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CLINICAL PRACTICE GUIDELINE

2014 ACC/AHA Guideline on Perioperative Cardiovascular Evaluation and Management of Patients Undergoing Noncardiac Surgery

A Report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines

Developed in Collaboration With the American College of Surgeons, American Society of Anesthesiologists, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Anesthesiologists, and Society of Vascular Medicine

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PREAMBLE

The American College of Cardiology (ACC) and the American Heart Association (AHA) are committed to the prevention and management of cardiovascular diseases through professional education and research for clinicians, providers, and patients. Since 1980, the ACC and AHA have shared a responsibility to translate scientific evidence into clinical practice guidelines (CPGs) with recommendations to standardize and improve cardiovascular health. These CPGs, based on systematic methods to evaluate and classify evidence, provide a cornerstone of quality cardiovascular care.

In response to published reports from the Institute of Medicine (1,2) and the ACC/AHA's mandate to evaluate new knowledge and maintain relevance at the point of care, the ACC/AHA Task Force on Practice Guidelines (Task Force) began modifying its methodology. This modernization effort is published in the 2012 Methodology Summit Report (3) and 2014 perspective article (4). The Latter recounts the history of the collaboration, changes over time, current policies, and planned initiatives to meet the needs of an evolving health-care environment. Recommendations on value in proportion to resource utilization will be incorporated as high-quality comparative-effectiveness data become available (5). The relationships between CPGs and data standards, appropriate use criteria, and performance measures are addressed elsewhere (4).

Intended Use—CPGs provide recommendations applicable to patients with or at risk of developing cardiovascular disease. The focus is on medical practice in the United States, but CPGs developed in collaboration with other organizations may have a broader target. Although CPGs may be used to inform regulatory or payer decisions, the intent is to improve quality of care and be aligned with the patient's best interest.

Evidence Review—Guideline writing committee (GWC) members are charged with reviewing the literature; weighing the strength and quality of evidence for or against particular tests, treatments, or procedures; and estimating expected health outcomes when data exist. In analyzing the data and developing CPGs, the GWC uses evidence-based methodologies developed by the Task Force (6). A key component of the ACC/AHA CPG methodology is the development of recommendations on the basis of all available evidence. Literature searches focus on randomized controlled trials (RCTs) but also include registries, nonrandomized comparative and descriptive studies, case series, cohort studies, systematic reviews, and expert opinion. Only selected references are cited in the CPG. To ensure that CPGs remain current, new data are reviewed biannually by the GWCs and the Task Force to determine if recommendations should be updated or modified. In general, a target cycle of 5 years is planned for full revision (1).

The Task Force recognizes the need for objective, independent Evidence Review Committees (ERCs) to address key clinical questions posed in the PICOTS format (P = population; I = intervention; C = comparator; O = outcome; T = timing; S = setting). The ERCs include methodologists, epidemiologists, clinicians, and biostatisticians who systematically survey, abstract, and assess the quality of the evidence base (3,4). Practical considerations, including time and resource constraints, limit the ERCs to addressing key clinical questions for which the evidence relevant to the guideline topic lends itself to systematic review and analysis when the systematic review could impact the sense or strength of related recommendations. The GWC develops recommendations on the basis of the systematic review and denotes them with superscripted "SR" (i.e., ^{SR}) to emphasize support derived from formal systematic review.

Guideline-Directed Medical Therapy—Recognizing advances in medical therapy across the spectrum of cardiovascular diseases, the Task Force designated the term "guideline-directed medical therapy" (GDMT) to represent recommended medical therapy as defined mainly by Class I measures—generally a combination of lifestyle modification and drug- and device-based therapeutics. As medical science advances, GDMT evolves, and hence GDMT is preferred to "optimal medical therapy." For GDMT and all other recommended drug treatment regimens, the reader should confirm the dosage with product insert material and carefully evaluate for contraindications and possible drug interactions. Recommendations are limited to treatments, drugs, and devices approved for clinical use in the United States.

Class of Recommendation and Level of Evidence—Once recommendations are written, the Class of Recommendation (COR; i.e., the strength the GWC assigns to the recommendation, which encompasses the anticipated magnitude and judged certainty of benefit in proportion to risk) is assigned by the GWC. Concurrently, the Level of Evidence (LOE) rates the scientific evidence supporting the effect of the intervention on the basis of the type, quality, quantity, and consistency of data from clinical trials and other reports (**Table 1**) (4).

Relationships With Industry and Other Entities—The ACC and AHA exclusively sponsor the work of GWCs, without commercial support, and members volunteer their time for this activity. The Task Force makes every effort to avoid actual, potential, or perceived conflicts of interest that might arise through relationships with industry or other entities (RWI). All GWC members and reviewers are required to fully disclose current industry relationships or personal interests, from 12 months before initiation of the writing effort. Management of RWI involves selecting a balanced GWC and requires that both the chair and a majority of GWC members have no relevant RWI (see Appendix 1 for the definition of relevance). GWC members are restricted with regard to writing or voting on sections to which their RWI apply. In addition, for transparency, GWC members' comprehensive disclosure information is available as an online supplement. Comprehensive disclosure information for the Task Force is also available as an online supplement. The Task Force strives to avoid bias by selecting experts from a broad array of backgrounds representing different geographic regions, genders, ethnicities, intellectual perspectives/biases, and scopes of clinical practice. Selected organizations and professional societies with related interests and expertise are invited to participate as partners or collaborators.

Individualizing Care in Patients With Associated Conditions and Comorbidities—The ACC and AHA recognize the complexity of managing patients with multiple conditions, compared with managing patients with a single disease, and the challenge is compounded when CPGs for evaluation or treatment of several coexisting illnesses are discordant or interacting (7). CPGs attempt to define practices that meet the needs of patients in most, but not all, circumstances and do not replace clinical judgment.

Clinical Implementation—Management in accordance with CPG recommendations is effective only when followed; therefore, to enhance the patient's commitment to treatment and compliance with lifestyle adjustment, clinicians should engage the patient to participate in selecting interventions on the basis of the patient's individual values and preferences, taking associated conditions and comorbidities into consideration (e.g., shared decision making). Consequently, there are circumstances in which deviations from these CPGs are appropriate.

TABLE 1 Applying Classification of Recommendations and Level of Evidence

ESTIMATE OF CERTAINTY (PRECISION) OF TREATMENT EFFECT	SIZE OF TREATMENT EFFECT: CLASS I *Benefit >>> Risk* Procedure/Treatment **SHOULD** be performed/ administered	CLASS IIa *Benefit >> Risk* *Additional studies with focused objectives needed* **IT IS REASONABLE** to perform procedure/administer treatment	CLASS IIb *Benefit ≥ Risk* *Additional studies with broad objectives needed; additional registry data would be helpful* Procedure/Treatment **MAY BE CONSIDERED**	CLASS III *No Benefit* or CLASS III *Harm* Procedure/ Test / Treatment COR III: No benefit / Not Helpful / No Proven Benefit COR III: Harm / Excess Cost w/o Benefit or Harmful / Harmful to Patients
LEVEL A Multiple populations evaluated* Data derived from multiple randomized clinical trials or meta-analyses	■ Recommendation that procedure or treatment is useful/effective ■ Sufficient evidence from multiple randomized trials or meta-analyses	■ Recommendation in favor of treatment or procedure being useful/effective ■ Some conflicting evidence from multiple randomized trials or meta-analyses	■ Recommendation's usefulness/efficacy less well established ■ Greater conflicting evidence from multiple randomized trials or meta-analyses	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Sufficient evidence from multiple randomized trials or meta-analyses
LEVEL B Limited populations evaluated* Data derived from a single randomized trial or nonrandomized studies	■ Recommendation that procedure or treatment is useful/effective ■ Evidence from single randomized trial or nonrandomized studies	■ Recommendation in favor of treatment or procedure being useful/effective ■ Some conflicting evidence from single randomized trial or nonrandomized studies	■ Recommendation's usefulness/efficacy less well established ■ Greater conflicting evidence from single randomized trial or nonrandomized studies	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Evidence from single randomized trial or nonrandomized studies
LEVEL C Very limited populations evaluated* Only consensus opinion of experts, case studies, or standard of care	■ Recommendation that procedure or treatment is useful/effective ■ Only expert opinion, case studies, or standard of care	■ Recommendation in favor of treatment or procedure being useful/effective ■ Only diverging expert opinion, case studies, or standard of care	■ Recommendation's usefulness/efficacy less well established ■ Only diverging expert opinion, case studies, or standard of care	■ Recommendation that procedure or treatment is not useful/effective and may be harmful ■ Only expert opinion, case studies, or standard of care
Suggested phrases for writing recommendations	should is recommended is indicated is useful/effective/beneficial	is reasonable can be useful/effective/beneficial is probably recommended or indicated	may/might be considered may/might be reasonable usefulness/effectiveness is unknown/unclear/uncertain or not well established	COR III: No Benefit: is not recommended; is not indicated; should not be performed/ administered/ other; is not useful/ beneficial/ effective COR III: Harm: potentially harmful; causes harm; associated with excess morbidity/mortality; should not be performed/ administered/ other
Comparative effectiveness phrases†	treatment/strategy A is recommended/indicated in preference to treatment B treatment A should be chosen over treatment B	treatment/strategy A is probably recommended/indicated in preference to treatment B it is reasonable to choose treatment A over treatment B		

A recommendation with Level of Evidence B or C does not imply that the recommendation is weak. Many important key clinical questions addressed in the guidelines do not lend themselves to clinical trials. Although randomized trials are unavailable, there may be a very clear clinical consensus that a particular test or therapy is useful or effective.
*Data available from clinical trials or registries about the usefulness/efficacy in different subpopulations, such as sex, age, history of diabetes mellitus, history of prior myocardial infarction, history of heart failure, and prior aspirin use.
†For comparative-effectiveness recommendations (Class I and IIa; Level of Evidence A and B only), studies that support the use of comparator verbs should involve direct comparisons of the treatments or strategies being evaluated.

The recommendations in this CPG are the official policy of the ACC and AHA until they are superseded by a published addendum, focused update, or revised full-text CPG.

Jeffrey L. Anderson, MD, FACC, FAHA
Chair, ACC/AHA Task Force on Practice Guidelines

1. INTRODUCTION

1.1. Methodology and Evidence Review

The recommendations listed in this CPG are, whenever possible, evidence based. In April 2013, an extensive evidence review was conducted, which included a literature review through July 2013. Other selected references published through May 2014 were also incorporated by the GWC. Literature included was derived from research involving human subjects, published in English, and indexed in MEDLINE (through PubMed), EMBASE, the Cochrane Library, Agency for Healthcare Research and Quality Reports, and other selected databases relevant to this CPG. The relevant data are included in evidence tables in the Data Supplement available online. Key search words included but were not limited to the following: *anesthesia protection; arrhythmia; atrial fibrillation; atrioventricular block; bundle branch block; cardiac*

ischemia; cardioprotection; cardiovascular implantable electronic device; conduction disturbance; dysrhythmia; electrocardiography; electrocautery; electromagnetic interference; heart disease; heart failure; implantable cardioverter-defibrillator; intraoperative; left ventricular ejection fraction; left ventricular function; myocardial infarction; myocardial protection; National Surgical Quality Improvement Program; pacemaker; perioperative; perioperative pain management; perioperative risk; postoperative; preoperative; preoperative evaluation; surgical procedures; ventricular premature beats; ventricular tachycardia; and *volatile anesthetics.*

An independent ERC was commissioned to perform a systematic review of a key question, the results of which were considered by the GWC for incorporation into this CPG. See the systematic review report published in conjunction with this CPG (8) and its respective data supplements.

1.2. Organization of the GWC

The GWC was composed of clinicians with content and methodological expertise, including general cardiologists, subspecialty cardiologists, anesthesiologists, a surgeon, a hospitalist, and a patient representative/lay volunteer. The GWC included representatives from the ACC, AHA, American College of Surgeons, American Society of Anesthesiologists, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society (HRS), Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Anesthesiologists, and Society for Vascular Medicine.

1.3. Document Review and Approval

This document was reviewed by 2 official reviewers each from the ACC and the AHA; 1 reviewer each from the American College of Surgeons, American Society of Anesthesiologists, American Society of Echocardiography, American Society of Nuclear Cardiology, HRS, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Anesthesiologists, Society of Hospital Medicine, and Society for Vascular Medicine; and 24 individual content reviewers (including members of the ACC Adult Congenital and Pediatric Cardiology Section Leadership Council, ACC Electrophysiology Section Leadership Council, ACC Heart Failure and Transplant Section Leadership Council, ACC Interventional Section Leadership Council, and ACC Surgeons' Council). Reviewers' RWI information was distributed to the GWC and is published in this document (Appendix 2).

This document was approved for publication by the governing bodies of the ACC and the AHA and endorsed by the American College of Surgeons, American Society of Anesthesiologists, American Society of Echocardiography, American Society of Nuclear Cardiology, Heart Rhythm Society, Society for Cardiovascular Angiography and Interventions, Society of Cardiovascular Anesthesiologists, Society of Hospital Medicine, and Society of Vascular Medicine.

1.4. Scope of the CPG

The focus of this CPG is the perioperative cardiovascular evaluation and management of the adult patient undergoing noncardiac surgery. This includes preoperative risk assessment and cardiovascular testing, as well as (when indicated) perioperative pharmacological (including anesthetic) management and perioperative monitoring that includes devices and biochemical markers. This CPG is intended to inform all the medical professionals involved in the care of these patients. The preoperative evaluation of the patient undergoing noncardiac surgery can be performed for multiple purposes, including 1) assessment of perioperative risk (which can be used to inform the decision to proceed or the choice of surgery and which includes the patient's perspective), 2) determination of the need for changes in management, and 3) identification of cardiovascular conditions or risk factors requiring longer-term management. Changes in management can include the decision to change medical therapies, the decision to perform further cardiovascular interventions, or recommendations about postoperative monitoring. This may lead to recommendations and discussions with the perioperative team about the optimal location and timing of surgery (e.g., ambulatory surgery center versus outpatient hospital, or inpatient admission) or alternative strategies.

The key to optimal management is communication among all of the relevant parties (i.e., surgeon, anesthesiologist, primary caregiver, and consultants) and the patient. The goal of preoperative evaluation is to promote patient engagement and facilitate shared decision making by providing patients and their providers with clear, understandable information about perioperative cardiovascular risk in the context of the overall risk of surgery.

The Task Force has chosen to make recommendations about care management on the basis of available evidence from studies of patients undergoing noncardiac surgery. Extrapolation from data from the nonsurgical arena or cardiac surgical arena was made only when no other data were available and the benefits of extrapolating the data outweighed the risks.

During the initiation of the writing effort, concern was expressed by Erasmus University about the scientific integrity of studies led by Poldermans (9). The GWC reviewed 2 reports from Erasmus University published on the Internet (9,10), as well as other relevant articles on this body of scientific investigation (11–13). The 2012 report from Erasmus University concluded that the conduct in the DECREASE (Dutch Echocardiographic

Cardiac Risk Evaluation Applying Stress Echocardiography) IV and V trials "was in several respects negligent and scientifically incorrect" and that "essential source documents are lacking" to make conclusions about other studies led by Poldermans (9). Additionally, Erasmus University was contacted to ensure that the GWC had up-to-date information. On the basis of the published information, discussions between the Task Force and GWC leadership ensued to determine how best to treat any study in which Poldermans was the senior investigator (i.e., either the first or last author). The Task Force developed the following framework for this document:

1. The ERC will include the DECREASE trials in the sensitivity analysis, but the systematic review report will be based on the published data on perioperative beta blockade, with data from all DECREASE trials excluded.
2. The DECREASE trials and other derivative studies by Poldermans should not be included in the CPG data supplements and evidence tables.
3. If nonretracted DECREASE publications and/or other derivative studies by Poldermans are relevant to the topic, they can only be cited in the text with a comment about the finding compared with the current recommendation but should not form the basis of that recommendation or be used as a reference for the recommendation.

The Task Force and the GWC believe that it is crucial, for the sake of transparency, to include the nonretracted publications in the text of the document. This is particularly important because further investigation is occurring simultaneously with deliberation of the CPG recommendations. Because of the availability of new evidence and the international impact of the controversy about the DECREASE trials, the ACC/AHA and European Society of Cardiology/European Society of Anesthesiology began revising their respective CPGs concurrently. The respective GWCs performed their literature reviews and analyses independently and then developed their recommendations. Once peer review of both CPGs was completed, the GWCs chose to discuss their respective recommendations for beta-blocker therapy and other relevant issues. Any differences in recommendations were discussed and clearly articulated in the text; however, the GWCs aligned a few recommendations to avoid confusion within the clinical community, except where international practice variation was prevalent.

In developing this CPG, the GWC reviewed prior published CPGs and related statements. **Table 2** lists these publications and statements deemed pertinent to this effort and is intended for use as a resource. However, because of the availability of new evidence, the current CPG may include recommendations that supersede those previously published.

1.5. Definitions of Urgency and Risk

In describing the temporal necessity of operations in this CPG, the GWC developed the following definitions by consensus. An *emergency* procedure is one in which life or limb is threatened if not in the operating room where there is time for no or very limited or minimal clinical evaluation, typically within <6 hours. An *urgent* procedure is one in which there may be time for a limited clinical evaluation, usually when life or limb is threatened if not in the operating room, typically between 6 and 24 hours. A *time-sensitive* procedure is one in which a delay of >1 to 6 weeks to allow for an evaluation and significant changes in management will negatively affect outcome. Most oncologic procedures would fall into this category. An *elective* procedure is one in which the procedure could be delayed for up to 1 year. Individual institutions may use slightly different definitions, but this framework could be mapped to local categories. A *low-risk* procedure is one in which the combined surgical and patient characteristics predict a risk of a major adverse cardiac event (MACE) of death or myocardial infarction (MI) of <1%. Selected examples of low-risk procedures include cataract and plastic surgery (34,35). Procedures with a risk of MACE of ≥1% are considered *elevated risk*. Many previous risk-stratification schema have included intermediate- and high-risk classifications. Because recommendations for intermediate- and high-risk procedures are similar, classification into 2 categories simplifies the recommendations without loss of fidelity. Additionally, a risk calculator has been developed that allows more precise calculation of surgical risk, which can be incorporated into perioperative decision making (36). Approaches to establishing low and elevated risk are developed more fully in Section 3.

2. CLINICAL RISK FACTORS

2.1. Coronary Artery Disease

Perioperative mortality and morbidity due to coronary artery disease (CAD) are untoward complications of noncardiac surgery. The incidence of cardiac morbidity after surgery depends on the definition, which ranges from elevated cardiac biomarkers alone to the more classic definition with other signs of ischemia (37–39). In a study of 15 133 patients who were >50 years of age and had noncardiac surgery requiring an overnight admission, an isolated peak troponin T value of ≥0.02 ng/mL occurred in 11.6% of patients. The 30-day mortality rate in this cohort with elevated troponin T values was 1.9% (95% confidence interval [CI]: 1.7% to 2.1%) (40).

MACE after noncardiac surgery is often associated with prior CAD events. The stability and timing of a recent MI impact the incidence of perioperative morbidity and mortality. An older study demonstrated very high

TABLE 2 Associated CPGs and Statements

Title	Organization	Publication Year (Reference)
CPGs		
Management of patients with atrial fibrillation	AHA/ACC/HRS	2014 (14)
Management of valvular heart disease	AHA/ACC	2014 (15)
Management of heart failure	ACC/AHA	2013 (16)
Performing a comprehensive transesophageal echocardiographic examination	ASE/SCA	2013 (17)
Management of ST-elevation myocardial infarction	ACC/AHA	2013 (18)
Diagnosis and management of patients with stable ischemic heart disease	ACC/AHA/AATS/PCNA/SCAI/STS	2012 (18a) 2014 (19)
Focused update incorporated into the 2007 guidelines for the management of patients with unstable angina/non-ST-elevation myocardial infarction*	ACC/AHA	2012 (20)
Red blood cell transfusion	AABB	2012 (21)
Management of patients with peripheral artery disease: focused update and guideline	ACC/AHA	2011 (22) 2006 (23)
Diagnosis and treatment of hypertrophic cardiomyopathy	ACC/AHA	2011 (24)
Coronary artery bypass graft surgery	ACC/AHA	2011 (25)
Percutaneous coronary intervention	ACC/AHA/SCAI	2011 (26)
Perioperative transesophageal echocardiography	American Society of Anesthesiologists/SCA	2010 (27)
Management of adults with congenital heart disease	ACC/AHA	2008 (28)
Statements		
Perioperative beta blockade in noncardiac surgery: a systematic review	ACC/AHA	2014 (8)
Basic perioperative transesophageal echocardiography examination	ASE/SCA	2013 (29)
Practice advisory for preanesthesia evaluation	American Society of Anesthesiologists	2012 (30)
Cardiac disease evaluation and management among kidney and liver transplantation candidates	AHA/ACC	2012 (31)
Inclusion of stroke in cardiovascular risk prediction instruments	AHA/American Stroke Association	2012 (32)
Perioperative management of patients with implantable defibrillators, pacemakers and arrhythmia monitors: facilities and patient management	HRS/American Society of Anesthesiologists	2011 (33)

*The 2012 UA/NSTEMI CPG (20) is considered policy at the time of publication of this CPG; however, a full, revised CPG will be published in 2014.

AABB indicates American Association of Blood Banks; AATS, American Association for Thoracic Surgery; ACC, American College of Cardiology; AHA, American Heart Association; ASE, American Society of Echocardiography; CPG, clinical practice guideline; HRS, Heart Rhythm Society; PCNA, Preventive Cardiovascular Nurses Association; SCAI, Society for Cardiovascular Angiography and Interventions; SCA, Society of Cardiovascular Anesthesiologists; STEMI, ST-elevation myocardial infarction; STS, Society of Thoracic Surgeons; and UA/NSTEMI, unstable angina/non-ST-elevation myocardial infarction.

morbidity and mortality rates in patients with unstable angina (41). A study using discharge summaries demonstrated that the postoperative MI rate decreased substantially as the length of time from MI to operation increased (0 to 30 days = 32.8%; 31 to 60 days = 18.7%; 61 to 90 days = 8.4%; and 91 to 180 days = 5.9%), as did the 30-day mortality rate (0 to 30 days = 14.2%; 31 to 60 days = 11.5%; 61 to 90 days = 10.5%; and 91 to 180 days = 9.9%) (42). This risk was modified by the presence and type of coronary revascularization (coronary artery bypass grafting [CABG] versus percutaneous coronary interventions [PCIs]) that occurred at the time of the MI (43). Taken together, the data suggest that ≥60 days should elapse after a MI before noncardiac surgery in the absence of a coronary intervention. A recent MI, defined as having occurred within 6 months of noncardiac surgery, was also found to be an independent risk factor for perioperative stroke, which was associated with an 8-fold increase in the perioperative mortality rate (44).

A patient's age is an important consideration, given that adults (those ≥55 years of age) have a growing prevalence of cardiovascular disease, cerebrovascular disease, and diabetes mellitus (45), which increase overall risk for MACE when they undergo noncardiac surgery. Among older adult patients (those >65 years of age) undergoing noncardiac surgery, there was a higher reported incidence of acute ischemic stroke than for those ≤65 years of age (46). Age >62 years is also an independent risk factor for perioperative stroke (44). More postoperative complications, increased length of hospitalization, and inability to return home after hospitalization were also more pronounced among "frail" (e.g., those with impaired cognition and with dependence on others in instrumental activities of daily living), older adults >70 years of age (47).

