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Assessing and Reducing the Cardiac Risk of Noncardiac Surgery

Andrew Auerbach, MD, MPH; Lee Goldman, MD

Accurate estimation of a patient's risk for postoperative cardiac events (eg, myocardial infarction, unstable angina, ventricular tachycardia, pulmonary edema, and death) after noncardiac surgery can guide allocation of clinical resources, use of preventive therapies, and priorities for future research. This review addresses selected issues in clinical risk assessment, approaches to using diagnostic tests, choices among preventive interventions, and postoperative monitoring. Although we have not used a formal systematic review protocol, we emphasize evidence published after the American College of Cardiology/American Heart Association (ACC/AHA)¹ and American College of Physicians (ACP)² guidelines, outline the limitations of the evidence, and suggest clinical approaches. A summary of our review of the evidence is presented in Table 1, and suggested approaches using these data are presented in Table 2 and Figures 1 and 2.

Preoperative Clinical Assessment: Developing Initial Estimates of Risk

A. Risk Stratification With Consensus Algorithms and Empirical Risk Indices

Consensus-derived algorithms^{1,2} such as those suggested by the AHA/ACC¹ approximate clinical decision making and incorporate specific recommendations. However, differences among algorithms may lead to conflicting advice.³ Implementation of the AHA/ACC algorithm may reduce length of stay and resource use^{4,5} and improve outcomes,⁶ although studies reporting better outcomes incorporated the use of adrenergic modulating agents.⁶ The ACP² algorithm, based in part Detsky's risk index,⁷ has not, to the best of our knowledge, been examined prospectively.

Risk indices,^{8,9} which are derived in hundreds or thousands of patients through the use of rigorous statistical methods and then tested in thousands of patients, require clinicians to sum weights assigned to risk factors and do not automatically provide guidance as to how to act after a score is calculated. In 3 studies that have prospectively compared risk indices head to head,^{10–12} the Revised Cardiac Risk Index (RCRI)¹² performed best; the original index⁸ was the second best in 2 studies^{9,10} and equivalent to the modified index⁷ in the third.¹¹

Evidence Limitations

ACC/AHA and ACP algorithms and risk indices were developed in patients seen a decade or more ago, when perioperative care was quite different (see below).

Summary

The AHA/ACC¹ guidelines and the RCRI⁹ are useful, although different, approaches to documenting cardiac risk. The RCRI has been tested extensively and provides accurate estimates of risk that can be used to direct subsequent steps in care (Table 2).

B. Use of Exercise Capacity as a Preoperative Screening Tool

Patient report of poor exercise tolerance (eg, inability to walk ≥ 4 blocks) is associated with 2-fold-higher odds for postoperative complications and a nearly 5-fold increase in odds for myocardial ischemia after adjustment for clinical risk.¹³ In the larger RCRI study,⁹ however, functional status was not independently associated with risk.

Evidence Limitations

The positive predictive value of poor exercise capacity in the perioperative setting is only 10%,¹³ with a negative predictive value of 95%. If patients reduce exertion because of cardiac symptoms but still meet a 4-MET threshold, clinicians will underestimate risk. Conversely, noncardiac functional limitations (eg, knee or back pain) may falsely overestimate cardiac risk.

Summary

Exercise capacity is most informative when patients report exercise-induced cardiopulmonary symptoms; the ability to exercise to at least 4 METS reduces risk somewhat. Inability to exercise, especially if limitations may not be due to cardiopulmonary symptoms, has a poor positive predictive power and often requires further evaluation (Figure 1).

C. Valvular Heart Disease

Aortic stenosis is a strong risk for perioperative complications,^{14,15} with an independent relative risk (RR) of 5.2 for gradients 25 to 50 mm Hg and 6.8 for gradients >50 mm Hg.^{14,16}

Mitral stenosis, seen predominantly in patients who spent their childhoods in developing countries, may be underappreciated clinically and increases the risk of perioperative atrial arrhythmias. Except for risks associated

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TABLE 1. Perioperative Cardiac Risk Management: Practices, Evidence, and Recommendations

Practice	Evidence Strength, Weaknesses
Estimating preoperative cardiac risk	
Summary recommendation	Because algorithmic guidelines have unknown statistical properties, clinicians should first risk-stratify patients using validated risk indexes; risk estimates from this step should then be used to direct additional risk stratification efforts according to patient's predicted risk (Recommendation Level 1, Evidence Grade B).
Identifying patients with poor exercise tolerance	
Summary recommendation	Patients who report poor functional status (<4 METS) and have 1–2 RCRI criteria (Figure 2) and those who have a history of angina or claudication are generally appropriate for noninvasive testing (Recommendation Level 1, Evidence Grade B).
Identifying patients with aortic stenosis	
Summary recommendation	Clinicians should screen specifically for aortic stenosis during a careful preoperative physical examination. Patients with physical findings consistent with outflow tract obstruction should be referred for echocardiography (Recommendation Level 1, Evidence Grade C).
Identifying patients with hypertension	
Summary recommendation	Patients should continue antihypertensive medications up to the morning of surgery and resume them, either orally or intravenously, as soon as possible postoperatively. ²⁴ General consensus is to delay surgery if blood pressure is sustained $\geq 180/110$ mm Hg in patients with cardiovascular disease (Recommendation Level 2a, Evidence Grade C).
Identifying patients with pulmonary hypertension and congenital heart disease	
Summary recommendation	No data are specific to the perioperative setting; beneficial therapies for chronic use are generally recommended (Recommendation Level 2b, Evidence Grade C).
Identifying patients with hypertrophic cardiomyopathy	
Summary recommendation	Management should be similar to nonoperative settings (Recommendation Level 2, Evidence Grade C).
Identifying patients with heart failure, arrhythmias	
Summary recommendation	When possible, surgery should be delayed when heart failure or arrhythmias are unstable, meet accepted criteria for new interventions, or are likely to represent unremediated ischemic disease. Optimal management of patients with stable heart failure or adequately treated arrhythmias should adhere to published guidelines (Recommendation Level 2, Evidence Grade C).
Refining initial risk estimates: risk stratification tests	
Noninvasive stress tests	
Summary recommendation	Pharmacological stress testing should be pursued in patients who have at least 1 or 2 RCRI criteria and who have limited functional status (Figure 2). Patients at higher risk (>20% risk) according to initial estimates (RCRI >3) may still have high perioperative risks despite a negative noninvasive study (>5% posttest probability with negative test) (Recommendation Level 1, Evidence Grade A).
Refining initial risk estimates: risk stratification tests	
Echocardiography	
Summary recommendation	Preoperative echocardiography should not be obtained routinely but should be used when valvular disease, left ventricular dysfunction, or pulmonary hypertension is suspected, according to published guidelines (Recommendation Level 1, Evidence Grade B).
Clinical approaches for reducing risks: practices under the purview of the surgical team	
Maintaining normal body temperature	
Summary recommendation	Maintaining normal body temperature usually should be a goal of the operative team because it poses little risk and has salutary effects on cardiac risk, wound infection rates, and recovery times (Recommendation Level 1, Evidence Grade A).
Anesthetic approach: general vs neuroaxial anesthesia	
Summary recommendation	Neuroaxial anesthesia, especially when continued postoperatively, has consistently been better than or at least as good as general anesthesia, but evidence limitations make it difficult to make broad recommendations (Recommendation Level 2a, Evidence Grade A).
Endovascular or laparoscopic approach	
Summary recommendation	Although the extent of benefit is not well quantified, laparoscopic and endovascular techniques pose a lower cardiovascular risk because they pose a lower physiological stress (and reduce risk for ischemia) and reduce other medical complications that may lead to cardiac events (Recommendation Level 2c, Evidence Grade A).

