CHAPTER 14

Cardiopulmonary Assessment for Major Vascular Reconstructive Procedures

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Careful preoperative assessment of cardiopulmonary function is essential in the planning of major arterial reconstructive surgery. In fact, recognition and treatment of underlying cardiac or pulmonary disease may be of greater importance in some patients than the performance of the vascular surgical procedure itself. Additionally, the preoperative evaluation affords an opportunity for the physician to institute risk factor modification that may be of particular benefit in this high-risk patient pool. Coronary artery disease causes many, if not the majority, of immediate and late postoperative deaths following peripheral vascular surgical procedures. Although the role of impaired pulmonary function in contributing to operative mortality with peripheral vascular procedures is not as well defined as is cardiac disease, postoperative morbidity attributed to severe pulmonary disease is well recognized.

Coronary artery disease is clearly an important factor in determining the eventual outcome of vascular reconstructions in many patients. For example, cardiac complications after carotid endarterectomy, abdominal aortic aneurysm resection, and lower extremity revascularization at the Cleveland Clinic were responsible for 43% of early deaths, and fatal myocardial infarctions occurred in 20% of the survivors during an 8-year period of follow-up (1). In this later experience, 5- and 10-year actuarial survivals were 82% and 49%, respectively, among patients without antecedent indications of coronary artery disease, compared with 67% and 31% at these same time points among those suspected of having coronary artery disease. Myocardial infarction at this same institution accounted for 37% of early postoperative deaths among 343 patients undergoing operations for abdominal aortic aneurysm and 52% of early postoperative deaths among 273 undergoing operations for lower extremity ischemia (2,3). Others have encountered similar mortality and morbidity rates, a clear reflection that patients with peripheral vascular disease often have coexistent life-threatening coronary artery disease (4), and the risk of cardiac events appears to be as great during vascular reconstructions for severe infrainguinal vascular disease as for aortic disease (5).

Preoperative Cardiac Assessment

The value of screening for coronary artery disease depends, in part, on the incidence of confirmed disease among patients undergoing peripheral vascular surgical reconstructions. Among 1000 patients subjected to mandatory coronary arteriography before undergoing aortic reconstruction, lower extremity revascularization, or carotid artery surgery between 1978 and 1982 at the Cleveland Clinic, only 8% had normal coronary arteries (6). In this same series, coronary artery disease was considered mild to moderate in 32%, advanced but compensated in 29%, severe but surgically correctable in 25%, and inoperable in 6%. Severe coronary artery disease was present in 36% of patients being treated for abdominal aortic aneurysms, 32% of those being treated for cerebrovascular disease, and 28% of those undergoing operation for lower extremity ischemia. Surgically correctable severe coronary artery disease affected 34% of patients having a positive cardiac history or abnormal electrocardiogram (ECG), and a surprising 14% of those with a negative cardiac history and normal ECG. Thus, neither the specificity nor sensitivity of the patient's history and routine ECG appears adequate for screening purposes.

Cardiac risk in surgery patients was assessed by Goldman and his colleagues, who evaluated 1001 patients undergoing noncardiac procedures in a classic study published more than 20 years ago (7). Nine independent factors were found to represent significant cardiac risks, including:

1. an S3 gallop or jugulovenous distension;
2. myocardial infarction during the 6 months before surgery;
3. rhythm other than sinus or premature atrial contractions;
4. more than five premature ventricular contractions per minute;
5. intraperitoneal, intrathoracic, or aortic operations;
6. age greater than 70 years;
7. significant aortic stenosis;
8. emergency operative procedures; and
9. poor general health evidenced by hypoxemia, hypercarbia, hypokalemia, chronic liver disease, or impaired renal function.

Using multivariate analysis, these risk factors correctly predicted and classified 81% of subsequent cardiac outcomes and became known as the Goldman index. Unfortunately, this index was not particularly useful in early assessments of patients undergoing vascular surgery (8,9) and has not been found useful in more recent times (10,11). Similarly, other clinical scoring systems, such as the Detsky modified risk index, the Dripps-ASA classification, and the Cooperman probability equation have not proved useful for the accurate prediction of postoperative outcome in patients undergoing peripheral vascular surgery (11).

On the other hand, certain clinical information gained from a scoring system is relevant to the patient facing vascular surgery. Classification of cardiac risks by Evans in 566 patients subjected to peripheral vascular procedures revealed six variables having significant individual associations with cardiovascular complications (12), including:

1. presence of congestive heart failure;
2. prior myocardial infarction;
3. prior stroke;
4. arrhythmia;
5. abnormal ECG; and
6. angina.

Applying these factors in an equation defining risk, postoperative cardiac complications occurred in a predictable fashion, affecting 1.3% of low-risk patients as opposed to 23.2% of high-risk patients.

The role of prior myocardial infarction is well established as a dominant risk factor for perioperative myocardial events in all surgical patients. In a Mayo Clinic study, patients undergoing operation within 3 months of a transmural myocardial infarction experienced a 27% reinfarction rate (13). This decreased to 11% within 6 months, and the reinfarction rate for longer periods was 4% to 5%. The recommendation that at least 6 months pass between a previous myocardial infarction and subsequent elective surgery was advanced by these data. Although in a study between 1973 to 1976, perioperative reinfarction occurred in 36% and 26% of those from 0 to 3 months and from 4 to 6 months after myocardial infarction, from 1977 to 1982 only 5.7% and 2.3% experienced reinfarction during the same times following their initial infarction (14). This suggests that contemporary perioperative monitoring and cardiac support have caused a decrease in reinfarction rates. A number of basic tests are available for preoperative cardiac assessment (Table 14.1), and their use in practice deserves individualized discussion.

Stress Electrocardiography

Stress electrocardiography was one of the first screening tests for cardiac disease (15–18). Findings initially reported to correlate with physiologically important coronary artery stenoses included typical angina pectoris and a positive exercise test with more than 1.0 mm of ST-segment depression in three or more leads; a positive exercise test and an abnormal thallium scan; and a positive exercise test with 2.0 mm of ST-segment depression in three or more leads (19). However, a study of 100 patients requiring arterial reconstructive surgery employing either treadmill testing or arm ergometry revealed that the degree of ST-segment depression was not a good predictor of cardiac complications unless the patient also failed to achieve 85% of the predicted maximum heart rate (20). Those with ST-segment depression of more than 1.0 mm and less than 85% predicted maximum heart rate had a 33% myocardial complication rate, whereas those patients with a positive stress test who were able to achieve greater than 85% of their predicted maximum heart rate had no complications ($p < 0.05$).

Unfortunately, many vascular surgical patients cannot adequately participate in exercise-related stress testing. Gage and his colleagues reported that only 76% of

TABLE 14.1 Preoperative cardiac assessment

	Low Risk	Moderate Risk	High Risk
Stress ECG	Normal ECG, >85% predicted maximum heart rate	Abnormal ECG, 75–85% predicted maximum heart rate	Abnormal ECG, < 75% predicted maximum heart rate
Radionuclide angiocardiography	Ejection fraction >55%	Ejection fraction 36–55%	Ejection fraction < 35%
Dipyridamole–thallium scan	No defect or redistribution	Fixed defect without redistribution (scar from prior infarction)	Thallium redistribution, especially with congestive heart failure, angina, prior infarction, or diabetes mellitus
Dobutamine stress echocardiography	No wall motion abnormality	Resting wall motion abnormality; worsening of pre-existing wall motion abnormality	New wall motion abnormality
Coronary angiography	No disease, mild compensated disease, or corrected disease	Advanced but compensated disease	Severe uncorrected or inoperable disease

patients were able to undergo adequate stress for testing purposes (15). Among 38 of 50 cases in their experience in whom the stress studies were complete, 25 were abnormal, but only 15 were confirmed by coronary arteriography to be truly positive. Just as important was the fact that a third of patients without cardiac symptoms and a normal ECG exhibited an abnormal stress test, indicating once again that silent coronary artery disease among vascular surgery patients is common. Further concern regarding screening with exercise-stress electrocardiograms has been expressed by Weiner, who noted that 65% of men and 33% of women with angina and significant coronary artery disease had negative exercise studies (18). The actual predictive value of these tests depends on the disease prevalence, which is relatively low, a factor that further lessens their screening value.

