Advances in nuclear cardiology: Preoperative risk stratification

Kenneth A. Brown, MD, FACC

The determination of cardiac risk and the formulation of risk-management strategies have become an essential part of the perioperative care of patients undergoing noncardiac surgery. Over the past 2 decades, nuclear cardiology techniques have developed into an important component of such management. This review will explore the major advances of nuclear cardiology in this clinical setting, examining the historical background and context, as well as the evolution of current data and concepts, and will present a hint of future areas of research.

HISTORICAL BACKGROUND

The development of nuclear cardiology techniques for assessing cardiac risk and guiding therapy in patients scheduled for noncardiac surgery has been driven by several factors. First, perioperative cardiac morbidity and death comprise a major medical and economic health care problem, consuming $12 billion in the United States alone.[1] Furthermore, perioperative cardiac events carry especially poor outcomes. Mortality rates associated with perioperative myocardial infarction (MI) have ranged historically from 26% to 70%, averaging 50%.[2] Even with decades of medical advances, the perioperative MI mortality rate remains very substantial, with recent reports of 15% to 26%.[3,4]

Second, the expense and outcome of perioperative cardiac events are primarily related to coronary heart disease, as the majority of perioperative cardiac events are related to underlying coronary artery disease (CAD).[5-8] Nuclear cardiology techniques are particularly well suited for diagnostic and prognostic evaluation in this population.

Third, there was a growing recognition that clinical assessment of cardiac risk was inadequate in surgical cohorts that had a high prevalence of CAD. The clinical criteria for cardiac risk determination developed by Goldman et al,[9] Detsky et al,[10] Dripps et al,[11] and others[12-14] were derived from general surgical populations in whom the prevalence of CAD is quite low, reflecting the 1% to 10% prevalence of CAD in the general population, based on age. The application of clinical risk criteria generated from low-prevalence CAD cohorts may not have relevance in high-prevalence CAD surgical cohorts such as vascular surgery, where approximately 60% of patients have CAD, many of whom are asymptomatic.[5] In fact, Jeffrey et al[15] found that the Goldman index greatly underestimated the risk of cardiac events in patients undergoing elective abdominal aortic aneurysm surgery. The cardiac event rate was 8% in class I patients, who were predicted to have an event rate of less than 1%. Similarly, Lette et al[16] showed that vascular surgery patients who were identified as low risk by the clinical criteria of Goldman et al, Detsky et al, Dripps et al/American Society of Anesthesiologists, or Yeager et al[13] actually had perioperative cardiac death or MI rates of 5% to 8%, far higher than predicted by the clinical indices and significantly higher than observed in patients with normal stress myocardial perfusion imaging (MPI) results (Figure 1). Although more recent attempts to modify these classic scoring systems have improved the predictive value of clinical risk indices, they remain insensitive for identifying cardiac risk in patients who undergo high-risk vascular procedures.[17] Such inadequacies of clinical criteria led to an interest in the predictive value of cardiac imaging techniques such as stress nuclear MPI in this setting.

Fourth, although it was recognized that stress testing in general could be helpful in assessing the response of coronary heart disease patients to the stresses of noncardiac surgery, many potential candidates for such evaluation were unable to perform exercise stress testing. Age, co-morbidity, and especially lower-extremity vascular disease frequently precluded exercise stress testing as an option. Fortunately, interest in a nuclear imaging option was developing at the same time that pharmacologic stress (in particular, vasodilator stress) became available as an alternative to exercise stress.

Thus stress nuclear MPI was poised to assist physicians in making rational recommendations when asked to

From the Cardiology Unit, University of Vermont College of Medicine, Fletcher Allen Medical Center, Burlington, Vt.

Reprint requests: Kenneth A. Brown, MD, FACC, Cardiology Unit, University of Vermont College of Medicine, Fletcher Allen Medical Center, Burlington, VT 05401; *kenneth.brown@vtmednet.org.*

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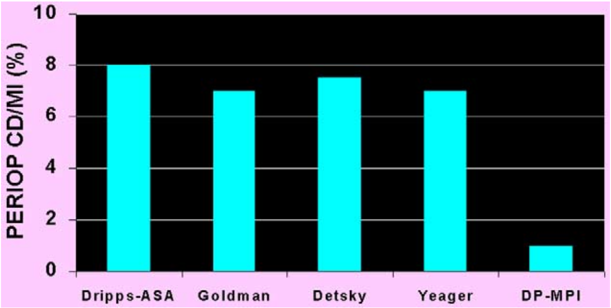


Figure 1. Perioperative (*PERIOP*) cardiac death (*CD*)/MI rate in patients defined as low risk by various clinical scoring indices and dipyridamole (*DP*) stress MPI. *ASA*, American Society of Anesthesiologists.

evaluate a patient before noncardiac surgery and to help assess the risk/benefit ratio of deciding whether to proceed with such planned surgery.

EVOLUTION OF CURRENT DATA AND CONCEPTS

General Predictive Value

Preoperative risk stratification with stress nuclear MPI was first reported by Boucher et al[18] in 1985. They performed dipyridamole–thallium 201 MPI in 48 patients with evidence of CAD before peripheral vascular surgery. Perioperative cardiac events could not be predicted by clinical factors. However, they found that 8 of 16 patients (50%) with reversible Tl-201 defects had cardiac events compared with 0 of 32 patients without reversible defects ($P < .0001$), and a new growth area in nuclear cardiology was set in motion. Since this landmark study, many other subsequent studies[19-42] have confirmed the central element of these findings: reversible defects are the best predictor of perioperative cardiac events, confirmed by a large meta-analysis of perioperative stress imaging studies.[42] However, it remains instructive to examine the evolution of data as it relates to the maturation of clinical thinking about the utility of cardiac imaging in the preoperative setting.

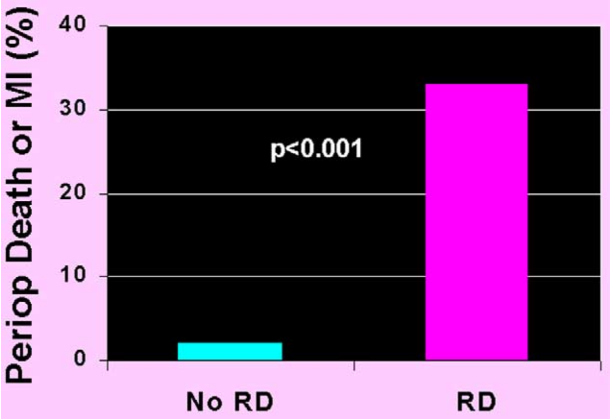


Figure 2. Perioperative (*Periop*) cardiac death/MI rate in patients with or without reversible defects (*RD*) on preoperative stress nuclear MPI.