A history of cerebrovascular disease has been shown to predict perioperative MACE (32).

See Online Data Supplements 1 and 2 for additional information on CAD and the influence of age and sex. An extensive consideration of CAD in the context of noncardiac surgery, including assessment for ischemia and other aspects, follows later in this document.

2.2. Heart Failure

Patients with clinical heart failure (HF) (active HF symptoms or physical examination findings of peripheral edema, jugular venous distention, rales, third heart sound, or chest x-ray with pulmonary vascular redistribution or pulmonary edema) or a history of HF are at significant risk for perioperative complications, and widely used indices of cardiac risk include HF as an independent prognostic variable (37,48,49).

The prevalence of HF is increasing steadily (50), likely because of aging of the population and improved survival with newer cardiovascular therapies. Thus, the number of patients with HF requiring preoperative assessment is increasing. The risk of developing HF is higher in the elderly and in individuals with advanced cardiac disease, creating the likelihood of clustering of other risk factors and comorbidities when HF is manifest.

2.2.1. Role of HF in Perioperative Cardiac Risk Indices

In the Original Cardiac Risk Index, 2 of the 9 independent significant predictors of life-threatening and fatal cardiac complications—namely, the presence of preoperative third heart sound and jugular venous distention—were associated with HF and had the strongest association with perioperative MACE (48). Subsequent approaches shifted the emphasis to history of HF (37) and defined HF by a combination of signs and symptoms, such as history of HF, pulmonary edema, or paroxysmal nocturnal dyspnea; physical examination showing bilateral rales or third heart sound gallop; and chest x-ray showing pulmonary vascular redistribution. This definition, however, did not include important symptoms such as orthopnea and dyspnea on exertion (16). Despite the differences in definition of HF as a risk variable, changes in demographics, changes in the epidemiology of patients with cardiovascular comorbidities, changes in treatment strategies, and advances in the perioperative area, population-based studies have demonstrated that HF remains a significant risk for perioperative morbidity and mortality. In a study that used Medicare claims data, the risk-adjusted 30-day mortality and readmission rate in patients undergoing 1 of 13 predefined major noncardiac surgeries was 50% to 100% higher in patients with HF than in an elderly control group without a history of CAD or HF (51,52). These results suggest that patients with HF who undergo major surgical procedures have substantially higher risks of operative death and hospital readmission than do other patients. In a population-based data analysis of 4 cohorts of 38 047 consecutive patients, the 30-day postoperative mortality rate was significantly higher in patients with nonischemic HF (9.3%), ischemic HF (9.2%), and atrial fibrillation (AF) (6.4%) than in those with CAD (2.9%) (53). These findings suggest that although perioperative risk-prediction models place greater emphasis on CAD than on HF, patients with active HF have a significantly higher risk of postoperative death than do patients with CAD. Furthermore, the stability of a patient with HF plays a significant role. In a retrospective single-center cohort study of patients with stable HF who underwent elective noncardiac surgery between 2003 and 2006, perioperative mortality rates for patients with stable HF were not higher than for the control group without HF, but these patients with stable HF were more likely than patients without HF to have longer hospital stays, require hospital readmission, and have higher long-term mortality rates (54). However, all patients in this study were seen in a preoperative assessment, consultation, and treatment program; and the population did not include many high-risk patients. These results suggest improved perioperative outcomes for patients with stable HF who are treated according to GDMT.

2.2.2. Risk of HF Based on Left Ventricular Ejection Fraction: Preserved Versus Reduced

Although signs and/or symptoms of decompensated HF confer the highest risk, severely decreased (<30%) left ventricular ejection fraction (LVEF) itself is an independent contributor to perioperative outcome and a long-term risk factor for death in patients with HF undergoing elevated-risk noncardiac surgery (55). Survival after surgery for those with a LVEF ≤29% is significantly worse than for those with a LVEF >29% (56). Studies have reported mixed results for perioperative risk in patients with HF and preserved LVEF, however. In a meta-analysis using individual patient data, patients with HF and preserved LVEF had a lower all-cause mortality rate than did of those with HF and reduced LVEF (the risk of death did not increase notably until LVEF fell below 40%) (57). However, the absolute mortality rate was still high in patients with HF and preserved LVEF as compared with patients without HF, highlighting the importance of presence of HF. There are limited data on perioperative risk stratification related to diastolic dysfunction. Diastolic dysfunction with and without systolic dysfunction has been associated with a significantly higher rate of MACE, prolonged length of stay, and higher rates of postoperative HF (58,59).

2.2.3. Risk of Asymptomatic Left Ventricular Dysfunction

Although symptomatic HF is a well-established perioperative cardiovascular risk factor, the effect of

asymptomatic left ventricular (LV) dysfunction on perioperative outcomes is unknown. In 1 prospective cohort study on the role of preoperative echocardiography in 1005 consecutive patients undergoing elective vascular surgery at a single center, LV dysfunction (LVEF <50%) was present in 50% of patients, of whom 80% were asymptomatic (58). The 30-day cardiovascular event rate was highest in patients with symptomatic HF (49%), followed by those with asymptomatic systolic LV dysfunction (23%), asymptomatic diastolic LV dysfunction (18%), and normal LV function (10%). Further studies are required to determine if the information obtained from the assessment of ventricular function in patients without signs or symptoms adds incremental information that will result in changes in management and outcome such that the appropriateness criteria should be updated. It should be noted that the 2011 appropriate use criteria for echocardiography states it is "inappropriate" to assess ventricular function in patients without signs or symptoms of cardiovascular disease in the preoperative setting (60). For preoperative assessment of LV function, see Section 5.2.

2.2.4. Role of Natriuretic Peptides in Perioperative Risk of HF

Preoperative natriuretic peptide levels independently predict cardiovascular events in the first 30 days after vascular surgery (61–66) and significantly improve the predictive performance of the Revised Cardiac Risk Index (RCRI) (61). Measurement of biomarkers, especially natriuretic peptides, may be helpful in assessing patients with HF and with diagnosing HF as a postoperative complication in patients at high risk for HF. Further prospective randomized studies are needed to assess the utility of such a strategy (Section 3.1).

2.3. Cardiomyopathy

There is little information on the preoperative evaluation of patients with specific nonischemic cardiomyopathies before noncardiac surgery. Preoperative recommendations must be based on a thorough understanding of the pathophysiology of the cardiomyopathy, assessment and management of the underlying process, and overall management of the HF.

Restrictive Cardiomyopathies: Restrictive cardiomyopathies, such as those associated with cardiac amyloidosis, hemochromatosis, and sarcoidosis, pose special hemodynamic and management problems. Cardiac output in these cardiomyopathies with restrictive physiology is both preload and heart rate dependent. Significant reduction of blood volume or filling pressures, bradycardia or tachycardia, and atrial arrhythmias such as AF/atrial flutter may not be well tolerated. These patients require a multidisciplinary approach, with optimization of the underlying pathology, volume status, and HF status including medication adjustment targeting primary disease management.

Hypertrophic Obstructive Cardiomyopathy: In hypertrophic obstructive cardiomyopathy, decreased systemic vascular resistance (arterial vasodilators), volume loss, or reduction in preload or LV filling may increase the degree of dynamic obstruction and further decrease diastolic filling and cardiac output, with potentially untoward results. Overdiuresis should be avoided, and inotropic agents are usually not used in these patients because of increased LV outflow gradient. Studies have reported mixed results for perioperative risk in patients with hypertrophic obstructive cardiomyopathy. Most studies were small, were conducted at a single center, and reflect variations in patient populations, types of surgery, and management (67–69).

Arrhythmogenic Right Ventricular (RV) Cardiomyopathy and/or Dysplasia: In 1 autopsy study examining a series of 200 cases of sudden death associated with arrhythmogenic RV cardiomyopathy and/or dysplasia, death occurred in 9.5% of cases during the perioperative period (70). This emphasizes the importance of close perioperative evaluation and monitoring of these patients for ventricular arrhythmia. Most of these patients require cardiac electrophysiologist involvement and consideration for an implantable cardioverter-defibrillator (ICD) for long-term management.

In a retrospective analysis of 1700 forensic autopsies of patients with sudden, unexpected perioperative death over 17 years, pathological examination showed cardiac lesions in 47 cases, arrhythmogenic RV cardiomyopathy in 18 cases, CAD in 10 cases, cardiomyopathy in 8 cases, structural abnormalities of the His bundle in 9 cases, mitral valve prolapse in 1 case, and acute myocarditis in 1 case, suggesting the importance of detailed clinical histories and physical examinations before surgery for detection of these structural cardiac abnormalities (71).

Peripartum Cardiomyopathy: Peripartum cardiomyopathy is a rare cause of dilated cardiomyopathy that occurs in approximately 1 in 1000 deliveries and manifests during the last few months of pregnancy or the first 6 months of the postpartum period. It can result in severe ventricular dysfunction during late puerperium (72). Prognosis depends on the recovery of the LV contractility and resolution of symptoms within the first 6 months after onset of the disease. The major peripartum concern is to optimize fluid administration and avoid myocardial depression while maintaining stable intraoperative hemodynamics (73). Although the majority of patients remain stable and recover, emergency delivery may be life-saving for the mother as well as the infant. Acute and critically ill patients with refractory peripartum cardiomyopathy may require mechanical support with an intra-aortic balloon pump, extracorporeal membrane

oxygenation, continuous-flow LV assist devices, and/or cardiac transplantation (74).

See Online Data Supplement 3 for additional information on HF and cardiomyopathy.

2.4. Valvular Heart Disease: Recommendations

See the 2014 valvular heart disease CPG for the complete set of recommendations and specific definitions of disease severity (15) and Online Data Supplement 4 for additional information on valvular heart disease.

CLASS I

1. **It is recommended that patients with clinically suspected moderate or greater degrees of valvular stenosis or regurgitation undergo preoperative echocardiography if there has been either 1) no prior echocardiography within 1 year or 2) a significant change in clinical status or physical examination since last evaluation (60).** ***(Level of Evidence: C)***
2. **For adults who meet standard indications for valvular intervention (replacement and repair) on the basis of symptoms and severity of stenosis or regurgitation, valvular intervention before elective noncardiac surgery is effective in reducing perioperative risk (15).** ***(Level of Evidence: C)***

Significant valvular heart disease increases cardiac risk for patients undergoing noncardiac surgery (37,48). Patients with suspected valvular heart disease should undergo echocardiography to quantify the severity of stenosis or regurgitation, calculate systolic function, and estimate right heart pressures. Evaluation for concurrent CAD is also warranted, with electrocardiography exercise testing, stress echocardiographic or nuclear imaging study, or coronary angiography, as appropriate.

Emergency noncardiac surgery may occur in the presence of uncorrected significant valvular heart disease. The risk of noncardiac surgery can be minimized by 1) having an accurate diagnosis of the type and severity of valvular heart disease, 2) choosing an anesthetic approach appropriate to the valvular heart disease, and 3) considering a higher level of perioperative monitoring (e.g., arterial pressure, pulmonary artery pressure, transesophageal echocardiography), as well as managing the patient postoperatively in an intensive care unit setting.

2.4.1. Aortic Stenosis: Recommendation

CLASS IIa

1. **Elevated-risk elective noncardiac surgery with appropriate intraoperative and postoperative hemodynamic monitoring is reasonable to perform in patients with asymptomatic severe aortic stenosis (AS) (48,75–84).** ***(Level of Evidence: B)***

In the Original Cardiac Risk Index, severe AS was associated with a perioperative mortality rate of 13%, compared with 1.6% in patients without AS (48). The mechanism of MACE in patients with AS likely arises from the anesthetic agents and surgical stress that lead to an unfavorable hemodynamic state. The occurrence of hypotension and tachycardia can result in decreased coronary perfusion pressure, development of arrhythmias or ischemia, myocardial injury, cardiac failure, and death.

With the recent advances in anesthetic and surgical approaches, the cardiac risk in patients with significant AS undergoing noncardiac surgery has declined. In a single, tertiary-center study, patients with moderate AS (aortic valve area: 1.0 cm^2 to 1.5 cm^2) or severe AS (aortic valve area <1.0 cm^2) undergoing nonemergency noncardiac surgery had a 30-day mortality rate of 2.1%, compared with 1.0% in propensity score–matched patients without AS (p=0.036) (75). Postoperative MI was more frequent in patients with AS than in patients without AS (3.0% versus 1.1%; p=0.001). Patients with AS had worse primary outcomes (defined as composite of 30-day mortality and postoperative MI) than did patients without AS (4.4% versus 1.7%; p=0.002 for patients with moderate AS; 5.7% versus 2.7%; p=0.02 for patients with severe AS). Predictors of 30-day death and postoperative MI in patients with moderate or severe AS include high-risk surgery (odds ratio [OR]: 7.3; 95% CI: 2.6 to 20.6), symptomatic severe AS (OR: 2.7; 95% CI: 1.1 to 7.5), coexisting moderate or severe mitral regurgitation (MR) (OR: 9.8; 95% CI: 3.1 to 20.4), and pre-existing CAD (OR: 2.7; 95% CI: 1.1 to 6.2).

For patients who meet indications for aortic valve replacement (AVR) before noncardiac surgery but are considered high risk or ineligible for surgical AVR, options include proceeding with noncardiac surgery with invasive hemodynamic monitoring and optimization of loading conditions, percutaneous aortic balloon dilation as a bridging strategy, and transcatheter aortic valve replacement (TAVR). Percutaneous aortic balloon dilation can be performed with acceptable procedural safety, with the mortality rate being 2% to 3% and the stroke rate being 1% to 2% (76–78,84). However, recurrence and mortality rates approach 50% by 6 months after the procedure. Single-center, small case series from more than 25 years ago reported the use of percutaneous aortic balloon dilation in patients with severe AS before noncardiac surgery (79–81). Although the results were acceptable, there were no comparison groups or long-term follow-up. The PARTNER (Placement of Aortic Transcatheter Valves) RCT demonstrated that TAVR has superior outcomes for patients who are not eligible for surgical AVR (1-year mortality rate: 30.7% for TAVR versus 50.7% for standard therapy) and similar efficacy for patients who are at high risk for surgical AVR (1-year mortality rate: 24.2% for TAVR versus 26.8% for surgical AVR) (82,83). However, there are no data for the efficacy or safety of TAVR for patients with AS who are undergoing noncardiac surgery.

2.4.2. Mitral Stenosis: Recommendation

CLASS IIb

1. **Elevated-risk elective noncardiac surgery using appropriate intraoperative and postoperative hemodynamic monitoring may be reasonable in asymptomatic patients with severe mitral stenosis if valve morphology is not favorable for percutaneous mitral balloon commissurotomy.** *(Level of Evidence: C)*

Patients with severe mitral stenosis are at increased risk for noncardiac surgery and should be managed similarly to patients with AS. The main goals during the perioperative period are to monitor intravascular volume and to avoid tachycardia and hypotension. It is crucial to maintain intravascular volume at a level that ensures adequate forward cardiac output without excessive rises in left atrial pressure and pulmonary capillary wedge pressure that could precipitate acute pulmonary edema.

Patients with mitral stenosis who meet standard indications for valvular intervention (open mitral commissurotomy or percutaneous mitral balloon commissurotomy) should undergo valvular intervention before elective noncardiac surgery (85). If valve anatomy is not favorable for percutaneous mitral balloon commissurotomy, or if the noncardiac surgery is an emergency, then noncardiac surgery may be considered with invasive hemodynamic monitoring and optimization of loading conditions. There are no reports of the use of percutaneous mitral balloon commissurotomy before noncardiac surgery; however, this procedure has excellent outcomes when used during high-risk pregnancies (86,87).

2.4.3. Aortic and Mitral Regurgitation: Recommendations

CLASS IIa

1. **Elevated-risk elective noncardiac surgery with appropriate intraoperative and postoperative hemodynamic monitoring is reasonable in adults with asymptomatic severe MR.** *(Level of Evidence: C)*
2. **Elevated-risk elective noncardiac surgery with appropriate intraoperative and postoperative hemodynamic monitoring is reasonable in adults with asymptomatic severe aortic regurgitation (AR) and a normal LVEF.** *(Level of Evidence: C)*

Left-sided regurgitant lesions convey increased cardiac risk during noncardiac surgery but are better tolerated than stenotic valvular disease (88,89). AR and MR are associated with LV volume overload. To optimize forward cardiac output during anesthesia and surgery, 1) preload should be maintained because the LV has increased size and compliance, and 2) excessive systemic afterload should be avoided so as to augment cardiac output and reduce the regurgitation volume. For patients with severe AR or MR, the LV forward cardiac output is reduced because of the regurgitant volume.

Patients with moderate-to-severe AR and severe AR undergoing noncardiac surgery had a higher in-hospital mortality rate than did case-matched controls without AR (9.0% versus 1.8%; p=0.008) and a higher morbidity rate (16.2% versus 5.4%; p=0.003), including postoperative MI, stroke, pulmonary edema, intubation >24 hours, and major arrhythmia (88). Predictors of in-hospital death included depressed LVEF (ejection fraction [EF] <55%), renal dysfunction (creatinine >2 mg/dL), high surgical risk, and lack of preoperative cardiac medications. In the absence of trials addressing perioperative management, patients with moderate-to-severe AR and severe AR could be monitored with invasive hemodynamics and echocardiography and could be admitted postoperatively to an intensive care unit setting when undergoing surgical procedures with elevated risk.

In a single, tertiary-center study, patients with moderate-to-severe MR and severe MR undergoing nonemergency noncardiac surgery had a 30-day mortality rate similar to that of propensity score–matched controls without MR (1.7% versus 1.1%; p=0.43) (89). Patients with MR had worse primary outcomes (defined as composite of 30-day death and postoperative MI, HF, and stroke) than did patients without MR (22.2% versus 16.4%; p<0.02). Important predictors of postoperative adverse outcomes after noncardiac surgery were EF <35%, ischemic cause of MR, history of diabetes mellitus, and history of carotid endarterectomy. Patients with moderate-to-severe MR and severe MR undergoing noncardiac surgery should be monitored with invasive hemodynamics and echocardiography and admitted postoperatively to an intensive care unit setting when undergoing surgical procedures with elevated risk.

2.5. Arrhythmias and Conduction Disorders

Cardiac arrhythmias and conduction disorders are common findings in the perioperative period, particularly with increasing age. Although supraventricular and ventricular arrhythmias were identified as independent risk factors for perioperative cardiac events in the Original Cardiac Risk Index (48), subsequent studies indicated a lower level of risk (37,90,91). The paucity of studies that address surgical risk conferred by arrhythmias limits the ability to provide specific recommendations. General recommendations for assessing and treating arrhythmias can be found in other CPGs (14,92,93). In 1 study using continuous electrocardiographic monitoring, asymptomatic ventricular arrhythmias, including couplets and nonsustained ventricular tachycardia, were not associated with an increase in cardiac complications after noncardiac surgery (94). Nevertheless, the presence of an arrhythmia in the preoperative setting should prompt investigation into underlying cardiopulmonary disease, ongoing myocardial ischemia or MI, drug toxicity, or metabolic derangements, depending on the nature and acuity of the arrhythmia and the patient's history.

AF is the most common sustained tachyarrhythmia; it is particularly common in older patients who are likely to be undergoing surgical procedures. Patients with a preoperative history of AF who are clinically stable generally do not require modification of medical management or special evaluation in the perioperative period, other than adjustment of anticoagulation (Section 6.2.7). The potential for perioperative formation of left atrial thrombus in patients with persistent AF may need to be considered if the operation involves physical manipulation of the heart, as in certain thoracic procedures. Ventricular arrhythmias, whether single premature ventricular contractions or nonsustained ventricular tachycardia, usually do not require therapy unless they result in hemodynamic compromise or are associated with significant structural heart disease or inherited electrical disorders. Although frequent ventricular premature beats and nonsustained ventricular tachycardia are risk factors for the development of intraoperative and postoperative arrhythmias, they are not associated with an increased risk of nonfatal MI or cardiac death in the perioperative period (94,95). However, patients who develop sustained or nonsustained ventricular tachycardia during the perioperative period may require referral to a cardiologist for further evaluation, including assessment of their ventricular function and screening for CAD.

High-grade cardiac conduction abnormalities, such as complete atrioventricular block, if unanticipated, may increase operative risk and necessitate temporary or permanent transvenous pacing (96). However, patients with intraventricular conduction delays, even in the presence of a left or right bundle-branch block, and no history of advanced heart block or symptoms, rarely progress to complete atrioventricular block perioperatively (97). The presence of some pre-existing conduction disorders, such as sinus node dysfunction and atrioventricular block, requires caution if perioperative beta-blocker therapy is being considered. Isolated bundle-branch block and bifascicular block generally do not contraindicate use of beta blockers.

2.5.1. Cardiovascular Implantable Electronic Devices: Recommendation

See Section 6.4 for intraoperative/postoperative management of cardiovascular implantable electronic devices (CIEDs).

CLASS I

1. **Before elective surgery in a patient with a CIED, the surgical/procedure team and clinician following the CIED should communicate in advance to plan perioperative management of the CIED.** *(Level of Evidence: C)*

The presence of a pacemaker or ICD has important implications for preoperative, intraoperative, and postoperative patient management. Collectively termed CIEDs, these devices include single-chamber, dual-chamber, and biventricular hardware configurations produced by several different manufacturers, each with different software designs and programming features. Patients with CIEDs invariably have underlying cardiac disease that can involve arrhythmias, such as sinus node dysfunction, atrioventricular block, AF, and ventricular tachycardia; structural heart disease, such as ischemic or nonischemic cardiomyopathy; and clinical conditions, such as chronic HF or inherited arrhythmia syndromes. Preoperative evaluation of such patients should therefore encompass an awareness not only of the patient's specific CIED hardware and programming, but also of the underlying cardiac condition for which the device was implanted. In particular, cardiac rhythm and history of ventricular arrhythmias should be reviewed in patients with CIEDs.

To assist clinicians with the perioperative evaluation and management of patients with CIEDs, the HRS and the American Society of Anesthesiologists jointly developed an expert consensus statement published in July 2011 and endorsed by the ACC and the AHA (33). Clinicians caring for patients with CIEDs in the perioperative setting should be familiar with that document and the consensus recommendations contained within.

The HRS/American Society of Anesthesiologists expert consensus statement acknowledges that because of the complexity of modern devices and the variety of indications for which they are implanted, the perioperative management of patients with CIEDs must be individualized, and a single recommendation for all patients with CIEDs is not appropriate (33). Effective communication between the surgical/procedure team and the clinician following the patient with a CIED in the outpatient setting is the foundation of successful perioperative management and should take place well in advance of elective procedures. The surgical/procedure team should communicate with the CIED clinician/team to inform them of the nature of the planned procedure and the type of electromagnetic interference (EMI) (i.e., electrocautery) likely to be encountered. The outpatient team should formulate a prescription for the perioperative management of the CIED and communicate it to the surgical/procedure team.