An attempt to better quantitate exercise stress testing evolved from an evaluation of 2842 patients undergoing exercise electrocardiography within 6 weeks of cardiac catheterization (21). This study described a treadmill score, defined as exercise time—(5 × ST deviation)—(4 × treadmill angina index). Patients with three-vessel disease and a score of −11 or less had a 5-year survival of 67% versus a 5-year survival of 93% with a score of +7 or more. The value of such a system to predict operative complications in patients undergoing peripheral vascular surgical procedures remains to be determined.

Radionuclide Ventriculography

Radionuclide ventriculography also serves as a screening test for coronary artery disease (22). This test is relatively precise at measuring the cardiac ejection, with correlations between dye dilution and $^{99}Tc^{m}$ pertechnetate determined cardiac output measurements being 0.94 in healthy individuals and 0.89 in patients with a history of coronary artery disease. Nuclide scanning defines the volumes of the heart during end-diastole and end-systole. Analvsis of 300 to 400 cardiac cycles allows accurate quantitation of the ventricular ejection fraction. Such gated-pool radionuclide ventriculograms (MUGA scans) provide quantitative data regarding cardiac function.

Among patients at the New York University Medical Center undergoing major abdominal aortic reconstructions who had preoperative radionuclide ventriculography, perioperative myocardial infarction was 0%, with a MUGA-determined ejection fraction between 56% and 85%, 20% with an ejection fraction between 36% and 55%, and 80% if the ejection fraction was less than 35% (23). In a British study of patients undergoing aortic surgery, ejection fractions greater and less than 30% were associated with cardiac-related deaths in 2.7% and 75% respectively (24). Similar experiences have been reported in patients undergoing extremity revascularizations (25). The importance of ejection fraction defining overall survival has also been noted for patients undergoing carotid endarterectomy (26), abdominal aortic aneurysm repair (27), and lower extremity revascularization (28,29). Finally, the effect of exercise on the ejection fraction provides further prognostic information regarding the severity of the underlying coronary artery disease (30).

Radionuclide Myocardial Imaging

Thallium-201 chloride provides a marker of myocardial blood flow, and allows recognition of decreased or redistributed flow during increased cardiac activity, a finding suggesting that the cardiac muscle is at risk (Fig. 14. 1). In this regard, a fixed defect on both stress and rest thallium scanning, such as would occur in the region of previous myocardial infarction and fibrosis, represents a less hazardous situation than would occur with redistribution. Such fixed defects represent nonreactive ventricular scar.

Thallium studies using maximal coronary vasodilation with intravenous administration of dipyridamole were an outgrowth of difficulties in achieving adequate stress using treadmill exercise with both electrocardiographic as well as radionuclide studies (31–36). These testing methods have overcome difficulties in testing pa-

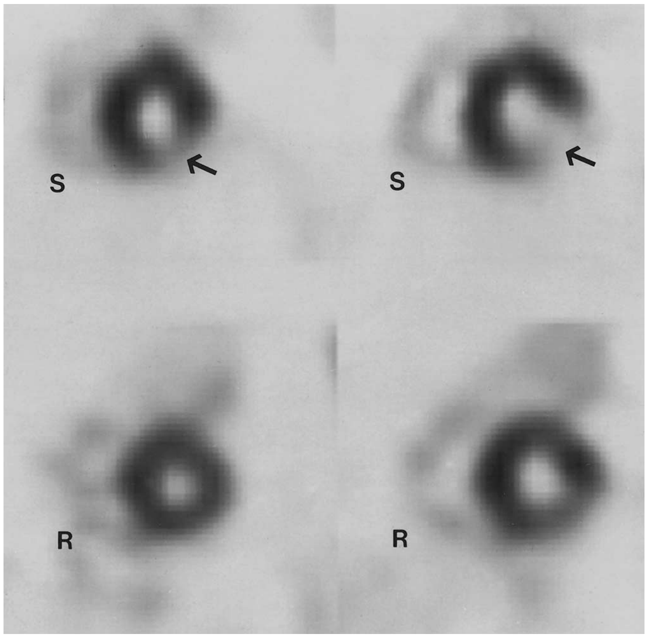

FIGURE 14.1 Radionuclide myocardial imaging with thallium-201 chloride. Perfusion defect during stress (S) in the inferolateral left ventricle (*arrows*) that is not present 3 hours later during recovery (R). Such redistribution of myocardial blood flow establishes the existence of tissue that is vulnerable to further ischemic injury. (Reproduced by permission from Haimovici H, Callow AD, et al. eds. Vascular surgery principles and techniques, 3rd edn. East Norwalk, CT: Appleton & Lange, 1989: 197.)

tients with extremity vascular disease who cannot adequately exercise, as well as those receiving beta-blockers who are unable to increase their heart rate and generate an acceptable rate-pressure product. An early evaluation of thallium–dipyridamole studies was performed by Brewster and his colleagues at Massachusetts General Hospital on 54 patients, nearly equally divided between aortic and peripheral arterial reconstructive procedures (34). In this experience, 22 patients, including five who had evidence of an old myocardial infarction on ECG, exhibited a normal test, and none developed postoperative cardiac ischemic events. Among the remaining 15 patients who demonstrated thallium redistribution, seven patients experienced definite myocardial ischemia postoperatively, including one fatal myocardial infarction, three nonfatal transmural myocardial infarctions, and four instances in which unstable angina developed. In this study, perioperative myocardial ischemia did not correlate with age greater than 70 years, a history of angina pectoris, the type of operation performed, or with anginal discomfort and ST-segment changes accompanying administration of dipyridamole. Most importantly, a previous myocardial infarction in this study was not predictive of perioperative ischemic events unless accompanied by thallium redistribution.

Cutler reported on 116 patients undergoing dipyridamole stress–thallium studies. Among these patients, 60 had normal preoperative scans with no myocardial infarctions after abdominal aortic aneurysm surgery, and 31 had abnormal preoperative scans, with eight suffering myocardial infarctions (35). The risks of developing a myocardial infarction were 12 times greater in a patient having an abnormal scan. Such positive scans occurred with similar frequencies with clinically asymptomatic as well as symptomatic coronary artery disease.

A second published study on dipyridamole stress–thallium testing from the Massachusetts General Hospital involved a total of 111 patients (36). In the first 61 patients studied, myocardial events occurred in 8 of 18 patients with preoperative thallium redistribution compared with no events in 43 patients without thallium redistribution. In a subsequent portion of this study, patients were categorized as those without evidence of congestive heart failure, angina pectoris, previous myocardial infarction, or diabetes mellitus, as opposed to those with one or more of these factors. None of the 23 patients in whom these clinical conditions were absent had adverse outcomes, despite the fact that six exhibited thallium redistribution. On the other hand, 27 patients had more than one of these clinical risk factors, and of 18 patients with redistribution, eight experienced postoperative ischemic events, compared with only two events among the nine patients without redistribution. Thus, dipyridamole–thallium scanning may be useful in stratifying patients at risk of myocardial ischemia when one or more clinical markers of cardiac disease or diabetes exist. The overall incidence of perioperative ischemic events in this series was 45% with thallium redistribution, compared with 7% without redistribution.

Overall, combining five studies from the literature, the incidence of perioperative cardiac events in aortic surgery patients was 22% with a positive scan and 0.5% in those with a negative scan, including fatal myocardial infarction in 8.1% of those with a positive scan compared with 0% in those with a negative scan (33,35–38). The thallium scan has been quantitated so as to increase its predictive value, by determining the number of myocardial segments with redistribution, the maximal severity of the reversible defect, and the amount of myocardial tissue at risk (11). Likewise, delayed imaging has been advocated by some who observed that fixed defects initially on thallium scanning may show late redistribution and indicate a high risk of myocardial infarction (10), and by others who suggest that fixed defects correlate in a significant fashion with long-term cardiac morbidity and deaths (39). Thallium reinjection 4 hours after the first injection is a means of improving detection of ischemic cardiac muscle that initially appeared as a fixed defect on the primary image, with up to 49% of initial fixed defects demonstrating improved or normal thallium uptake after a second injection (40).