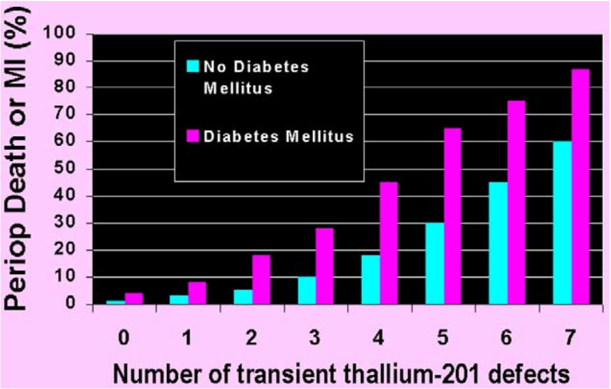


Figure 3. Perioperative (*Periop*) cardiac death/MI rate as a function of reversible defects on vasodilator stress MPI and history of diabetes mellitus.

The next logical step in the development of data was taken by Leppo et al[41] by comparing the predictive value of dipyridamole–Tl-201 MPI with clinical stress and electrocardiographic parameters using a multivariate analysis. They found that the best predictor of perioperative death or MI was the presence of reversible perfusion defects: 14 of 42 patients (33%) with reversible defects died or had MI compared with only 1 of 47 (2%) without reversible defects ($P < .001$) (Figure 2). In a subgroup of patients undergoing exercise, the presence of reversible defects remained the best predictor of outcome.

Extent of Jeopardized Viable Myocardium

These findings, of course, are consistent with a very large body of work demonstrating that the presence of jeopardized viable myocardium, reflected in reversible defects on stress MPI, has powerful prognostic value in a wide spectrum of coronary heart disease from chronic CAD to acute coronary syndromes.[39,40] However, one of the fundamental tenets of the prognostic value of stress nuclear MPI is that cardiac risk is not simply categorical (yes/no based on presence or absence of perfusion abnormalities) but rather is best understood as a continuum, proportional to the extent of myocardium at risk reflected in the extent of reversible defects.[39,40] Thus a small degree of jeopardized viable myocardium reflects only a small risk of cardiac events. Therefore the next important advancement in the thinking and evolution of

Table 1. Pharmacologic MPI for preoperative assessment of cardiac risk

Study	Thallium redistribution (%)	Perioperative events MI/ death (%)	Ischemia: Positive predictive value (%)	Normal scan: Negative predictive value (%)
Vascular surgery only				
Boucher et al[18] (1985)	33	6	19	100
Cutler and Leppo[19] (1987)	47	10	20	100
Fletcher et al[20] (1988)	22	4	37	100
Sachs et al[21] (1988)	31	4	14	100
Eagle et al[22] (1989)	41	8	16	98
Younis et al[23] (1990)	36	7	15	100
Mangano[25] (1991)	37	5	5	95
Lette et al[26] (1992)	45	8	17	99
Hendel et al[27] (1992)	51	9	14	99
Kresowik et al[28] (1993)	39	3	4	98
Baron et al[29] (1994)	35	5	4	96
Bry et al[30] (1994)	46	7	11	100
Koutelou et al[31] (1995)	44	3	6	100
Marshall et al[24] (1995)	47	10	16	97
Total (weighted average) (2417 total patients)	42	7	12	99
Other surgery				
Coley et al[33] (1992)	36	4	11	99
Shaw et al[34] (1992)	47	10	21	100
Brown et al[35] (1993)	33	5	13	99
Younis et al[36] (1994)	31	9	18	98
Stratmann et al[37] (1996)	29	4	6	99
Van Damme et al[38] (1997)	34	2	N/A	N/A
Total (weighted average) (923 total patients)	33	6	13	99

N/A, Not available.

nuclear MPI preoperative risk stratification was to demonstrate a similar link between the extent of jeopardized viable myocardium and cardiac risk. Lette et al[43] showed that patients could be classified as being at low, medium, or high risk for perioperative cardiac events based on the number of segments with reversible defects. Similarly, Brown and Rowen[35] showed that the perioperative cardiac death/MI rate was directly related to the extent of jeopardized viable myocardium reflected in the number of segments with reversible defects (Figure 3). These findings allowed clinicians to have more latitude in determining perioperative patient care, as cardiac risk assessment could be more "fine-tuned."

Integration With Clinical Data

Contemporaneous with these developments, investigators were recognizing that although preoperative stress nuclear MPI had very powerful negative predictive value for perioperative cardiac events (99%), its positive predictive value was more limited (10%-15%) (Table 1).[18-38] Although a 10% to 15% perioperative death or MI rate is clearly "high risk," nevertheless, the large majority of patients with positive test results did not have cardiac events, leading to inefficiencies of resource utilization. These findings are in part explained by the lack of any quantification of provokable ischemia seen on stress MPI in most of the studies. As just discussed, patients with small degrees of ischemia are at low risk for cardiac events, and most of these studies did not distinguish between small, medium, or large ischemia seen on MPI. Nevertheless, it was recognized that whereas clinical criteria alone may be inadequate to risk-stratify patients preoperatively, combining them with imaging could lead to a more selective, cost-effective use of MPI.

Eagle et al[14] used a multivariate analysis of clinical

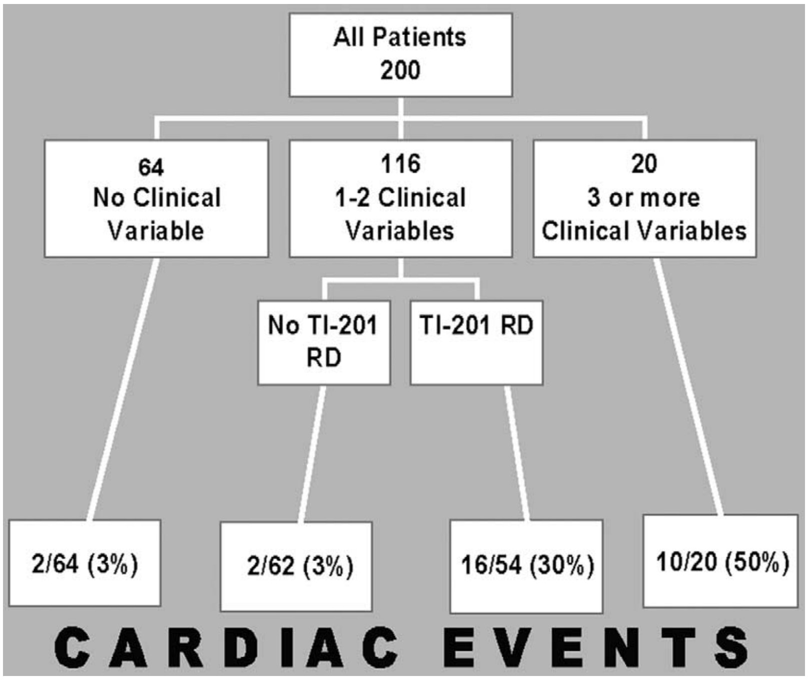


Figure 4. Interaction of clinical risk factors and Tl-201 stress imaging data on outcome in 200 patients undergoing noncardiac surgery. *RD*, Reversible defects.