The CIED prescription can usually be made from a review of patient records, provided that patients are evaluated at least annually (for pacemakers) or semiannually (for ICDs). In some circumstances, patients will require additional preoperative in-person evaluation or remote CIED interrogation. The prescription may involve perioperative CIED interrogation or reprogramming (including changing pacing to an asynchronous mode and/or inactivating ICD tachytherapies), application of a magnet over the CIED with or without postoperative CIED interrogation, or use of no perioperative CIED

interrogation or intervention (98,99). Details of individual prescriptions will depend on the nature and location of the operative procedure, likelihood of use of monopolar electrocautery, type of CIED (i.e., pacemaker versus ICD), and dependence of the patient on cardiac pacing.

See Online Data Supplement 26 for additional information on CIEDs.

2.6. Pulmonary Vascular Disease: Recommendations

CLASS I

1. **Chronic pulmonary vascular targeted therapy (i.e., phosphodiesterase type 5 inhibitors, soluble guanylate cyclase stimulators, endothelin receptor antagonists, and prostanoids) should be continued unless contraindicated or not tolerated in patients with pulmonary hypertension who are undergoing noncardiac surgery.** *(Level of Evidence: C)*

CLASS IIa

1. **Unless the risks of delay outweigh the potential benefits, preoperative evaluation by a pulmonary hypertension specialist before noncardiac surgery can be beneficial for patients with pulmonary hypertension, particularly for those with features of increased perioperative risk (100)*.** *(Level of Evidence: C)*

The evidence on the role of pulmonary hypertension in perioperative mortality and morbidity in patients undergoing noncardiac surgery is based on observational data and is predominantly related to Group 1 pulmonary hypertension (i.e., pulmonary arterial hypertension) (101–107). However, complication rates are consistently high, with mortality rates of 4% to 26% and morbidity rates, most notably cardiac and/or respiratory failure, of 6% to 42% (101–106). A variety of factors can occur during the perioperative period that may precipitate worsening hypoxia, pulmonary hypertension, or RV function. In addition to the urgency of the surgery and the surgical risk category, risk factors for perioperative adverse events in patients with pulmonary hypertension include the severity of pulmonary hypertension symptoms, the degree of RV dysfunction, and the performance of surgery in a center without expertise in pulmonary hypertension (101–106). Patients with pulmonary arterial hypertension due to other causes, particularly with features of increased perioperative risk, should undergo a thorough preoperative risk assessment in a center with the necessary medical and anesthetic expertise in pulmonary hypertension, including an assessment of functional capacity, hemodynamics, and echocardiography that includes evaluation of RV function. Right heart catheterization can also be used preoperatively to confirm the severity of illness and distinguish primary pulmonary hypertension from secondary causes of elevated pulmonary artery pressures, such as left-sided HF. Patients should have optimization of pulmonary hypertension and RV status preoperatively and should receive the necessary perioperative management on a case-by-case basis.

See Online Data Supplement 6 for additional information on pulmonary vascular disease.

2.7. Adult Congenital Heart Disease

Several case series have indicated that performance of a surgical procedure in patients with adult congenital heart disease (ACHD) carries a greater risk than in the normal population (108–113). The risk relates to the nature of the underlying ACHD, the surgical procedure, and the urgency of intervention (108–113). For more information, readers are referred to the specific recommendations for perioperative assessment in the ACC/AHA 2008 ACHD CPG (28). When possible, it is optimal to perform the preoperative evaluation of surgery for patients with ACHD in a regional center specializing in congenital cardiology, particularly for patient populations that appear to be at particularly high risk (e.g., those with a prior Fontan procedure, cyanotic ACHD, pulmonary arterial hypertension, clinical HF, or significant dysrhythmia).

3. CALCULATION OF RISK TO PREDICT PERIOPERATIVE CARDIAC MORBIDITY

3.1. Multivariate Risk Indices: Recommendations

See **Table 3** for a comparison of the RCRI, American College of Surgeons National Surgical Quality Improvement Program (NSQIP) Myocardial Infarction and Cardiac Arrest (MICA), and American College of Surgeons NSQIP Surgical Risk Calculator. See Online Data Supplement 7 for additional information on multivariate risk indices.

CLASS IIa

1. **A validated risk-prediction tool can be useful in predicting the risk of perioperative MACE in patients undergoing noncardiac surgery (37,114,115).** *(Level of Evidence: B)*

CLASS III: NO BENEFIT

1. **For patients with a low risk of perioperative MACE, further testing is not recommended before the planned operation (34,35).** *(Level of Evidence: B)*

Different noncardiac operations are associated with different risks of MACE. Operations for peripheral vascular disease are

*Features of increased perioperative risk in patients with pulmonary hypertension include: 1) diagnosis of Group 1 pulmonary hypertension (i.e., pulmonary arterial hypertension), 2) other forms of pulmonary hypertension associated with high pulmonary pressures (pulmonary artery systolic pressures >70 mm Hg) and/or moderate or greater RV dilatation and/or dysfunction and/or pulmonary vascular resistance >3 Wood units, and 3) World Health Organization/New York Heart Association class III or IV symptoms attributable to pulmonary hypertension (101–107).

generally performed among those with the highest perioperative risk (116). The lowest-risk operations are generally those without significant fluid shifts and stress. Plastic surgery and cataract surgery are associated with a very low risk of MACE (34). Some operations can have their risk lowered by taking a less invasive approach. For example, open aortic aneurysm repair has a high risk of MACE that is lowered when the procedure is performed endovascularly (117). The number of different surgical procedures makes assigning a specific risk of a MACE to each procedure difficult. In addition, performing an operation in an emergency situation is understood to increase risk.

The RCRI is a simple, validated, and accepted tool to assess perioperative risk of major cardiac complications (MI, pulmonary edema, ventricular fibrillation or primary cardiac arrest, and complete heart block) (37). It has 6 predictors of risk for major cardiac complications, only 1 of which is based on the procedure—namely, "Undergoing suprainguinal vascular, intraperitoneal, or intrathoracic surgery." A patient with 0 or 1 predictor(s) of risk would have a low risk of MACE. Patients with ≥2 predictors of risk would have elevated risk.

Two newer tools have been created by the American College of Surgeons, which prospectively collected data on operations performed in more than 525 participating hospitals in the United States. Data on more than 1 million operations have been used to create these risk calculators (114) (www.riskcalculator.facs.org).

The American College of Surgeons NSQIP MICA risk-prediction rule was created in 2011 (115), with a single study—albeit large and multicenter—describing its derivation and validation (http://www.surgicalriskcalculator.com/miorcardiacarrest). This tool includes adjusted ORs for different surgical sites, with inguinal hernia as the reference group. Target complications were defined as cardiac arrest (defined as "chaotic cardiac rhythm requiring initiation of basic or advanced life support") or MI (defined as ≥1 of the following: documented electrocardiographic findings of MI, ST elevation of ≥1 mm in >1 contiguous leads, new left bundle-branch block, new Q-wave in ≥2 contiguous leads, or troponin >3 times normal in setting of suspected ischemia). Using these definitions of outcome and chart-based data collection methods, the authors of the risk calculator derived a risk index that was robust in the derivation and validation stages and appeared to outperform the RCRI (which was tested in the same dataset) in discriminative power, particularly among patients undergoing vascular surgery.

The American College of Surgeons NSQIP Surgical Risk Calculator uses the specific current procedural terminology code of the procedure being performed to enable procedure-specific risk assessment for a diverse group of outcomes (114). The procedure is defined as being an emergency case or not an emergency case. For the American College of Surgeons NSQIP, to be an emergency case, the "principal operative procedure must be performed during the hospital admission for the diagnosis AND the surgeon and/or anesthesiologist must report the case as emergent" (118). The calculator also includes 21 patient-specific variables (e.g., age, sex, body mass index, dyspnea, previous MI, functional status). From this input, it calculates the percentage risk of a MACE, death, and 8 other outcomes. This risk calculator may offer the best estimation of surgery-specific risk of a MACE and death.

Some limitations to the NSQIP-based calculator should be noted: It has not been validated in an external population outside the NSQIP, and the definition of MI includes only ST-segment MIs or a large troponin bump (>3 times normal) that occurred in symptomatic patients. An additional disadvantage is the use of the American Society of Anesthesiology Physical Status Classification, a common qualitatively derived risk score used by anesthesiologists. This classification has poor inter-rater reliability even among anesthesiologists and may be unfamiliar to clinicians outside that specialty (119,120). Clinicians would also need to familiarize themselves with the NSQIP definitions of functional status or "dependence," concepts that are thought to be important in perioperative risk assessment algorithms but that have not been included in multivariable risk indices to date (for more information on functional status, see Section 4).

3.2. Inclusion of Biomarkers in Multivariable Risk Models

Several studies have examined the potential utility of including biomarkers—most commonly preoperative natriuretic peptides (brain natriuretic peptide or N-terminal probrain natriuretic peptide) and C-reactive protein—in preoperative risk indices as an approach to identify patients at highest risk (64,121–125). These studies and 2 subsequent meta-analyses suggest that biomarkers may provide incremental predictive value (62,66). However, most studies had significant variation in the time frame in which these biomarkers were obtained, were observational, did not include a control arm, and did not require biomarkers routinely or prospectively. Furthermore, there are no data to suggest that targeting these biomarkers for treatment and intervention will reduce the postoperative risk. In addition, several of these studies were investigations conducted by Poldermans (121,126–130).

4. APPROACH TO PERIOPERATIVE CARDIAC TESTING

4.1. Exercise Capacity and Functional Capacity

Functional status is a reliable predictor of perioperative and long-term cardiac events. Patients with reduced functional status preoperatively are at increased risk of complications. Conversely, those with good functional

TABLE 3 Comparison of the RCRI, the American College of Surgeons NSQIP MICA, and the American College of Surgeons NSQIP Surgical Risk Calculator

	RCRI (131)	American College of Surgeons NSQIP MICA (115)	American College of Surgeons NSQIP Surgical Risk Calculator (114)
Criteria	…	Increasing age	Age
	Creatinine ≥2 mg/dL	Creatinine >1.5 mg/dL	Acute renal failure
	HF	…	HF
	…	Partially or completely dependent functional status	Functional status
	Insulin-dependent diabetes mellitus	…	Diabetes mellitus
	Intrathoracic, intra-abdominal, or suprainguinal vascular surgery	Surgery type: • Anorectal • Aortic • Bariatric • Brain • Breast • Cardiac • ENT • Foregut/hepatopancreatobiliary • Gallbladder/adrenal/appendix/spleen • Intestinal • Neck • Obstetric/gynecological • Orthopedic • Other abdomen • Peripheral vascular • Skin • Spine • Thoracic • Vein • Urologic	Procedure (CPT Code)
	History of cerebrovascular accident or TIA	…	…
	…	…	American Society of Anesthesiologists Physical Status Class
	…	…	Wound class
	…	…	Ascites
	…	…	Systemic sepsis
	…	…	Ventilator dependent
	…	…	Disseminated cancer
	…	…	Steroid use
	…	…	Hypertension
	Ischemic heart disease	…	Previous cardiac event
	…	…	Sex
	…	…	Dyspnea
	…	…	Smoker
	…	…	COPD
	…	…	Dialysis
	…	…	Acute kidney injury
	…	…	BMI
	…	…	Emergency case

Continued on the next page

status preoperatively are at lower risk. Moreover, in highly functional asymptomatic patients, it is often appropriate to proceed with planned surgery without further cardiovascular testing.

If a patient has not had a recent exercise test before noncardiac surgery, functional status can usually be estimated from activities of daily living (132). Functional capacity is often expressed in terms of metabolic equivalents (METs), where 1 MET is the resting or basal oxygen consumption of a 40-year-old, 70-kg man. In the perioperative literature, functional capacity is classified as excellent (>10 METs), good (7 METs to 10 METs),

TABLE 3 Continued

	RCRI (131)	American College of Surgeons NSQIP MICA (115)	American College of Surgeons NSQIP Surgical Risk Calculator (114)
Use outside original cohort	Yes	No	No
Sites	Most often single-site studies, but findings consistent in multicenter studies	Multicenter	Multicenter
Outcome and risk factor ascertainment	Original: research staff, multiple subsequent studies using variety of data collection strategies	Trained nurses, no prospective cardiac outcome ascertainment	Trained nurses, no prospective cardiac outcome ascertainment
Calculation method	Single point per risk factor	Web-based or open-source spreadsheet for calculation (http://www.surgicalriskcalculator.com/miorcardiacarrest)	Web-based calculator (www.riskcalculator.facs.org)

BMI indicates body mass index; COPD, chronic obstructive pulmonary disease; CPT, current procedural terminology; ENT, ear, nose, and throat; HF, heart failure; NSQIP MICA, National Surgical Quality Improvement Program Myocardial Infarction Cardiac Arrest; NSQIP, National Surgical Quality Improvement Program; RCRI, Revised Cardiac Risk Index; TIA, transient ischemic attack; and …, not applicable.

moderate (4 METs to 6 METs), poor (<4 METs), or unknown. Perioperative cardiac and long-term risks are increased in patients unable to perform 4 METs of work during daily activities. Examples of activities associated with <4 METs are slow ballroom dancing, golfing with a cart, playing a musical instrument, and walking at approximately 2 mph to 3 mph. Examples of activities associated with >4 METs are climbing a flight of stairs or walking up a hill, walking on level ground at 4 mph, and performing heavy work around the house.

Functional status can also be assessed more formally by activity scales, such as the DASI (Duke Activity Status Index) (**Table 4**) (133) and the Specific Activity Scale (134). In 600 consecutive patients undergoing noncardiac surgery, perioperative myocardial ischemia and cardiovascular events were more common in those with poor functional status (defined as the inability to walk 4 blocks or climb 2 flights of stairs) even after adjustment for other risk factors (132). The likelihood of a serious complication was inversely related to the number of blocks that could be walked (p=0.006) or flights of stairs that could be climbed (p=0.01). Analyses from the American College of Surgeons NSQIP dataset have shown that dependent functional status, based on the need for assistance with activities of daily living rather than on METs, is associated with significantly increased risk of perioperative morbidity and mortality (135,136).

See Online Data Supplement 8 for additional information on exercise capacity and functional capacity.

4.2. Stepwise Approach to Perioperative Cardiac Assessment: Treatment Algorithm

See **Figure 1** for a stepwise approach to perioperative cardiac assessment.

The GWC developed an algorithmic approach to perioperative cardiac assessment on the basis of the

TABLE 4 Duke Activity Status Index

Activity	Weight
Can you…	
1. take care of yourself, that is, eating, dressing, bathing, or using the toilet?	2.75
2. walk indoors, such as around your house?	1.75
3. walk a block or 2 on level ground?	2.75
4. climb a flight of stairs or walk up a hill?	5.50
5. run a short distance?	8.00
6. do light work around the house like dusting or washing dishes?	2.70
7. do moderate work around the house like vacuuming, sweeping floors, or carrying in groceries?	3.50
8. do heavy work around the house like scrubbing floors or lifting or moving heavy furniture?	8.00
9. do yardwork like raking leaves, weeding, or pushing a power mower?	4.50
10. have sexual relations?	5.25
11. participate in moderate recreational activities like golf, bowling, dancing, doubles tennis, or throwing a baseball or football?	6.00
12. participate in strenuous sports like swimming, singles tennis, football, basketball, or skiing?	7.50

Reproduced with permission from Hlatky et al. (133).

available evidence and expert opinion, the rationale of which is outlined throughout the CPG. The algorithm incorporates the perspectives of clinicians caring for the patient to provide informed consent and help guide perioperative management to minimize risk. It is also crucial to incorporate the patient's perspective with regard to the assessment of the risk of surgery or alternative therapy and the risk of any GDMT or coronary and valvular interventions before noncardiac surgery. Patients may elect to forgo a surgical intervention if the risk of perioperative morbidity and mortality is extremely high; soliciting this information from the patient before surgery is a key part of shared decision making.

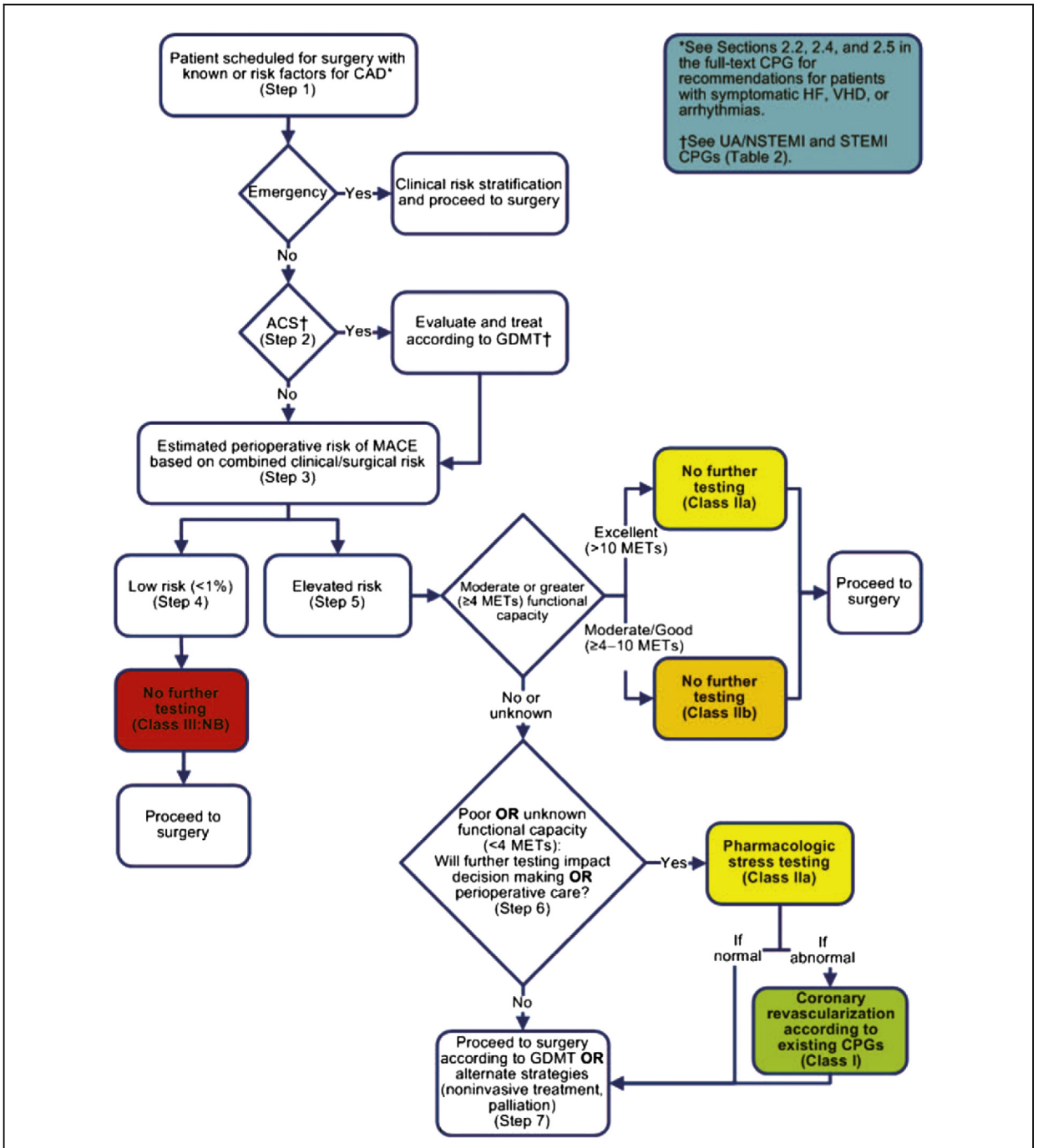

FIGURE 1 Stepwise Approach to Perioperative Cardiac Assessment for CAD

Continued on the next page

5. SUPPLEMENTAL PREOPERATIVE EVALUATION

See **Table 5** for a summary of recommendations for supplemental preoperative evaluation.

5.1. The 12-Lead Electrocardiogram: Recommendations

CLASS IIa

1. **Preoperative resting 12-lead electrocardiogram (ECG) is reasonable for patients with known coronary heart disease, significant arrhythmia, peripheral arterial disease, cerebrovascular disease, or other significant structural heart disease, except for those undergoing low-risk surgery (137–139).** *(Level of Evidence: B)*

CLASS IIb

1. **Preoperative resting 12-lead ECG may be considered for asymptomatic patients without known coronary heart disease, except for those undergoing low-risk surgery (37,138–140).** *(Level of Evidence: B)*

CLASS III: NO BENEFIT

1. **Routine preoperative resting 12-lead ECG is not useful for asymptomatic patients undergoing low-risk surgical procedures (35,141).** *(Level of Evidence: B)*

In patients with established coronary heart disease, the resting 12-lead ECG contains prognostic information relating to short- and long-term morbidity and mortality. In addition, the preoperative ECG may provide a useful baseline standard against which to measure changes in the postoperative period. For both reasons, particularly the latter, the value of the preoperative 12-lead ECG is likely to increase with the risk of the surgical procedure, particularly for patients with known coronary heart disease, arrhythmias, peripheral arterial disease, cerebrovascular disease, or other significant structural heart disease (137,138).

The prognostic significance of numerous electrocardiographic abnormalities has been identified in observational studies, including arrhythmias (48,142), pathological Q-waves (37,142), LV hypertrophy (139,142), ST depressions (137,139,142), QTc interval prolongation (138,143), and bundle-branch blocks (140,142). However, there is poor concordance across different observational studies as to which abnormalities have prognostic significance and which do not; a minority of studies found no prognostic significance in the preoperative ECG (141,144,145). The implications of abnormalities on the preoperative 12-lead ECG, increase with patient age and with risk factors for coronary heart disease. However, a standard age or risk factor cutoff for use of preoperative electrocardiographic testing has not been defined. Likewise, the optimal time interval between obtaining a 12-lead ECG and elective surgery is unknown. General consensus suggests that an interval of 1 to 3 months is adequate for stable patients.

See Online Data Supplement 9 for additional information on the 12-lead ECG.