Finally, two studies suggest that select patients undergoing aortic surgery may undergo thallium testing, and not all patients need to undergo such preoperative evaluations. In one study, patients undergoing abdominal aortic aneurysm repair had critical coronary artery disease predicted by a history of myocardial infarction, stable angina, or an abnormal echocardiogram (36% vs. 0% without such a history) (41). This study suggested that thallium scanning was not necessary in the absence of such findings. In a second study (42), vascular surgery patients were stratified on admission by analysis of five key risk factors:

1. age greater than 70 years;
2. diabetes;
3. Q-wave on ECG;
4. history of ventricular arrhythmia requiring therapy;
5. history of active angina.

Among the 151 patients with abdominal aortic aneurysms and 51 patients with aortoiliac occlusive disease, preoperative thallium scans were found necessary in 29%, coronary arteriograms were performed in 11%, and preoperative cardiac intervention (percutaneous transluminal coronary angioplasty or surgery) was undertaken in 9% of patients. The overall operative mortality was excellent at 2%, with major cardiac morbidity occurring in 4%. Only 20% of those with zero or one risk factor underwent thallium scans while 50% of those patients with two or more factors underwent testing. Although this was not a prospective randomized study, the authors suggest that patients with zero to one risk factors need not undergo preoperative testing, while those with two or more risk factors should undergo testing. Importantly, no single clinical marker of coronary artery disease predicted the adverse cardiac events in this series.

A cautionary note regarding thallium-stress imaging is warranted in hypertensive patients with a low likelihood of coronary artery disease who have had diastolic pressures exceeding 90 mmHg for at least 2 years. These patients are more likely to have abnormal scans than normotensive patients, perhaps as a reflection of limited coronary reserve due to hypertension-related myocardial hypertrophy (43). Such findings may lessen the specificity of these tests. A second word of caution relates to the potential of dipyridamole-induced myocardial ischemia, allegedly caused by coronary "steal" in the presence of epicardial coronary collateral vessels (44). This potential hazard has received little attention given the large number of useful studies performed without occurrence of this complication. Finally, not all groups have concluded that dipyridamole–thallium scintigraphy is useful. In a study of 60 patients undergoing vascular reconstruction in which the investigators were unaware of the scan results, the sensitivity of the test was only 40% to 54%, the specificity only 65–71%, the positive predictive value only 27% to 47%, and the negative predictive value only 61% to 82% (45). Furthermore, although thallium scans are most often used in the preoperative evaluation of the aortic surgery patient, the cost and time required to perform this test have been questioned by some authors. Thus, controversy remains as to the precise effectiveness of thallium scanning as a preoperative screening procedure.

Dobutamine Stress Echocardiography

Stress echocardiography has evolved as a means of assessing the adequacy of the coronary artery circulation. In 60 patients undergoing aortic surgery (27 with aneurysms and 33 with occlusive disease), a 4.6% cardiac event rate (1/22) was found in those with a negative study, while a 29% cardiac event rate affected patients with an abnormal test (46). In fact, patients with a new wall motion abnormality suffered a 39.1% cardiac event rate. In a second report, 51 patients undergoing resection of abdominal aortic aneurysms, 46 aortofemoral bypasses, and 39 infrainguinal arterial reconstructions were studied (47). The dobutamine echocardiogram was positive in 35 of the patients in this study, including five who died of myocardial infarction, nine who had unstable angina, and one who developed pulmonary edema. By multivariate analysis, only age greater than 70 years and new wall motion abnormalities were significant as to their predictive value. In a third study, dobutamine stress echocardiography in 98 consecutive patients undergoing vascular surgery resulted in 70 normal studies, 23 studies with new or worsening wall motion abnormalities, and five equivocal studies (48). All negative studies were associated with uneventful surgical procedures. Of the 23 patients with positive studies, 19 underwent cardiac catheterization, all revealing greater than 50% lumen narrowings in one or more major coronary distributions, and 13 underwent preoperative coronary artery bypass; four of ten positive patients without preoperative coronary revascularizations suffered a perioperative cardiac event.

The safety of dobutamine stress echocardiography has been addressed in an experience involving 1118 patients (49). An aggressive dobutamine dosing regimen was used, and atropine was employed in 420 (37%) of these patients. There were no deaths, episodes of myocardial infarction, or sustained ventricular tachycardia, and noncardiac side effects were infrequent. Approximately 20% of patients developed angina that was well treated with sublingual nitroglycerin or short-acting beta-blockers. The above studies and others from the cardiology literature suggest that dobutamine stress echocardiography may eventually replace thallium studies in the preoperative evaluation of the vascular surgery patient as a more cost-effective study.

Perioperative Holter monitoring has been advocated as a means of revealing occult coronary artery disease. The presence of 1 hour or more of ischemia appears to be the cutoff point predicting overall cardiac morbidity and mortality (50). Likewise, myocardial ischemia noted with the use of a two-channel Holter recorder, for 2 days before surgery, during surgery, and 2 days after surgery, was associated with a 2.8-fold increase in the odds of an adverse cardiac outcome (51). The exact role for this technology is not clear in relation to thallium scanning and stress echocardiography.

Arteriography

The most accurate means of identifying anatomic and surgically correctable coronary artery disease in patients who are candidates for peripheral vascular surgery is arteriography. However, arteriography cannot identify functionally important disease. Its use as a screening test has been questioned by many, including surgeons from the Mayo Clinic where routine coronary artery bypass plus aortic aneurysmectomy in certain subgroups carries a risk exceeding that of aneurysm resection alone (52,53). Mortality among patients at the Mayo Clinic who have not had prior coronary artery bypass before aortic aneurysm resection in the age group of 50 to 69 was due to a cardiac cause 70% of the time, compared with 50% for patients 70 to 79 years old, and 33% for patients older than 80 years.

In 1996, the American College of Cardiology and the American Heart Association published guidelines for perioperative cardiovascular evaluation for noncardiac surgery (54) (Table 14.2). These guidelines indicate that asymptomatic patients with a history of coronary revascularization within 5 years need no further coronary evaluation preoperatively. Other patients are risk stratified based on clinical predictors and cardiac risk for the planned surgical procedure. All vascular procedures are considered "high-risk," including peripheral vascular procedures. Patients with high-risk predictors such as unstable coronary syndromes, decompensated CHF, significant arrhythmias, or severe vascular disease may benefit from coronary angiography before vascular surgery. With that in mind, the only patients who may proceed to vascular surgery without coronary evaluation are those who can perform > 4 METS of physical activity and have no intermediate clinical predictors such as angina, prior myocardial infarction, compensated or prior CHF, or diabetes. All other patients require stress evaluation for risk stratification, including all patients whose physical activity is generally below 4 METS. Activities associated with 4 METS of activity include baking, slow ballroom dancing, golfing with a cart, playing a musical instrument, or walking at 2–3 mph. Most patients with claudication cannot achieve a workload of 4 METS.

Naturally, the risk of stress testing and the potential of subsequent coronary arteriography and intervention must be weighed in the individual patient. Some evidence is emerging that, patients undergoing carotid endarterectomy under local anesthesia suffer fewer cardiac complications than with general anesthesia (55). But this is the result of a meta-analysis of nonrandomized data, and will require additional data for confirmation. Most patients undergoing any vascular procedure, irrespective of their stress test results, will also benefit from perioperative beta blockade and aggressive postoperative lipid treatment.