and imaging data in 200 vascular patients undergoing preoperative dipyridamole–Tl-201 imaging. Although reversible Tl-201 defects were the best predictor of perioperative cardiac events, 5 clinical variables (history of angina, Q waves, ventricular ectopy requiring treatment, diabetes, age >70 years) were also significant multivariate predictors. Using these clinical variables for screening, the investigators showed that the benefit of stress MPI for risk stratification was greatest in the intermediate-risk subgroup that had 1 or 2 clinical risk factors (Figure 4). In this subgroup with an overall risk of 15%, stress MPI provided a further 10-fold stratification of risk: 3% event rate without reversible defects versus 30% with reversible defects. In patients with no clinical risk factors, the perioperative risk was low and additional testing was not required. On the other hand, in those with 3 or more clinical risk factors, the risk of cardiac events was high and additional testing was also not required.

L'Italien et al[44] analyzed pooled data from several centers and found that clinical information could separate patients into low-risk (3%), intermediate-risk (8%), and high-risk (19%) subgroups. When dipyridamole–Tl-201 MPI data were applied, there was no significant impact on the low- or high-risk patients. However, in the group at intermediate clinical risk, which comprised 51% of the total population, MPI data reclassified more than 85% of this cohort into either low-risk or high-risk categories. Thus these studies suggest that clinical data can be used as a first line of risk stratification, reserving the more sensitive but more expensive stress MPI testing for the intermediate-risk subgroup. However, stress MPI may still have value also in the patients at low clinical risk. In the study of Eagle et al,[14] the risk of cardiac events in patients without clinical risk factors increased from 3% overall to 12% when reversible MPI defects were present, compared with 0% when no reversible defects were present. Similarly, Hendel and Leppo[45]

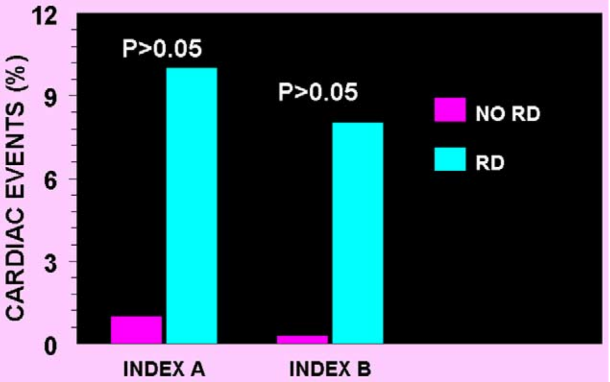


Figure 5. Perioperative cardiac event rate as a function of presence or absence of reversible defects (*RD*) on preoperative stress MPI in patients classified as low risk by clinical criteria defined by Eagle et al index A[12] or index B.[14]

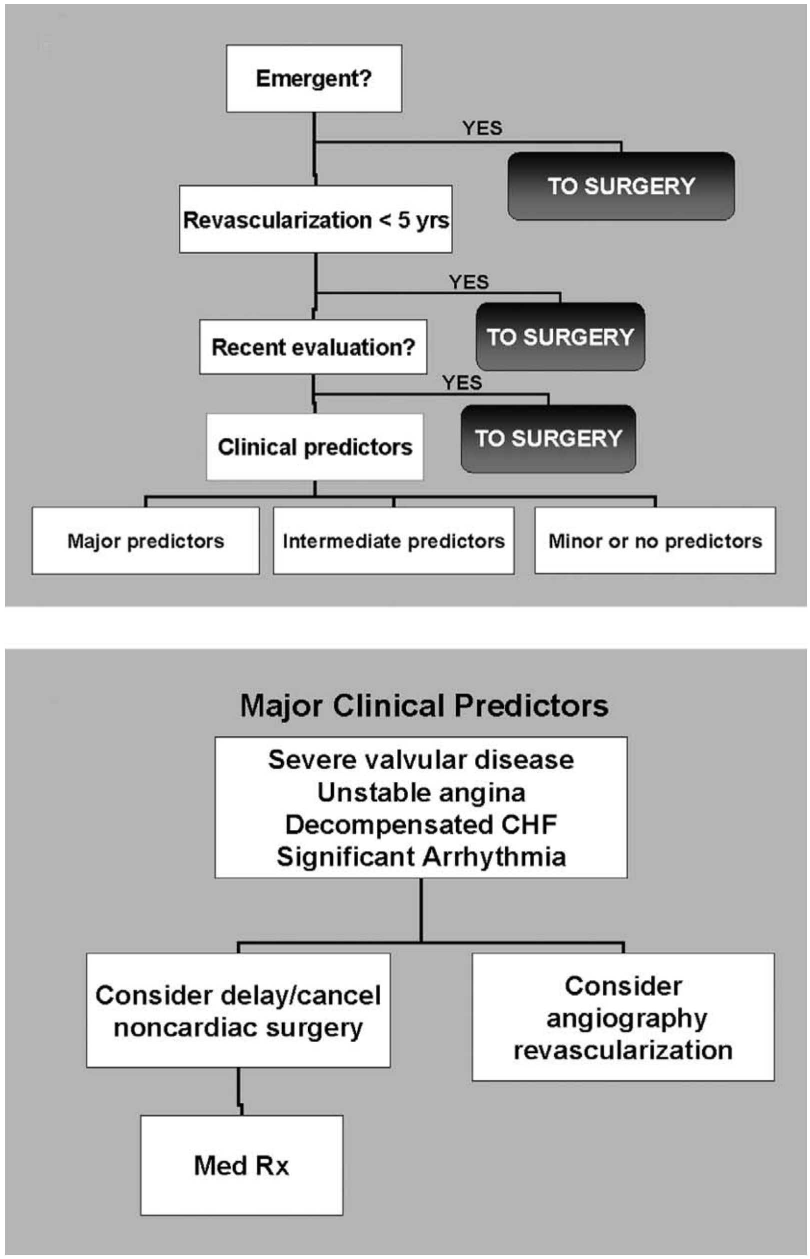
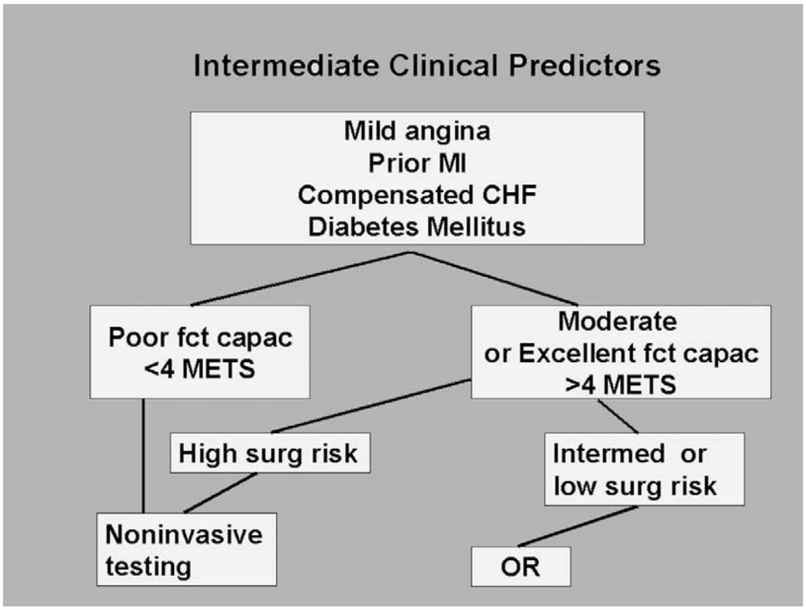