TABLE 1. Continued

Practice	Evidence Strength, Weaknesses
Clinical approaches for reducing risks: practices under the purview of the cardiology consultant	
Pulmonary artery catheterization	
Summary recommendation	Few if any noncardiac surgery patients should receive pulmonary artery catheterization (Recommendation Level 3, Evidence Grade A)
Perioperative adrenergic modulation	
Summary recommendation	Patients with ≥ 2 RCRI criteria and no long-term indication for β -blockade should receive β -blockers at the time of noncardiac surgery and have them continued at least 7, and optimally 30, d afterwards. β -Blockade should be started and continued indefinitely in patients with appropriate medical histories (eg, history of myocardial infarction) (Recommendation Level 2a, Evidence Grade A).
Other anti-ischemic medications	
Summary recommendation	Prophylactic calcium channel blockers are of uncertain benefit; nitrates can reduce ischemia but not major events. Both classes of drugs remain useful for treating myocardial ischemia if it develops, but neither is superior to adrenergic modulation (Recommendation Level 2a, Evidence Grade B).
Perioperative use of HMG-CoA reductase inhibitors (statins)	
Summary recommendation	Consultants should start statin lipid-lowering agents before noncardiac surgery whenever long-term lipid-lowering therapy is indicated (Recommendation Level 2a, Evidence Grade B).
Preoperative coronary revascularization	
Summary recommendation	Patients who are at high clinical risk (eg, RCRI >3) and those who have high-risk features on noninvasive stress testing should be considered for diagnostic catheterization. Evidence supports coronary revascularization only if the patient would require it in the absence of a planned surgery ¹ or if angiography reveals left main disease, multivessel disease with a depressed ejection fraction, or aortic stenosis, in which case the patient would not have been eligible for the recent randomized trial ⁹⁴ (Recommendation Level 1, Evidence Grade A).
Perioperative management of anticoagulation	
Summary recommendation	Prophylactic anticoagulation reduces the use of venous thromboembolism (Recommendation Level 1, Evidence Grade A). The timing and the intensity of restarting warfarin anticoagulation to prevent systemic embolization depend on the patient's underlying disorder and its attendant risk for thrombotic complications. In lower-risk patients, anticoagulation can be withheld safely until risk of postoperative bleeding is past; higher-risk patients (such as those with atrial fibrillation and a history of stroke) should be considered candidates for early reinstatement of full-dose anticoagulation (Recommendation Level 2b, Evidence Grade B).
Valvuloplasty	
Summary recommendation	Aortic valvuloplasty should be considered when patients with aortic stenosis need emergent or urgent noncardiac surgery. Patients with significant stenosis undergoing elective noncardiac surgery should be considered for surgical valve replacement (Recommendation Level 2b, Evidence Grade C).
Anemia	
Summary recommendation	Patients who have a history of cardiac disease may benefit from a hematocrit >30 , although this recommendation is extrapolated from nonoperative settings (Recommendation Level 2a, Evidence Grade C).
Identifying patients at continued risk	
Postoperative ECG and cardiac enzyme monitoring	
Summary recommendation	Immediate postoperative (eg, in the recovery room) ECGs provide information that is prognostically important and should be obtained routinely. Postoperative telemetry and serial troponin measurements should be obtained in patients deemed high risk before surgery and in patients with hemodynamic instability, ECG findings, or clinical symptoms suggestive of ischemia during surgery or postoperatively (Recommendation Level 2b, Evidence Grade C).
Postoperative unstable angina and myocardial infarction	
Summary recommendation	In the absence of data, therapy must be individualized on the basis of the risks and benefits of anticoagulation, thrombolysis, and PCI in relationship to the surgical procedure (Recommendation Level 2b, Evidence Grade C).
Postoperative heart failure and pulmonary edema	
Summary recommendation	Treatment should be based on usual care of heart failure, with a focus on evaluation for ischemic causes (Recommendation Level 2b, Evidence Grade C).

TABLE 1. Continued

Practice	Evidence Strength, Weaknesses
Postoperative arrhythmias	
Summary recommendations	Prophylactic β -blockers or diltiazem reduce postoperative arrhythmias in thoracic surgical patients. When arrhythmias develop, evaluation and treatment should focus on noncardiac causes and treatment of the arrhythmia itself (Recommendation Level 2a, Evidence Grade C).
Postoperative hypertension	
Summary recommendations	Diuresis and analgesia should be mainstays of therapy whether or not the patient has a history of hypertension. Nitroprusside, nitroglycerin, labetalol, and nicardipine are good agents (Recommendation Level 2b, Evidence Grade C).
Postoperative general medical care	
Summary recommendations	Tight postoperative glucose control may provide benefit, particularly in the ICU setting. Postoperative transfusions should keep the hemoglobin level >7 mg/dL and perhaps >10 mg/dL in cardiac patients (Recommendation Level 2a, Evidence Grade B). Comanagement systems and rapid response teams are promising but remain unproven (Recommendation Level 2b, Evidence Grade B).

Classification of recommendations: class 1=conditions for which there is evidence and/or general agreement that a given procedure or treatment is useful and effective; class 2=conditions for which there is conflicting evidence and/or a divergence of opinion about the usefulness/efficacy of a procedure or treatment; class 2a=weight of evidence/opinion is in favor of usefulness/efficacy; class 2b=usefulness/efficacy is less well established by evidence/opinion; class 3=conditions for which there is evidence and/or general agreement that the procedure/treatment is not useful/effective and in some cases may be harmful; level of evidence A=data are derived from multiple randomized clinical trials or meta-analyses; level of evidence B=data are derived from a single randomized trial or nonrandomized studies; and level of evidence C=only consensus opinion of experts, case studies, or standard of care.

with anticoagulation and a higher risk of endocarditis, no reliable data suggest that patients with prosthetic heart valves have different risks than patients with similar degrees of native valvular disease and heart failure. Other valvular diseases are important primarily because of their association with heart failure or arrhythmias.¹⁷ Guidelines for prevention of bacterial endocarditis should be followed.¹⁸

Evidence Limitations

Patients with aortic stenosis who are referred for noncardiac surgery are probably healthier than the overall population of patients with aortic stenosis. The true risks are unknown because, in the absence of routine screening echocardiography, some patients go to surgery with undiagnosed aortic stenosis.

Summary

Patients undergoing noncardiac surgery should be assessed by careful cardiac auscultation, with echocardiography in patients with findings suspicious for aortic stenosis (Figure 1). For native valvular lesions other than aortic stenosis and for patients with prosthetic mitral valves, the degree of heart failure is the best indication of risk.