Empiric Beta Blockade

Preoperative cardiac evaluation and intervention comes with risks, particularly in patients with atheromatous vessels and renal insufficiency, conditions common in patients requiring vascular surgery. A multicenter study involving 173 patients with abnormal dobutamine echocardiograms tested standard therapy against empiric perioperative treatment with the β_1-selective antagonist bisoprolol (56). In this study, 173 patients with planned vascular surgery who had abnormal dobutamine stress echocardiograms were evaluated. Of these, 53 were excluded because they were already taken beta-blocking drugs, and eight were excluded because of extensive wall motion abnormalities during the stress or rest portion of the test. Patients were treated with bisoprolol 5 mg daily for at least 1 week preoperatively, and for 30 days postoperatively. In patients whose heart rate remained above 60 beats per minute, the dose was increased to 10 mg daily. Control patients received standard peroperative care without beta blockade.

TABLE 14.2 Preoperative risk stratification for patients undergoing vascular surgery

Presentation	Preoperative Approach
Emergent surgery	Proceed to operating room Consider beta blockade Postoperative risk stratification and risk factor management
Coronary revascularization within 5 years or recent coronary evaluation in patient with no recurrent signs or symptoms	Proceed to operating room Consider beta blockade Postoperative risk factor management
Patients with major clinical predictors (unstable coronary syndromes, decompensated CHF, significant arrhythmias, or severe valvular disease)	Consider coronary angiography and subsequent care dictated by the findings Consider delay or cancellation of noncardiac surgery
Patients with intermediate clinical predictors (mild angina, prior MI, compensated or prior CHF, diabetes)	Noninvasive testing with subsequent care dictated by the findings
Patients with minor or no clinical predictors (advanced age, abnormal ECG, rhythm other than sinus, low functional capacity, history of stroke, uncontrolled systemic hypertension)	If functional capacity exceeds 4 METS: proceed to operating room and consider beta blockade If functional capacity is 4 METS or less, perform noninvasive testing

The results of this study showed a statistically significant decrease in death due to cardiac causes and in nonfatal myocardial infarction in patients treated with bisoprolol. While the patients at highest risk were excluded from randomization, this study shows a clear beneficial effect of perioperative beta blockade in patients undergoing vascular surgery, and who have evidence of coronary insufficiency. Additionally, perioperative beta-blocker use has also been associated with decreased occurrence of atrial fibrillation, which can occur in many patients 2 to 4 days postoperatively (57). With this information, it may be reasonable to treat all patients undergoing vascular surgery with beta blockade to achieve a heart rate of about 60 and/or to use intravenous metoprolol to achieve a heart rate of < 80 in patients who are unable to take oral medication.

Intraoperative Cardiac Management

Intraoperative risk analysis based on anesthetic classification has allowed definition of overall operative mortality rates. For example, the mortality in class I ASA risk patients is 0.1%, while the mortality in class V ASA patients is 9.4% (58). However, this classification does not distinguish treatable factors contributing to myocardial infarction, which may affect 50% to 60% of patients undergoing certain major vascular procedures. Surgeons should be familiar with those intraoperative maneuvers that decrease the cardiac risks of peripheral vascular reconstructions.

Swan–Ganz catheter placement has allowed for more optimal fluid administration during performance of vascular procedures. Such monitoring is of particular use in patients with decreased systolic function in whom seemingly minor variations in preload and afterload can cause considerable variation in cardiac output and renal function. It is important to minimize the time that a Swan–Ganz catheter remains in place. Once fluid status and cardiac output can be adequately (albeit not optimally) monitored by noninvasive means (blood pressure, urine output, renal function), the catheter should be removed to decrease the chance of infection. The Brigham group has reported on Swan–Ganz catheter monitoring preoperatively to determine Starling responses to incremental infusions of salt-poor albumin and lactated Ringer's solution, with subsequent pulmonary capillary wedge pressures maintained intraoperatively and postoperatively at levels consistent with optimal left ventricular performance as predicted by the preoperative studies (59). They reported 110 consecutive patients undergoing elective or urgent repair of abdominal aortic aneurysms, with no 30-day mortality, a 0.9% in-hospital mortality, and a 5-year cumulative survival of 84%. Increased arterial pressures were treated with sodium nitroprusside as a vasodilator, but monitoring of the cardiac index and pulmonary capillary wedge pressures suggested that this was seldom necessary and at times hazardous. In fact, the Brigham group does not now use vasodilators during aortic cross-clamping. Others have had similar experiences, and have reported that optimal fluid management with aortic reconstruction included administration of balanced salt solutions rather than hypotonic solutions (60).

Maintenance of pulmonary capillary wedge pressures with volume expansion is often supplemented with both inotropic drugs and afterload-reducing agents (61). These drugs become important because the diastolic compliance or the relation between the wedge pressure and the end-diastolic volume index may decrease after aortic declamping (62). This is probably a reflection of early myocardial ischemia, and under such circumstances the wedge pressure may need to be restored to a higher level to return the cardiac index to acceptable levels. Others have also suggested that careful titration of the pulmonary artery catheter wedge pressure may lower the frequency of adverse intraoperative cardiac events, cardiac morbidity, and early graft thromboses in patients undergoing peripheral vascular surgical procedures (63).

Other types of intraoperative monitoring contribute to improved myocardial performance and detection of early myocardial ischemia. One such technique includes online computerized monitoring of systolic time intervals, left ventricular pre-ejection times, left ventricular ejection times, and ratios of left ventricular pre-ejection time to election time (64). Experience with this type of monitoring revealed systolic time intervals to be sensitive indices for dosing anesthetic and vasoactive drugs, while pulmonary artery diastolic pressures appeared more specific for administering blood and fluids.

Perhaps a more direct approach to assess intraoperative cardiac function and myocardial ischemia is two-dimensional transesophageal echocardiography (65,66). In a study of 24 ASA class III and IV patients, half underwent supraceliac clamping and half underwent suprarenal-infraceliac or infrarenal aortic cross-clamping, with a special 3.5-MHz two-dimensional electrocardiographic transducer placed in the esophagus to provide a cross-sectional view of the left ventricle through the base of the papillary muscle (65). Supraceliac aortic occlusion caused major increases in left ventricular end-systolic and end-diastolic areas, decreases in ejection fraction, and frequent wall motion abnormalities. Suprarenal clamping caused similar but less pronounced effects, while infrarenal clamping caused minimal changes. Wedge pressures changes often did not correlate with findings of two-dimensional electrocardiography. For example, with supraceliac aortic cross-clamping, wedge pressures and systemic pressures were normal in 10 of 12 patients, whereas 11 of 12 developed wall motion abnormalities indicative of myocardial ischemia. Two-dimensional echocardiography in another study of 50 patients revealed 24 individuals who developed segmental wall motion abnormalities, of whom only six had exhibited concomitant ST-segment changes on ECG (66).

Thus intraoperative two-dimensional transesophageal echocardiography appears to be a sensitive means of identifying segmental wall motion abnormalities indicative of early myocardial ischemia that occur before either ST-segment changes or abnormal wedge pressures develop. In addition, transesophageal Doppler monitoring has been found to correlate with thermodilution cardiac output measurements taken at end-expiration, with *r* values of 0.94 (preclamp), 0.70 (during clamping), and 0.85 (after clamping) (67).

Vasodilators administered during aortic cross-clamping decrease the systemic arterial blood pressure and afterload that the heart must pump against. Nitroglycerin and nitroprusside are the most common agents used to achieve this effect. Nitroglycerin is a potent venous vasodilator and a mild arterial vasodilator. It decreases myocardial oxygen demand, lessens myocardial ischemia by reducing diastolic volume, and may increase oxygen delivery to ischemic myocardium by dilating coronary arteries and collateral vessels. Nitroprusside, on the other hand, is a relatively balanced arterial and venous vasodilator. It has greater relaxing effects on coronary resistance vessels and less influence on coronary collateral vessels. In this regard, nitroprusside decreases blood flow in the ischemic myocardium of patients with stable angina and increases ST-segment elevations in those with acute myocardial infarction, supporting the suggestion by Fremes and his colleagues that it may cause myocardial oxygen supply to be reduced in patients with significant cardiac disease (68). In a related study by this later group, 33 hypertensive patients undergoing coronary bypass procedures had their arterial pressure decreased to 85 mmHg with both nitroglycerin and nitroprusside, but only the nitroglycerin resulted in improved myocardial metabolism, as assessed by myocardial lactate flux (69).