Figure 6. ACC/AHA guidelines for evaluating patients before noncardiac surgery. *CHF*, Congestive heart failure; *Med Rx*, medical therapy; *fct capac*, functional capacity; *METS*, metabolic equivalents; *surg*, surgical; *intermed*, intermediate; *OR*, operating room; *EKG*, electrocardiogram; *Hx CVA*, history of cerebrovascular accident; *HT*, hypertension.

found that in patients considered to be at low risk by the criteria of Eagle et al, the cardiac event rate was approximately 10% when reversible defects were present on preoperative stress MPI compared with 1% or lower when reversible defects were absent (Figure 5).

These data have led to a consensus recommendation from the American College of Cardiology/American Heart Association (ACC/AHA) taking into account clinical predictors, functional capacity, and the type/risk of noncardiac surgery[46] (Figure 6). Although somewhat complicated, the indications for noninvasive stress cardiac imaging boil down to identification of at least two of three considerations: (1) intermediate clinical predictors, (2) poor functional capacity, and/or (3) high-risk noncardiac surgery (Table 2). Bartels et al[47] showed that by using a protocol modeled after the ACC/AHA recommendations, in a series of 203 patients scheduled for aortic vascular surgery, the cardiac mortality rate for the



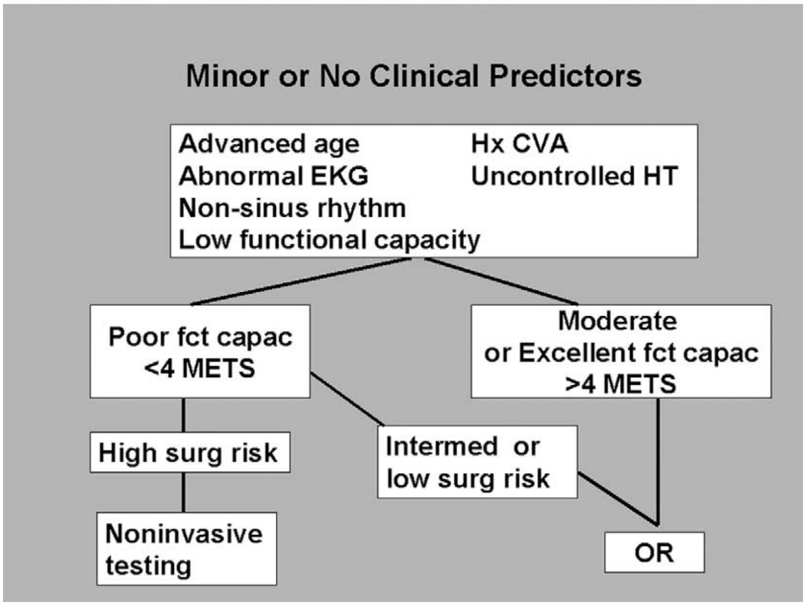


Figure 6. Continued

cohort was only 1%, presumably reflecting the impact of diagnostic testing on perioperative care. More recently, Froehlich et al[48] described the impact of an educational program designed to implement the ACC/AHA guidelines before elective abdominal aortic vascular surgery. They examined the use of preoperative stress testing, coronary angiography, and revascularization before and after implementation of the ACC/AHA guidelines. There were marked reductions in rates of preoperative stress testing (88% to 47%), angiography (24% to 11%), and revascularization (24% to 2%), as well as preoperative cost ($1087 to $171), that were maintained over a 2 year period. Importantly, perioperative outcome was not adversely affected. In fact, there was a trend toward a lower perioperative death/MI rate (11% to 4%, $P = .08$). Before implementation, extensive preoperative stress testing was used similarly in both patients at low clinical risk and patients at high clinical risk (84% vs 91%, $P = .29$). After implementation, the stress testing rate in patients at low clinical risk was only half that of patients at high clinical risk (31% vs 61%, $P < .005$). These data provide compelling evidence that a rational integration of

Table 2. Simplified approach to ACC/AHA preoperative evaluation guidelines[46]: Proceed to stress imaging if two or more factors present

1. Intermediate clinical predictors are present (mild angina, prior MI, compensated CHF, or diabetes)
2. Poor functional capacity (<4 METs)
3. High-risk surgical procedure (emergency major operations, aortic repair or peripheral vascular, prolonged surgical procedures with large fluid shifts and/or blood loss)

CHF, Congestive health failure; *METs,* Metabolic equivalents.

clinical data and preoperative noninvasive testing can be achieved to optimize resource utilization and patient outcome.

Long-Term Risk

When the prevalence of underlying CAD is high, such as in peripheral vascular disease subgroups, patients will remain at risk for cardiac events in the long term even if they survive the immediate perioperative period event-free. Because long-term outcome can also potentially influence perioperative management decisions, including whether to proceed with the planned noncardiac surgery, the ability of preoperative stress MPI to predict late cardiac events can have important clinical value. On the basis of work in other cohorts of patients with a high prevalence of CAD, such as after MI or with chronic stable angina,[40,41] it is not surprising that stress MPI predicts long-term cardiac events in the postoperative vascular population as well. Hendel et al[49] examined the early and late predictive value of preoperative dipyridamole–Tl-201 MPI before vascular surgery. Reversible defects were the best predictor of early postoperative death or MI, whereas fixed defects were the best predictor of late cardiac events (30 months) (Figure 7). In contrast, Younis et al[50] found that reversible defects were the best predictor of both early and late cardiac events (Figure 8). Importantly, the overall death or MI rate was approximately 50% by 2 years in patients with reversible defects, which comprised approximately 20% of the cohort. Identification of such a sizable high-risk group can influence decisions about whether to proceed with planned noncardiac surgery. A longer follow-up

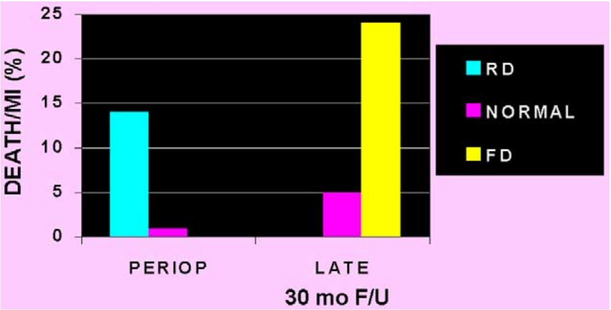


Figure 7. Perioperative (*PERIOP*) and late death/MI rate as a function of preoperative stress MPI results. *RD,* Reversible defects; *FD,* fixed defects; *F/U,* follow-up.