D. Heart Failure

Heart failure is a well-described risk for postoperative cardiac complications, equivalent to or perhaps even greater than ischemic heart disease.¹⁹

Evidence Limitations

No data document an optimal approach to managing heart failure before, during, or after noncardiac surgery.

Summary

A general recommendation is to control heart failure optimally preoperatively while avoiding overdiuresis that may exacerbate intraoperative hypotension. β -Blockade may not

be an appropriate acute therapy because it should be begun and titrated carefully in the outpatient setting.

E. Arrhythmias

Ventricular and atrial arrhythmias were initially identified as important predictors of perioperative cardiac complications,⁸ but subsequent data⁹ indicate that this link is explained by the severity of underlying ischemic heart disease and heart failure.

Evidence Limitations

Other than trials to prevent postoperative atrial fibrillation, the evidence base is slim.

Summary

Arrhythmias reflect the severity of coronary disease or heart failure, so preoperative assessment should focus on these possibilities, unless the arrhythmia would warrant treatment independent of the planned surgery. Indications for implantation of pacemakers and cardioverter-defibrillators should follow guidelines in nonoperative settings.²⁰

F. Systemic Hypertension

Except for 1 study,²¹ hypertension has not been an independent risk factor for perioperative cardiac events unless it is very marked (ie, systolic blood pressure >180 mm Hg or diastolic pressure >110 mm Hg²²). In 1 small randomized trial,²³ patients with a history of hypertension without other cardiac disease and who had a diastolic blood pressure of 110 to 130 mm Hg on preoperative evaluations were randomized to postponement of surgery until blood pressure was controlled or to proceeding with surgery after 10 mg intranasal nifedipine; neither group had any postoperative cardiac complications or strokes.

Evidence Limitations

Large-scale trials might identify benefits of interventions to address hypertension.

TABLE 2. Clinical Factors Important in Assessing Perioperative Cardiac Risk

RCRI criteria ⁴
Patient is at risk if he or she has any one of the following
High-risk surgical procedure, defined as
Thoracic, abdominal, or pelvic vascular (e.g., aorta, renal, mesenteric) surgery
Ischemic heart disease, defined as
History of myocardial infarction
History of or current angina
Use of sublingual nitroglycerin
Positive exercise test
Q waves on ECG
Patients who have undergone PTCA or CABG and who have chest pain presumed to be of ischemic origin
Heart failure, defined as*
Left ventricular failure by physical examination
History of paroxysmal nocturnal dyspnea
History of pulmonary edema
S3 or bilateral rales on physical examination
Pulmonary edema on chest x-ray
Cerebrovascular disease, defined as
History of transient ischemic attack
History of cerebrovascular accident
Insulin-dependent diabetes mellitus
Chronic renal insufficiency, defined as
Baseline creatinine ≥ 2.0 mg/dL

*Use of β -blockers must be individualized and used with caution in patients with heart failure.

Summary

Patients should continue antihypertensive medications up to the morning of surgery and resume them as soon as possible postoperatively.²⁴ In patients with underlying cardiovascular disease, limited data support delaying surgery if diastolic pressure exceeds 110 mm Hg.

G. Pulmonary Hypertension and Congenital Heart Disease

Limited data are available on the risk of perioperative myocardial infarction in patients with pulmonary hypertension, but the mortality rate in these patients is very high (7% in patients with pulmonary artery systolic pressures of 68 mm Hg), as are rates of respiratory failure.²⁵ Adverse outcomes are associated with severity of right ventricular strain, worse functional status, and a history of pulmonary embolism.²⁵ Data are insufficient to recommend perioperative use of prostacyclin, inhaled nitrous oxide, or sildenafil.^{26,27}

Patients with congenital heart disease have a 3.5-fold-increased risk of perioperative complications with noncardiac surgery,²⁸ with risks depending on the extent of surgery and severity of the underlying abnormality, cyanosis, and heart failure.²⁹

Evidence Limitations

No large studies guide perioperative care of pulmonary hypertension or congenital heart disease specifically.

Summary

It is unclear what interventions, except antibiotic prophylaxis,¹⁸ may reduce operative risk in patients with pulmonary hypertension or congenital heart disease.

H. Hypertrophic Cardiomyopathy

Patients with hypertrophic cardiomyopathy are at risk for exacerbation of dynamic outflow obstruction if they become volume depleted as anesthesia (neuroaxial or general) decreases venous return. Nevertheless, in 2 case studies, outcomes in these patients have been good, with no deaths, 2 myocardial infarctions, and 1 episode of ventricular tachycardia requiring cardioversion reported in 133 noncardiac surgeries.^{30,31}

Evidence Limitations

Data are meager.

Summary

Management is similar to nonoperative settings: avoidance of hypovolemia, vasodilators, and pure β -adrenergic agents and emphasis on fluid repletion and α -adrenergic agents.

Refining Initial Risk Estimates: Risk Stratification Tests

A. Noninvasive Stress Testing

Patients at higher risk after initial evaluation are often referred for noninvasive testing, and 3 general conclusions are reasonable.^{32–34} First, exercise and pharmacological stress testing have excellent negative predictive values (between 90% and 100%) but poor positive predictive values (between 6% and 67%), making them more useful for reducing risk estimates when negative (or normal) than for identifying very high risk when positive. Second, compared with exercise testing, pharmacological stress tests have superior discriminative power and can be used in patients with functional limitations, the majority of patients referred for noninvasive testing. Third, dobutamine echocardiography may be preferable because of higher specificity,³³ because it assesses ventricular and valvular function as well as pulmonary pressures, and because its findings may be more independent of clinical risk.

Evidence Limitations

Extensive evidence supports the ability of stress testing to provide reassurance when “negative.” Clinicians, however, tend to rely too much on “positive” tests. Additionally, most studies enrolled patients at higher risk (eg, with known coronary disease or undergoing vascular surgery), potentially inflating estimates of positive predictive value and making the sensitivity and specificity of testing in lower risk subgroups less certain.

In practice, a 2% pretest probability of a cardiac complication (eg, 2 RCRI points) and a positive dobutamine echocardiogram (sensitivity, 85%; specificity, 70%)³³ yield a posttest probability of 5%. In contrast, a higher-risk patient (9% risk, 4 RCRI points) with a negative dobutamine echocardiogram has a posttest probability of 2%; in this same patient, a positive test raises posttest probability to 20%.