Volume loading may be an important adjunct to the use of vasodilators. The Brigham group reported on 50 patients undergoing abdominal aortic aneurysm resection, of whom 10 received customary preoperative maintenance fluids, 23 received 1500 mL of balanced salt solution in the 12 hours before the operative procedure in order to keep the pulmonary capillary wedge pressure at 10 to 13 mmHg, and 17 received the same fluid regimen with the addition of vasodilators (70). Fourteen of the latter patients received nitroprusside at a rate of 1.5 to 6.0 μg/kg/min, and three received nitroglycerin at a rate of 0.5 to 3.5 μg/kg/min. Both vasodilators were given after aortic cross-clamping to control afterload, and additional volume expansion was used to maintain a constant preload. However, the mean arterial blood pressure and cardiac index fell, and furthermore the cardiac index remained depressed after aortic declamping. These events occurred with increased pulmonary capillary wedge pressures without corresponding increases in cardiac index, suggesting myocardial depression. In this setting vasodilators did not appear useful.

The combined administration of inotropic and vasodilator agents in patients after coronary artery bypass grafting has been advocated by the Stanford group (71). Volume loading with the addition of vasodilators and dopamine increased the cardiac index 45%, increased the left ventricular stroke work index 30%, decreased systemic vascular resistance 41%, and decreased mean arterial pressure only 10%. In comparison with dopamine alone, addition of vasodilators and volume infusion increased the cardiac index 14% and decreased systemic vascular resistance 24%, without a significant change in the left ventricular stroke work index. This form of combined therapy appears to facilitate beneficial responses from both drugs, while minimizing their individual disadvantages. In this regard, the usefulness of dopamine is limited if the preload is decreased, when its enhanced inotropic activity may actually increase myocardial oxygen demand and consumption. Similarly, nitroprusside alone is contraindicated when left ventricular failure is complicated by hypotension, when it may also decrease cardiac output if the preload is inadequate. The usefulness of vasodilators in cardiac surgery procedures may relate to the severe vasoconstriction known to occur after coronary artery grafting and cardiopulmonary bypass (71). In addition, cardiac output with ventricular failure is more sensitive to afterload than preload, and patients with severe ventricular failure would more likely benefit from nitroprusside afterload reduction.

Another important issue regarding vasodilators is their effect on regional blood flow in ischemic tissue. For example, it is in patients requiring high thoracic-aortic cross-clamping that vasodilator therapy should be most useful. However; as noted in canine experiments, thoracic aortic cross-clamping and infusion of nitroprusside causes the mean arterial blood pressure below the occlusion to decrease, causing further reductions in renal and spinal cord blood flow, events that may negate any cardiac protection afforded by the vasodilator (72,73). On the other hand, during infrarenal aortic cross-clamping in similar laboratory studies, nitroprusside caused a 30% decrease in arterial pressure, brought cardiac output back down to baseline, and appeared to normalize hepatic and intrarenal blood flow (74). Thus, with infrarenal aortic occlusion, renal and splanchnic blood flow do not appear to be adversely affected by the administration of nitroprusside.

In summary, vasodilator and inotropic drug use during aortic cross-clamping is controversial. Those with the poorest myocardial function, most dependent on afterload reduction, would appear to benefit the greatest from use of vasodilators, but perfusion pressures below the level of high aortic cross-clamping in such settings must be closely monitored to ensure adequate regional blood flow to vital organs.

Finally, there is the issue of intraoperative thoracic epidural anesthesia combined with light general anesthesia versus standard balanced general anesthesia for patients undergoing aortic surgery. In a study of 173 patients equally divided between these two techniques undergoing operations for abdominal aortic aneurysms and aortoiliac occlusive disease, thoracic epidural offered no advantage over general anesthesia (75). A similar conclusion was reached comparing epidural versus general anesthesia in patients undergoing infrainguinal arterial reconstruction (76).

Preoperative Pulmonary Assessment

Adequate pulmonary assessment is dependent on acquisition of a detailed history, the presence or absence of specific physical findings, measurement of arterial blood gases, and performance of certain pulmonary function tests using spirometric techniques.

Historically, the number of pack-years of smoking becomes important, with 20 pack-years appearing to be the level at which significant pulmonary risks become apparent (77). The presence or extent of shortness of breath with activity, prior episodes of respiratory failure, existence of asthma, and exposure to noxious environmental agents are all relevant in assessing the pulmonary status. The quantity and nature of sputum production is particularly important in patients with long-standing lung disease, because this may allow one to distinguish chronic bronchitis from emphysema.

The physical examination easily detects hypoventilation in weak or debilitated patients, and hyperinflation in patients with chronic obstructive pulmonary disease. The ability to climb one or two flights of stairs at a steady pace without dyspnea is a practical test, and if such cannot be done, further tests may be needed to define the pulmonary status. Chest radiographs augment the findings of routine physical examination.

Arterial blood gases should be measured preoperatively on all patients identified as being at high risk by history, physical examination, or spirometric testing. Oxygenation is assessed by measuring PaO_2 during room-air breathing, and is dependent on the appropriate matching of alveolar gas to pulmonary blood flow. Ventilation is assessed by measuring $PaCO_2$, inasmuch as CO_2 removal is dependent entirely on alveolar ventilation. Arterial blood gases define both alveolar hypoventilation ($PaCO_2$ >45 mmHg) and significant right-to-left shunting, diffusion block and ventilation–perfusion mismatch (PaO_2 <70 mmHg).

Definitions of normal pulmonary function tests (Table 12.3) are useful in assessing the preoperative status of vascular surgery patients. Tidal volume (V_T) is the amount of air exchanged during a normal resting ventilatory cycle. Vital capacity (VC), also known as forced expiratory volume (FEV) or forced vital capacity (FVC), is the volume of air expelled with maximal exhalation after a maximal inspiration. Functional residual capacity (FRC) is the volume of air remaining in the lungs after V_T exhalation. Typical normal values for these volumes are V_T of 7 to 8 mL/kg of body weight, VC of 30 to 50 mL/kg of body weight, and FRC of 15 to 30 mL/kg of body weight. Volume measurements are reported as the percentage of predicted value, with 80% to 120% being considered within the normal range.

TABLE 14.3 Preoperative pulmonary assessment

	Normal	High Risk
Vital capacity (VC)	30–55 mL/kg; > 80% predicted	< 30–50%
Forced expiratory volume in 1 second (FEV_1)	> 80% predicted	< 40–50%
Maximal midexpiratory flow ($FEF_{25–75}$)	150–200 L/min; > 80% predicted	< 35–50%
Maximal ventilatory volume (MVV)	150–500 L/min; > 80% predicted	< 35–50%
PaO_2 room air	85 ± 5 mmHg	< 50–55 mmHg
$PaCO_2$ room air	40 ± 4 mmHg	> 45–55 mmHg

Expiratory flow rates are commonly expressed as volume/time, such as $FEV_{0.5}$, which defines the volume of forced expiration over 0.5 second. This measure is dependent on patient effort and reveals the existence or absence of obstructive airway disease. Flow measurements are also expressed as a percentage of the expected value for the individual patient being studied. FEV_1 is a similar measure except that it assesses volume exhaled over 1 second. The $FEF_{25–75}$ (maximal mid-expiratory flow rate, MMFR) is most sensitive to disease in smaller airways and is considered normal when greater than 80% predicted or 150 to 200 L/min. The maximal ventilatory volume (MVV) an individual can generate is highly dependent on patient effort, the ratio of dead space to tidal volume, and lung compliance. MVV usually ranges between 150 and 500 L/min. MVV is one of the more sensitive tests for predicting pulmonary complications because an abnormal value (< 80% predicted) may be caused by general patient weakness as well as pulmonary disease.