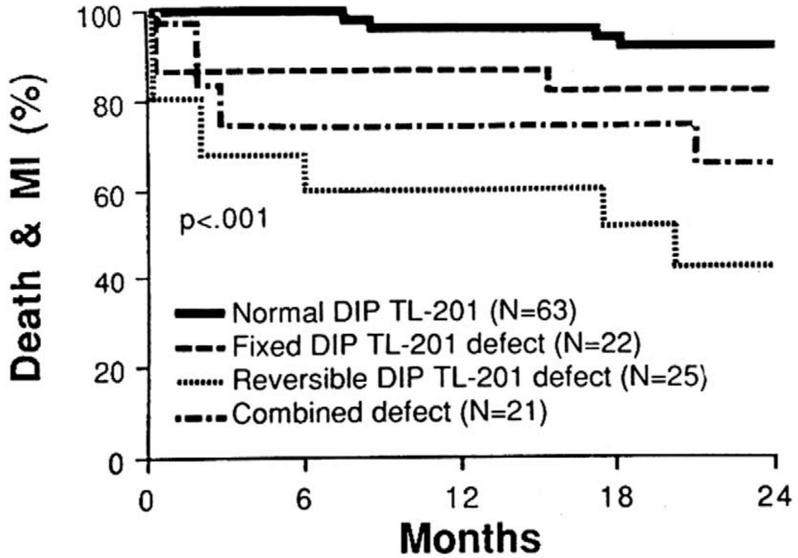


Figure 8. Long-term postoperative MI-free survival as a function of preoperative dipyridamole (*DIP*)–Tl-201 MPI results. (Used with permission from Younis LT, Aguirre F, Byers S, et al. Perioperative and long-term prognostic value of intravenous dipyridamole thallium scintigraphy in patients with peripheral vascular disease. Am Heart J 1990;119:1287-92.)

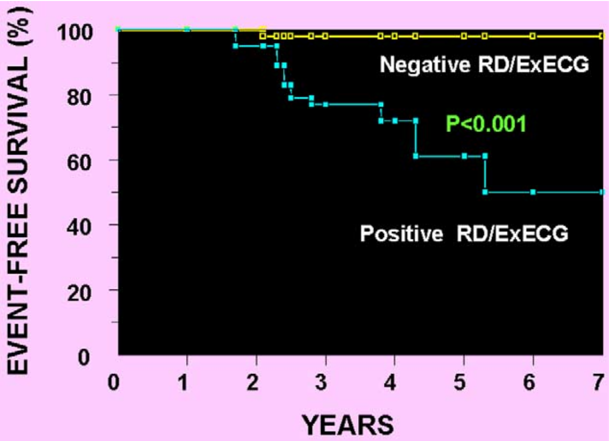


Figure 9. Long-term postoperative event-free survival as a function of exercise MPI and exercise electrocardiography results. *positive RD/ExECG*, Reversible defect present with positive exercise electrocardiography; *negative RD/ExECG*, no reversible defects with negative exercise electrocardiography.

study has been reported for patients undergoing carotid endarterectomy.[51] Although perioperative risk was nil, patients with reversible defects on MPI with a positive stress electrocardiogram showed a high late cardiac event rate that approached 50% by 7 years compared with only 2% in patients without provokable ischemia (Figure 9). Thus preoperative stress MPI continues to predict cardiac events beyond the early perioperative period and can influence therapeutic strategies.

Impact of Therapy and Strategy on Perioperative Outcome

The previous studies outlined thus far establish the ability of stress nuclear MPI (in concert with clinical data) to distinguish low-risk patients who can go on to undergo scheduled noncardiac surgery from high-risk patients who require additional consideration. Two important issues remain: (1) Are there management strategies that can reduce the cardiac event rate in high-risk patients? (2) Does this entire approach of preoperative noninvasive imaging actually lead to a better short- and long-term outcome?

β-Blockers. Several studies have suggested an ameliorating effect of β-blockers when used perioperatively. In a case-controlled study, Pasternack et al[52] showed that the use of metoprolol was associated with a lower perioperative MI rate (3%) compared with control subjects (17%) ($P < .05$) in 83 patients undergoing abdominal aortic aneurysm repair. In a much larger case-controlled series of 2088 vascular surgery patients, β-blockers were associated with a 50% reduction in perioperative MI.[4] Metoprolol has also been associated with a lower frequency of perioperative ischemia (2% versus 28%, $P < .05$) in a randomized trial of 200 patients undergoing noncardiac surgery.[53] More recently, a randomized trial by Mangano et al[54] showed a long-term benefit from bisoprolol over a 2-year follow-up, even though the drug was administered only during the hospitalization. Perhaps more relevant to the current discussion, Froehlich et al[55] retrospectively examined the outcome of high-risk patients as a function of β-blocker treatment (Table 3). Perioperative death occurred in 11% to 12% of patients with reversible defects on preoperative stress MPI or with prior MI if they were not treated with β-blockers perioperatively compared with 0% if they were treated with β-blockers. Though not a randomized trial, these data do suggest that β-blockers can reduce the risk associated with reversible defects on preoperative MPI. This conclusion is supported by a randomized trial of bisoprolol versus placebo in 112 patients scheduled for major vascular surgery who had positive dobutamine echocardiography.[56] Although patients with the highest-risk echocardiograms were excluded, the 30-day postoperative cardiac death/MI rate was 34% in patients receiving placebo compared with only 3% in patients receiving perioperative bisoprolol ($P < .001$) (Figure 10).