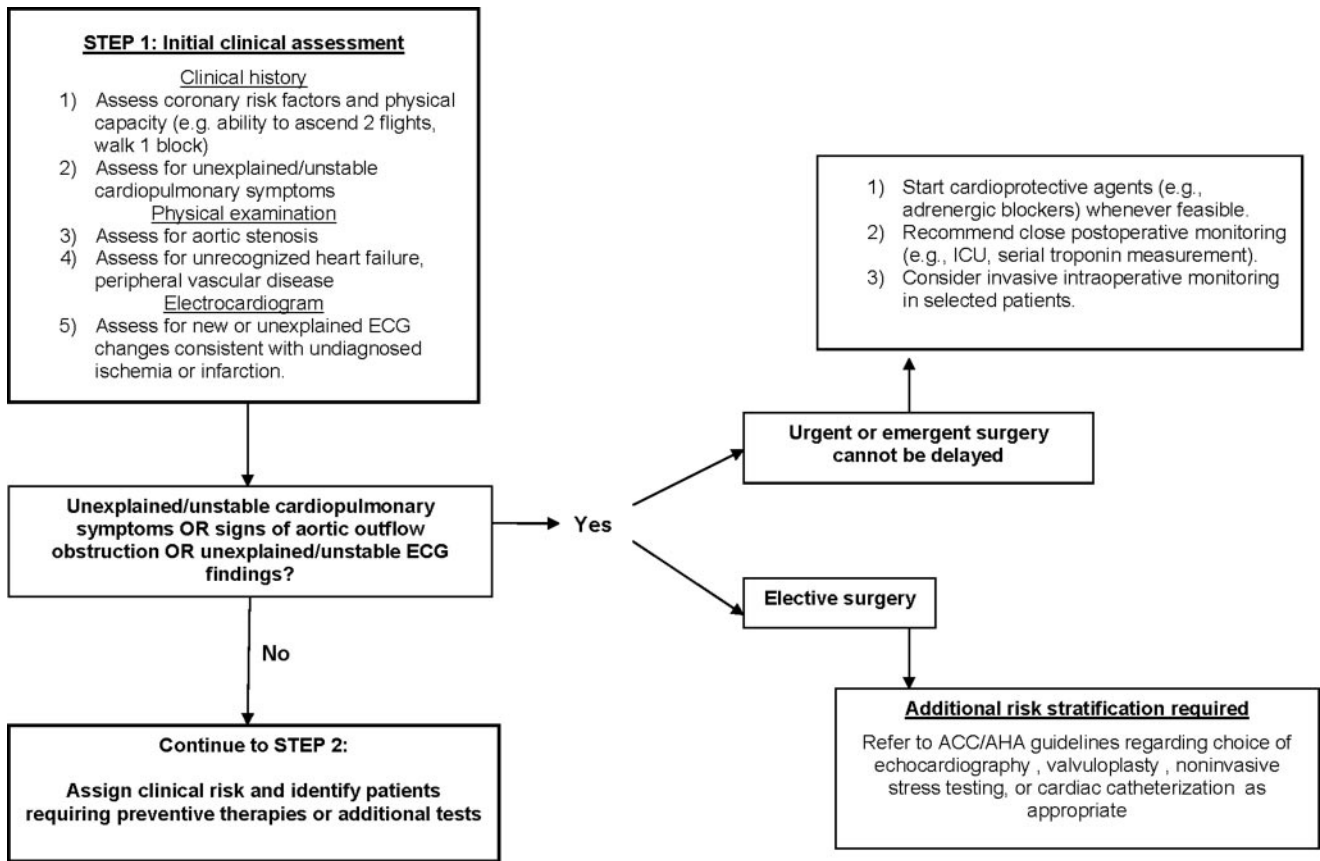


Figure 1. Suggested initial clinical assessment of patients undergoing noncardiac surgery.

Summary

Pharmacological stress tests markedly reduce clinical risk estimates in all but the highest-risk patients, in whom additional testing may be appropriate (Figure 2). Whether judicious use of noninvasive tests improves outcomes remains unproved.³⁵ Dobutamine echocardiography may have superior test characteristics and can provide additional information, but these advantages have yet to be shown to be clinically important. As a result, choices among noninvasive tests should be based on the need to assess valvular or ventricular function and on which test is most reliable and available locally.

B. Echocardiography

Echocardiograms assess several conditions (eg, left ventricular dysfunction, aortic stenosis) that pose risks for surgery,¹⁷ but routine echocardiographic screening is not helpful.³⁶ Preoperative echocardiography is appropriate in patients who meet AHA/ACC clinical guidelines and who would require echocardiography even if no surgery was planned,³⁷ as well as in patients with a systolic murmur with characteristics (eg, peaks late, obscures the second heart sound, or is associated with delayed carotid upstroke³⁸) suggestive of aortic stenosis, especially in symptomatic patients.

Evidence Limitations

Other than to detect aortic stenosis, evidence to support preoperative echocardiograms is indirect.

Summary

Patients in whom echocardiography would be indicated in the absence of a planned surgery³⁷ and patients with signs or symptoms suggestive of aortic stenosis should have a preoperative echocardiogram (Figure 1).

Approaches to Reducing Risk

Approaches for preventing cardiac complications include practices that are under the purview of the anesthesiologist and surgeon but of which the cardiology consultant should be aware, as well as interventions that are properly recommended or managed by cardiologists.

A. Practices Under the Purview of the Anesthesiologist and Surgeon

1. Maintaining Normothermia

Core body temperature may fall between 1°C and 2°C in the first hour of anesthesia.³⁹ Cooling produces shivering and activation of the sympathetic nervous system, leading to perioperative ischemia^{39,40} and a higher risk for myocardial infarction and death.²¹ Normal core temperature can be maintained during surgery with warmed intravenous fluids and inspired gases, as well as forced air blankets.

One randomized trial of perioperative warming in 300 patients “at risk” and undergoing major abdominal or vascular surgery suggested that cardiac events occurred less frequently in the normothermic group (1.4% versus 6.3%;