Static compliance is defined as the V_T divided by the peak inspiratory pressure and is normally 100 to 200 mL/cmH_2O. An esophageal balloon is required to measure compliance. Effective compliance is the V_T/plateau pressure on a ventilator, with normal being greater than 50 mL/cmH_2O. Inspiratory force (IF) is defined as the maximal subatmospheric pressure that can be exerted on a closed airway. A normal IF is –100 cmH_2O, with –20 cmH_2O being the lower limit of acceptability.

Patients with obstructive defects have an essentially normal VC but abnormal expiratory air flows such as FEV_1, $FLV_{0.5}$, and $FEF_{25–75}$, whereas patients with restrictive defects have a low VC but normal expiratory air flows. Some have suggested that the MVV, as measured directly or approximated by the $FEV_1 \times 30$, is the best test to predict postoperative pulmonary complications. With a MVV less than 50% of predicted, respiratory complications developed in a high proportion of patients undergoing thoracotomy, and in the majority, multiple complications ensued (78). Other more detailed tests such as measurement of functional residual capacity using helium dilution or nitrogen washout, diffusing capacity, or response of arterial PaO_2 to breathing 100% oxygen are rarely necessary in these preoperative assessments.

Variations in pulmonary function studies over a 24-h period for patients with normal lungs were 500 for FEV_1, 5% for FVC, and 13% for FEF_{25-75}. Similar variations in patients with chrome obstructive pulmonary disease were 130, 0, 11%, and 23% respectively (79). Thus, with interventions such as use of bronchodilators, these percentages represent the minimal changes necessary to assume that a significant therapeutic effect has occurred.

The importance of blood gas analysis and spirometrically derived pulmonary function tests is evidenced in a pulmonary complication rate of 3% in patients with chronic obstructive pulmonary disease with normal preoperative tests, compared with pulmonary complications in 70% of those with abnormal tests, the most important predictor being a $PaCO_2$ greater than 45 mmHg and a PaO_2 less than 60 mmHg (80).

Even patients at increased risk with seemingly prohibitive function, such as MVV less than 50 L/min and FEF_{25-75} less than 50 L/min, can undergo major operative procedures with a low mortality and an acceptable pulmonary complication rate (81). Some have questioned the value of preoperative spirometry to detect surgically important occult disease with a beneficial effect on patient outcome (82). Poor performance on spirometric testing is not a contraindication to a major vascular procedure, but rather a means of identifying those patients who will require special preoperative preparation and attention to postoperative mechanical ventilation.

Patients with chronic obstructive pulmonary disease, asthma, or chronic bronchitis should undergo respiratory flow measurements before and after administration of bronchodilators. Intensive preoperative preparation using these agents and respirator exercises until pulmonary function is optimized, as documented by spirometry, has reduced by half the pulmonary complication rate associated with chronic obstructive pulmonary disease (83). Postoperative respiratory complications in these patients are best prevented by discontinuation of smoking and vigorous preoperative and postoperative pulmonary toilet (84).

In a small series of patients at Duke University undergoing abdominal aortic aneurysm resection with very severe preoperative pulmonary compromise, there was no mortality, and only 20% required prolonged ventilatory support (85). Preoperatively all patients stopped smoking for at least 1 month, pulmonary infection was treated with antibiotics, nebulized bronchodilators and humidified air were administered, and exercises were instituted that stressed improved inspiratory effort. Intraoperatively, blood filters were used for all blood transfusions, minimization of anesthetic time was emphasized, blood use was lessened, and the pulmonary capillary wedge pressure was used as a guide for fluid administration. Postoperatively, these patients were mechanically ventilated, but extubated as soon as possible. They were reintubated early if such became necessary. The amount of narcotics usually given was reduced, and patients were ambulated early. All of these factors lessened operative mortality and morbidity in vascular surgery patients whose preoperative pulmonary function was marginal.

Another issue regarding patients at high risk of pulmonary complications during aortic reconstruction has been the use of the left flank retroperitoneal incision rather than the more standard transperitoneal approach (86,87). This incision may decrease pulmonary complications, although not all groups have found this to be the case (88).

Conclusion

The objectives of perioperative cardiopulmonary assessment and intervention in patients who are candidates for vascular surgery are twofold. First is performance of the surgical procedure with minimal morbidity and mortality. Second is an improved long-term survival of the patient, in particular by reducing late cardiac mortality. Patients undergoing preoperative coronary artery bypass prior to peripheral vascular reconstructions have been found to have excellent outcomes, with operative mortality reported as low as 0.2% in one large study (89). Even severely ill patients have been able to undergo abdominal aortic aneurysm resection with a mortality rate under 6%, despite such factors as the use of home oxygen, a PaO_2 less than 50 mmHg, FEF_{25-75} less than 25%, New York Heart Association classification III or IV, active angina pectoris, an ejection fraction less than 30%, recent congestive heart failure, complex ventricular ectopy, large left ventricular aneurysms, severe valvular heart disease, or unreconstructable coronary artery disease (90). The late 43% mortality from heart disease reported by Crawford and his colleagues among 949 patients undergoing treatment for aortoiliac occlusive disease should be lessened in contemporary practice (91). For instance, 5-year survival rates of more than 90% may be expected following coronary artery reconstruction, even in patients with multiple-vessel disease (92–94).

One of the first long-term studies on an aggressive preoperative cardiac assessment and management in patients undergoing peripheral vascular surgery involved 246 patients with infrarenal abdominal aortic aneurysms treated at the Cleveland Clinic (95). Severe coronary artery disease was documented in 39%, of whom 28% underwent myocardial revascularization with a mortality rate of 5.7%. A total of 56 patients in this subset underwent staged aneurysm repair with an accompanying 1.8% mortality rate. Over the follow-up interval, 25% of the patients in this group died, leaving a 5-year survival rate of 75%, but there was only a 5% cardiac mortality rate. This survival was nearly identical to that for patients having both trivial coronary lesions and severe coronary involvement without an aneurysm who had undergone coronary revascularization, and was much better than the reported 5-year survival rate of only 29% for patients with uncorrectable or inoperable coronary artery disease. Although some might contend that expensive and invasive coronary screening programs are unnecessary in the majority of patients undergoing vascular surgery including elective aortic surgery and carotid surgery (96–98), considerable evidence supports more aggressive treatment of correctable coronary artery disease in vascular surgery patients, either in the preoperative/perioperative period or in the postoperative period. The challenge for vascular surgeons is to better define those situations that will allow for improved specificity of noninvasive cardiac testing while maintaining excellent sensitivity for detecting important coronary artery disease.