Coronary revascularization. Accumulating data suggest that revascularization of high-risk patients before noncardiac surgery can reduce their preoperative risk. In a series of 500 patients scheduled for abdominal aortic aneurysm surgery, 240 had symptomatic or electrocardiographic evidence of CAD and were referred for additional testing, including stress MPI.[57] Of 212 patients who were considered to be at low risk and were not

Table 3. Perioperative outcome as a function of β-blocker treatment

	Perioperative cardiac death		
	β-Blockers	**No β-blockers**	***P* value**
Tl-201 reversible defects	0/48 (0%)	8/65 (12%)	.02
History of MI	0/51 (0%)	9/84 (11%)	.01

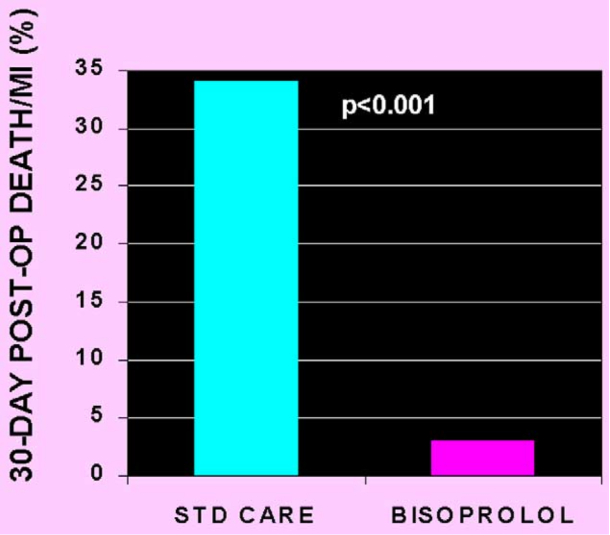


Figure 10. Thirty-day postoperative (*POST-OP*) death/MI rate in patients receiving bisoprolol versus standard (*STD*) perioperative care.

referred for coronary revascularization, 12 (6%) died or had MI perioperatively. A smaller subgroup of 28 patients was considered to be at high risk and underwent coronary revascularization before surgery. None of these patients had a perioperative cardiac event, suggesting that coronary revascularization can reduce perioperative cardiac risk. Subsequently, Elliot et al[58] used dobutamine stress Tl-201 MPI before scheduled vascular surgery. Reversible defects were seen in 42 patients, of whom 15 were denied vascular surgery based on imaging results. Among 18 patients with MPI ischemia who went on to undergo vascular surgery without preoperative coronary revascularization, 5 (18%) died or had MI perioperatively. However, no cardiac events occurred in the 9 patients who underwent coronary revascularization before vascular surgery.

Younis et al[59] described the outcome of 72 patients

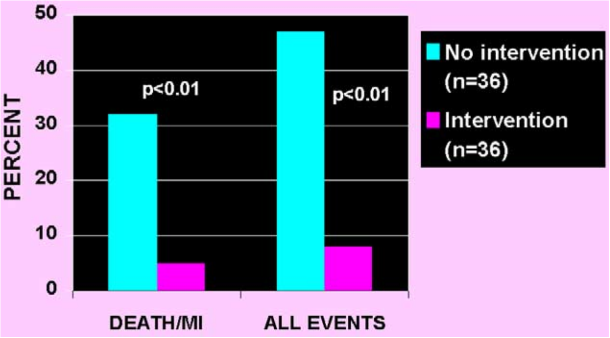


Figure 11. Perioperative death/MI and all–cardiac event rate in patients who received preoperative therapeutic intervention versus those who did not receive it.

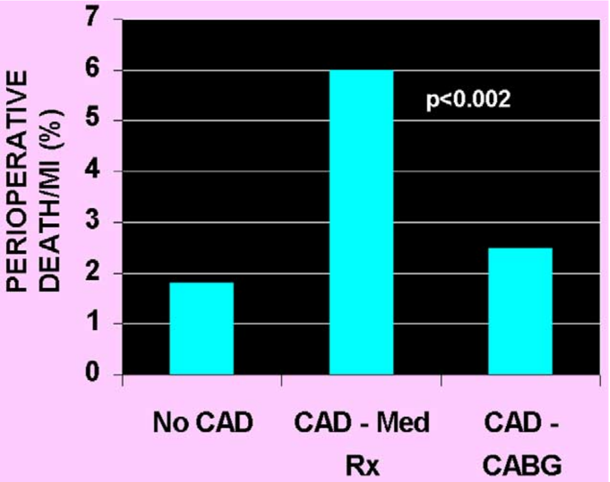


Figure 12. Perioperative death/MI rate in patients undergoing noncardiac surgery who had no CAD, CAD treated medically (*Med Rx*), and CAD treated with coronary artery bypass grafting (*CABG*).

who had abnormal dipyridamole–Tl-201 MPI results before major noncardiac surgery. The perioperative death/MI rate was 31% in 36 patients undergoing noncardiac surgery without any intervention compared with only 6% in 36 patients undergoing coronary revascularization or intensification of anti-ischemic medication before noncardiac surgery ($P < .01$) (Figure 11). Of note, none of the 6 patients undergoing coronary revascularization had a cardiac event compared with 2 of 30 patients (7%) with medical intensification alone.

These studies suggest that preoperative coronary revascularization can turn high-risk patients into low-risk patients. Although the number of patients was small, the study of Younis et al[59] also raised the possibility that coronary revascularization may be more effective than medical intervention for lowering risk. This concern is supported by a more recent analysis of Coronary Artery Surgery Study (CASS) data.[60] In this population, patients with CAD were randomized to medical treatment or bypass surgery. The authors looked at the subgroup of patients who subsequently underwent noncardiac surgery. They found that for high-risk surgery (abdominal, vascular, thoracic, and head/neck), the outcome was better in patients who had undergone prior coronary bypass surgery than those treated medically (death/MI rate, 2.5% versus 6.0%, respectively; $P < .002$). The cardiac event rate of the patients who underwent bypass surgery approached that of patients without CAD (Figure 12). The benefit of bypass surgery appeared greatest in patients with multivessel CAD, and the protective effect of bypass surgery appeared to remain intact for at least 6 years. Although these latter two studies suggest an advantage of revascularization over medical therapy for

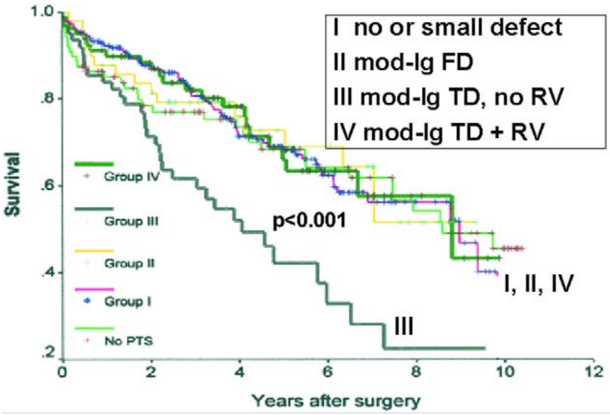


Figure 13. Long-term survival after noncardiac surgery in patients with preoperative stress MPI. Group I: Patients with no or small defects; group II: patients with moderate to large (*mod-lg*) fixed defects (*FD*); group III: patients with moderate to large transient defects (*TD*) without coronary revascularization (*RV*); group IV: patients with moderate to large transient defects who underwent coronary revascularization. (Used with permission from Landesberg G, Mosseri M, Wolf YG, et al. Preoperative thallium scanning, selective coronary revascularization, and long-term survival after major vascular surgery. Circulation 2003;108:177-83.)

reducing perioperative risk, one must recognize that medical treatment was not optimized in either study. For example, in the study of Younis et al, intensification of medical treatment included the use of nitrates and calcium channel blockers, which have not been shown to improve outcome perioperatively. With regard to the CASS data, the medical treatment was not specified and the percentage of patients who were taking β-blockers was not reported.[60] Thus more data are needed to compare the relative benefit of coronary revascularization versus an intense medical regimen, including full β-blockade.