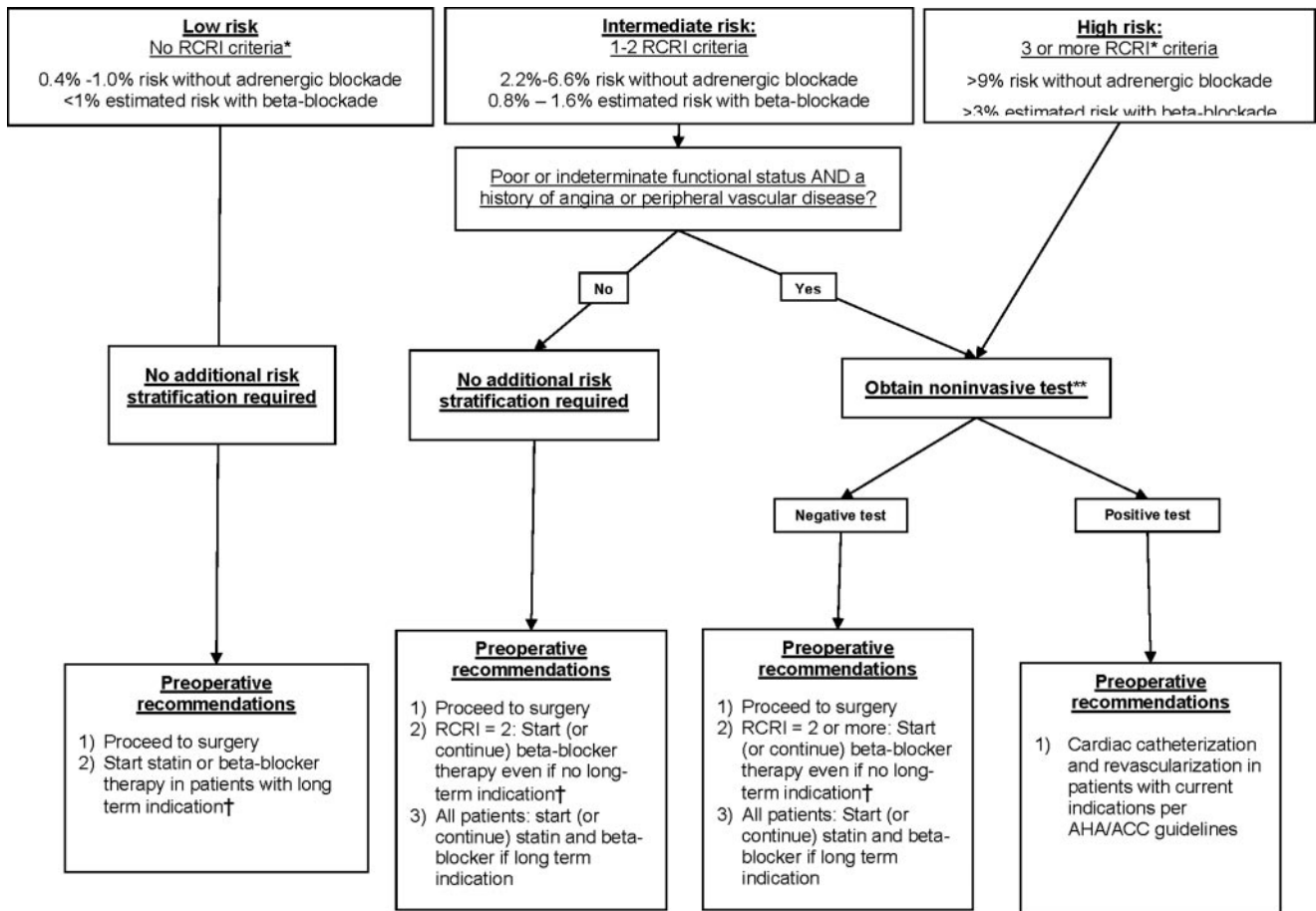


Figure 2. Additional risk stratification and treatment before noncardiac surgery. Recommendations for risk stratification and cardioprotective approach in patients undergoing noncardiac surgery. β -Blockade and statin therapy should be considered in all patients with a long-term indication for these drugs. Patients who meet criteria for perioperative β -blockade but have no long-term indication should have β -blockers continued at least 7, and optimally 30, days after surgery. *RCRI.⁹ **Options for noninvasive tests include dipyridole thallium scintigraphy, sestamibi scintigraphy, or stress echocardiography. Testing should be performed only in patients who, were they to have a positive noninvasive test and subsequently undergo coronary angiography, are likely to meet guidelines for coronary revascularization.¹³¹ †Use of β -blockers must be individualized and begun with caution in patients with heart failure.

$P=0.02$).⁴¹ In addition, hypothermia was a predictor of morbid cardiac events (RR, 2.2; 95% CI, 1.1 to 4.7).

Evidence Limitations

The only randomized trial was underpowered to detect differences in cardiac outcomes, but other studies suggest that maintaining body temperature speeds recovery in the postanesthesia care unit⁴² and reduces surgical site infection risk,⁴³ further increasing its attractiveness.

Summary

Low potential for harm and ready availability of warming methods make normothermia a promising approach to reduce perioperative cardiac events. However, forced-air warming is not appropriate during certain surgical procedures in which core temperature is intentionally reduced (eg, neurosurgical procedures).

2. Anesthetic Approach

Several well-designed meta-analyses have examined the impact of general anesthesia and neuroaxial (epidural, spinal) anesthesia on cardiac complications,^{44–47} and the

cardiologic consultant should understand this evidence while deferring to the anesthesiologist. One review of 141 trials of 9559 patients found that overall mortality was about one third less (odds ratio [OR], 0.70; 95% CI, 0.54 to 0.90) in patients randomized to neuroaxial anesthesia than in patients who received general anesthesia⁴⁶; similar benefits were seen for noncardiac complications, including thromboembolism and pneumonia. In the 30 trials that provided information on a total of 140 cardiac events, odds for postoperative myocardial infarction were lower in patients undergoing neuroaxial anesthesia, but this difference was not quite statistically significant (OR, 0.67; 95% CI, 0.45 to 1.00). Recent meta-analyses of neuroaxial versus general anesthesia for discrete procedures (eg, hip fracture and carotid endarterectomy) have confirmed similar benefits for pulmonary and thrombotic complications but did not observe a reduction in cardiac events.^{45,47} Another meta-analysis of 11 randomized trials suggested that analgesia continued via the neuroaxial approach for >24 hours postoperatively further reduced the rate of

perioperative myocardial infarction (3.8% lower; 95% CI, 7.4% lower to 0.2% lower).⁴⁴

Evidence Limitations

Studies included in meta-analyses were of high-quality but used differing definitions of cardiac events and provided little information about factors that clinicians use in preoperative evaluations. In addition, these studies cannot discern whether reductions in noncardiac outcomes (eg, postoperative pneumonia) were responsible for reduced cardiac events because cardiac and noncardiac events often coexist (or cause one another).⁴⁸ Most importantly, the meta-analyses were unable to differentiate between intraoperative and postoperative regional anesthesia. Finally, older randomized trials did not find a benefit of regional anesthesia, suggesting that some effects may be institution or protocol dependent or that other advances in technique (eg, cardioprotective inhalation agents) may play a role.

Summary

Studies of neuroaxial versus general anesthesia suggest that modern neuroaxial anesthetic techniques may carry a lower risk for postoperative cardiac complications, but this finding remains controversial. Neuroaxial anesthesia helps control pain⁴⁹ and may reduce pulmonary and thrombotic complications, making this approach attractive even if it does not lower cardiac risk. Decisions about anesthetic technique should be made by the anesthesiologist on the basis of local expertise and patient preferences.

3. Laparoscopic and Endovascular Techniques

In general, laparoscopic techniques speed postoperative recovery and reduce risk for most postoperative complications, particularly pulmonary complications and surgical site infections.^{50–52} Perhaps because laparoscopic patients stay in hospital for shorter periods of time, surprisingly few data focus on cardiac complications.

Early data also suggest that endovascular techniques are lower risk in patients with vascular disease. Carotid angioplasty with stenting is associated with less perioperative troponin elevation compared with traditional endarterectomy.⁵³ Endovascular repair of abdominal aortic aneurysm is associated with lower short-term mortality than open repair (4.7% versus 9.8% in-hospital mortality),⁵⁴ produces elevations in troponin-T less frequently,⁵⁵ but has no effect on long-term mortality.^{56,57}

Evidence Limitations

Few studies provide direct measures of cardiac risks after laparoscopic procedures or endovascular procedures.

Summary

Less invasive techniques are likely to lower acute cardiac risk compared with open procedures because they do not produce as severe hemodynamic perturbations (eg, fluid shifts) or noncardiac complications that cause cardiac events.⁴⁸

B. Practices at Least Partly Under the Purview of the Cardiology Consultant

1. Prophylactic Antibiotics

Recommendations for antimicrobial prophylaxis against bacterial endocarditis¹⁸ and surgical site infection⁵⁸ have been reviewed in detail elsewhere.