References

1. Hertzer NR. Clinical experience with preoperative coronary angiography. J Vasc Surg 1985; 2: 510.
2. Hertzer NR. Fatal myocardial infarction following abdominal aortic aneurysm resection. Three hundred forty-three patients followed 6–11 years postoperatively. Ann Surg 1980; 192: 667.
3. Hertzer NR. Fatal myocardial infarction following lower extremity revascularization. Two hundred seventy-three patients followed six to eleven postoperative years. Ann Surg 1981; 193: 492.
4. Nicolaides AN. The diagnosis and assessment of coronary artery disease in vascular patients. J Vasc Surg 1985; 2: 501.
5. Krupski WC, Layug EL, et al. Comparison of cardiac morbidity between aortic and infrainguinal operations. J Vasc Surg 1992; 15: 354.
6. Beven EG. Routine coronary angiography in patients undergoing surgery for abdominal aortic aneurysm and lower extremity occlusive disease. J Vasc Surg 1986; 3: 682.
7. Goldman L, Caldera DL, et al. Multifactorial index of cardiac risk in noncardiac surgical procedures. N Engl J Med 1977; 297: 845.
8. Calvin JE, Kieser TM, et al. Cardiac mortality and morbidity after vascular surgery. Can J Surg 1986; 29: 93.
9. Jeffrey CC, Kunsman J, et al. A prospective evaluation of cardiac risk index Anesthesiology 1983; 58: 462.
10. McEnroe CS, O'Donnell TF, et al. Comparison of ejection fraction and Goldman risk factor analysis to dipyridamole–thallium 201 studies in the evaluation of cardiac morbidity after aortic aneurysm surgery. J Vasc Surg 1990; 11: 497.
11. Lette J, Waters D, et al. Multivariate clinical models and quantitative dipyridani–thallium imaging to predict cardiac morbidity and death after vascular reconstruction. J Vasc Surg 1991; 14: 160.
12. Cooperman M, Pflug B, et al. Cardiovascular risk factors in patients with peripheral vascular disease. Surgery 1978; 84: 505.
13. Steen PA, Tinker JH, Tarhan S. Myocardial reinfarction after anesthesia and surgery. JAMA 1978; 239: 2566.
14. Rao TLK, Jacobs KR. Reinfarction following anesthesia in patients with myocardial infarction, Anesthesiology 1983; 59: 449.
15. Gage AA, Bhayana JN, et al. Assessment of cardiac risk in surgical patients. Arch Surg 1977; 112: 1488.
16. Cutler BS, Wheeler HB, et al. Assessment of operative risk with electrocardiographic exercise testing in patients with peripheral vascular disease. Am J Surg 1979; 1 37: 484.
17. Cutler BS, Wheeler RB, et al. Applicability and interpretation of electrocardiographic stress testing in patients with peripheral vascular disease. Am J Surg 1981; 141: 501.
18. Weiner DA, Ryan TJ, et al. Exercise stress testing. Correlations among history of angina, ST-segment response and relevance of coronary-artery disease in the coronary artery surgery study (CASS). N EngI J Med 1979; 301: 230.
19. Selwyn AR. The value of Holter monitoring in managing patients with coronary artery disease. Circulation 1987; 75 (Suppl 11): 11–31.
20. McPhail N, Calvin JE, et al. The use of preoperative exercise testing to predict cardiac complications after arterial reconstruction.J Vasc Surg 1988; 7: 60.
21. Mark DB, Hlatky MA, et al. Exercise treadmill score for predicting prognosis in coronary artery disease. Ann Intern Med 1987; 106: 793.
22. Jones RH, Douglas JM, et al. Noninvasive radionuclide assessment of cardiac function in patients with peripheral vascular disease. Surgery 1979; 85: 59.
23. Pasternack PF, Imparato AM, 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.
24. Mosley JG, Clarke JMF, et al. Assessment of myocardial function before aortic surgery by radionuclide angiocardiography. Br J Surg 1985; 72: 886.
25. Pasternack PF, Imparato AM, et al. The value of the radionuclide angiogram in the prediction of parioperative myocardial infarction in patients undergoing lower extremity revascularization procedures. Circulation 1985; 72 (Suppl): Il-213.
26. Kazmers A, Cerqueira MD. Zierler E. The role of preoperative radionuclide left ventricular ejection fraction for risk assessment in carotid surgery Arch Surg 1988; 123: 416.
27. 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.
28. Kazmers A, Cerqueira MD, Zierler RE. Perioperative and late outcome in patients with left ventricular ejection fraction of 35% or less who require major vascular surgery. J Vasc Surg 1988; 8: 307.
29. Kazmers A, Moneta GL., et al. The role of preoperative radionuclide ventriculography in defining outcome after revascularizarion of the extremity. Surg Gynecol Obstet 1990; 171: 481.
30. Bonow RD. Exercise testing and radionuclide procedures in high-risk populations. Circulation 1987; 75 (Suppl): 11–18.
31. Albro PC, Gould KL, et al. Noninvasive assessment of coronary stenoses by myocardial imaging during phar-

macologic coronary vasodilation: III. Clinical trials. Am J Cardiol 1978; 42: 751.
32. Leppo J, Boucher CA, et al. Serial thallium-201 myocardial imaging after dipyridamole infusion: diagnostic utility in detecting coronary stenoses and relationship to regional wall motion. Circulation 1982; 66: 649.
33. Boucher CA, Brewster DC, et al. Determination of cardiac risk by dipyridamole–thallium imaging before peripheral vascular surgery. N Engl J Med 1985; 312: 398.
34. Brewster DC, Okada RD, et al. Selection of patients for preoperative coronary angiography: use of dipvridamole-stress-thallium myocardial imaging. J Vasc Surg 1985; 2: 504.
35. Cutler BS, Leppo JA. Dipyridamole thallium 201 scintigraphy to detect coronary artery disease before abdominal aortic surgery. J Vasc Surg 1987; 5: 91.
36. Eagle KA, Singer DE, et al. Dipyridamole–thallium scanning in patients undergoing vascular surgery: optimizing preoperative evaluation of cardiac risk. JAMA 1987; 257: 2185.
37. Sachs RN, Tellier P, et al. Assessment by dipyridamole thallium-201 myocardial scintigraphy of coronary risk before peripheral vascular surgery. Surgery 1988; 103: 584.
38. Fletcher JP, Antico VF, et al. Dipyridamole–thallium scan for screening of coronary artery disease prior to vascular surgery. J Cardio Vasc Surg 1988; 29: 666.
39. Cutler BS, Hendel RC, Leppo JA. Dipyridamole–thallium scintigraphy predicts periopcrative and long-term survival after major vascular surgery. J Vasc Surg 1992; 15: 972.
40 Dilsizian V, Rocco TP, et al. Enhanced detection of ischemic but viable myocardium by the reinjection of thallium after stress-redistribution imaging. N Engl J Med 1990; 323: 141.
41. Strawn DJ, Guernsey JM. Dipyridamole thallium scanning in the evaluation of coronary artery disease in elective abdominal aortic surgery. Arch Surg 1991; 126: 880.
42. Cambria RP, Brewster DC, et al. The impact on selective use of dipyridamole–thallium scans and surgical factors on the current morbidity of aortic surgery. J Vasc Surg 1992; 15: 43.
43. Schulman DS, Francis CK, et al. Thallium-201 stress imaging in hypertensive patients. Hypertension 1987; 10: 16.
44. Keltz TN, Innerfield M, et al. Dipyridamole-induced myocardial ischemia. JAMA 1987; 257: 1515.
45. Mangano DT; London MJ, et al. Dipyridamole thallium-201 scintigraphy as a preoperative screening test: a reexamination of its predictive potential. Circulation 1991; 84: 492.
46. Lalka SG, Sawada SG, et al. Dobutamine stress echocardiography as a predictor of cardiac events associated with aortic surgery. J Vasc Surg 1992; 15: 831.
47. Poldermans D, Fioretti PM, et al. Dobutamine stress echocardiography for assessment of perioperative cardiac risk in patients undergoing major vascular surgery. Circulation 1993; 87: 1506.
48. Davila-Roman VG, Waggoner AD, et al. Dobutamine stress echocardiography predicts surgical outcome in patients with an aortic aneurysm and peripheral vascular disease. J Am Coll Cardiol 1993; 21: 957.
49. Mertes H, Sawada SG, et al. Symptoms, adverse effects, and complications associated with dobutamine stress echocardiography. Experience in 1,118 patients. Circulation 1993; 88: 15.
50. Pasternack PF, Grossi EA, et al. Silent myocardial ischemia monitoring predicts late as well as perioperative cardiac events in patients undergoing vascular surgery. J Vasc Surg 1992; 16: 171
51. Mangano DT, Browner WS, et al. Association of penrioperative myocardial ischemia with cardiac morbidity and mortality in men undergoing noncardiac surgery. N Engl J Med 1990; 323: 1781.
52. Brown OW, Hollier LH, et al. Abdominal aortic aneurysm and coronary artery disease. A reassessment. Arch Surg 1981; 116: 1484.
53. Reigel MM, Hollier LH, et al. Late survival in abdominal aortic aneurysm patients: the role of selected myocardial revascularization on the basis of clinical symptoms. J Vasc Surg 1987; 5: 222.
54. Eagle KA. Brundage BH, 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(4): 910–48.
55. McCleary AJ, Maritati G, Gough MJ. Carotid endarterectomy; local or general anaesthesia? Eur J Vasc Endovasc Surg 2001; 22(1): 1–12.
56. Poldermans D, Boersma E, et al. The effect of bisoprolol on perioperative mortality and myocardial infarction in high-risk patients undergoing vascular surgery. Dutch Echocardiographic Cardiac Risk Evaluation Applying Stress Echocardiography Study Group. N Engl J Med 341: 1789–94, 1999.
57. Blackshear JL, Kopecky SL, et al. Management of atrial fibrillation in adults: prevention of thromboembolism and symptomatic treatment. Mayo Clin Proc 1996; 71: 150–60.
58. Vacanti CJ, VanHouten RJ, Hill RC. A statistical analysis of the relationship of physical status to postoperative mortality in 68, 388 cases. Anesth Analg 1970; 49: 564.
59. Whittemore AD, Clowes AW, et al. Aortic aneurysm repair: reduced operative mortality associated with maintenance of optimal cardiac performance. Ann Surg 1980; 192: 4 14.
60. Romberger RA, McGregor B, DePalma RG. Optimal fluid management after aortic reconstruction: a prospective study of two crystalloid solutions. J Vasc Surg 1986; 4: 164.
61. Babu SC, Sharma PVP, et al. Monitor-guided responses. Operability with safety is increased in patients with peripheral vascular disease. Arch Surg 1980; 115: 1384.
62. Kalman PG, Wellwood MR, et al. Cardiac dysfunction during abdominal aortic operation: the limitations of pulmonary wedge pressures. J Vasc Surg 1986, 3: 773.
63. Berlauk JF, Abrams JH, et al. Preoperative optimization of cardiovascular hemodynamics improves outcome in peripheral vascular surgery: a prospective, randomized clinical trial. Ann Surg 1991; 214: 289.
64. Dauchot PJ, DePalma R, et al. Detection and prevention of cardiac dysfunction during aortic surgery. J Surg Res 1979; 26: 574.