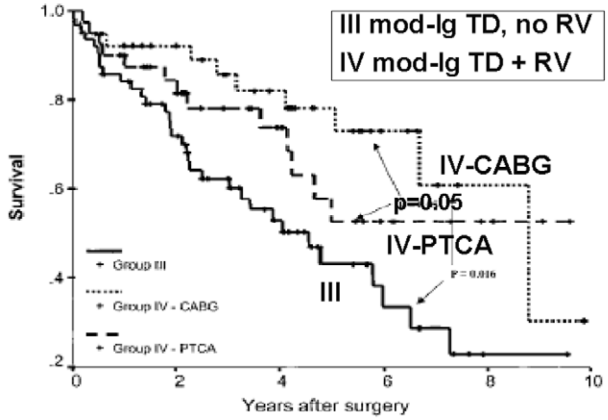


Figure 14. Long-term survival after noncardiac surgery in patients with preoperative stress MPI. Group III: Patients with moderate to large (*mod-lg*) transient defects (*TD*) without coronary revascularization (*RV*); group IV: patients with moderate to large transient defects who underwent coronary revascularization with coronary artery bypass grafting (*CABG*) versus PTCA. (Used with permission from Landesberg G, Mosseri M, Wolf YG, et al. Preoperative thallium scanning, selective coronary revascularization, and long-term survival after major vascular surgery. Circulation 2003;108:177-83.)

Impact of coronary revascularization on long-term outcome. As discussed above, preoperative stress MPI can determine not only perioperative risk but also long-term outcome after surgery. A recent study suggests that preoperative coronary revascularization can substantially improve long-term outcome in high-risk patients.[61] A series of 407 major vascular surgery patients had preoperative stress MPI and were followed up for a mean of 55 months.[61] The long-term outcome of patients with moderate to large reversible defects who did not undergo coronary revascularization was substantially worse than that of patients with no or small defects (Figure 13). However, the mortality rate of patients with moderate to large reversible defect who did undergo revascularization was reduced to that of the group with no or small reversible defects (Figure 13). Propensity score analysis showed that the benefit of revascularization was present across a wide spectrum of clinical and MPI data. Furthermore, the benefit of revascularization was similar when left ventricular function was normal or reduced. Finally, there was a trend toward a better outcome with bypass surgery compared with coronary angioplasty ($P = .05$) (Figure 14).

Coronary angioplasty/stenting. Available data are limited regarding the impact of preoperative percutaneous coronary intervention (PCI) on outcomes after noncardiac surgery. In a nonrandomized study Gottlieb et al[62] examined the outcome of 194 patients undergoing percutaneous transluminal coronary angioplasty (PTCA) performed 3 to 49 days (median, 11 days) before vascular surgery. A low postoperative cardiac event rate was observed: 1 death (0.5%) and 1 nonfatal MI (0.5%). Posner et al[63] compared the outcome of a series of patients undergoing PTCA before noncardiac surgery with a case-controlled matched population of normal subjects and patients with CAD who did not undergo revascularization before noncardiac surgery. Patients undergoing PTCA had twice the cardiac event rate as normal subjects. However, the overall cardiac event rate (including angina and heart failure) was half that for the group with CAD without revascularization, although there was no difference in MI or mortality rate. The authors concluded that there was no benefit for prophylactic preoperative PTCA. Furthermore, recent studies have raised special concerns regarding the use of coronary stents before noncardiac surgery. Kaluza et al[64] described the outcome of 40 consecutive patients under-

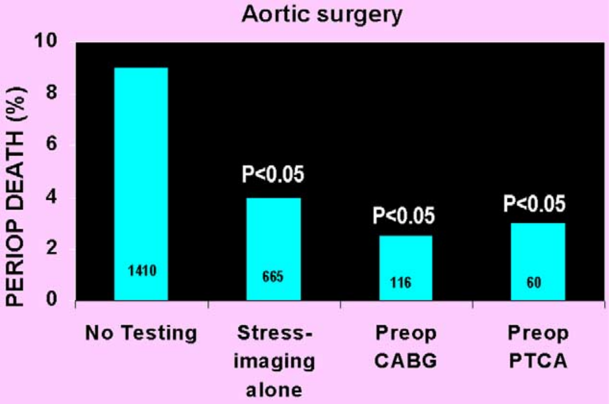


Figure 15. Perioperative (*PERIOP*) mortality rate after aortic vascular surgery as a function of preoperative (*Preop*) management. *CABG*, Coronary artery bypass grafting. *P* values reflect comparisons to no testing group.

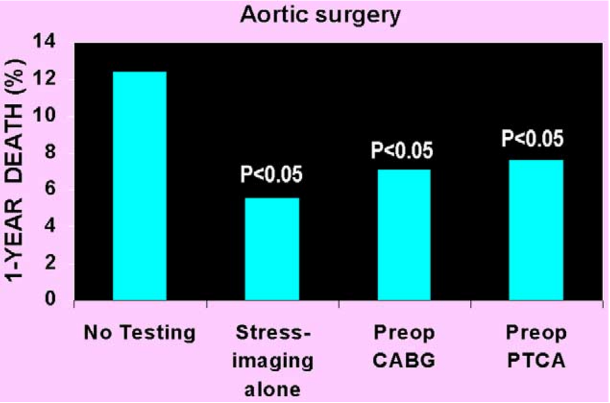


Figure 17. One-year mortality rate after aortic vascular surgery as a function of preoperative (*Preop*) management. *CABG*, Coronary artery bypass grafting. *P* values reflect comparisons to no testing group.

going coronary intervention with stents less than 6 weeks (mean, 13 days) before noncardiac surgery. There were 8 deaths (20%) (6 fatal MIs and 2 fatal bleeding episodes) and 1 nonfatal MI. The cardiac events were time-related, as all occurred in patients undergoing noncardiac surgery less than 14 days after PCI, with a 34% mortality rate in this subgroup. Patients undergoing noncardiac surgery 1 day after PCI had an 80% mortality rate (4/5). Most MIs appeared to be related to cessation of aspirin or ticlopidine at the time of noncardiac surgery. The authors recommended deferring noncardiac surgery after PCI until the adenosine 5-diphosphate (ADP)-receptor inhibitor is stopped. A similar concern about preoperative PCI/stenting was raised by a recent report from Wilson et al[65] describing the outcome of 207 patients undergoing noncardiac surgery 2 months or less after coronary stenting. Death or MI occurred in 7 patients, all in the 168 patients undergoing noncardiac within 6 weeks of PCI (event rate = 4%). These studies suggest that noncardiac surgery should be postponed for at least 6 weeks after coronary stenting. Conversely, if noncardiac surgery is more urgent and a high risk of ischemic cardiac events is identified, options other than PCI/stenting should be considered, including intensive β-blockade, bypass surgery, or possibly non-stenting PTCA.

