at all when applied to consecutive unselected vascular surgery patients.

Dipyridamole thallium scintigraphy can also be used in patients undergoing nonvascular surgery if they are at high enough risk for the test to be potentially useful. In one such study (57), redistribution on the dipyridamole thallium scintiscan was useful for predicting postoperative cardiac complications, although all such patients were also more than 70 yr old or had known congestive heart failure; two cardiac deaths occurred, both in patients who were in Class III or Class IV on the original multifactorial risk index.

An alternative to dipyridamole thallium scintigraphy is ambulatory ischemia monitoring. In one study (10), there were 12 major postoperative cardiac events among 32 patients with asymptomatic preoperative ambulatory ischemia compared with just one event among 144 patients without preoperative ischemia. Although preoperative ischemia was the single most important predictor of postoperative complications, the test was not helpful in a low-risk group of patients who were less than 70 yr old, were Class I on the original risk index, and had no history of angina, myocardial infarction, or diabetes (10). In subsequent studies by our group, the appearance of asymptomatic postoperative ischemia was of almost equivalent prognostic importance to asymptomatic preoperative ischemia, while intraoperative ischemia, although a statistically significant predictor of postoperative events, was substantially less predictive than either preoperative or postoperative ischemia (38).

In a prospective study of 474 men with coronary artery disease or at high risk for it (6), asymptomatic preoperative ischemia was again a significant univariate predictor of major postoperative events, but in this latter series it was slightly less important than asymptomatic postoperative ischemia (odds ratio 3.3 for postoperative ischemia compared with 3.1 for preoperative ischemia). Once again, asymptomatic intraoperative ischemia was a statistically significant univariate predictor of postoperative events but was not nearly as important as preoperative or postoperative ischemia. Several other studies (58–60) also have documented the importance of asymptomatic preoperative and postoperative ischemia for predicting postoperative events. Postoperative ischemia is especially important if it persists for 4 h or more (61).

These studies on ambulatory ischemia make several important clinical points. First, both preoperative and postoperative ischemia are important, and they are roughly equivalent in importance; intraoperative ischemia, although predictive of postoperative events, is not nearly as predictive as preoperative and postoperative ischemia. Second, the same types of selection criteria that can be used to increase the utility of dipyridamole thallium scintigraphy can also be used to increase the utility of ambulatory ischemia monitoring. Third, experience with postoperative ischemia monitoring has demonstrated that there is often a period of 1–4 h or more between the appearance of asymptomatic ischemia and the development of a clinical event. These data suggest a "window of opportunity" for possible treatment if patients could be monitored effectively.

Stress echocardiography using dipyridamole or dobutamine (62–66) has been reported by several authors to predict postoperative complications. This technique requires experienced echocardiographers, and the cumulative number of patients who have undergone this test is too low for definitive conclusions at present. Nevertheless, some data suggest that stress echocardiography may be associated with fewer false-positive results than dipyridamole thallium scintigraphy or ambulatory ischemia monitoring. However, it is likely that stress echocardiography, like dipyridamole thallium scintigraphy and ambulatory ischemia monitoring, will be most useful in patients whose functional status cannot be determined by the history or by exercise stress testing. Ischemia monitoring remains the only one of these three modalities that is useful for continuous postoperative surveillance.

Measurement of radionuclide ejection fraction identified patients who were at higher risk for postoperative complications in one study (67), but many studies have questioned its incremental value for predicting major postoperative events (68–70) even after exercise (44). In the largest study (9), the radionuclide ejection fraction was predictive of postoperative congestive heart failure but was not an independent predictor of postoperative myocardial infarction, prolonged myocardial ischemia, or cardiac death.

Noninvasive preoperative tests, whether with exercise or pharmacologic stress, carry few direct risks and may seem desirable because of the added information they provide. However, these tests should be recommended only when they are sufficiently likely to lead to an appropriate change in management.

Integrated Approach to the Patient with Ischemic Heart Disease

By combining the history, information contained in cardiac risk indices, and the judicious use of diagnostic tests, patients with known angina can be stratified effectively preoperatively (Table 6). In patients who are low risk by this integrated approach, further invasive testing does not appear to be indicated, and surgery should be undertaken with appropriate preoperative, intraoperative, and postoperative management.

If patients are not at low risk by this approach, one option is to intensify the medical regimen and to reevaluate the patient. A second approach is to recommend coronary arteriography and then to revascularize any appropriate lesions. A third approach is to proceed to surgery, usually after optimization of medical treatment, with more intense perioperative monitoring and treatment (71). The limited data available suggest that coronary revascularization should be recommended in situations in which it would be advised regardless of the noncardiac surgery, but that medical management is probably equivalent in other patients. However, the particular choice must be made for each individual patient, with the recognition that the plethora of prognostic studies are currently associated with a dearth of therapeutic trials (72–74). Future research must focus on appropriate trials of interventions in situations in which the risk of complications is sufficiently high that additional preoperative studies are likely to be informative. Furthermore, the cardiac patient continues to be at risk for noncardiac complications throughout the hospitalization (75) and for future cardiac complications after hospitalization (76).

In the meantime, coordinated assessment and management by all involved physicians is required to optimize the outcome of the cardiac patient undergoing noncardiac surgery. A collegial and mutually respectful collaboration is needed, in which each participant recognizes the expertise of the other but simultaneously avoids over-concern with protecting his or her own turf.

Table 6. General Approach to Patients with Angina

1. Assess functional capacity by history.
2. If the history is reliable and the patient is Class I or early Class II (can carry two grocery bags up a flight of stairs), surgery is low risk.
3. If history is unreliable, do an exercise tolerance test.
4. If history is unreliable or unhelpful and the patient is unable to exercise, do dipyridamole thallium scintigraphy, ambulatory ischemia monitoring, or stress echocardiography.

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