2. Pulmonary Artery Catheters

Use of a pulmonary artery catheter may be directed by the cardiology consultant or surgeon, but anesthesiologists more commonly make this decision. Catheter-guided optimization of volume status and cardiac output has no obvious benefit,^{59,60} and multicenter randomized trials confirmed that routine pulmonary artery catheterization provides no benefit after noncardiac surgery⁶¹ or in the intensive care unit.⁶²

Evidence Limitations

Although it is possible that subgroups benefit, no data are available to define these populations.

Summary

Evidence increasingly supports the idea that pulmonary artery catheters produce at least as much harm as benefit. No data define patient groups (eg, those with pulmonary hypertension) in which this balance is more in patients' favor.

3. Adrenergic Modulation

Support for adrenergic modulation (with β -blockers and α agonists) to prevent postoperative cardiac complications has been the subject of several reviews.^{63–65} Since these reviews were published, a randomized trial of metoprolol in 500 vascular surgery patients (published in abstract form)⁶⁶ showed no significant difference in rates of a combined end point of mortality, myocardial infarction, heart failure, and ventricular arrhythmia at 30 days (10.1% in metoprolol group versus 12%; $P=0.4$). A recent randomized trial of 107 aortic surgery patients without a prior myocardial infarction or positive dobutamine stress test suggested that metoprolol started on admission and continued for 7 days did not significantly reduce cardiac events.⁶⁷ All randomized trials published to date were recently summarized in a well-designed meta-analysis that suggested that too few data exist to determine definitively whether or not perioperative β -blockade is efficacious.⁶⁸ A well-designed observational trial using administrative data from nearly 700 000 patients suggested that perioperative β -blockade provided a protective benefit only in higher-risk (eg, RCRI ≥ 2 points) patients. In those at lower risk, β -blockade appeared to increase risk for complications, even if the patient's 1 risk factor was diabetes or coronary disease.⁶⁹

α -Adrenergic agonists have been the subject of 2 meta-analyses and a subsequent randomized trial. In 1 meta-analysis, α -2 agonists reduced mortality by 53% (RR, 0.47; 95% CI, 0.25 to 0.90) and postoperative myocardial infarction by 34% (RR, 0.66; 95% CI, 0.46 to 0.94) in vascular patients but had no benefit in others.⁷⁰ These results were confirmed in another meta-analysis that calculated that 83 patients needed to be treated with α agonists to prevent 1 cardiac event.⁷¹ A recent placebo-controlled, randomized trial⁷² suggested that a simple strategy of 4 days of transdermal and oral clonidine reduced perioperative ischemia and mortality.

Evidence Limitations

Most studies of perioperative adrenergic modulation focused on selected patients or specific procedures (eg, vascular surgery), making it difficult to translate to other settings. In addition, some of these agents (eg, intravenous atenolol, mivazerol) are not widely available in the United States.

The most important limitation is that <1100 patients have been randomized in published studies of β -blockers and only \approx 1750 patients have been randomized to α -2 agonists. Perioperative trials of adrenergic modulators are consistent with evidence supporting their use in other patient populations, but larger studies may not confirm a beneficial effect. Ongoing Canadian (POISE) and European (DECREASE IV) trials should address sample size limitations.

Summary

Recent negative results in studies of β -blockade suggest that the magnitude of benefit in smaller trials is not generalizable to broader populations, so therapy should target patients at moderate to higher risk (RCRI \geq 2 points; Table 2). In patients with heart failure, in whom lower doses are often used, decisions must be individualized; medication should be started while the patient is stable (generally as an outpatient) and then titrated carefully.

In all eligible patients undergoing major noncardiac surgical procedures (eg, procedures that require at least 2 days of hospital stay), adrenergic agents should be started and/or titrated to a target heart rate of 60 to 65 bpm before anesthesia is begun. No data are available for minor surgery or for short-stay procedures, in which the benefits of adrenergic blockade are likely to be minimal and the risks may outweigh the benefits.

Two trials using adrenergic agents started immediately before the induction of anesthesia^{72,73} showed a protective effect, particularly when intravenous agents were used to achieve a target heart rate before surgery, but other trials began oral agents well beforehand.⁷⁴ In this latter scenario, the cardiologist consultant would play a key role in ensuring adequate adrenergic blockade. Evidence is insufficient to support any β -blocker over another, although metoprolol is available in both oral and intravenous forms, thereby permitting smoother transitions and quicker dose titration in surgical patients. All patients who have long-term indications for β -blockers and who are not on them before surgery should have the agent continued indefinitely. Patients without a long-term indication should have their agent continued for at least 7, and optimally 30, days afterward.⁶⁵

Although 1 meta-analysis suggested that β -blockers may be more efficacious than α -2 agonists,⁷¹ no prospective trials have compared β -blockers and α -2 agonists head to head. Both have similar side effects (eg, hypotension, bradycardia), share salutary effects on pain control, produce adverse pulmonary effects in very few patients,⁷⁵ and have benefits that far outweigh risks even in diabetic patients.⁷⁶ Transdermal clonidine is more convenient to administer, but α -2 agonists have no first-line indication outside the perioperative setting, making β -blockers preferable in most patients.

Few hospitals are currently able to deliver perioperative adrenergic blockade consistently.⁷⁷ If future trials confirm a protective benefit, the opportunity to reduce mortality may be large.⁷⁸

4. Other Antiischemic Medications

One meta-analysis suggests that neither calcium channel blockers nor nitroglycerin reduces perioperative cardiac events or mortality,⁷¹ whereas a second suggested that nondi-

hydropyridine calcium channel blockers had a salutary effect.⁷⁹ Acute withdrawal of aspirin may increase the risk of an acute coronary syndrome an average of 8.5 days after discontinuation, but continuing aspirin increases perioperative bleeding 1.5-fold.⁸⁰ Among 6 randomized trials that evaluated aspirin versus placebo in vascular surgery, the incidence of myocardial infarction, nonfatal stroke, or vascular death was reduced among patients who were randomized to aspirin, but the benefit was not quite statistically significant (OR, 0.76; 95% CI, 0.54 to 1.05).⁸¹ In comparison, in a study of aspirin therapy as prophylaxis for patients undergoing hip fracture surgery, there were more ischemic cardiac events (myocardial infarction or death) among patients randomized to aspirin (relative hazard, 1.33; 95% CI, 1.00 to 1.78).⁸²

Evidence Limitations

No data support the use of aspirin (or clopidigrel) to reduce perioperative cardiac risk.

Summary

A general recommendation is to continue antianginal medications but not to add prophylactic calcium channel blockers or nitrates except when used in conjunction with β -blockers. Low-dose aspirin may be safely continued in some cases,⁸³ but evidence-based recommendations about perioperative use of antiplatelet agents are difficult to make.

5. HMG-CoA Reductase Inhibitors (Statins)

Five observational studies^{84–88} and a small randomized trial⁸⁹ suggest that patients receiving statin therapy at the time of surgery (and afterward) have lower rates of perioperative cardiac events and lower mortality, with relative reductions in risk between 80%⁸⁴ and 30%⁸⁶ compared with patients not receiving statins. In the 1 randomized trial of 100 vascular surgery patients, 20 mg/d atorvastatin begun 1 month before surgery and continued for 45 days,⁸⁹ with β -blockers included per protocol, reduced the combined outcome of cardiac mortality, myocardial infarction, stroke, or unstable angina (4 versus 13 patients; $P=0.03$), and no patient required discontinuation of the drug because of side effects. Whether the benefits of statins are magnified⁸⁶ or blunted⁸⁸ by β -blockers is unclear.