Impact of preoperative testing on outcome. The above discussion provides compelling evidence that management strategies can reduce cardiac risk in patients undergoing noncardiac surgery. Such strategies depend on identification of high-risk patients who are most likely to benefit from medical and revascular-

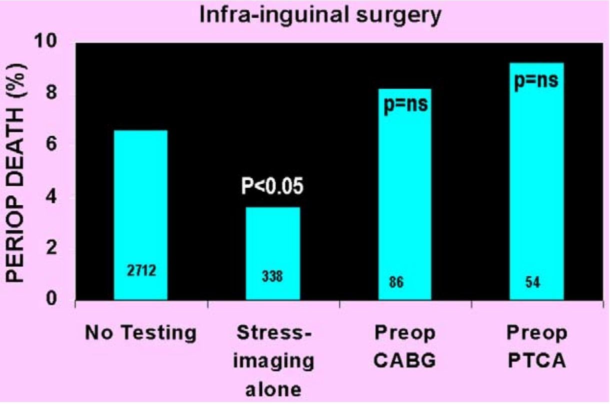


Figure 16. Perioperative (*PERIOP*) mortality rate after infrainguinal vascular surgery as a function of preoperative (*Preop*) management. *P* values reflect comparisons to no testing group. *CABG*, Coronary artery bypass grafting; *ns*, not significant.

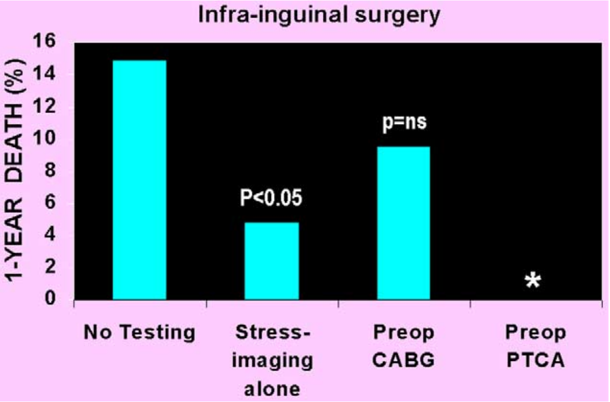


Figure 18. One-year mortality rate after infrainguinal vascular surgery as a function of preoperative (*Preop*) management. *CABG*, Coronary artery bypass grafting. Data for PTCA patients are not presented because of the very small sample size. *P* values reflect comparisons to no testing group.

ization interventions. Is there evidence that noninvasive preoperative testing can lead to a better outcome? Recent data suggest that it can.

Fleisher et al[66] examined a 5% sample of the Medicare population (6895 patients) undergoing aortic or infrainguinal vascular surgery. Perioperative and 1-year mortality rates were then examined as a function of no preoperative testing versus preoperative stress imaging, bypass surgery, or PTCA. They found that perioperative and 1-year mortality rates were substantial in both groups (7% and 11%, respectively, for aortic surgery; 6% and 16%, respectively, for infrainguinal surgery). Preoperative stress imaging was performed in 29% of aortic surgery patients and 12% of infrainguinal surgery patients. This was followed by bypass surgery or PTCA in 27% of patients undergoing stress imaging in the aortic cohort and 29% undergoing stress imaging in the infrainguinal cohort. No patient underwent coronary revascularization without prior stress imaging. The perioperative mortality rate of aortic surgery patients was reduced by more than 50% when preoperative stress imaging was performed compared with no testing (Figure 15). Important differences were seen with regard to the impact of revascularization between the two cohorts. Preoperative bypass surgery or PTCA after stress imaging improved outcome in the aortic surgery patients (Figure 15). However, in the infrainguinal surgery cohort, coronary revascularization was associated with a high perioperative mortality rate that was not different from the no-testing group (Figure 16). In the subgroup with stress imaging but no revascularization, the perioperative mortality rate was significantly reduced compared with the no-testing group, presumably reflecting intensification of perioperative medical therapy in patients identified as being at high risk. At 1-year follow-up, the outcome in the aortic cohort remained better in patients undergoing preoperative stress imaging and was lowest in the revascularized subgroups (Figure 17). In the infrainguinal cohort the 1-year outcome remained better in the subgroup undergoing preoperative stress imaging without revascularization compared with no testing (Figure 18). However, the 1-year outcome was not different in the revascularized patients compared with the no-testing group. Importantly, these data emphasize the potential hazards of coronary revascularization in patients scheduled for infrainguinal vascular surgery in contrast to aortic surgery and suggest that the former cohort is a higher-risk population overall. Overall, however, this study supports the use of stress imaging before vascular surgery and provides important evidence that perioperative and long-term outcome can be improved by the information provided.

Summary

Preoperative stress MPI can be used in concert with clinical data to identify low-risk patients who can go on to undergo planned noncardiac surgery. It can also identify high-risk patients, providing an opportunity to ameliorate this risk. Studies suggest that medical and revascularization interventions can reduce the perioperative risk in patients identified as high risk by stress MPI and that early and late outcome is improved when such preoperative testing is used.

FUTURE DIRECTIONS

It will be important to further develop the data supporting the impact of preoperative stress MPI on perioperative and long-term outcome, particularly in nonvascular surgery. In addition, more information is needed on the risks of preoperative coronary artery stenting as it relates to the timing of noncardiac surgery. It will also be helpful to examine the impact of ventricular function on outcome and the interaction of function and ischemia on prognosis, as the advent of technetium-based imaging agents has made acquisition of simultaneous function and perfusion data routine.

There are also new developing technologies that are exploring the identification of the “vulnerable plaque”[67] that may have implications for preoperative risk stratification. It may be hypothesized that identification of active, inflammatory plaques may strongly influence outcome, especially in the perioperative state, where clotting activation is intensified. In combination with known data on the prognostic value of jeopardized viable myocardium, such new imaging techniques may be able to substantially improve the positive predictive value of preoperative noninvasive testing and further advance the already well-established clinical value of this approach.

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