FIGURE 1 LEGEND

Colors correspond to the Classes of Recommendations in Table 1. **Step 1:** In patients scheduled for surgery with risk factors for or known CAD, determine the urgency of surgery. If an emergency, then determine the clinical risk factors that may influence perioperative management and proceed to surgery with appropriate monitoring and management strategies based on the clinical assessment (see Section 2.1 for more information on CAD). (For patients with symptomatic HF, VHD, or arrhythmias, see Sections 2.2, 2.4, and 2.5 for information on evaluation and management.) **Step 2:** If the surgery is urgent or elective, determine if the patient has an ACS. If yes, then refer patient for cardiology evaluation and management according to GDMT according to the UA/NSTEMI and STEMI CPGs (18,20). **Step 3:** If the patient has risk factors for stable CAD, then estimate the perioperative risk of MACE on the basis of the combined clinical/surgical risk. This estimate can use the American College of Surgeons NSQIP risk calculator (http://www.surgicalriskcalculator.com) or incorporate the RCRI (131) with an estimation of surgical risk. For example, a patient undergoing very low-risk surgery (e.g., ophthalmologic surgery), even with multiple risk factors, would have a low risk of MACE, whereas a patient undergoing major vascular surgery with few risk factors would have an elevated risk of MACE (Section 3). **Step 4:** If the patient has a low risk of MACE (<1%), then no further testing is needed, and the patient may proceed to surgery (Section 3). **Step 5:** If the patient is at elevated risk of MACE, then determine functional capacity with an objective measure or scale such as the DASI (133). If the patient has moderate, good, or excellent functional capacity (≥4 METs), then proceed to surgery without further evaluation (Section 4.1). **Step 6:** If the patient has poor (<4 METs) or unknown functional capacity, then the clinician should consult with the patient and perioperative team to determine whether further testing will impact patient decision making (e.g., decision to perform original surgery or willingness to undergo CABG or PCI, depending on the results of the test) or perioperative care. If yes, then pharmacological stress testing is appropriate. In those patients with unknown functional capacity, exercise stress testing may be reasonable to perform. If the stress test is abnormal, consider coronary angiography and revascularization depending on the extent of the abnormal test. The patient can then proceed to surgery with GDMT or consider alternative strategies, such as noninvasive treatment of the indication for surgery (e.g., radiation therapy for cancer) or palliation. If the test is normal, proceed to surgery according to GDMT (Section 5.3). **Step 7:** If testing will not impact decision making or care, then proceed to surgery according to GDMT or consider alternative strategies, such as noninvasive treatment of the indication for surgery (e.g., radiation therapy for cancer) or palliation. ACS indicates acute coronary syndrome; CABG, coronary artery bypass graft; CAD, coronary artery disease; CPG, clinical practice guideline; DASI, Duke Activity Status Index; GDMT, guideline-directed medical therapy; HF, heart failure; MACE, major adverse cardiac event; MET, metabolic equivalent; NB, No Benefit; NSQIP, National Surgical Quality Improvement Program; PCI, percutaneous coronary intervention; RCRI, Revised Cardiac Risk Index; STEMI, ST-elevation myocardial infarction; UA/NSTEMI, unstable angina/non-ST-elevation myocardial infarction; and VHD, valvular heart disease.

TABLE 5 Summary of Recommendations for Supplemental Preoperative Evaluation

Recommendations	COR	LOE	References
The 12-lead ECG			
Preoperative resting 12-lead ECG is reasonable for patients with known coronary heart disease or other significant structural heart disease, except for low-risk surgery	IIa	B	(137–139)
Preoperative resting 12-lead ECG may be considered for asymptomatic patients, except for low-risk surgery	IIb	B	(37,138–140)
Routine preoperative resting 12-lead ECG is not useful for asymptomatic patients undergoing low-risk surgical procedures	III: No Benefit	B	(35,141)
Assessment of LV function			
It is reasonable for patients with dyspnea of unknown origin to undergo preoperative evaluation of LV function	IIa	C	N/A
It is reasonable for patients with HF with worsening dyspnea or other change in clinical status to undergo preoperative evaluation of LV function	IIa	C	N/A
Reassessment of LV function in clinically stable patients may be considered	IIb	C	N/A
Routine preoperative evaluation of LV function is not recommended	III: No Benefit	B	(146–148)
Exercise stress testing for myocardial ischemia and functional capacity			
For patients with elevated risk and excellent functional capacity, it is reasonable to forgo further exercise testing and proceed to surgery	IIa	B	(132,135,136,162,163)
For patients with elevated risk and unknown functional capacity it may be reasonable to perform exercise testing to assess for functional capacity if it will change management	IIb	B	(162–164)
For patients with elevated risk and moderate to good functional capacity, it may be reasonable to forgo further exercise testing and proceed to surgery	IIb	B	(132,135,136)
For patients with elevated risk and poor or unknown functional capacity it may be reasonable to perform exercise testing with cardiac imaging to assess for myocardial ischemia	IIb	C	N/A
Routine screening with noninvasive stress testing is not useful for low-risk noncardiac surgery	III: No Benefit	B	(165,166)
Cardiopulmonary exercise testing			
Cardiopulmonary exercise testing may be considered for patients undergoing elevated risk procedures	IIb	B	(171–179)
Noninvasive pharmacological stress testing before noncardiac surgery			
It is reasonable for patients at elevated risk for noncardiac surgery with poor functional capacity to undergo either DSE or MPI if it will change management	IIa	B	(183–187)
Routine screening with noninvasive stress testing is not useful for low-risk noncardiac surgery	III: No Benefit	B	(165,166)
Preoperative coronary angiography			
Routine preoperative coronary angiography is not recommended	III: No Benefit	C	N/A

COR indicates Class of Recommendation; DSE, dobutamine stress echocardiogram; ECG, electrocardiogram; HF, heart failure; LOE, Level of Evidence; LV, left ventricular; MPI, myocardial perfusion imaging; and N/A, not applicable.

5.2. Assessment of LV Function: Recommendations

CLASS IIa

1. It is reasonable for patients with dyspnea of unknown origin to undergo preoperative evaluation of LV function. *(Level of Evidence: C)*
2. It is reasonable for patients with HF with worsening dyspnea or other change in clinical status to undergo preoperative evaluation of LV function. *(Level of Evidence: C)*

CLASS IIb

1. Reassessment of LV function in clinically stable patients with previously documented LV dysfunction may be considered if there has been no assessment within a year. *(Level of Evidence: C)*

CLASS III: NO BENEFIT

1. Routine preoperative evaluation of LV function is not recommended (146–148). *(Level of Evidence: B)*

The relationship between measures of resting LV systolic function (most commonly LVEF) and perioperative events has been evaluated in several studies of subjects before noncardiac surgery (56,58,146–161). These studies demonstrate an association between reduced LV systolic function and perioperative complications, particularly postoperative HF. The association is strongest in patients at high risk for death. Complication risk is associated with the degree of systolic dysfunction, with the greatest risk seen in patients with an LVEF at rest <35%. A preoperatively assessed low EF has a low sensitivity but a relatively high specificity for the prediction of perioperative cardiac events. However, it has only modest incremental predictive power over clinical risk factors. The role of echocardiography in the prediction of risk in patients with clinical HF is less well studied. A cohort of patients with a history of HF demonstrated that preoperative LVEF <30% was associated with an increased risk of perioperative

complications (55). Data are sparse on the value of preoperative diastolic function assessment and the risk of cardiac events (58,59).

In patients who are candidates for potential solid organ transplantation, a transplantation-specific CPG has suggested it is appropriate to perform preoperative LV function assessment by echocardiography (31).

See Online Data Supplement 10 for additional information on assessment of LV function.

5.3. Exercise Stress Testing for Myocardial Ischemia and Functional Capacity: Recommendations

CLASS IIa

1. For patients with elevated risk and excellent (>10 METs) functional capacity, it is reasonable to forgo further exercise testing with cardiac imaging and proceed to surgery (132,135,136,162,163). *(Level of Evidence: B)*

CLASS IIb

1. For patients with elevated risk and unknown functional capacity, it may be reasonable to perform exercise testing to assess for functional capacity if it will change management (162–164). *(Level of Evidence: B)*
2. For patients with elevated risk and moderate to good (≥4 METs to 10 METs) functional capacity, it may be reasonable to forgo further exercise testing with cardiac imaging and proceed to surgery (132,135,136). *(Level of Evidence: B)*
3. For patients with elevated risk and poor (<4 METs) or unknown functional capacity, it may be reasonable to perform exercise testing with cardiac imaging to assess for myocardial ischemia if it will change management. *(Level of Evidence: C)*

CLASS III: NO BENEFIT

1. Routine screening with noninvasive stress testing is not useful for patients at low risk for noncardiac surgery (165,166). *(Level of Evidence: B)*

Several studies have examined the role of exercise testing to identify patients at risk for perioperative complications. (162–164,167–170) Almost all of these studies were conducted in patients undergoing peripheral vascular surgery, because these patients are generally considered to be at the highest risk (162,164,167–169). Although they were important contributions at the time, the outcomes in most of these studies are not reflective of contemporary perioperative event rates, nor was the patient management consistent with current standards of preventive and perioperative cardiac care. Furthermore, many used stress protocols that are not commonly used today, such as non-Bruce protocol treadmill tests or arm ergometry. However, from the available data, patients able to achieve approximately 7 METs to 10 METs have a low risk of perioperative cardiovascular events (162,164), and those achieving <4 METs to 5 METs have an increased risk of perioperative cardiovascular events (163,164). Electrocardiographic changes with exercise are not as predictive (162–164,169).

The vast majority of data on the impact of inducible myocardial ischemia on perioperative outcomes are based on pharmacological stress testing (Sections 5.5.1–5.5.3), but it seems reasonable that exercise stress echocardiography or radionuclide myocardial perfusion imaging (MPI) would perform similarly to pharmacological stress testing in patients who are able to exercise adequately.

See Online Data Supplement 11 for additional information on exercise stress testing for myocardial ischemia and functional capacity.

5.4. Cardiopulmonary Exercise Testing: Recommendation

CLASS IIb

1. Cardiopulmonary exercise testing may be considered for patients undergoing elevated risk procedures in whom functional capacity is unknown (171–179). *(Level of Evidence: B)*

Cardiopulmonary exercise testing has been studied in different settings, including before abdominal aortic aneurysm surgery (172–174,180); major abdominal surgery (including abdominal aortic aneurysm resection) (175–177); hepatobiliary surgery (178); complex hepatic resection (171); lung resection (181); and colorectal, bladder, or kidney cancer surgery (179). These studies varied in patient population, definition of perioperative complications, and what was done with the results of preoperative testing, including decisions about the appropriateness of proceeding with surgery. However, a consistent finding among the studies was that a low anaerobic threshold was predictive of perioperative cardiovascular complications (171,173,177), postoperative death (172,174,175), or midterm and late death after surgery (174,179,180). An anaerobic threshold of approximately 10 mL O_2/kg/min was proposed as the optimal discrimination point, with a range in these studies of 9.9 mL O_2/kg/min to 11 mL O_2/kg/min. Although exercise tolerance can be estimated from instruments such as the DASI (133) or the incremental shuttle walk test, in 1 study, a significant number of patients with poor performance by these measures had satisfactory peak oxygen consumption and anaerobic threshold on cardiopulmonary exercise testing (182). That particular study was not powered to look at postoperative outcomes.

See Online Data Supplement 12 for additional information on cardiopulmonary exercise testing.

5.5. Pharmacological Stress Testing

5.5.1. Noninvasive Pharmacological Stress Testing Before Noncardiac Surgery: Recommendations

CLASS IIa

1. It is reasonable for patients who are at an elevated risk for noncardiac surgery and have poor functional capacity

(<4 METs) to undergo noninvasive pharmacological stress testing (either dobutamine stress echocardiogram [DSE] or pharmacological stress MPI) if it will change management (183–187). ***(Level of Evidence: B)***

CLASS III: NO BENEFIT

1. **Routine screening with noninvasive stress testing is not useful for patients undergoing low-risk noncardiac surgery (165,166).** ***(Level of Evidence: B)***

Pharmacological stress testing with DSE, dipyridamole/adenosine/regadenoson MPI with thallium-201, and/or technetium-99m and rubidium-82 can be used in patients undergoing noncardiac surgery who cannot perform exercise to detect stress-induced myocardial ischemia and CAD. At the time of GWC deliberations, publications in this area confirmed findings of previous studies rather than providing new insight as to the optimal noninvasive pharmacological preoperative stress testing strategy (31,60,149,165,183–185,188–204).

Despite the lack of RCTs on the use of preoperative stress testing, a large number of single-site studies using either DSE or MPI have shown consistent findings. These findings can be summarized as follows:

- The presence of moderate to large areas of myocardial ischemia is associated with increased risk of perioperative MI and/or death.
- A normal study for perioperative MI and/or cardiac death has a very high negative predictive value.
- The presence of an old MI identified on rest imaging is of little predictive value for perioperative MI or cardiac death.
- Several meta-analyses have shown the clinical utility of pharmacological stress testing in the preoperative evaluation of patients undergoing noncardiac surgery.

In terms of which pharmacological test to use, there are no RCTs comparing DSE with pharmacological MPI perioperatively. A retrospective, meta-analysis comparing MPI (thallium imaging) and stress echocardiography in patients scheduled for elective noncardiac surgery showed that a moderate to large defect (present in 14% of the population) detected by either method predicted postoperative cardiac events. The authors identified a slight superiority of stress echocardiography relative to nongated MPI with thallium in predicting postoperative cardiac events (204). However, in light of the lack of RCT data, local expertise in performing pharmacological stress testing should be considered in decisions about which pharmacological stress test to use.

The recommendations in this CPG do not specifically address the preoperative evaluation of patients for kidney or liver transplantation because the indications for stress testing may reflect both perioperative and long-term outcomes in this population. The reader is directed to the AHA/ACC scientific statement titled "Cardiac disease evaluation and management among kidney and liver transplantation candidates" for further recommendations (31).

See Online Data Supplement 13 for additional information on noninvasive pharmacological stress testing before noncardiac surgery.

5.5.2. Radionuclide MPI

The role of MPI in preoperative risk assessment in patients undergoing noncardiac surgery has been evaluated in several studies (166,190,193,195,197,199,202–206). The majority of MPI studies show that moderate to large reversible perfusion defects, which reflect myocardial ischemia, carry the greatest risk of perioperative cardiac death or MI. In general, an abnormal MPI test is associated with very high sensitivity for detecting patients at risk for perioperative cardiac events. The negative predictive value of a normal MPI study is high for MI or cardiac death, although postoperative cardiac events do occur in this population (204). Most studies have shown that a fixed perfusion defect, which reflects infarcted myocardium, has a low positive predictive value for perioperative cardiac events. However, patients with fixed defects have shown increased risk for long-term events relative to patients with a normal MPI test, which likely reflects the fact that they have CAD. Overall, a reversible myocardial perfusion defect predicts perioperative events, whereas a fixed perfusion defect predicts long-term cardiac events.

See Online Data Supplement 14 for additional information on radionuclide MPI.

5.5.3. Dobutamine Stress Echocardiography

The role of DSE in preoperative risk assessment in patients undergoing noncardiac surgery has been evaluated in several studies (186,187,207–220). The definition of an abnormal stress echocardiogram in some studies was restricted to the presence of new wall motion abnormalities with stress, indicative of myocardial ischemia, but in others also included the presence of akinetic segments at baseline, indicative of MI. These studies have predominantly evaluated the role of DSE in patients with an increased perioperative cardiovascular risk, particularly those undergoing abdominal aortic or peripheral vascular surgery. In many studies, the results of the DSE were available to the managing clinicians and surgeons, which influenced perioperative management, including the preoperative use of diagnostic coronary angiography and coronary revascularization, and which intensified medical management, including beta blockade.

Overall, the data suggest that DSE appears safe and feasible as part of a preoperative assessment. Safety and feasibility have been demonstrated specifically in

patients with abdominal aortic aneurysms, peripheral vascular disease, morbid obesity, and severe chronic obstructive pulmonary disease—populations in which there had previously been safety concerns (186,187,213,214,220–222). Overall, a positive test result for DSE was reported in the range of 5% to 50%. In these studies, with event rates of 0% to 15%, the ability of a positive test result to predict an event (nonfatal MI or death) ranged from 0% to 37%. The negative predictive value is invariably high, typically in the range of 90% to 100%. In interpreting these values, one must consider the overall perioperative risk of the population and the potential results stress imaging had on patient management. Several large studies reporting the value of DSE in the prediction of cardiac events during noncardiac surgery for which Poldermans was the senior author are not included in the corresponding data supplement table (223–225); however, regardless of whether the evidence includes these studies, conclusions are similar.

See Online Data Supplement 15 for additional information on DSE.

5.6. Stress Testing—Special Situations

In most ambulatory patients, exercise electrocardiographic testing can provide both an estimate of functional capacity and detection of myocardial ischemia through changes in the electrocardiographic and hemodynamic response. In many settings, an exercise stress ECG is combined with either echocardiography or MPI. In the perioperative period, most patients undergo pharmacological stress testing with either MPI or DSE.

In patients undergoing stress testing with abnormalities on their resting ECG that impair diagnostic interpretation (e.g., left bundle-branch block, LV hypertrophy with "strain" pattern, digitalis effect), concomitant stress imaging with echocardiography or MPI may be an appropriate alternative. In patients with left bundle-branch block, exercise MPI has an unacceptably low specificity because of septal perfusion defects that are not related to CAD. For these patients, pharmacological stress MPI, particularly with adenosine, dipyridamole, or regadenoson, is suggested over exercise stress imaging.

In patients with indications for stress testing who are unable to perform adequate exercise, pharmacological stress testing with either DSE or MPI may be appropriate. There are insufficient data to support the use of dobutamine stress magnetic resonance imaging in preoperative risk assessment (221).

Intravenous dipyridamole and adenosine should be avoided in patients with significant heart block, bronchospasm, critical carotid occlusive disease, or a condition that prevents their being withdrawn from theophylline preparations or other adenosine antagonists; regadenoson has a more favorable side-effect profile and appears safe for use in patients with bronchospasm. Dobutamine should be avoided in patients with serious arrhythmias or severe hypertension. All stress agents should be avoided in unstable patients. In patients in whom echocardiographic image quality is inadequate for wall motion assessment, such as those with morbid obesity or severe chronic obstructive lung disease, intravenous echocardiography contrast (187,222) or alternative methods, such as MPI, may be appropriate. An echocardiographic stress test is favored if an assessment of valvular function or pulmonary hypertension is clinically important. In many instances, either exercise stress echocardiography/DSE or MPI may be appropriate, and local expertise may help dictate the choice of test.

At the time of publication, evidence did not support the use of an ambulatory ECG as the only diagnostic test to refer patients for coronary angiography, but it may be appropriate in rare circumstances to direct medical therapy.

5.7. Preoperative Coronary Angiography: Recommendation

CLASS III: NO BENEFIT

1. **Routine preoperative coronary angiography is not recommended.** *(Level of Evidence: C)*

Data are insufficient to recommend the use of coronary angiography in all patients (i.e., routine testing), including for those patients undergoing any specific elevated-risk surgery. In general, indications for preoperative coronary angiography are similar to those identified for the nonoperative setting. The decreased risk of coronary computerized tomography angiography compared with invasive angiography may encourage its use to determine preoperatively the presence and extent of CAD. However, any additive value in decision making of coronary computed tomography angiography and calcium scoring is uncertain, given that data are limited and involve patients undergoing noncardiac surgery (226).

The recommendations in this CPG do not specifically address the preoperative evaluation of patients for kidney or liver transplantation because the indications for angiography may be different. The reader is directed to the AHA/ACC scientific statement titled "Cardiac disease evaluation and management among kidney and liver transplantation candidates" for further recommendations (31).

See Online Data Supplement 16 for additional information on preoperative coronary angiography.

6. PERIOPERATIVE THERAPY

See **Table 6** for a summary of recommendations for perioperative therapy.

6.1. Coronary Revascularization Before Noncardiac Surgery: Recommendations

CLASS I

1. Revascularization before noncardiac surgery is recommended in circumstances in which revascularization is indicated according to existing CPGs (25,26). *(Level of Evidence: C)* (See Table A in Appendix 3 for related recommendations.)

CLASS III: NO BENEFIT

1. It is not recommended that routine coronary revascularization be performed before noncardiac surgery exclusively to reduce perioperative cardiac events (116). *(Level of Evidence: B)*

Patients undergoing risk stratification before elective noncardiac procedures and whose evaluation recommends CABG surgery should undergo coronary revascularization before an elevated-risk surgical procedure (227). The cumulative mortality and morbidity risks of both the coronary revascularization procedure and the noncardiac surgery should be weighed carefully in light of the individual patient's overall health, functional status, and prognosis. The indications for preoperative surgical coronary revascularization are identical to those recommended in the 2011 CABG CPG and the 2011 PCI CPG and the accumulated data on which those conclusions were based (25,26) (See Table A in Appendix 3 for the related recommendations).

The role of preoperative PCI in reducing untoward perioperative cardiac complications is uncertain given the available data. Performing PCI before noncardiac surgery should be limited to 1) patients with left main disease whose comorbidities preclude bypass surgery without undue risk and 2) patients with unstable CAD who would be appropriate candidates for emergency or urgent revascularization (25,26). Patients with ST-elevation MI or non-ST-elevation acute coronary syndrome benefit from early invasive management (26). In such patients, in whom noncardiac surgery is time sensitive despite an increased risk in the perioperative period, a strategy of balloon angioplasty or bare-metal stent (BMS) implantation should be considered.

There are no prospective RCTs supporting coronary revascularization, either CABG or PCI, before noncardiac surgery to decrease intraoperative and postoperative cardiac events. In the largest RCT, CARP (Coronary Artery Revascularization Prophylaxis), there were no differences in perioperative and long-term cardiac outcomes with or without preoperative coronary revascularization by CABG or PCI in patients with documented CAD, with the exclusion of those with left main disease, a LVEF <20%, and severe AS (116). A follow-up analysis reported improved outcomes in the subset who underwent CABG compared with those who underwent PCI (228). In an additional analysis of the database of patients who underwent coronary angiography in both the randomized and nonrandomized portion of the CARP trial, only the subset of patients with unprotected left main disease showed a benefit from preoperative coronary artery revascularization (229). A second RCT also demonstrated no benefit from preoperative testing and directed coronary revascularization in patients with 1 to 2 risk factors for CAD (230), but the conduct of the trial was questioned at the time of the GWC's discussions (9).

See Online Data Supplement 17 for additional information on coronary revascularization before noncardiac surgery.

6.1.1. Timing of Elective Noncardiac Surgery in Patients With Previous PCI: Recommendations

CLASS I

1. Elective noncardiac surgery should be delayed 14 days after balloon angioplasty *(Level of Evidence: C)* and 30 days after BMS implantation (231–233). *(Level of Evidence B)*
2. Elective noncardiac surgery should optimally be delayed 365 days after drug-eluting stent (DES) implantation (234–237). *(Level of Evidence: B)*

CLASS IIa

1. In patients in whom noncardiac surgery is required, a consensus decision among treating clinicians as to the relative risks of surgery and discontinuation or continuation of antiplatelet therapy can be useful. *(Level of Evidence: C)*

CLASS IIb†

1. Elective noncardiac surgery after DES implantation may be considered after 180 days if the risk of further delay is greater than the expected risks of ischemia and stent thrombosis (234,238). *(Level of Evidence: B)*

CLASS III: HARM

1. Elective noncardiac surgery should not be performed within 30 days after BMS implantation or within 12 months after DES implantation in patients in whom dual antiplatelet therapy (DAPT) will need to be discontinued perioperatively (231–237,239). *(Level of Evidence: B)*
2. Elective noncardiac surgery should not be performed within 14 days of balloon angioplasty in patients in whom aspirin will need to be discontinued perioperatively. *(Level of Evidence: C)*

Patients who require both PCI and noncardiac surgery merit special consideration. PCI should not be performed as a prerequisite in patients who need noncardiac surgery unless

†Because of new evidence, this is a new recommendation since the publication of the 2011 PCI CPG (26).