Evidence Limitations

The literature describing perioperative statins is from observational studies with substantial potential for confounding and 1 very small randomized trial.

Summary

Studies in the perioperative period are generally consistent with the benefit of statins in acute coronary syndromes,⁹⁰ but current evidence does not support starting statins preoperatively in patients without a long-term indication. Nevertheless, the perioperative period provides an excellent opportunity to begin or titrate statins in patients in a manner consistent with published recommendations (Figure 2).⁹¹ Consultants should also ensure statins (and β -blockers) are not discontinued in error after surgery.

6. Cardiac Catheterization and Prophylactic Coronary Revascularization

Older studies observed that, after including the mortality associated with the CABG itself, CABG provided no overall

benefit for patients without standard clinical indications, although subgroups with advanced disease might do better.⁹² CABG and percutaneous coronary intervention (PCI), most often angioplasty without stenting, appear to provide equal protective benefit perioperatively.⁹³ In a recent multicenter randomized trial⁹⁴ of patients who were at moderate or high risk on the RCRI,⁹ had a 70% stenosis in at least 1 coronary artery amenable to PCI or CABG (and did not have left main disease, an ejection fraction <20%, or aortic stenosis), and who underwent either abdominal aortic aneurysm surgery or lower extremity arterial reconstruction on average 3 months after CABG (99 pts) or at least 2 weeks after PCI (141 pts), similar proportions in both arms (11.6% in the revascularization arm and 14.3% of control patients; $P=0.37$) had postoperative elevations of troponin-I. There were no differences in in-hospital mortality ($P=0.87$) or in mortality up to 6 years after randomization, either overall or within prespecified higher-risk subgroups.

Evidence Limitations

The randomized trial⁹⁴ was too small to provide information about the importance of specific symptoms or functional status.

Summary

Patients who have a high clinical risk (eg, RCRI >3) and who have high-risk features on noninvasive stress testing should be considered for diagnostic catheterization (Figure 2). However, there is no compelling evidence to pursue “prophylactic” preoperative coronary revascularization unless it would be pursued “if the patient walked into your office.” Revascularization may also be appropriate if diagnostic catheterization reveals conditions (left main disease, multivessel disease with depressed ejection fraction) that would have excluded these patients from published trials.

In the randomized trial, patients could proceed to noncardiac surgery as soon as 2 weeks after PCI. Surgery soon after balloon angioplasty may be safe,⁹⁵ whereas a 6- to 8-week delay of antiplatelet therapy appears to be safer and preferable after stenting with bare-metal stents^{96,97} because of the increased risk of in-stent thrombosis after premature discontinuation of antiplatelet therapy. Patients with drug-eluting stents are at an increased risk for stent thrombosis for a longer period after stenting compared with patients who receive a bare-metal stent.⁹⁸ For this reason, balloon angioplasty may be a preferred choice in a patient who is known to need noncardiac surgery within the next 6 weeks, with the option of placing a stent for better long-term efficacy after recovery from the noncardiac procedure.

However, as of the writing of this article, there are no specific data on how patients with drug eluting stents should be managed in the perioperative period or how to manage patients who have bare-metal stents and require noncardiac surgery within 6 weeks of stent placement. If the surgical procedure is a clear contraindication to continuing usual poststent antiplatelet therapy, possible options include continuing low-dose aspirin therapy (eg, 81 mg QD) or continuing clopidogrel at a lower dose for lower-risk patients. For patients at highest risk (eg, more recent drug-eluting stent, history of in-stent thrombosis, unprotected left main or

bifurcation stenting), the use of a short-acting intravenous glycoprotein IIB/IIIa inhibitor should be considered “bridge” therapy, beginning before surgery and stopping as needed for as short a time as possible during and just after surgery until oral agents can be reinitiated. In the absence of outcome data to support any of these suggestions, cardiologists, surgeons, and anesthesiologists will need to weigh the perceived risks and benefits of stopping or continuing antiplatelet agents through the perioperative period on a case-by-case basis.

7. Perioperative Prophylaxis of Thromboembolism and Systemic Embolization

Substantial data document the benefit of perioperative anticoagulation to prevent venous thromboembolism.⁹⁹ For prevention of systemic embolization, the long-term indication for warfarin can guide postoperative anticoagulation. Low-risk groups have an annual thrombotic risk (without anticoagulation) of <4% (eg, atrial fibrillation without prior stroke, cardiomyopathy without atrial fibrillation); moderate-risk patients have a risk between 4% and 7% (eg, mechanical aortic valve); and high-risk patients (eg, mechanical mitral valve, atrial fibrillation with prior stroke) have an annual risk of >7%.

Evidence Limitations

No randomized data are available for patients on chronic anticoagulation.

Summary

Routine prophylaxis of venous thromboembolism should follow established guidelines.⁹⁹ For patients at risk for systemic embolization, the general recommendation is to withhold therapeutic anticoagulation in low-risk patients throughout hospitalization and then restart warfarin after discharge, to begin treatment-dose anticoagulation in selected patients at moderate embolic risk (eg, low risk of perioperative bleeding) during hospitalization, and to begin treatment-dose anticoagulation in all high-risk patients as soon as possible after surgery.^{100,101}

8. Valvuloplasty

Valvuloplasty is of clear benefit for mitral stenosis¹⁰² but of limited, short-term benefit for patients with aortic stenosis.¹⁰³ Nevertheless, observational case series suggest that aortic valvuloplasty can provide a short-term bridge through noncardiac surgery.¹⁰⁴

Evidence Limitations

This evidence base is slim.

Summary

Valvuloplasty should be considered in patients with significant aortic stenosis when noncardiac surgery is urgent or emergent. In other situations, the risks of noncardiac surgery, its impact on the patient’s survival and quality of life, and the patient’s suitability for surgical valve replacement should be weighed carefully.

9. Anemia

A low hemoglobin level worsens outcome in heart failure, and treatment to raise the hemoglobin level to >12.5 g/dL improves outcomes.¹⁰⁵ Perioperative morbidity and mortality

increase dramatically as the hemoglobin level falls from 10 g/dL to 6 g/dL in patients with pre-existing cardiovascular disease.^{106–109}

Evidence Limitations

No data confirm that preoperative transfusion for anemia improves outcomes.

Summary

Extrapolated data suggest that anemic patients with important cardiac disease should be transfused to a preoperative hematocrit of ≥ 30 .

Postoperative Monitoring and Treatment of Events

A. Cardiac Biomarkers and ECG

Postoperative ischemia^{110–113} and elevations in cardiac biomarkers (specifically troponin)^{114–117} are associated with higher risk for later cardiac events. Ischemia on an immediate postoperative ECG in the recovery room increases the probability of a major postoperative cardiac complication in both low-risk (OR, 4.9; 95% CI, 1.6 to 15) and high-risk (OR, 2.0; 95% CI, 1.0 to 3.7) patients.¹¹³ However, the positive predictive value of ST-segment monitoring (particularly intraoperative ST-segment monitoring) is questionable, and few of these studies included a protocol for acting on perioperative ischemia or elevations in troponins. Substantial circumstantial data suggest that a large proportion of myocardial infarctions may be missed clinically in the immediate postoperative period.¹¹⁸

Evidence Limitations

Few data guide clinicians seeking to preoperatively identify patients in whom to recommend postoperative telemetry, serial 12-lead ECGs, and/or serial troponins.