65. Roizen MF, Beaupre PN, et al. Monitoring with two-dimensional transesophageal echocardiography. Comparison of myocardial function in patients undergoing supraceliac, suprarenal–infraceliac, or infrarenal aortic occlusion. J Vasc Surg 1984; 1: 300.
66. Smith JS, Cahalan MK, et al. lntraoperative detection of myocardial ischemia in high-risk patients: electrocardiography versus two-dimensional transesophageal echocardiography. Circulation 1985; 72: 1015.
67. Perrino AC Jr, Fleming J, LaMantia KR. Transesophageal doppler cardiac output monitoring: performance during aortic reconstructive surgery. Anesth Analg 1991; 73: 705.
68. Fremes SE, Weisel RD, et al. A comparison of nitroglycerin and nitroprusside. II. The effects of volume loading. Ann Thorac Surg 1985; 39: 61.
69. Fremes SE, Weisel RD, et al. A comparison of nitroglycerin and nitroprusside. I. Treatment of postoperative hypertension. Ann Thorac Surg 1985; 39: 53.
70. Grindlinger GA, Vegas AM, et al. Volume loading and vasodilators in abdominal aortic aneurysmectomy. Am J Surg 1980; 139: 480.
71. Miller DC, Stinson EB, et al. Postoperative enhancement of left ventricular performance by combined inotropic vasodilator therapy with preload control. Surgery 1980; 88: 108.
72. Gelman S, Reves JG, et al. Regional blood flow during cross-clamping of the thoracic aorta and infusion of sodium nitroprusside. J Thorac Cardiovasc Surg 1983; 85: 287.
73. Lasehinger JC, Owen J, et al. Detrimental effects of sodium nitroprusside on spinal cord motor tract perfusion during thoracic aortic cross-clamping. Surg Forum 1987; 38: 195.
74. Gelman S, Petel K, et al. Renal and splanchnic circulation during infrarenal aortic cross-clamping. Arch Surg 1984; 119: 1394.
75. Baton J-F, Bertrand M, et al. Combined epidural and general anesthesia versus general anesthesia for abdominal aortic surgery. Anesthesiology 1991; 75: 611.
76. Rivets SP, Scher LA, et al. Epidural versus general anesthesia for infrainguinal arterial reconstruction. J Vasc Surg 1991; 14: 764.
77. Auchincloss JH. Preoperative evaluation of pulmonary function. Surg Clin N Am 1974; 54: 1015.
78. Boysen PG, Block AJ, Moulder PV. Relationship between preoperative pulmonary function tests and complications after thoracotomy. Surg Gynecol Obstet 1981; 153: 813.
79. Pennock BE, Rogers RM, McCaffree DR. Changes in measured spirometric indices. What is significant? Chest 1981; 80: 97.
80. Gaensler ES, Weisel RD. The risks in abdominal and thoracic surgery in COPD. Postgrad Med 1973; 54: 183.
81. Williams CD, Brenowitz JB. "Prohibitive" lung function and major surgical procedures. Am J Surg 1976; 132: 763.
82 Lawrence VA, Page CP, Harris GD. Preoperative spirometry before abdominal operations. A critical appraisal of its predictive value. Arch Intern Med 1989; 149: 280.
83. Gracey DR, Divertie MB, Didier EP. Preoperative pulmonary preparation of patients with chronic obstructive pulmonary disease. A prospective study. Chest 1979; 76: 123.
84. Jackson CV. Preoperative pulmonary evaluation. Arch Intern Med 1988; 148: 2120.
85. Smith PK, Fuchs JCA, Sabiston DC. Surgical management of aortic abdominal aneurysms in patients with severe pulmonary insufficiency. Surg Gynecol Obstet 1980; 151: 407.
86. Sicard GA, Freeman MB, et al. Comparison between the transabdominal and retroperitoneal approach for reconstruction of the infrarenal abdominal aorta. J Vasc Surg 1987; 5: 19.
87. Shephard AD, Tollefson DJF, at al. Left flank retroperitoneal exposure: a technical aid to complex aortic reconstruction. J Vasc Surg 1991; 14: 283.
88. Cambria RP, Brewster DC, at al. Transperitoneal versus retroperitoneal approach for aortic reconstruction: a randomized prospective study. J Vasc Surg 1990; 11: 314
89. Reul GJ Jr, Cooley DA, et al. Thc effect of coronary bypass on the outcome of peripheral vascular operations in 1093 patients. J Vasc Surg 1986; 3: 788.
90. Rollier LH, Reigel MM, et al. Conventional repair of abdominal aortic aneurysm in the high-risk patient: a plea for abandonment of nonresective treatment. J Vasc Surg 1986; 3: 712.
91. Crawford ES, Bomberger RA, et al. Aortoiliac occlusive disease: factors influencing survival and function following reconstructive operation over a twenty-five year period. Surgery 1981; 90: 1055.
92. Crawford ES, Morris GC Jr, et al. Operative risk in patients with previous coronary artery bypass. Ann Thorac Surg 1978; 26: 215.
93. Loop FD, Cosgrove DM, et al. An 11 year evolution of coronary arterial surgery (1967–1978). Ann Surg 1979; 190: 444.
94. Mahar LJ, Steen PA, et al. Perioperative myocardial infarction in patients with coronary artery disease with and without aorta-coronary bypass grafts. J Thorac Cardiovasc Surg 1978; 76: 533
95. Hertzer NR, Young JR, et al. Late results of coronary bypass in patients with infrarenal aortic aneurysms. The Cleveland Clinic Study. Ann Surg 1987; 205: 360.
96. Golden MA, Whittemore AD, et al. Selective evaluation and management of coronary artery disease in patients undergoing repair of abdominal aortic aneurysms. Ann Surg 1990; 212: 415.
97. Taylor LM, Yeager RA, et al. The incidence of perioperative myocardial infarction in general vascular surgery. J Vasc Surg 1991; 15: 52.
98. Yeager RA, Moneta GL, et al. Analysis of risk factors for myocardial infarction following carotid endarterectomy. Arch Surg 1989; 124: 1142.