TABLE 6 Summary of Recommendations for Perioperative Therapy

Recommendations	COR	LOE	References
Coronary revascularization before noncardiac surgery			
Revascularization before noncardiac surgery is recommended when indicated by existing CPGs	I	C	(25,26)
Coronary revascularization is not recommended before noncardiac surgery exclusively to reduce perioperative cardiac events	III: No Benefit	B	(116)
Timing of elective noncardiac surgery in patients with previous PCI			
Noncardiac surgery should be delayed after PCI	I	C: 14 d after balloon angioplasty B: 30 d after BMS implantation	N/A (231–233)
Noncardiac surgery should optimally be delayed 365 d after DES implantation	I	B	(234–237)
A consensus decision as to the relative risks of discontinuation or continuation of antiplatelet therapy can be useful	IIa	C	N/A
Elective noncardiac surgery after DES implantation may be considered after 180 d	IIb*	B	(234,238)
Elective noncardiac surgery should not be performed in patients in whom DAPT will need to be discontinued perioperatively within 30 d after BMS implantation or within 12 mo after DES implantation	III: Harm	B	(231–237,239)
Elective noncardiac surgery should not be performed within 14 d of balloon angioplasty in patients in whom aspirin will need to be discontinued perioperatively	III: Harm	C	N/A
Perioperative beta-blocker therapy			
Continue beta blockers in patients who are on beta blockers chronically	I	B ^{SR}†	(242–248)
Guide management of beta blockers after surgery by clinical circumstances	IIa	B ^{SR}†	(241,248,251)
In patients with intermediate- or high-risk preoperative tests, it may be reasonable to begin beta blockers	IIb	C ^{SR}†	(225)
In patients with ≥3 RCRI factors, it may be reasonable to begin beta blockers before surgery	IIb	B ^{SR}†	(248)
Initiating beta blockers in the perioperative setting as an approach to reduce perioperative risk is of uncertain benefit in those with a long-term indication but no other RCRI risk factors	IIb	B ^{SR}†	(242,248,257)
It may be reasonable to begin perioperative beta blockers long enough in advance to assess safety and tolerability, preferably >1 d before surgery	IIb	B ^{SR}†	(241,258–260)
Beta-blocker therapy should not be started on the d of surgery	III: Harm	B ^{SR}†	(241)
Perioperative statin therapy			
Continue statins in patients currently taking statins	I	B	(283–286)
Perioperative initiation of statin use is reasonable in patients undergoing vascular surgery	IIa	B	(287)
Perioperative initiation of statins may be considered in patients with a clinical risk factor who are undergoing elevated-risk procedures	IIb	C	N/A
Alpha-2 agonists			
Alpha-2 agonists are not recommended for prevention of cardiac events	III: No Benefit	B	(291–295)
ACE inhibitors			
Continuation of ACE inhibitors or ARBs is reasonable perioperatively	IIa	B	(300,301)
If ACE inhibitors or ARBs are held before surgery, it is reasonable to restart as soon as clinically feasible postoperatively	IIa	C	N/A
Antiplatelet agents			
Continue DAPT in patients undergoing urgent noncardiac surgery during the first 4 to 6 wk after BMS or DES implantation, unless the risk of bleeding outweighs the benefit of stent thrombosis prevention	I	C	N/A
In patients with stents undergoing surgery that requires discontinuation $P2Y_{12}$ inhibitors, continue aspirin and restart the $P2Y_{12}$ platelet receptor-inhibitor as soon as possible after surgery	I	C	N/A
Management of perioperative antiplatelet therapy should be determined by consensus of treating clinicians and the patient	I	C	N/A
In patients undergoing nonemergency/nonurgent noncardiac surgery without prior coronary stenting, it may be reasonable to continue aspirin when the risk of increased cardiac events outweighs the risk of increased bleeding	IIb	B	(298,306)

Continued on the next page

TABLE 6 Continued

Recommendations	COR	LOE	References
Initiation or continuation of aspirin is not beneficial in patients undergoing elective noncardiac noncarotid surgery who have not had previous coronary stenting	III: No Benefit	B C: If risk of ischemic events outweighs risk of surgical bleeding	(298) N/A
Perioperative management of patients with CIEDs			
Patients with ICDs should be on a cardiac monitor continuously during the entire period of inactivation, and external defibrillation equipment should be available. Ensure that ICDs are reprogrammed to active therapy	I	C	(336)

*Because of new evidence, this is a new recommendation since the publication of the 2011 PCI CPG (26).
†These recommendations have been designated with a ^{SR} to emphasize the rigor of support from the ERC's systematic review.

ACE indicates angiotensin-converting-enzyme; ARB, angiotensin-receptor blocker; BMS, bare-metal stent; CIED, cardiovascular implantable electronic device; COR, Class of Recommendation; CPG, clinical practice guideline; DAPT, dual antiplatelet therapy; DES, drug-eluting stent; ERC, Evidence Review Committee; ICD, implantable cardioverter-defibrillator; LOE, Level of Evidence; N/A, not applicable; PCI, percutaneous coronary intervention; RCRI, Revised Cardiac Risk Index; and ^{SR}, systematic review.

it is clearly indicated for high-risk coronary anatomy (e.g., left main disease), unstable angina, MI, or life-threatening arrhythmias due to active ischemia amenable to PCI. If PCI is necessary, then the urgency of the noncardiac surgery and the risk of bleeding and ischemic events, including stent thrombosis, associated with the surgery in a patient taking DAPT need to be considered (see Section 6.2.6 for more information on antiplatelet management). If there is little risk of bleeding or if the noncardiac surgery can be delayed ≥12 months, then PCI with DES and prolonged aspirin and $P2Y_{12}$ platelet receptor-inhibitor therapy is an option. Some data suggest that in newer-generation DESs, the risk of stent thrombosis is stabilized by 6 months after DES implantation and that noncardiac surgery after 6 months may be possible without increased risk (234,238). If the elective noncardiac surgery is likely to occur within 1 to 12 months, then a strategy of BMS and 4 to 6 weeks of aspirin and $P2Y_{12}$ platelet receptor-inhibitor therapy with continuation of aspirin perioperatively may be an appropriate option. Although the risk of restenosis is higher with BMS than with DES, restenotic lesions are usually not life threatening, even though they may present as an acute coronary syndrome, and they can usually be dealt with by repeat PCI if necessary. If the noncardiac surgery is time sensitive (within 2 to 6 weeks) or the risk of bleeding is high, then consideration should be given to balloon angioplasty with provisional BMS implantation. If the noncardiac surgery is urgent or an emergency, then the risks of ischemia and bleeding, and the long-term benefit of coronary revascularization must be weighed. If coronary revascularization is absolutely necessary, CABG combined with the noncardiac surgery may be considered.

See Online Data Supplement 18 for additional information on strategy of percutaneous revascularization in patients needing elective noncardiac surgery.

6.2. Perioperative Medical Therapy

6.2.1. Perioperative Beta-Blocker Therapy: Recommendations

See the ERC systematic review report, "Perioperative beta blockade in noncardiac surgery: a systematic review for the 2014 ACC/AHA guideline on perioperative cardiovascular evaluation and management of patients undergoing noncardiac surgery" for the complete evidence review on perioperative beta-blocker therapy (8), and see Online Data Supplement 19 for more information about beta blockers. The tables in Online Data Supplement 19 were reproduced directly from the ERC's systematic review for your convenience. These recommendations have been designated with an ^{SR} to emphasize the rigor of support from the ERC's systematic review.

As noted in the Scope of this CPG (Section 1.4), the recommendations in Section 6.2.1 are based on a separately commissioned review of the available evidence, the results of which were used to frame our decision making. Full details are provided in the ERC's systematic review report (8) and data supplements. However, 3 key findings were powerful influences on this CPG's recommendations:

1. The systematic review suggests that preoperative use of beta blockers was associated with a reduction in cardiac events in the studies examined, but few data support the effectiveness of preoperative administration of beta blockers to reduce risk of surgical death.
2. Consistent and clear associations exist between beta-blocker administration and adverse outcomes, such as bradycardia and stroke.
3. These findings were quite consistent even when the DECREASE studies (230,240) in question or the POISE (Perioperative Ischemic Evaluation) (241) were excluded. Stated alternatively, exclusion of these

studies did not substantially affect estimates of risk or benefit.

CLASS I

1. **Beta blockers should be continued in patients undergoing surgery who have been on beta blockers chronically (242–248).** *(Level of Evidence: B)* SR

If well tolerated, continuing beta blockers in patients who are currently receiving them for longitudinal reasons, particularly when longitudinal treatment is provided according to GDMT, such as for MI, is recommended (See Table B in Appendix 3 for applicable recommendations from the 2011 secondary prevention CPG) (249). Multiple observational studies support the benefits of continuing beta blockers in patients who are undergoing surgery and who are on these agents for longitudinal indications (242–248). However, these studies vary in their robustness in terms of their ability to deal with confounding due to the indications for beta blockade or ability to discern whether the reasons for discontinuation are in themselves associated with higher risk (independent of beta-blocker discontinuation), which led to the Level of Evidence B determination. This recommendation is consistent with the Surgical Care Improvement Project National Measures (CARD-2) as of November 2013 (250).

CLASS IIa

1. **It is reasonable for the management of beta blockers after surgery to be guided by clinical circumstances, independent of when the agent was started (241,248,251).** *(Level of Evidence: B)* SR

This recommendation requires active management of patients on beta blockers during and after surgery. Particular attention should be paid to the need to modify or temporarily discontinue beta blockers as clinical circumstances (e.g., hypotension, bradycardia (252), bleeding) (251) dictate. Although clinical judgment will remain a mainstay of this approach, evidence suggests that implementation of and adherence to local practice guidelines can play a role in achieving this recommendation (253).

CLASS IIb

1. **In patients with intermediate- or high-risk myocardial ischemia noted in preoperative risk stratification tests, it may be reasonable to begin perioperative beta blockers (225).** *(Level of Evidence: C)* SR

The risks and benefits of perioperative beta blocker use appear to be favorable in patients who have intermediate- or high-risk myocardial ischemia noted on preoperative stress testing (225,254). The decision to begin beta blockers should be influenced by whether a patient is at risk for stroke (46,255,256) and whether the patient has other relative contraindications (such as uncompensated HF).

CLASS IIb

2. **In patients with 3 or more RCRI risk factors (e.g., diabetes mellitus, HF, CAD, renal insufficiency, cerebrovascular accident), it may be reasonable to begin beta blockers before surgery (248).** *(Level of Evidence: B)* SR

Observational data suggest that patients appear to benefit from use of beta blockers in the perioperative setting if they have ≥3 RCRI risk factors. In the absence of multiple risk factors, it is unclear whether preoperative administration is safe or effective; again, it is important to gauge the risk related to perioperative stroke or contraindications in choosing to begin beta blockers.

CLASS IIb

3. **In patients with a compelling long-term indication for beta-blocker therapy but no other RCRI risk factors, initiating beta blockers in the perioperative setting as an approach to reduce perioperative risk is of uncertain benefit (242,248,257).** *(Level of Evidence: B)* SR

Although beta blockers improve long-term outcomes when used in patients according to GDMT, it is unclear whether beginning beta blockers before surgery is efficacious or safe if a long-term indication is not accompanied by additional RCRI criteria. Rather, a preferable approach might be to ensure beta blockers are initiated as soon as feasible after the surgical procedure.

CLASS IIb

4. **In patients in whom beta-blocker therapy is initiated, it may be reasonable to begin perioperative beta blockers long enough in advance to assess safety and tolerability, preferably more than 1 day before surgery (241,258–260).** *(Level of Evidence: B)* SR

It may be reasonable to begin beta blockers long enough in advance of the operative date that clinical effectiveness and tolerability can be assessed (241,258–260).

Beginning beta blockers ≤1 day before surgery is at a minimum ineffective and may in fact be harmful (8,241,248,261). Starting the medication 2 to 7 days before surgery may be preferred, but few data support the need to start beta blockers >30 days beforehand (258–260). It is important to note that even in studies that included preoperative dose titration as an element of their algorithm, patients' drug doses rarely changed after an initial dose was chosen (254,262). In addition, the data supporting "tight" heart rate control is weak (262), suggesting that clinical assessments for tolerability are a key element of preoperative strategies (258–260).

CLASS III: HARM

1. **Beta-blocker therapy should not be started on the day of surgery (241).** *(Level of Evidence: B)* SR

The GWC specifically recommends against starting beta blockers on the day of surgery in beta-blocker-naïve patients (241), particularly at high initial doses, in long-acting form, and if there no plans for dose titration or monitoring for adverse events.

6.2.1.1. Evidence on Efficacy of Beta-Blocker Therapy

Initial interest in using beta blockers to prevent postoperative cardiac complications was supported by a small number of RCTs and reviews (225,254,263,264). Perioperative beta blockade was quickly adopted because the potential benefit of perioperative beta blockers was large (265) in the absence of other therapies, initial RCTs did not suggest adverse effects, and the effects of beta blockers in surgical patients were consistent with effects in patients with MI (e.g., reducing mortality rate from coronary ischemia).

However, these initial data were derived primarily from small trials, with minimum power, of highly screened patient populations undergoing specific procedures (e.g., vascular surgery) and using agents (e.g., intravenous atenolol, oral bisoprolol) not widely available in the United States. Limitations of initial studies provided the rationale for studies that followed (241,266), of which 3 showed no cardiac outcome or mortality difference between beta-blocker-treated and -untreated patients (257,267,268). Additional information was provided by a meta-analysis of all published studies that suggested potential harm as well as a lower protective effect (269); a robust observational study also suggested an association between use of beta blockers in low-risk patients and higher surgical mortality rate (242).

Publication of POISE, a multicenter study of adequate size and scope to address sample size, generalizability, and limitations of previous studies, added further complexity to the evidence base by suggesting that use of beta blockers reduced risks for cardiac events (e.g., ischemia, AF, need for coronary interventions) but produced a higher overall risk—largely related to stroke and higher rate of death resulting from noncardiac complications (241). However, POISE was criticized for its use of a high dose of long-acting beta blocker and for initiation of the dose immediately before noncardiac surgery. In fact, a lower starting dose was used in the 3 studies that saw both no harm and no benefit (257,267,270). Moreover, POISE did not include a titration protocol before or after surgery.

The evidence to this point was summarized in a series of meta-analyses suggesting a mixed picture of the safety and efficacy of beta blockers in the perioperative setting (269,271–273). These evidence summaries were relatively consistent in showing that use of perioperative beta blockers could reduce perioperative cardiac risk but that they had significant deleterious associations with bradycardia, stroke, and hypotension.

Adding further complexity to the perioperative beta-blocker picture, concern was expressed by Erasmus University about the scientific integrity of studies led by Poldermans (9); see Section 1.4 for further discussion. For transparency, we included the nonretracted publications in the text of this document if they were relevant to the topic. However, the nonretracted publications were not used as evidence to support the recommendations and were not included in the corresponding data supplement.

6.2.1.2. Titration of Beta Blockers

There are limited trial data on whether or how to titrate beta blockers in the perioperative setting or whether this approach is more efficacious than fixed-dose regimens. Although several studies (254,263) included dose titration to heart rate goal in their protocol, and separate studies suggested that titration is important to achieving appropriate anti-ischemic effects (274), it appears that many patients in the original trials remained on their starting medication dose at the time of surgery, even if on a research protocol.

Studies that titrated beta blockers, many of which are now under question, also tended to begin therapy >1 day before surgery, making it difficult to discern whether dose titration or preoperative timing was more important to producing any potential benefits of beta blockade.

Several studies have evaluated the intraclass differences in beta blockers (according to duration of action and beta-1 selectivity) (261,275–278), but few comparative trials exist at the time of publication, and it is difficult to make broad recommendations on the basis of evidence available at this time. Moreover, some intraclass differences may be influenced more by differences in beta-adrenoceptor type than by the medication itself (279). However, data from POISE suggest that initiating long-acting beta blockers on the day of surgery may not be a preferable approach.

6.2.1.3. Withdrawal of Beta Blockers

Although few studies describe risks of withdrawing beta blockers in the perioperative time period (243,246), longstanding evidence from other settings suggests that abrupt withdrawal of long-term beta blockers is harmful (280–282), providing the major rationale for the ACC/AHA Class I recommendation. There are fewer data to describe whether short-term (1 to 2 days) perioperative use of beta blockers, followed by rapid discontinuation, is harmful.

6.2.1.4 Risks and Caveats

The evidence for perioperative beta blockers—even excluding the DECREASE studies under question and

POISE—supports the idea that their use can reduce perioperative cardiac events. However, this benefit is offset by a higher relative risk for perioperative strokes and uncertain mortality benefit or risk (242,248,254). Moreover, the time horizon for benefit in some cases may be farther in the future than the time horizon for adverse effects of the drugs.

In practice, the risk-benefit analysis of perioperative beta blockers should also take into account the frequency and severity of the events the therapy may prevent or produce. That is, although stroke is a highly morbid condition, it tends to be far less common than MACE. There may be situations in which the risk of perioperative stroke is lower, but the concern for cardiac events is elevated; in these situations, beta blocker use may have benefit, though little direct evidence exists to guide clinical decision making in specific scenarios.

6.2.2. Perioperative Statin Therapy: Recommendations

CLASS I

1. **Statins should be continued in patients currently taking statins and scheduled for noncardiac surgery (283–286).** ***(Level of Evidence: B)***

CLASS IIa

1. **Perioperative initiation of statin use is reasonable in patients undergoing vascular surgery (287).** ***(Level of Evidence: B)***

CLASS IIb

1. **Perioperative initiation of statins may be considered in patients with clinical indications according to GDMT who are undergoing elevated-risk procedures.** ***(Level of Evidence: C)***

Lipid lowering with statin agents is highly effective for primary and secondary prevention of cardiac events (288). Data from statin trials are now robust enough to allow the GWC to directly answer the critical questions of what works and in whom without estimating cardiovascular risk. The effectiveness of this class of agents in reducing cardiovascular events in high-risk patients has suggested that they may improve perioperative cardiovascular outcomes. A placebo-controlled randomized trial followed patients on atorvastatin for 6 months (50 patients on atorvastatin and 50 patients on placebo) who were undergoing vascular surgery and found a significant decrease in MACE in the treated group (287). In a Cochrane analysis, pooled results from 3 studies, with a total of 178 participants, were evaluated (289). In the statin group, 7 of 105 (6.7%) participants died within 30 days of surgery, as did 10 of 73 (13.7%) participants in the control group. However, all deaths occurred in a single study population, and estimates were therefore derived from only 1 study. Two additional RCTs from Poldermans also evaluated the efficacy of fluvastatin compared with placebo and demonstrated a significant reduction in MACE in patients at high risk, with a trend toward improvement in patients at intermediate risk (240,290).

Most of the data on the impact of statin use in the perioperative period comes from observational trials. The largest observational trial used data from hospital administrative databases (283). Patients who received statins had a lower crude mortality rate and a lower mortality rate when propensity matched. An administrative database from 4 Canadian provinces was used to evaluate the relationship between statin use and outcomes in patients undergoing carotid endarterectomy for symptomatic carotid disease (284); this study found an inverse correlation between statin use and in-hospital mortality, stroke or death, or cardiovascular outcomes. A retrospective cohort of 752 patients undergoing intermediate-risk, noncardiac, nonvascular surgery was evaluated for all-cause mortality rate (285). Compared with nonusers, patients on statin therapy had a 5-fold reduced risk of 30-day all-cause death. Another observational trial of 577 patients revealed that patients undergoing noncardiac vascular surgery treated with statins had a 57% lower chance of having perioperative MI or death at 2-year follow-up, after controlling for other variables (286).

The accumulated evidence to date suggests a protective effect of perioperative statin use on cardiac complications during noncardiac surgery. RCTs are limited in patient numbers and types of noncardiac surgery. The time of initiation of statin therapy and the duration of therapy are often unclear in the observational trials. The mechanism of benefit of statin therapy prescribed perioperatively to lower cardiac events is unclear and may be related to pleiotropic as well as cholesterol-lowering effects. In patients meeting indications for statin therapy, starting statin therapy perioperatively may also be an opportunity to impact long-term health (288).

See Online Data Supplement 20 for additional information on perioperative statin therapy.

6.2.3. Alpha-2 Agonists: Recommendation

CLASS III: NO BENEFIT

1. **Alpha-2 agonists for prevention of cardiac events are not recommended in patients who are undergoing noncardiac surgery (291–295).** ***(Level of Evidence: B)***

Several studies examined the role of alpha-agonists (clonidine and mivazerol) for perioperative cardiac protection (291,293,294,296).

In a meta-analysis of perioperative alpha-2 agonist administration through 2008, comprising 31 trials enrolling 4578 patients, alpha-2 agonists overall reduced death and myocardial ischemia (295). The most notable effects were with vascular surgery. Importantly, sudden discontinuation of long-term alpha-agonist treatment

can result in hypertension, headache, agitation, and tremor.

A 2004 prospective, double-blinded, clinical trial on patients with or at risk for CAD investigated whether prophylactic clonidine reduced perioperative myocardial ischemia and long-term death in patients undergoing noncardiac surgery (297). Patients were randomized to clonidine (n=125) or placebo (n=65). Prophylactic clonidine administered perioperatively significantly reduced myocardial ischemia during the intraoperative and postoperative period (clonidine: 18 of 125 patients or 14%; placebo: 20 of 65 patients or 31%; p=0.01). Moreover, administration of clonidine had minimal hemodynamic effects and reduced postoperative mortality rate for up to 2 years (clonidine: 19 of 125 patients or 15%; placebo: 19 of 65 patients or 29%; relative risk: 0.43; 95% CI: 0.21 to 0.89; p=0.035).

POISE-2 enrolled patients in a large multicenter, international, blinded, 2 × 2 factorial RCT of acetyl-salicylic acid and clonidine (298). The primary objective was to determine the impact of clonidine compared with placebo and acetyl-salicylic acid compared with placebo on the 30-day risk of all-cause death or nonfatal MI in patients with or at risk of atherosclerotic disease who were undergoing noncardiac surgery. Patients in the POISE-2 trial were randomly assigned to 1 of 4 groups: acetyl-salicylic acid and clonidine together, acetyl-salicylic acid and clonidine placebo, an acetyl-salicylic acid placebo and clonidine, or an acetyl-salicylic acid placebo and a clonidine placebo. Clonidine did not reduce the rate of death or nonfatal MI. Clonidine did increase the rate of nonfatal cardiac arrest and clinically important hypotension.

See Online Data Supplement 21 for additional information on alpha-2 agonists.

6.2.4. Perioperative Calcium Channel Blockers

A 2003 meta-analysis of perioperative calcium channel blockers in noncardiac surgery identified 11 studies involving 1007 patients (299). Calcium channel blockers significantly reduced ischemia (relative risk: 0.49; 95% CI: 0.30 to 0.80; p=0.004) and supraventricular tachycardia (relative risk: 0.52; 95% CI: 0.37 to 0.72; p<0.0001). Calcium channel blockers were associated with trends toward reduced death and MI. In post hoc analyses, calcium channel blockers significantly reduced death/MI (relative risk: 0.35; 95% CI: 0.15 to 0.86; p=0.02). The majority of these benefits were attributable to diltiazem. Dihydropyridines and verapamil did not decrease the incidence of myocardial ischemia, although verapamil decreased the incidence of supraventricular tachycardia. A large-scale trial is needed to define the value of these agents. Of note, calcium blockers with substantial negative inotropic effects, such as diltiazem and verapamil, may precipitate or worsen HF in patients with depressed EF and clinical HF.

See Online Data Supplement 22 for additional information on perioperative calcium channel blockers.