Summary

A single postoperative troponin and ECG should be obtained all patients with established coronary disease or peripheral vascular disease. This same approach may also provide useful information in patients at higher risk (eg, patients with diabetes, renal insufficiency, or cerebral vascular disease¹¹⁰).

B. Unstable Angina and Acute Myocardial Infarction

Despite clear criteria for diagnosis of acute myocardial infarction in nonoperative settings,¹¹⁹ there are no clear criteria for patients undergoing noncardiac surgery. One approach is to modify usual criteria by recognizing that after surgery a troponin elevation will typically be detected closer to its peak, so a gradual fall may be more diagnostic than a typical rise. Creatine kinase-MB is decidedly inferior to troponins in the perioperative patient.¹¹⁸

Evidence Limitations

There are no data that definitively extrapolate results of randomized trials for the treatment of the acute coronary syndromes or ST-elevation acute myocardial infarction to the perioperative setting.

Summary

The risk of bleeding from aggressive anticoagulation, particularly if PCIs are pursued, must be weighed against risks of suboptimal therapy for ischemia or myocardial infarction. As in nonoperative settings, primary PCI is preferred for postoperative ST-elevation acute myocardial infarction.

C. Postoperative Heart Failure and Pulmonary Edema

Both general and regional anesthesia cause peripheral vasodilatation, and venous return to the heart is reduced by positive-pressure ventilation, whereas usual perioperative therapy emphasizes fluid replacement. Not surprisingly, the cessation of positive-pressure ventilation and the conclusion of general or regional anesthesia can lead to substantial increases in intravascular volume and venous return, thereby challenging the patient's capacity to achieve a rapid and effective diuresis. A natural diuresis typically occurs within 48 hours, as antidiuretic hormone levels increased by the stress of surgery return toward normal and as fluid that may have been "third spaced" at the operative site is mobilized intravascularly.

The risk of postoperative pulmonary edema may be as high as 7.6%, with a peak risk in the first 36 hours after surgery.¹²⁰ Administration of $>67 \text{ mL} \cdot \text{kg}^{-1} \cdot \text{d}^{-1}$ of fluids is associated with the development of fatal postoperative pulmonary edema.¹²⁰

Evidence Limitations

No randomized trials are available.

Summary

Treatment is generally similar to that for pulmonary edema in the nonoperative setting. An emergency ECG and a troponin level are useful for diagnosing acute myocardial ischemia, which may often be painless in the postoperative setting,¹¹⁸ as well as cardiac arrhythmias. Special attention must be paid to the patient's oxygenation and to the hematocrit level.

D. Postoperative Arrhythmias

Postoperative arrhythmias are often precipitated by noncardiac problems such as hypoxia, bleeding, pain, fever, or infection.^{48,121} Increased intravascular volume, whether iatrogenic or resulting from primary cardiac dysfunction, is a common contributing factor.

Supraventricular tachycardias are more common after thoracic surgery, occurring in $\geq 15\%$ cases,¹²² than other types of noncardiac surgery; risk factors include a faster preoperative heart rate and older age.¹²³ Nonsustained ventricular tachycardia is not independently associated with a worse prognosis and need not be treated.¹²⁴

For thoracic surgery, randomized trials indicate that calcium channel blockers or β -blockers can reduce the incidence of postoperative atrial fibrillation by 50% to 60%, but β -blockers increase the risk of pulmonary edema 2-fold. Neither class of medication reduces mortality.¹²² In patients with postoperative supraventricular tachycardia unresponsive to adenosine, esmolol appears to be better than diltiazem for rapid conversion to sinus rhythm.¹²⁵ Digitalis may precipitate atrial fibrillation, and data on other medications are limited.

New-onset atrial fibrillation raises embolic risks, but the strategy of rate control with anticoagulation used in the chronic setting is not attractive in postoperative patients at high risk for bleeding. Patients with new postoperative atrial fibrillation should be evaluated aggressively for noncardiac precipitants. In most patients, atrial fibrillation will resolve within 36 to 48 hours; if it does not, specific antiarrhythmic measures should be taken to try to resolve it within 72 hours, after which anticoagulation is generally recommended. Whether low-dose anticoagulation to prevent venous thromboembolism is also efficacious for reducing the risk of systemic embolization in postoperative patients with atrial fibrillation is unknown.

Evidence Limitations

Randomized trial data are limited.

Summary

Specific antiarrhythmic therapy in the postoperative setting is no different than in the nonoperative setting, but it will rarely be effective unless the precipitants, which are usually noncardiac in origin, are identified and addressed. Except for caution about anticoagulation, treatment is otherwise the same as in the nonoperative setting. β -Blockers or calcium channel blockers can reduce postoperative tachyarrhythmias, but β -blockers are preferred in patients who may benefit more broadly from them (see above).

E. Postoperative Hypertension

Most postoperative hypertension, like postoperative heart failure and pulmonary edema, occurs in the recovery room or in the first 48 hours after surgery. Postoperative hypertension is generally precipitated by intravascular volume overload, pain, and agitation. It occurs more commonly after vascular, head and neck, or neurosurgical procedures.¹²⁶ Randomized trials, often in selected patient populations, show roughly equivalent benefits for nitroprusside, nitroglycerin, labetalol, and nicardipine.¹²⁶

Evidence Limitations

Most trials have been in selected patients.

Summary

Therapy should include diuresis and analgesia. Nitroprusside, nitroglycerin, labetalol, and nicardipine are first-line options.

F. Postoperative General Medical Care

In a large trial of postoperative patients initially intubated in an intensive care unit, tight glucose control reduced hospital mortality from 10% to 7.2%.¹²⁷ For postoperative anemia, a restrictive strategy of transfusion triggered by a hemoglobin level of 7 mg/dL was superior to a more aggressive approach (an 8-mg/dL threshold) in a randomized trial.¹²⁸ Medical comanagement¹²⁹ and the availability of a rapid response team¹³⁰ have had inconsistent benefits.

Evidence Limitations

Data are scanty for the myriad postoperative medical issues.

Summary

Tight control of diabetes is probably worthwhile. On the basis of other evidence,^{108,109,111,112} patients with cardiovascular

disease may benefit from maintaining hemoglobin levels substantially higher than the 7-mg/dL level that is otherwise apparently adequate; however, fluid resuscitation is often more important than red cell transfusion acutely except when myocardial ischemia is evident. Better medical coverage, either routinely or at times when patients appear unstable, is promising but unproven.

Conclusions

In some situations, evidence obtained directly from perioperative studies can be used as the basis for decision making. Otherwise, we endorse the general concept that evidence-based care of cardiovascular disease in the ambulatory patient typically should be the foundation for recommendations about perioperative care. Any specific recommendations proposing that perioperative patients should be treated differently than they might otherwise be treated generally should not be adopted unless and until a sufficient evidence base is accumulated.

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None.

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