6.2.5. Angiotensin-Converting Enzyme Inhibitors: Recommendations

CLASS IIa

1. **Continuation of angiotensin-converting enzyme (ACE) inhibitors or angiotensin-receptor blockers (ARBs) perioperatively is reasonable (300,301).** ***(Level of Evidence: B)***
2. **If ACE inhibitors or ARBs are held before surgery, it is reasonable to restart as soon as clinically feasible postoperatively.** ***(Level of Evidence: C)***

ACE inhibitors are among the most prescribed drugs in the United States, but data on their potential risk and benefit in the perioperative setting is limited to observational analysis. One large retrospective study evaluated 79 228 patients (9905 patients on ACE inhibitors [13%] and 66 620 patients not on ACE inhibitors [87%]) who had noncardiac surgery (300). Among a matched, nested cohort in this study, intraoperative ACE inhibitor users had more frequent transient intraoperative hypotension but no difference in other outcomes. A meta-analysis of available trials similarly demonstrated hypotension in 50% of patients taking ACE inhibitors or ARBs on the day of surgery but no change in important cardiovascular outcomes (i.e., death, MI, stroke, kidney failure) (301). One study evaluated the benefits of the addition of aspirin to beta blockers and statins, with or without ACE inhibitors, for postoperative outcome in high-risk consecutive patients undergoing major vascular surgery (302). The combination of aspirin, beta blockers, and statin therapy was associated with better 30-day and 12-month risk reduction for MI, stroke, and death than any of the 3 medications independently. The addition of an ACE inhibitor to the 3 medications did not demonstrate additional risk-reduction benefits. There is similarly limited evidence on the impact of discontinuing ACE inhibitors before noncardiac surgery (303,304). In these and other small trials, no harm was demonstrated with holding ACE inhibitors and ARBs before surgery (303,304), but all studies were underpowered and did not target any particular clinical group. Consequently, there are few data to direct clinicians about whether specific surgery types or patient subgroups are most likely to benefit from holding ACE inhibitors in the perioperative time period.

Although there is similarly sparse evidence to support the degree of harm represented by inappropriate discontinuation of ACE inhibitors after surgery (e.g., ACE inhibitors held but not restarted), there is reasonable evidence from nonsurgical settings to support worse outcomes in patients whose ACE inhibitors are discontinued inappropriately. Maintaining continuity of ACE inhibitors in the setting of treatment for HF or hypertension is

supported by CPGs (16,305). Data describing harms of ARBs are sparse, but treating such drugs as equivalent to ACE inhibitors is reasonable.

See Online Data Supplement 23 for additional information on ACE inhibitors.

6.2.6. Antiplatelet Agents: Recommendations

Please see **Figure 2** for an algorithm for antiplatelet management in patients with PCI and noncardiac surgery.

CLASS I

1. **In patients undergoing urgent noncardiac surgery during the first 4 to 6 weeks after BMS or DES implantation, DAPT should be continued unless the relative risk of bleeding outweighs the benefit of the prevention of stent thrombosis.** *(Level of Evidence: C)*
2. **In patients who have received coronary stents and must undergo surgical procedures that mandate the discontinuation of $P2Y_{12}$ platelet receptor–inhibitor therapy, it is recommended that aspirin be continued if possible and the $P2Y_{12}$ platelet receptor–inhibitor be restarted as soon as possible after surgery.** *(Level of Evidence: C)*
3. **Management of the perioperative antiplatelet therapy should be determined by a consensus of the surgeon, anesthesiologist, cardiologist, and patient, who should weigh the relative risk of bleeding with that of stent thrombosis.** *(Level of Evidence: C)*

CLASS IIb

1. **In patients undergoing nonemergency/nonurgent noncardiac surgery who have not had previous coronary stenting, it may be reasonable to continue aspirin when the risk of potential increased cardiac events outweighs the risk of increased bleeding (298,306).** *(Level of Evidence: B)*

CLASS III: NO BENEFIT

1. **Initiation or continuation of aspirin is not beneficial in patients undergoing elective noncardiac noncarotid surgery who have not had previous coronary stenting (298)** *(Level of Evidence: B)***, unless the risk of ischemic events outweighs the risk of surgical bleeding.** *(Level of Evidence: C)*

The risk of stent thrombosis in the perioperative period for both BMS and DES is highest in the first 4 to 6 weeks after stent implantation (231–239,307–309). Discontinuation of DAPT, particularly in this early period, is a strong risk factor for stent thrombosis (310,311). Should urgent or emergency noncardiac surgery be required, a decision to continue aspirin or DAPT should be individualized, with the risk weighed against the benefits of continuing therapy.

The risk of DES thrombosis during noncardiac surgery more than 4 to 6 weeks after stent implantation is low but is higher than in the absence of surgery, although the relative increased risk varies from study to study. This risk decreases with time and may be at a stable level by 6 months after DES implantation (234,238). The value of continuing aspirin alone or DAPT to prevent stent thrombosis or other ischemic events during noncardiac surgery is uncertain, given the lack of prospective trials. The risk of bleeding is likely higher with DAPT than with aspirin alone or no antiplatelet therapy, but the magnitude of the increase is uncertain (231,232,307–309,312). As such, use of DAPT or aspirin alone should be individualized on the basis of the considered potential benefits and risks, albeit in the absence of secure data. An algorithm for DAPT use based on expert opinion is suggested in **Figure 2**. There is no convincing evidence that warfarin, antithrombotics, cangrelor, or glycoprotein IIb/IIIa agents will reduce the risk of stent thrombosis after discontinuation of oral antiplatelet agents.

The value of aspirin in nonstented patients in preventing ischemic complications is uncertain. Observational data suggest that preoperative withdrawal of aspirin increases thrombotic complications (306); the PEP (Pulmonary Embolism Prevention) trial, which randomized 13 356 patients undergoing hip surgery to 160 mg aspirin or placebo, did not show benefit of aspirin (313). The POISE-2 trial randomized 10 010 patients who were undergoing noncardiac surgery and were at risk for vascular complications to aspirin 200 mg or placebo. Aspirin did not have a protective effect for MACE or death in patients either continuing aspirin or starting aspirin during the perioperative period (298). Aspirin use was associated with an increased risk of major bleeding. In the POISE-2 trial, aspirin was stopped at least 3 days (but usually 7 days) preoperatively. Patients within 6 weeks of placement of a BMS or within 1 year of placement of a DES were excluded from the trial, and the number of stented patients outside these time intervals was too small to make firm conclusions as to the risk-benefit ratio. Additionally, only 23% of the study population had known prior CAD, and the population excluded patients undergoing carotid endarterectomy surgery. Thus, continuation may still be reasonable in patients with high-risk CAD or cerebrovascular disease, where the risks of potential increased cardiovascular events outweigh the risks of increased bleeding.

See Online Data Supplement 24 for additional information on antiplatelet agents.

6.2.7. Anticoagulants

Use of therapeutic or full-dose anticoagulants (as opposed to the lower-dose anticoagulation often used for prevention of deep venous thrombosis) is generally discouraged because of their harmful effect on the ability to control and contain surgical blood loss. This section refers to the vitamin K antagonists and novel oral anticoagulant agents but excludes discussion of the

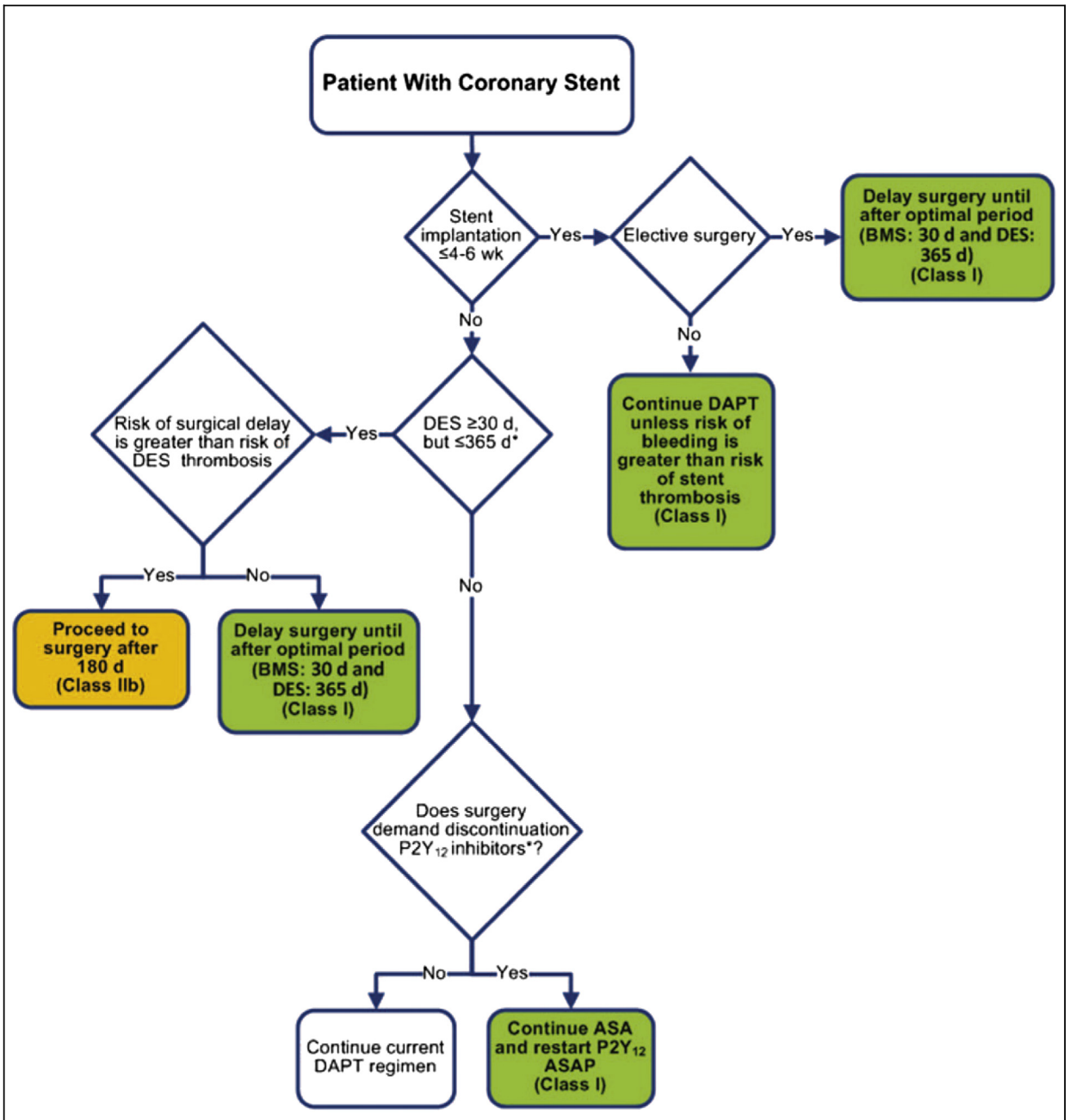

FIGURE 2 Algorithm for Antiplatelet Management in Patients With PCI and Noncardiac Surgery

Colors correspond to the Classes of Recommendations in Table 1. *Assuming patient is currently on DAPT. ASA indicates aspirin; ASAP, as soon as possible; BMS, bare-metal stent; DAPT, dual antiplatelet therapy; DES, drug-eluting stent; and PCI, percutaneous coronary intervention.

antiplatelet agents addressed in Section 6.2.6. Factor Xa inhibitors and direct thrombin inhibitors are examples of alternative anticoagulants now available for oral administration. Vitamin K antagonists (warfarin) are prescribed for stroke prevention in patients with AF, for prevention of thrombotic and thromboembolic complications in patients with prosthetic valves, and in patients requiring deep venous thrombosis prophylaxis and treatment. Factor Xa inhibitors are prescribed for prevention of stroke in the management of AF. Factor Xa inhibitors are not recommended for long-term anticoagulation of prosthetic valves because of an increased risk of thrombosis when compared with warfarin. The role of anticoagulants other than platelet inhibitors in the secondary

prevention of myocardial ischemia or MI has not been elucidated.

The risks of bleeding for any surgical procedure must be weighed against the benefit of remaining on anticoagulants on a case-by-case basis. In some instances in which there is minimal to no risk of bleeding, such as cataract surgery or minor dermatologic procedures, it may be reasonable to continue anticoagulation perioperatively. Two published CPGs address the management of perioperative anticoagulation in patients with prosthetic valves and patients with AF (14,15). Although research with newer agents (e.g., prothrombin complex concentrates for reversal of direct factor Xa inhibitor effect) is ongoing, the novel oral anticoagulant agents do not appear to be acutely reversible. Patients with prosthetic valves taking vitamin K antagonists may require bridging therapy with either unfractionated heparin or low-molecular-weight heparin, depending on the location of the prosthetic valve and associated risk factors for thrombotic and thromboembolic events. For patients with a mechanical mitral valve, regardless of the absence of additional risk factors for thromboembolism, or patients with an aortic valve and ≥1 additional risk factor (such as AF, previous thromboembolism, LV dysfunction, hypercoagulable condition, or an older-generation prosthetic aortic valve), bridging anticoagulation may be appropriate when interruption of anticoagulation for perioperative procedures is required and control of hemostasis is essential (15). For patients requiring urgent reversal of vitamin K antagonists, vitamin K and fresh frozen plasma or the newer prothrombin complex concentrates are options; however, vitamin K is not routinely recommended for reversal because the effect is not immediate and the administration of vitamin K can significantly delay the return to a therapeutic level of anticoagulation once vitamin K antagonists have been restarted.

Factor Xa inhibitors do not have a reversible agent available at this time. For patients with AF and normal renal function undergoing elective procedures during which hemostatic control is essential, such as major surgery, spine surgery, and epidural catheterization, discontinuation of anticoagulants for ≥48 hours is suggested. Monitoring activated partial thromboplastin time for dabigatran and prothrombin time for apixaban and rivaroxaban may be helpful; a level consistent with control levels suggests a low serum concentration of the anticoagulant (14).

There have been no studies on the benefit of anticoagulants on the prevention of perioperative myocardial ischemia or MI.

6.3. Management of Postoperative Arrhythmias and Conduction Disorders

AF and atrial flutter are the most common sustained arrhythmias that occur in the postoperative setting. However, clinicians must differentiate between atrial flutter, which is common in the postoperative setting (especially with underlying structural heart disease), and other supraventricular tachycardias that may respond to vagal maneuvers or nodal agents. The incidence of postoperative AF after noncardiac surgery varies widely in the literature, ranging from 0.37% in 1 large population-based study in noncardiothoracic surgery to 30% after major noncardiac thoracic surgery, such as esophagectomy and pneumonectomy (314–324). Peak incidence occurs 1 to 3 days postoperatively and is positively correlated with patient age, preoperative heart rate, and male sex (315,317,322,325). Treatment of postoperative AF is similar to that for other forms of new-onset AF, except that the potential benefit of anticoagulation needs to be balanced against the risk of postoperative bleeding.

Ventricular rate control in the acute setting is generally accomplished with beta blockers or nondihydropyridine calcium channel blockers (i.e., diltiazem or verapamil), with digoxin reserved for patients with systolic HF or with contraindications or inadequate response to other agents. Of note, beta blockers and calcium channel blockers with substantial negative inotropic effects, such as diltiazem or verapamil, may precipitate or worsen HF in patients with depressed EF or clinical HF. An additional benefit of beta blockers is that, compared with diltiazem, they may accelerate the conversion of postoperative supraventricular arrhythmias to sinus rhythm (326,327). Cardioversion of minimally symptomatic AF/atrial flutter is generally not required until correction of the underlying problems has occurred, which may lead to a return to normal sinus rhythm. Intravenous amiodarone may also be used to aid in restoring or maintaining sinus rhythm if its benefits outweigh the risk of hypotension and other side effects. As with patients outside the perioperative setting, cardioversion of postoperative AF should be performed when hemodynamic compromise is present.

Whereas numerous studies have been performed for prophylaxis of AF in the setting of cardiac surgery, comparatively few data exist in the setting of noncardiac surgery. One RCT of 130 patients undergoing lung resection surgery showed that perioperative amiodarone reduced the incidence of postoperative AF and reduced length of stay compared with placebo (328). However, the incidence of postoperative AF in the control group (32.3%) was higher than that seen in a large national database (12.6%) (321). Another RCT of 254 patients undergoing lung cancer surgery also showed a significant reduction in postoperative AF with amiodarone but no difference in length of stay or resource utilization (329,330). An RCT of 80 patients undergoing esophagectomy also showed a reduction in postoperative AF but not in length of stay (331). Recommendations for prophylaxis and management of postoperative AF after

cardiac and thoracic surgery are provided in the 2014 AF CPG (14).

If the patient develops a sustained, regular, narrow-complex tachycardia (supraventricular tachycardia), which is likely due to atrioventricular nodal reentrant tachycardia or atrioventricular reciprocating tachycardia, the supraventricular tachycardia frequently can be terminated with vagal maneuvers or with intravenous medications (adenosine or verapamil). Most antiarrhythmic agents (especially beta blockers, calcium channel blockers, and class IC antiarrhythmic agents) can be used to prevent further recurrences in the postoperative setting. Digoxin and calcium channel blockers should be avoided in the setting of pre-excited AF. The choice of individual agent will depend on the nature of the arrhythmia and whether the patient has associated structural heart disease. Recurrent supraventricular tachycardia is generally well treated with catheter ablation therapy (92).

Asymptomatic premature ventricular contractions generally do not require perioperative therapy or further evaluation. Very frequent ventricular ectopy or runs of nonsustained ventricular tachycardia may require antiarrhythmic therapy if they are symptomatic or result in hemodynamic compromise (332). Patients with new-onset postoperative complex ventricular ectopy, particularly polymorphic ventricular tachycardia, should be evaluated for myocardial ischemia, electrolyte abnormalities, or drug effects. Ventricular arrhythmias may respond to intravenous beta blockers, lidocaine, procainamide, or amiodarone. Electrical cardioversion should be used for sustained supraventricular or ventricular arrhythmias that cause hemodynamic compromise. Patients with ventricular arrhythmias in the setting of chronic cardiomyopathy or inherited arrhythmia syndromes despite GDMT should be evaluated for ICD therapy consistent with existing CPGs (332–334).

Bradyarrhythmias that occur in the postoperative period are usually sinus bradycardia secondary to some other cause, such as medication, electrolyte or acid-base disturbance, hypoxemia, or ischemia. Pain can also heighten vagal tone, leading to sinus bradycardia and even heart block, despite baseline normal conduction. New atrioventricular block after noncardiac surgery is rare. Sleep apnea may manifest as nocturnal bradycardia in the postoperative setting. Acutely, bradycardia may respond to atropine or aminophylline. Persistent symptomatic bradyarrhythmias due to sinus node dysfunction and atrioventricular block will respond to temporary transvenous pacing. Indications for permanent pacing are similar to those outside the perioperative setting (333,335). Management of patients with pre-existing pacemakers or ICDs is focused on restoring preoperative settings for those patients who had preoperative reprogramming. It is particularly important to ensure that tachytherapy in patients with ICDs has been restored before discharge from the facility (336).

See Online Data Supplement 25 for additional information on management of postoperative arrhythmias and conduction disorders.

6.4. Perioperative Management of Patients With CIEDs: Recommendation

CLASS I

1. **Patients with ICDs who have preoperative reprogramming to inactivate tachytherapy should be on cardiac monitoring continuously during the entire period of inactivation, and external defibrillation equipment should be readily available. Systems should be in place to ensure that ICDs are reprogrammed to active therapy before discontinuation of cardiac monitoring and discharge from the facility (336). *(Level of Evidence: C)***

To assist clinicians with the perioperative evaluation and management of patients with pacemakers and ICDs, the HRS and the American Society of Anesthesiologists together developed an expert consensus statement that was published in July 2011 and endorsed by the ACC and the AHA (33). Clinicians caring for patients with CIEDs in the perioperative setting should be familiar with that document and the consensus recommendations contained within.

A central concern in perioperative management of patients with CIEDs is the potential for interaction between the CIED and EMI, usually produced by monopolar electrocautery (337). If the procedure involves only bipolar electrocautery or harmonic scalpel or does not involve electrocautery, then interaction with the CIED is extremely unlikely, unless energy is applied directly to the CIED generator or leads in the operative field. With monopolar electrocautery, the principal concern is that EMI may cause transient inhibition of pacing in pacemaker-dependent patients (usually those with complete atrioventricular block) and/or inappropriate triggering of shocks in patients with ICDs. With technological advances in CIED hardware and filtering, the potential for more permanent adverse effects, such as electrical reset, inadvertent reprogramming, or damage to the CIED hardware or lead-tissue interface, has been largely eliminated.

In advance of elective surgical procedures, a perioperative CIED prescription should be developed by the clinician or team that follows the patient in the outpatient setting and communicated to the surgical/procedure team (Section 2.6). Depending on the patient's underlying cardiac rhythm, the type of CIED (pacemaker versus ICD), the location of the operative procedure, and the potential for EMI from electrocautery, the CIED prescription may involve reprogramming a pacemaker or ICD to an asynchronous pacing mode (i.e., VOO or DOO), reprogramming

an ICD to inactivate tachytherapies, application of a magnet over the CIED, or no perioperative intervention (98,99).

Regardless of the CIED prescription, through advance communication with the CIED follow-up outpatient clinician/team, the surgical/procedure team should be familiar with the type of CIED (pacemaker versus ICD), its manufacturer, the response of the CIED to magnet application, and the patient's underlying cardiac rhythm. External defibrillation equipment with transcutaneous pacing capability should be readily available in the operating room for patients with pacemakers or ICDs who are having surgical procedures during which EMI or physical disruption to the CIED system could occur. It is reasonable to have a magnet available for all patients with a CIED who are undergoing a procedure that could involve EMI. All patients with CIEDs should have plethysmographic or arterial pressure monitoring during the procedure, because electrocautery may interfere with electrocardiographic recording and determination of the patient's cardiac rhythm.

A final point concerns patients with ICDs who have tachytherapies inactivated preoperatively. Such patients are intrinsically more susceptible to perioperative ventricular arrhythmias and should have continuous cardiac monitoring during the entire period of ICD inactivation, with external defibrillation immediately available, if needed. In addition, at least 3 deaths have been reported to have been caused by failure to reactivate ICD tachytherapies in patients who had ICD therapy inactivated preoperatively, and this problem is likely to be underreported (336). It is therefore imperative that surgical services have systems in place to ensure that inactivated ICDs are reprogrammed to active therapy before discontinuation of cardiac monitoring and discharge from the facility.

See Online Data Supplement 26 for additional information on perioperative management of patients with CIEDs.

7. ANESTHETIC CONSIDERATION AND INTRAOPERATIVE MANAGEMENT

See **Table 7** for a summary of recommendations for anesthetic consideration and intraoperative management.

7.1. Choice of Anesthetic Technique and Agent

See Online Data Supplement 27 for additional information on choice of anesthetic technique and agent.

There are 4 main classifications of anesthesia: local anesthesia, regional anesthesia (including peripheral nerve blockade and neuraxial blockade), monitored anesthesia care (typically using intravenous sedation with or without local anesthesia), and general anesthesia (which includes volatile-agent anesthesia, total intravenous anesthesia, or a combination of volatile and intravenous anesthesia). The majority of the literature in this field focuses on 1 of 3 areas with regard to preventing perioperative myocardial adverse cardiac events.

7.1.1. Neuraxial Versus General Anesthesia

In patients for whom neuraxial anesthesia (epidural or spinal anesthesia) is an option as the primary anesthetic or as a supplement to general anesthesia, several factors, such as the type of surgery, patient comorbidities, and patient preferences, are crucial in determining risk versus benefits. A 2011 Cochrane review meta-analysis of 4 studies examining neuraxial anesthesia versus general anesthesia for lower-limb revascularization found an overall 4% MI rate in both groups (338). In 2001, an RCT of abdominal aortic surgery patients comparing a thoracic epidural/light general anesthesia technique with a general anesthetic technique alone demonstrated no significant difference in myocardial ischemia and MI rates between the groups (339). Therefore, in patients who are eligible for an intraoperative neuraxial anesthetic, there is no evidence to suggest a cardioprotective benefit from the use or addition of neuraxial anesthesia for intraoperative anesthetic management. The evidence relating to neuraxial anesthesia/analgesia for postoperative pain control is discussed in Section 7.2.

7.1.2. Volatile General Anesthesia Versus Total Intravenous Anesthesia: Recommendation

CLASS IIa

1. **Use of either a volatile anesthetic agent or total intravenous anesthesia is reasonable for patients undergoing noncardiac surgery, and the choice is determined by factors other than the prevention of myocardial ischemia and MI (340,341).** ***(Level of Evidence: A)***

Several studies have attempted to examine whether there is a myocardial protective benefit of volatile anesthetic use in general anesthesia when compared with total intravenous anesthesia (342). There is no evidence to suggest a difference in myocardial ischemia/MI rates between the use of volatile anesthesia and total intravenous anesthesia in patients undergoing noncardiac surgery. Although the benefit of using volatile anesthetic agents has been demonstrated in cardiac surgery, a reduction in myocardial ischemia or MI has not been demonstrated in noncardiac surgery (343–347). A meta-analysis of >6000 patients undergoing noncardiac surgery failed to demonstrate a difference in MI rates between patients who received volatile anesthesia and patients who received total intravenous anesthesia (340). However, the event MI rate in the meta-analysis of >79 studies was 0 for both groups. A randomized comparison of volatile anesthetic administration versus total intravenous administration in patients undergoing noncardiac surgery demonstrated no difference in either myocardial ischemia or MI between the 2 groups (341).

TABLE 7 Summary of Recommendations for Anesthetic Consideration and Intraoperative Management

Recommendations	COR	LOE	References
Volatile general anesthesia versus total intravenous anesthesia			
Use of either a volatile anesthetic agent or total intravenous anesthesia is reasonable for patients undergoing noncardiac surgery	IIa	A	(340,341)
Perioperative pain management			
Neuraxial anesthesia for *postoperative* pain relief can be effective to reduce MI in patients undergoing abdominal aortic surgery	IIa	B	(348)
Preoperative epidural analgesia may be considered to decrease the incidence of *preoperative* cardiac events in patients with hip fracture	IIb	B	(349)
Prophylactic intraoperative nitroglycerin			
Prophylactic intravenous nitroglycerin is not effective in reducing myocardial ischemia in patients undergoing noncardiac surgery	III: No Benefit	B	(292,355,356)
Intraoperative monitoring techniques			
Emergency use of perioperative TEE in patients with hemodynamic instability is reasonable in patients undergoing noncardiac surgery if expertise is readily available	IIa	C	N/A
Routine use of intraoperative TEE during noncardiac surgery is not recommended	III: No Benefit	C	N/A
Maintenance of body temperature			
Maintenance of normothermia may be reasonable to reduce perioperative cardiac events	IIb	B	(364,365)
Hemodynamic assist devices			
Use of hemodynamic assist devices may be considered when urgent or emergency noncardiac surgery is required in the setting of acute severe cardiac dysfunction	IIb	C	N/A
Perioperative use of pulmonary artery catheters			
Use of pulmonary artery catheterization may be considered when underlying medical conditions that significantly affect hemodynamics cannot be corrected before surgery	IIb	C	N/A
Routine use of pulmonary artery catheterization is not recommended	III: No Benefit	A	(380-382)

COR indicates Class of Recommendation; LOE, Level of Evidence; MI, myocardial infarction; N/A, not applicable; and TEE, transesophageal echocardiogram.

7.1.3. Monitored Anesthesia Care Versus General Anesthesia

There are no RCTs to suggest a preference for monitored anesthesia care over general anesthesia for reducing myocardial ischemia and MI.

7.2. Perioperative Pain Management: Recommendations

CLASS IIa

1. **Neuraxial anesthesia for postoperative pain relief can be effective in patients undergoing abdominal aortic surgery to decrease the incidence of perioperative MI (348).** ***(Level of Evidence: B)***

CLASS IIb

1. **Perioperative epidural analgesia may be considered to decrease the incidence of preoperative cardiac events in patients with a hip fracture (349).** ***(Level of Evidence: B)***

Pain management is fundamental to the care of the surgical patient, and pain is one of many factors that can contribute to the development of postoperative myocardial ischemia and MI. Postoperative pain is associated with myocardial ischemia; however, the best practices for perioperative pain management have not been completely elucidated (90,350-352). Most of the literature focusing on perioperative myocardial events compares epidural analgesia with intravenous analgesia. Importantly, the potential efficacy of epidural analgesia depends on the local system of care. A 2003 review of a large billing registry comparing epidural analgesia with other forms of analgesia failed to show a reduction in perioperative myocardial events (353); however, other studies, including a meta-analysis of RCTs, concluded that patients receiving epidural analgesia experienced a reduction in postoperative myocardial ischemia and MI (348,354). An RCT in 2001 examining the use of epidural anesthesia in patients undergoing abdominal surgery found no difference between epidural and intravenous analgesia in the prevention of perioperative MI, although a subgroup analysis demonstrated a reduction in MI in patients undergoing abdominal aortic procedures (354). In 2012, a Cochrane review of 15 RCTs comparing epidural analgesia with opioids for patients undergoing abdominal aortic surgery reported a decrease in MIs in the patients who received epidural analgesia (348). There is a paucity of studies on perioperative cardiac events with regard to various methods of pain control in the general surgical population.

Although the majority of perioperative MIs occur during the postoperative period, 1 RCT examined the incidence of preoperative cardiac events in elderly patients with hip fractures. The 64-patient study concluded that

preoperative pain control with epidural analgesia reduced the incidence of preoperative myocardial ischemia and preoperative MI, as well as HF and AF (349).

See Online Data Supplement 28 for additional information on perioperative pain management.

7.3. Prophylactic Perioperative Nitroglycerin: Recommendation

CLASS III: NO BENEFIT

1. **Prophylactic intravenous nitroglycerin is not effective in reducing myocardial ischemia in patients undergoing noncardiac surgery (292,355,356). *(Level of Evidence: B)***

There are no significant studies within the past 10 years examining the effect of prophylactic nitroglycerin on perioperative myocardial ischemia. Prior RCTs yielded conflicting results and were small (<50 patients) and unblinded (292,355,356).

See Online Data Supplement 29 for additional information on prophylactic intraoperative nitroglycerin.

7.4. Intraoperative Monitoring Techniques: Recommendations

CLASS IIa

1. **The emergency use of perioperative transesophageal echocardiogram (TEE) is reasonable in patients with hemodynamic instability undergoing noncardiac surgery to determine the cause of hemodynamic instability when it persists despite attempted corrective therapy, if expertise is readily available. *(Level of Evidence: C)***

CLASS III: NO BENEFIT

1. **The routine use of intraoperative TEE during noncardiac surgery to screen for cardiac abnormalities or to monitor for myocardial ischemia is not recommended in patients without risk factors or procedural risks for significant hemodynamic, pulmonary, or neurologic compromise. *(Level of Evidence: C)***

TEE is widely available and commonly used perioperatively in patients undergoing cardiac surgery. TEE has the capacity to assess biventricular and valvular function, intracardiac structures, the pericardial space, and the thoracic aorta (17,357,358). The use of TEE intraoperatively in a patient undergoing noncardiac surgery is less clear.

There are limited data evaluating intraoperative TEE in the assessment of regional myocardial function and any association with cardiac outcomes (359,360). Moreover, the data are insufficient in terms of predictive accuracy or cost-effectiveness to recommend routine TEE monitoring. In contrast, emergency use of perioperative TEE in patients with hemodynamic instability, to determine the cause of an unexplained, severe hemodynamic instability that persists despite attempted corrective therapy, is appropriate where available (27,29,361–363). CPGs for the appropriate use of TEE have been developed by the American Society of Anesthesiologists, the Society of Cardiovascular Anesthesiologists, and the American Society of Echocardiography (17,27,29). Many anesthesiologists are experts in TEE; the use of TEE by those with limited or no training should be avoided (27).

7.5. Maintenance of Body Temperature: Recommendation

CLASS IIb

1. **Maintenance of normothermia may be reasonable to reduce perioperative cardiac events in patients undergoing noncardiac surgery (364,365). *(Level of Evidence: B)***

Hypothermia has been associated with several perioperative complications, including wound infection, MACE, immune dysfunction, coagulopathy, increased blood loss, death, and transfusion requirements (365–372). However, interest is emerging in the therapeutic benefit of hypothermia in preservation of neurological function after head trauma, stroke, and cardiac arrest. Balancing the risks and benefits to determine the appropriate use of hypothermia in the perioperative and inpatient hospital setting is an area of active research.

There are 2 conflicting studies on hypothermia in relation to perioperative cardiac events. They were conducted in very different patient populations and with different goals. In a 1997 study, 300 patients with known cardiovascular disease or risk factors for cardiovascular disease were randomized to forced air warmers or ambient temperature. This study demonstrated a significantly higher incidence of a MACE (e.g., ischemia, infarction, cardiac arrest) or an electrocardiographic event, particularly ventricular tachycardia (365), in the ambient-temperature group.

A large multicenter trial published in 2010 randomized 1000 patients with subarachnoid hemorrhage to either normothermia or perioperative hypothermia to assess the efficacy of hypothermia in brain protection. This large study demonstrated no increased incidence of cardiovascular events either intraoperatively or postoperatively in the hypothermia-treated patients (364).

See Online Data Supplement 30 for additional information on maintenance of body temperature.

7.6. Hemodynamic Assist Devices: Recommendation

CLASS IIb

1. **Use of hemodynamic assist devices may be considered when urgent or emergency noncardiac surgery is required in the setting of acute severe cardiac dysfunction (i.e., acute MI, cardiogenic shock) that cannot be corrected before surgery. *(Level of Evidence: C)***

Rare case reports have noted the use of and complications associated with hemodynamic assist device therapy during noncardiac surgery. There are no published RCTs, retrospective reviews, meta-analyses, or case series of >10

patients. Therefore, there is no evidence for the routine use of hemodynamic assist devices in patients at surgical risk, and it is not recommended. That being said, the number of patients chronically supported with long-term implantable devices, including left, right, or biventricular assist devices or total artificial heart, for advanced HF is steadily increasing. While on mechanical circulatory support, patients may face medical problems requiring emergency or nonemergency noncardiac surgery with varying degrees of risk to the patient and mortality outcomes. Several series have been published reporting outcomes in patients with mechanical circulatory support undergoing noncardiac procedures, with the 30-day mortality rate ranging from 9% to 25% (373-379).

For perioperative management, a multidisciplinary approach and expert guidance on anticoagulation strategies, pump flow control, hemodynamic monitoring, infection, and bleeding prevention strategies are considered important. Specific recommendations on perioperative management of these patients are addressed in the International Society for Heart and Lung Transplantation CPGs for mechanical circulatory support (379).

7.7. Perioperative Use of Pulmonary Artery Catheters: Recommendations

CLASS IIb

1. **The use of pulmonary artery catheterization may be considered when underlying medical conditions that significantly affect hemodynamics (i.e., HF, severe valvular disease, combined shock states) cannot be corrected before surgery.** *(Level of Evidence: C)*

CLASS III: NO BENEFIT

1. **Routine use of pulmonary artery catheterization in patients, even those with elevated risk, is not recommended (380-382).** *(Level of Evidence: A)*

The theoretical basis for better outcomes with the routine use of pulmonary artery catheterization in noncardiac surgery derives from clinicians' improved understanding of perioperative hemodynamics. Unfortunately, the clinical trial data on which recommendations are made are sparse. Of the 3 main trials, 2 are underpowered (380-382). The largest trial randomly allocated the use of pulmonary artery catheters in 1994 patients at high surgical risk, defined by an American Society of Anesthesiologists risk score of III or IV (380). In this trial, there were no differences in mortality or morbidity, save for an increase in pulmonary embolism noted in the pulmonary artery catheter arm. Therefore, routine use of pulmonary artery catheterization in patients at elevated surgical risk does not improve outcomes and is not recommended.

See Online Data Supplement 31 for additional information on perioperative use of pulmonary artery catheters.

7.8. Perioperative Anemia Management

Anemia can contribute to myocardial ischemia, particularly in patients with CAD. In patients with CAD who are also anemic, ischemia can be triggered by both the lack of adequate oxygen delivery to poststenotic myocardium and a demand for increased cardiac output to supply oxygen to other vascular beds throughout the body. Transfusions to treat anemia are not without economic costs and individual health costs, in the form of an increased risk of infectious and noninfectious complications. Transfusion practices vary widely, and much of the literature attempts to address the clinical question of when to transfuse an asymptomatic patient below a preset hemoglobin level and when to transfuse patients experiencing symptoms of ischemia. The 2012 American Association of Blood Banks CPG and a 2011 RCT provide some additional information and guidance to clinicians navigating the complex interplay among anemia, transfusions, and attribution of symptoms to anemia (21,383).

In 2011, a RCT compared 2000 patients with either CAD or known CAD risk factors and a hemoglobin level <10 g/dL after hip fracture surgery who were treated with either a liberal transfusion strategy (hemoglobin <10 g/dL) or a conservative transfusion strategy (hemoglobin <8 g/dL or symptoms of anemia) (383). The endpoints of death and inability to walk at the 60-day follow-up were not found to be significantly different in either the liberal or conservative transfusion group. Additionally, although the study found no difference in MI, unstable angina, or in-hospital death between the 2 groups, it was not sufficiently powered to show a difference in the aforementioned areas if a difference existed (383).

The 2012 American Association of Blood Banks CPG, which is based on expert opinion and studies, recommends a restricted transfusion strategy (hemoglobin <7 g/dL to 8 g/dL) in asymptomatic, hemodynamically stable patients without CAD (21). The CPG also recommends adherence to a restrictive transfusion strategy in hospitalized patients with cardiovascular disease and consideration of transfusion for patients with symptoms (e.g., chest pain, orthostasis, congestive HF) or hemoglobin <8 g/dL (21). In postoperative patients, the recommended maintenance hemoglobin concentration is ≥8 g/dL, unless the patient exhibits symptoms. There were no specific recommendations for hemodynamically stable patients with acute coronary syndrome because of the lack of high-quality evidence for either a liberal or a restrictive transfusion strategy in these patients. The consensus of those experts recommended a symptom-guided approach to evaluating a hemoglobin level to determine whether to transfuse a patient with anemia.

8. PERIOPERATIVE SURVEILLANCE

8.1. Surveillance and Management for Perioperative MI: Recommendations

CLASS I

1. Measurement of troponin levels is recommended in the setting of signs or symptoms suggestive of myocardial ischemia or MI (40,384). *(Level of Evidence: A)*
2. Obtaining an ECG is recommended in the setting of signs or symptoms suggestive of myocardial ischemia, MI, or arrhythmia (384,385). *(Level of Evidence: B)*

CLASS IIb

1. The usefulness of postoperative screening with troponin levels in patients at high risk for perioperative MI, but without signs or symptoms suggestive of myocardial ischemia or MI, is uncertain in the absence of established risks and benefits of a defined management strategy (386–392). *(Level of Evidence: B)*
2. The usefulness of postoperative screening with ECGs in patients at high risk for perioperative MI but without signs or symptoms suggestive of myocardial ischemia, MI, or arrhythmia, is uncertain in the absence of established risks and benefits of a defined management strategy (384,385,393–395). *(Level of Evidence: B)*

CLASS III: NO BENEFIT

1. Routine postoperative screening with troponin levels in unselected patients without signs or symptoms suggestive of myocardial ischemia or MI is not useful for guiding perioperative management (40,384). *(Level of Evidence: B)*

Improvements in surgical outcomes and increasing difficulty in accurately predicting adverse cardiovascular events and death in patients before surgery have fostered efforts to improve early detection of myocardial injury and MI to prevent more serious complications. Routine screening with troponin for cardiac injury has been proposed as a method of early detection to ensure early intervention to avoid more serious complications. Among the studies, elevations of troponin of any level associate directly and consistently with increases in 30-day mortality rates (40,384,396). In the largest of the studies, the VISION (Vascular Events in Noncardiac Surgery Patients Cohort Evaluation) trial (40), troponin elevations predicted vascular and nonvascular mortality rates equally. Type 1 MI (i.e., related to ischemia from a primary coronary event, such as plaque rupture or thrombotic occlusion) causes <5% of troponin elevation postoperatively (384,396) and therefore constitutes a small minority of the vascular causes of troponin elevation. In a subsequent publication, the authors defined myocardial injury after noncardiac surgery as troponin elevation with or without symptoms of myocardial ischemia (38). Myocardial injury after noncardiac surgery is a novel classification that predicted 30-day mortality rate but diverges from the Third Universal Definition of MI (397) by combining type 1 and type 2 events (i.e., type 2 is secondary to ischemia from a supply-and-demand mismatch), despite their different pathophysiological origin. In a study of 2232 consecutive patients undergoing noncardiac surgery, 315 patients had elevation of troponin I, 9.5% had attendant ECG changes suggestive of cardiac ischemia, and 3.2% had typical chest pain showing that a small minority of troponin elevation results from type 1 MI (396). Additionally, none of these studies accounts for patients with troponin elevations before surgery, which may be seen in as many as 21% of high-risk patients (398) and may be even more common if high-sensitivity troponin assays are used. Finally, the median time between troponin elevation and death is >7 days after measurement, and none of the studies clarifies the specific cause of death. In the absence of a description of the specific cause of death and evidence for the use of the biomarker to prevent these events, the use of routine postoperative troponin measurement remains uncertain, even in patients at high risk for perioperative MI. Therefore, routine screening with troponin provides a nonspecific assessment of risk, does not indicate a specific course of therapy, and is not clinically useful outside of the patient with signs or symptoms of myocardial ischemia or MI. The value of postoperative troponin surveillance may be clarified after completion of MANAGE (Management of Myocardial Injury After Noncardiac Surgery Trial), which is testing the effects of 2 drugs (dabigatran and omeprazole) that may prevent death, major cardiovascular complications, and major upper gastrointestinal bleeding in patients who have had myocardial injury after noncardiac surgery (399). Of note, elevation in the MB fraction of creatine kinase may also be used to detect myocardial necrosis and possible MI, although its interpretation in the perioperative period is often complicated by the significant rise in overall creatine kinase seen with noncardiac surgery.

The role of postoperative electrocardiography remains difficult to define. As noted in in previous versions of this CPG, older studies have demonstrated that changes in the ECG, particularly ST-segment changes, are associated with increases in major cardiac complications—more than 2-fold compared with those without electrocardiographic changes (400). More recently, however, it has become clear that electrocardiography may not provide information sufficient for routine use. One study involved 337 vascular surgery patients in whom troponin I levels were collected within 48 hours of surgery and 12-lead ECGs were performed daily for 3 postoperative days (385). Forty percent of the subjects had elevated troponin levels, but ischemic changes on the ECG were noted in 6%. Whereas elevations in troponin predicted death at 1 year, electrocardiographic changes did not. Several large surgical trials have demonstrated the superiority of troponin testing to

ECG in identifying patients with types 1 and 2 MI (384,394) and suggest that troponin testing may be a superior initial test in the diagnosis of MI. There are no prospective randomized trials examining the value of adding ECGs to routine postoperative care. In addition, the interpretation of ECGs in the setting of critical illness is only moderately reliable among expert readers (401). The current use of ECGs may have developed as a method to screen for MI when little else was routinely available. In the absence of clinical trial data, a recommendation for routine postoperative ECGs cannot be made.

See Online Data Supplement 32 for additional information on surveillance and management for perioperative MI.

9. FUTURE RESEARCH DIRECTIONS

Current recommendations for perioperative cardiovascular evaluation and management for noncardiac surgery are based largely on clinical experience and observational studies, with few prospective RCTs. The GWC recommends that future research on perioperative evaluation and management span the spectrum from RCTs to regional and national registries to focus on patient outcomes. Development and participation in registries (such as the American College of Surgeons NSQIP, American Society of Anesthesiologists, and NACOR [National Anesthesia Clinical Outcomes Registry]) for patients undergoing noncardiac surgery will advance knowledge in the following areas:

1. *Surveillance*: How are we doing across different practices? What are the significant gaps in care?
2. *Discovery*: What new information can be learned? What new strategies or interventions can improve these gaps in care?
3. *Translation*: How can we best apply these strategies or interventions to practice?
4. *Dissemination*: How can we spread what works?

The US healthcare system must focus on achieving the triple aim of better patient care and experience, better population health, and lower cost per capita over time. The use of perioperative tests and treatments improves patient outcomes only when targeted at specific patient subsets. Implementation of ACC/AHA CPGs for perioperative cardiovascular evaluation and management has been demonstrated to improve patient outcomes and reduce costs (402-405). For example, routine perioperative stress testing in patients at low risk for cardiac events undergoing low-risk elective noncardiac surgery has no benefit, but it could have harm by exposing the patient to unnecessary treatments, such as medications or revascularization procedures. Alternatively, the interruption of perioperative medications such as statins and warfarin in situations not supported by evidence/perioperative CPGs can worsen patient outcomes (406).

Diagnostic cardiovascular testing continues to evolve, with newer imaging modalities being developed, such as coronary calcium scores, computed tomography angiography, and cardiac magnetic resonance imaging. The value of these modalities in preoperative screening is uncertain and warrants further study.

The use of perioperative beta blockers in beta-blocker-naïve patients undergoing noncardiac surgery remains controversial because of uncertainty about the following issues: 1) optimal duration for the initiation of beta blockers before elective noncardiac surgery; 2) optimal dosing and titration protocol perioperatively to avoid hemodynamic instability, including hypotension and bradycardia; and 3) which elevated-risk patient subsets would benefit the most from initiation of perioperative beta blocker. Although there is sufficient evidence that patients who are receiving long-term beta-blocker therapy should continue beta blockers perioperatively, their use in beta-blocker-naïve patients needs additional research to illuminate the benefit (avoidance of MI) versus harm (stroke). RCTs are needed to demonstrate when to start beta-blocker therapy before noncardiac surgery, the optimal type and dose, and titration protocol.

The risk-adjusted mortality rates after noncardiac surgery have declined significantly in the past decade (relative reductions of 11% to 19% for major cancer surgery and 36% for abdominal aortic aneurysm repair), a development that has been attributed to higher volumes, consolidation of high-risk surgery at high-volume hospitals, and implementation of CPGs and local risk-reducing strategies (407). Research also suggests that additional factors at the practice, clinician, and patient levels can impact patient outcomes after noncardiac surgery. For bariatric surgery, the technical skill of practicing surgeons assessed by peer ratings varied widely, and greater skill was associated with better patient outcomes. The bottom quartile of surgical skill was associated with higher complication rates than was the top quartile (14.5% versus 5.2%; $p<0.001$) (408).

As outlined in Section 8, the evidence base for the predictive value of biomarkers in the perioperative period has grown. However, the utility of this information in influencing management and outcome is unknown and is currently undergoing investigation. The results of these investigations could lead to changes in recommendations in the future.

To implement the recommendations of the current perioperative CPGs effectively, a "perioperative team approach" is needed. The perioperative team is intended to engage clinicians with appropriate expertise; enhance communication of the benefits, risks, and alternatives; and include the patient's preferences, values, and goals. Members of the perioperative team would include the patient and family, surgeon, anesthesiologist, cardiologist, hospitalist, primary care clinician, and additional clinicians (e.g., a congenital heart disease

specialist) depending on the unique circumstances of the patient. Shared decision making aims to take into account the patient's preferences, values, and goals and is useful for treatment decisions where there are alternatives with comparable outcomes or where patient action is needed, such as medication adherence. Future research will also be needed to understand how information on perioperative risk is incorporated into patient decision making.

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KEY WORDS ACC/AHA Clinical Practice Guideline, adrenergic beta-antagonists, anesthesia and analgesia, diagnostic techniques cardiovascular, monitoring intraoperative, perioperative care, troponin, platelet aggregation inhibitors, referral and consultation

APPENDIX 1. AUTHOR RELATIONSHIPS WITH INDUSTRY AND OTHER ENTITIES (RELEVANT)—2014 ACC/AHA GUIDELINE ON PERIOPERATIVE CARDIOVASCULAR EVALUATION AND MANAGEMENT OF PATIENTS UNDERGOING NONCARDIAC SURGERY (MARCH 2013)

Committee Member	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section*
Lee A. Fleisher (Chair)	University of Pennsylvania Health System Department of Anesthesiology and Critical Care—Chair	None	None	None	None	None	None	None
Kirsten E. Fleischmann (Vice Chair)	UCSF School of Medicine, Division of Cardiology—Professor of Clinical Medicine	None	None	None	None	None	None	None
Andrew D. Auerbach	UCSF Division of Hospital Medicine—Professor of Medicine in Residence	None	None	None	None	None	None	None
Susan A. Barnason	University of Nebraska Medical Center, College of Nursing—Professor and Director of the Doctor of Nursing Practice Program	None	None	None	None	None	None	None
Joshua A. Beckman	Harvard Medical School—Associate Professor of Medicine; Brigham and Women's Hospital Cardiovascular Fellowship Program—Director	• AstraZeneca • Bristol-Myers Squibb† • Novartis† • Merck	None	None	None	• Boston Scientific	None	6.1, 6.1.1, 6.2.1, 6.2.2, 6.2.4, 6.2.5, 6.2.6, 6.3, 6.4, 7.3, 7.4, and 7.7
Biykem Bozkurt	Winters Center for Heart Failure Research, Baylor College of Medicine—The Mary and Gordon Cain Chair, Professor of Medicine, and Director; Michael E. DeBakey VA Med Center Cardiology Section—Chief	None	None	None	• Forest Pharmaceuticals (PI)†	• Novartis	None	6.2.1, 6.2.2, and 6.2.5
Victor G. Davila-Roman	Washington University School of Medicine Anesthesiology and Radiology Cardiovascular Division—Professor of Medicine	• ValveXchange† • Boston Scientific† • St. Jude Medical†	None	None	None	None	None	2.4, 2.4.1, 2.4.2, 2.4.3, 5.7, 6.1, 6.1.1, 6.3, 6.4, 7.4, and 7.7
Marie D. Gerhard-Herman	Harvard Medical School—Associate Professor	None	None	None	None	None	None	None
Thomas A. Holly	Northwestern University Feinberg School of Medicine—Medical Director, Nuclear Cardiology; Associate Professor of Medicine and Radiology; Program Director, Cardiovascular Disease Fellowship	None	None	None	None	• Astellas‡	None	5.5.1 and 5.7
Garvan C. Kane	Mayo Clinic, Division of Cardiovascular Diseases—Codirector and Echocardiography Laboratory Consultant; Associate Professor of Medicine	None	None	None	None	None	None	None
Joseph E. Marine	Johns Hopkins University School of Medicine—Associate Professor of Medicine; Associate Director of Electrophysiology; Associate Division Chief of Cardiology	None	None	None	None	None	None	None

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APPENDIX 1. CONTINUED

Committee Member	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section*
M. Timothy Nelson	University of New Mexico—Professor; Program Director and Vice Chair of Education, Department of Surgery; Executive Medical Director, Adult Inpatient Services	None	None	None	None	None	None	None
Crystal C. Spencer	Spencer Meador Johnson—Lawyer	None	None	None	None	None	None	None
Annemarie Thompson	Duke University School of Medicine—Professor of Anesthesiology	None	None	None	None	None	None	None
Henry H. Ting	Mayo Clinic—Professor of Medicine; Mayo Clinic Quality Academy—Director; Mayo School for Continuous Professional Development—Associate Dean	None	None	None	None	None	None	None
Barry F. Uretsky	University of Arkansas for Medical Sciences—Clinical Professor of Medicine, Director of Interventional Cardiology	None	None	None	None	• St. Jude Medical†§	None	None
Duminda N. Wijeysundera (ERC Chair)	Li Ka Shing Knowledge Institute of St. Michael's Hospital—Scientist; Toronto General Hospital—Staff, Department of Anesthesia and Pain Management; University of Toronto—Assistant Professor, Department of Anesthesia and Institute of Health Policy Management and Evaluation; Institute for Clinical Evaluative Sciences—Adjunct Scientist	None	None	None	None	None	None	None

This table represents the relationships of committee members with industry and other entities that were determined to be relevant to this document. These relationships were reviewed and updated in conjunction with all meetings and/or conference calls of the writing committee during the document development process. The table does not necessarily reflect relationships with industry at the time of publication. A person is deemed to have a significant interest in a business if the interest represents ownership of ≥5% of the voting stock or share of the business entity, or ownership of ≥$10,000 of the fair market value of the business entity; or if funds received by the person from the business entity exceed 5% of the person's gross income for the previous year. Relationships that exist with no financial benefit are also included for the purpose of transparency. Relationships in this table are modest unless otherwise noted.

According to the ACC/AHA, a person has a *relevant* relationship IF: a) the *relationship or interest* relates to the same or similar subject matter, intellectual property or asset, topic, or issue addressed in the *document*; or b) the *company/entity* (with whom the relationship exists) makes a drug, drug class, or device addressed in the *document*, or makes a competing drug or device addressed in the *document*; or c) the *person or a member of the person's household* has a reasonable potential for financial, professional, or other personal gain or loss as a result of the issues/content addressed in the *document*.

*Writing committee members are required to recuse themselves from voting on sections to which their specific relationships with industry and other entities may apply.

†Significant relationship.

‡No financial benefit.

§Dr. Uretsky's relationship with St. Jude Medical began just before balloting of the recommendations and was not relevant during the writing stage.

ACC indicates American College of Cardiology; AHA, American Heart Association; ERC, Evidence Review Committee; PI, principal investigator; UCSF, University of California, San Francisco; and VA, Veterans Affairs.

APPENDIX 2. REVIEWER RELATIONSHIPS WITH INDUSTRY AND OTHER ENTITIES (RELEVANT)—2014 ACC/AHA GUIDELINE ON PERIOPERATIVE CARDIOVASCULAR EVALUATION AND MANAGEMENT OF PATIENTS UNDERGOING NONCARDIAC SURGERY (JUNE 2014)

Reviewer	Representation	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Kim Eagle	Official Reviewer—AHA	University of Michigan Health System—Albion Walter Hewlett Professor of Internal Medicine	None	None	None	• GORE • Medtronic	None	None
Dipti Itchhaporia	Official Reviewer—ACC Board of Trustees	Hoag Memorial Hospital Presbyterian—Robert and Georgia Roth Chair for Excellence in Cardiac Care; Director of Disease Management	None	None	None	None	None	None
Mary Lough	Official Reviewer—AHA	Stanford Hospital and Clinics—Critical Care Clinical Nurse Specialist	None	None	None	None	None	None
G. B. John Mancini	Official Reviewer—ACC Board of Governors	Vancouver Hospital Research Pavilion—Professor of Medicine	• Merck • Pfizer • Servier	None	None	• Merck*	• Miraculins*	None
Frank W. Sellke	Official Reviewer—ACC/AHA Task Force on Practice Guidelines	Brown Medical School, Rhode Island Hospital—Professor; Chief of Cardiothoracic Surgery	None	None	None	None	• CSL Behring • The Medicines Company	None
Michael Baker	Organizational Reviewer—ASE	Vanderbilt University—Assistant Professor of Medicine	None	None	None	None	• Medtronic†	None
Michael England	Organizational Reviewer—ASA	Tufts University School of Medicine—Division Chief, Cardiac Anesthesiology; Assistant Professor	None	• Hospira	None	None	None	None
Leonard Feldman	Organizational Reviewer—SHM	Johns Hopkins School of Medicine-Director, Medicine-Pediatrics Urban Health Residency Program; Assistant Professor of Pediatrics; Assistant Professor of Medicine	None	None	None	None	None	• Defendant, pulmonary embolism, 2013 • Defendant, aortic dissection, 2013 • Defendant, stroke, 2013 • Defendant, sudden cardiac death, 2013
Jason Kovacic	Organizational Reviewer—SCAI	Mount Sinai School of Medicine—Assistant Professor of Medicine	• AstraZeneca*	• AstraZeneca	None	None	None	None

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APPENDIX 2. CONTINUED

Reviewer	Representation	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Martin London	Organizational Reviewer—SCA	University of California, San Francisco Medical Center—Professor of Clinical Anesthesia	None	None	None	None	None	None
Rupa Mehta Sanghani	Organizational Reviewer—ASNC	University of Chicago Medicine—Director, Cardiac Rehabilitation; Assistant Professor of Medicine	• Astellas	• Astellas	None	None	None	None
Reena Pande	Organizational Reviewer—SVM	Brigham and Women's Hospital, Prevention Brigham and Women's Hospital—Associate Physician; Harvard Medical School, Professor	None	None	None	None	None	None
Jeanne Poole	Organizational Reviewer—HRS	University of Washington—Professor of Medicine, Division of Cardiology	• Biotronik • Boston Scientific* • Medtronic • St. Jude Medical	None	None	None	• Boston Scientific • Medtronic	None
Russell Postier	Organizational Reviewer—ACS	University of Oklahoma Health Sciences Center—John A. Schilling Professor and Chairman, Department of Surgery	None	None	None	None	None	None
M. Obadah N. Al-Chekakie	Content Reviewer—ACC Board of Governors	Cheyenne Regional Medical Group—Physician	None	None	None	None	None	None
Jeffrey L. Anderson	Content Reviewer—ACC/AHA Task Force on Practice Guidelines	Intermountain Medical Center—Associate Chief of Cardiology	• Sanofi-aventis • The Medicines Company	None	None	None	None	None
H. Vernon Anderson	Content Reviewer—ACC Interventional Section Leadership Council	University of Texas Cardiology Division—Professor of Medicine	None	None	None	None	• MedPlace Medical Devices (DSMB)	None
Hugh Calkins	Content Reviewer	Johns Hopkins Hospital—Professor of Medicine; Director of Electrophysiology	None	None	None	• St. Jude Medical*	None	None

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APPENDIX 2. CONTINUED

Reviewer	Representation	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Steven Cohn	Content Reviewer	University of Miami—Professor of Clinical Medicine; University of Miami Hospital—Director, Medical Consultation Service; University Health Preoperative Assessment Center—Medical Director	None	None	• AstraZeneca* • Bristol-Myers Squibb* • GlaxoSmithKline* • Merck* • Pfizer*	None	None	• Defendant, venous thromboemboli pulmonary embolism, 2013 • Defendant, preoperative evaluation, 2013
George Crossley	Content Reviewer—ACC Electrophysiology Section Leadership Council	St. Thomas Heart—Medical Director, Cardiac Services	• Boston Scientific • Medtronic*	• Medtronic* • Sanofi-aventis	None	None	None	• Defendant, pacemaker complication, 2012 • Defendant, EP procedure complication, 2013
P.J. Devereaux	Content Reviewer	McMaster University—Associate Professor, Departments of Clinical Epidemiology and Biostatistics; Juravinski Hospital and Cancer Centre—Head of Cardiology and the Perioperative Cardiovascular Service	None	None	None	• Abbott Diagnostics* • Bayer* • Boehringer Ingelheim* • Roche Diagnostics* • Stryker*	• Canadian Perioperative Guideline Chair	None
Richard Lange	Content Reviewer	University of Texas Health Science Center at San Antonio—Professor of Medicine	None	None	None	None	None	None
Maria Lantin-Hermoso	Content Reviewer—ACC Congenital and Pediatric Cardiology Section Leadership Council	Baylor College of Medicine—Associate Professor, Department of Pediatrics, Section of Cardiology; Texas Children's Hospital—Attending Physician	None	None	None	None	None	None
Srinivas Murali	Content Reviewer—ACC Board of Governors	Temple University School of Medicine—Professor of Medicine; Director, Division of Cardiovascular Medicine; Cardiovascular Institute Medical—Medical director	• Actelion • Bayer • Gilead • Lung Biotechnology	• Actelion	None	• Cardiokinetics • CVRx • Gilead • Ikaria • Medtronic • St. Jude Medical	None	None

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APPENDIX 2. CONTINUED

Reviewer	Representation	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
E. Magnus Ohman	Content Reviewer—ACC/AHA Task Force on Practice Guidelines	Duke University Medical Center—Professor of Medicine; Director, Program for Advanced Coronary Disease	• Abiomed* • AstraZeneca • Daiichi-Sankyo* • Gilead Sciences • Janssen Pharmaceuticals* • Pozen • Sanofi-aventis* • The Medicines Company	None	None	• Eli Lilly* • Gilead Sciences*	None	None
Gurusher Panjrath	Content Reviewer—ACC Heart Failure and Transplant Section Leadership Council	George Washington Heart and Vascular Institute—Assistant Professor of Medicine; Director, Heart Failure and Mechanical Support Program	None	None	None	None	None	None
Susan J. Pressler	Content Reviewer—ACC/AHA Task Force on Practice Guidelines	University of Michigan School of Nursing—Professor	None	None	None	None	• Pfizer†	None
Pasala Ravichandran	Content Reviewer—ACC Surgeons' Council	Oregon Health and Science University—Associate Professor	None	None	None	None	None	None
Ezra Amsterdam	Content Reviewer	University of California Davis Medical Center Division of Cardiology—Professor	None	None	None	None	None	None
John Erwin	Content Reviewer	Scott and White Hospital and Clinic—Senior Staff Cardiologist, Associate Professor of Medicine	None	None	None	• Eli Lilly (PI)*	None	None
Samuel Gidding	Content Reviewer—ACC/AHA Task Force on Practice Guidelines	Nemours/Alfred I. DuPont Hospital for Children—Chief, Division of Pediatric Cardiology	None	None	None	• GlaxoSmithKline*	None	None
Robert Hendel	Content Reviewer	University of Miami School of Medicine—Director Cardiac Imaging and Outpatient Services	• Adenosine Therapeutics • Astellas • Bayer	None	None	None	None	None
Glenn Levine	Content Reviewer	Baylor College of Medicine—Associate Professor of Medicine	None	None	None	None	None	None

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APPENDIX 2. CONTINUED

Reviewer	Representation	Employment	Consultant	Speakers Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
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ACC indicates American College of Cardiology; ACS, American College of Surgeons; AHA, American Heart Association; ASA, American Society of Anesthesiologists; ASE, American Society of Echocardiography; ASNC, American Society of Nuclear Cardiology; DSMB, data safety monitoring board; EP, electrophysiology; HRS, Heart Rhythm Society; PI, principal investigator; SCA, Society of Cardiovascular Anesthesiologists; SCAI, Society for Cardiovascular Angiography and Interventions; SHM, Society of Hospital Medicine; and SVM, Society for Vascular Medicine.

APPENDIX 3. RELATED RECOMMENDATIONS FROM OTHER CPGS

TABLE A Left Main CAD Revascularization Recommendations From the 2011 CABG and PCI CPGs

Anatomic Setting	COR	LOE	References
UPLM or complex CAD			
CABG and PCI	I—Heart Team approach recommended	C	(409–411)
CABG and PCI	IIa—Calculation of the STS and SYNTAX scores	B	(296,409,412–418)
UPLM*			
CABG	I	B	(419–425)
PCI	IIa—For SIHD when both of the following are present: 2. Anatomic conditions associated with a low risk of PCI procedural complications and a high likelihood of good long-term outcome (e.g., a low SYNTAX score of ≤22, ostial, or trunk left main CAD)	B	(412,414,418,426–444)
	3. Clinical characteristics that predict a significantly increased risk of adverse surgical outcomes (e.g., STS-predicted risk of operative mortality ≥5%)		
	IIa—For UA/NSTEMI if not a CABG candidate	B	(412,432–435, 440,441,443–445)
	IIa—For STEMI when distal coronary flow is TIMI flow grade <3 and PCI can be performed more rapidly and safely than CABG	C	(429,446,447)
	IIb—For SIHD when *both* of the following are present: 2. Anatomic conditions associated with a low-to-intermediate risk of PCI procedural complications and intermediate-to-high likelihood of good long-term outcome (e.g., low-intermediate SYNTAX score of <33, bifurcation left main CAD)	B	(412,414,418, 426–444,448)
	3. Clinical characteristics that predict an increased risk of adverse surgical outcomes (e.g., moderate-severe COPD, disability from prior stroke, or prior cardiac surgery; STS-predicted risk of operative mortality >2%)		
	III: Harm—For SIHD in patients (versus performing CABG) with unfavorable anatomy for PCI and who are good candidates for CABG	B	(412,414,418–425, 427,428)
3-vessel disease with or without proximal LAD artery disease*			
CABG	I	B	(421,425,449–452)
	IIa—It is reasonable to choose CABG over PCI in patients with complex 3-vessel CAD (e.g., SYNTAX >22) who are good candidates for CABG	B	(428,443,451,453,454)
PCI	IIb—Of uncertain benefit	B	(421,442,449,451,455)
2-vessel disease with proximal LAD artery disease*			
CABG	I	B	(421,425,449–452)
PCI	IIb—Of uncertain benefit	B	(421,449,451,455)
2-vessel disease without proximal LAD artery disease*			
CABG	IIa—With extensive ischemia	B	(456–459)
	IIb—Of uncertain benefit without extensive ischemia	C	(451)
PCI	IIb—Of uncertain benefit	B	(421,449,451,455)
1-vessel proximal LAD artery disease			
CABG	IIa—With LIMA for long-term benefit	B	(425,451,460,461)
PCI	IIb—Of uncertain benefit	B	(421,449,451,455)
1-vessel disease without proximal LAD artery involvement			
CABG	III: Harm	B	(425,449,456,457, 462–465)
PCI	III: Harm	B	(425,449,456,457, 462–465)
LV dysfunction			
CABG	IIa—EF 35% to 50%	B	(425,466–470)
CABG	IIb—EF <35% without significant left main CAD	B	(425,466–472)
PCI	Insufficient data		N/A

Continued on the next page

TABLE A Continued

Anatomic Setting	COR	LOE	References
Survivors of sudden cardiac death with presumed ischemia-mediated VT			
CABG	I	B	(473–475)
PCI	I	C	(474)
No anatomic or physiological criteria for revascularization			
CABG	III: Harm	B	(425,449,456,457, 462–465,476)
PCI	III: Harm	B	(425,449,456,457, 462–465,476)

*In patients with multivessel disease who also have diabetes mellitus, it is reasonable to choose CABG (with LIMA) over PCI (458,477–484) (*Class IIa; LOE: B*).

CABG indicates coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; COR, Class of Recommendation; CPG, clinical practice guideline; EF, ejection fraction; LAD, left anterior descending; LIMA, left internal mammary artery; LOE, Level of Evidence; LV, left ventricular; N/A, not applicable; PCI, percutaneous coronary intervention; SIHD, stable ischemic heart disease; STEMI, ST-elevation myocardial infarction; STS, Society of Thoracic Surgeons; SYNTAX, Synergy Between Percutaneous Coronary Intervention With TAXUS and Cardiac Surgery; TIMI, Thrombolysis In Myocardial Infarction; UA/NSTEMI, unstable angina/non-ST-elevation myocardial infarction; UPLM, unprotected left main disease; and VT, ventricular tachycardia.
Reproduced from Levine et al. (26) and Hillis et al. (25).

TABLE B GDMT Recommendations for Beta Blockers From 2011 Secondary Prevention CPG

Beta Blockers	**Class I** 1. Beta-blocker therapy should be used in all patients with LV systolic dysfunction (EF ≤40%) with HF or prior MI, unless contraindicated. (Use should be limited to carvedilol, metoprolol succinate, or bisoprolol, which have been shown to reduce mortality.) (485–487). ***(Level of Evidence: A)*** 2. Beta-blocker therapy should be started and continued for 3 years in all patients with normal LV function who have had MI or ACS (488–490). ***(Level of Evidence: B)*** **Class IIa** 1. It is reasonable to continue beta blockers >3 years as chronic therapy in all patients with normal LV function who have had MI or ACS (488–490). ***(Level of Evidence: B)*** 2. It is reasonable to give beta-blocker therapy in patients with LV systolic dysfunction (EF ≤40%) without HF or prior MI. ***(Level of Evidence: C)***

ACS indicates acute coronary syndrome; CPG, clinical practice guideline; EF, ejection fraction; GDMT, guideline-directed medical therapy; HF, heart failure; LV, left ventricular; and MI, myocardial infarction.
Reproduced from Smith Jr et al. (249)

APPENDIX 4. ABBREVIATIONS

ACE = angiotensin-converting enzyme
ACHD = adult congenital heart disease
AF = atrial fibrillation
AR = aortic regurgitation
ARB = angiotensin-receptor blocker
AS = aortic stenosis
AVR = aortic valve replacement
BMS = bare-metal stent
CABG = coronary artery bypass graft
CAD = coronary artery disease
CI = confidence interval
CIED = cardiovascular implantable electronic device
CPG = clinical practice guideline
DAPT = dual antiplatelet therapy
DES = drug-eluting stent
DSE = dobutamine stress echocardiogram
ECG = electrocardiogram
EF = ejection fraction
EMI = electromagnetic interference
ERC = Evidence Review Committee
GDMT = guideline-directed medical therapy
GWC = guideline writing committee
HF = heart failure
ICD = implantable cardioverter-defibrillator
LV = left ventricular
LVEF = left ventricular ejection fraction
MACE = major adverse cardiac event
MET = metabolic equivalent
MI = myocardial infarction
MPI = myocardial perfusion imaging
MR = mitral regurgitation
OR = odds ratio
PCI = percutaneous coronary intervention
RCT = randomized controlled trial
RV = right ventricular
TAVR = transcatheter aortic valve replacement
TEE = transesophageal echocardiogram