2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery: A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines Developed in Collaboration With the American Association for Thoracic Surgery, Society of Cardiovascular Anesthesiologists, and Society of Thoracic Surgeons

L. David Hillis, Peter K. Smith, Jeffrey L. Anderson, John A. Bittl, Charles R. Bridges, John G. Byrne, Joaquin E. Cigarroa, Verdi J. DiSesa, Loren F. Hiratzka, Adolph M. Hutter, Jr, Michael E. Jessen, Ellen C. Keeley, Stephen J. Lahey, Richard A. Lange, Martin J. London, Michael J. Mack, Manesh R. Patel, John D. Puskas, Joseph F. Sabik, Ola Selnes, David M. Shahian, Jeffrey C. Trost, and Michael D. Winniford

J. Am. Coll. Cardiol. 2011;58;e123-e210; originally published online Nov 7, 2011;
doi:10.1016/j.jacc.2011.08.009

Journal of the American College of Cardiology
© 2011 by the American College of Cardiology Foundation and the American Heart Association, Inc.
Published by Elsevier Inc.

Vol. 58, No. 24, 2011
ISSN 0735-1097/$36.00
doi:10.1016/j.jacc.2011.08.009

PRACTICE GUIDELINE

2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery

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

Developed in Collaboration With the American Association for Thoracic Surgery, Society of Cardiovascular Anesthesiologists, and Society of Thoracic Surgeons

Writing Committee Members*

L. David Hillis, MD, FACC, *Chair*†
Peter K. Smith, MD, FACC, *Vice Chair**†

Jeffrey L. Anderson, MD, FACC, FAHA*‡
John A. Bittl, MD, FACC§
Charles R. Bridges, MD, ScD, FACC, FAHA*†
John G. Byrne, MD, FACC†
Joaquin E. Cigarroa, MD, FACC†
Verdi J. DiSesa, MD, FACC†
Loren F. Hiratzka, MD, FACC, FAHA†
Adolph M. Hutter, Jr, MD, MACC, FAHA†
Michael E. Jessen, MD, FACC*†
Ellen C. Keeley, MD, MS†
Stephen J. Lahey, MD†
Richard A. Lange, MD, FACC, FAHA†§
Martin J. London, MD‖
Michael J. Mack, MD, FACC*¶
Manesh R. Patel, MD, FACC†
John D. Puskas, MD, FACC*†
Joseph F. Sabik, MD, FACC*#
Ola Selnes, PhD†
David M. Shahian, MD, FACC, FAHA**
Jeffrey C. Trost, MD, FACC*†
Michael D. Winniford, MD, FACC†

*Writing committee members are required to recuse themselves from voting on sections to which their specific relationships with industry and other entities may apply; see Appendix 1 for recusal information. †ACCF/AHA Representative. ‡ACCF/AHA Task Force on Practice Guidelines Liaison. §Joint Revascularization Section Author. ‖Society of Cardiovascular Anesthesiologists Representative. ¶American Association for Thoracic Surgery Representative. #Society of Thoracic Surgeons Representative. **ACCF/AHA Task Force on Performance Measures Liaison.

ACCF/AHA Task Force Members

Alice K. Jacobs, MD, FACC, FAHA, *Chair*
Jeffrey L. Anderson, MD, FACC, FAHA, *Chair-Elect*

Nancy Albert, PhD, CCNS, CCRN, FAHA
Mark A. Creager, MD, FACC, FAHA
Steven M. Ettinger, MD, FACC
Robert A. Guyton, MD, FACC
Jonathan L. Halperin, MD, FACC, FAHA
Judith S. Hochman, MD, FACC, FAHA
Frederick G. Kushner, MD, FACC, FAHA
E. Magnus Ohman, MD, FACC
William Stevenson, MD, FACC, FAHA
Clyde W. Yancy, MD, FACC, FAHA

This document was approved by the American College of Cardiology Foundation Board of Trustees and the American Heart Association Science Advisory and Coordinating Committee in July 2011, by the Society of Cardiovascular Anesthesiologists and the Society of Thoracic Surgeons in August 2011, and by the American Association for Thoracic Surgery in September 2011.

The American College of Cardiology Foundation requests that this document be cited as follows: Hillis LD, Smith PK, Anderson JL, Bittl JA, Bridges CR, Byrne JG, Cigarroa JE, DiSesa VJ, Hiratzka LF, Hutter AM Jr, Jessen ME, Keeley EC, Lahey SJ, Lange RA, London MJ, Mack MJ, Patel MR, Puskas JD, Sabik JF, Selnes O, Shahian DM, Trost JC, Winniford MD. 2011 ACCF/AHA guideline for coronary artery bypass graft surgery: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol 2011;58:e123–210.

This article is copublished in *Circulation*.

TABLE OF CONTENTS

Preamble

The medical profession should play a central role in evaluating the evidence related to drugs, devices, and procedures for the detection, management, and prevention of disease. When properly applied, expert analysis of available data on the benefits and risks of these therapies and procedures can improve the quality of care, optimize patient outcomes, and favorably affect costs by focusing resources on the most effective strategies. An organized and directed approach to a thorough review of evidence has resulted in the production of clinical practice guidelines that assist physicians in selecting the best management strategy for an individual patient. Moreover, clinical practice guidelines can provide a foundation for other applications, such as performance measures, appropriate use criteria, and both quality improvement and clinical decision support tools.

The American College of Cardiology Foundation (ACCF) and the American Heart Association (AHA) have jointly produced guidelines in the area of cardiovascular disease since 1980. The ACCF/AHA Task Force on Practice Guidelines (Task Force), charged with developing, updating, and revising practice guidelines for cardiovascular diseases and procedures, directs and oversees this effort. Writing committees are charged with regularly reviewing and evaluating all available evidence to develop balanced, patient-centric recommendations for clinical practice.

Experts in the subject under consideration are selected by the ACCF and AHA to examine subject-specific data and write guidelines in partnership with representatives from other medical organizations and specialty groups. Writing committees are asked to perform a formal literature review; weigh the strength of evidence for or against particular tests, treatments, or procedures; and include estimates of expected outcomes where such data exist. Patient-specific modifiers, comorbidities, and issues of patient preference that may influence the choice of tests or therapies are considered. When available, information from studies on cost is considered, but data on efficacy and outcomes constitute the primary basis for the recommendations contained herein.

In analyzing the data and developing recommendations and supporting text, the writing committee uses evidence-based methodologies developed by the Task Force (1). The Class of Recommendation (COR) is an estimate of the size of the treatment effect considering risks versus benefits in addition to evidence and/or agreement that a given treatment or procedure is or is not useful/effective or in some situations may cause harm. The Level of Evidence (LOE) is an estimate of the certainty or precision of the treatment effect. The writing committee reviews and ranks evidence supporting each recommendation with the weight of evidence ranked as LOE A, B, or C according to specific definitions that are included in Table 1. Studies are identified as observational, retrospective, prospective, or randomized where appropriate. For certain conditions for which inadequate data are available, recommendations are based on expert consensus and clinical experience and are ranked as LOE C. When recommendations at LOE C are supported by historical clinical data, appropriate references (including clinical reviews) are cited if available. For issues for which sparse data are available, a survey of current

JACC Vol. 58, No. 24, 2011
December 6, 2011:e123–210

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 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, 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.

practice among the clinicians on the writing committee is the basis for LOE C recommendations, and no references are cited. The schema for COR and LOE is summarized in Table 1, which also provides suggested phrases for writing recommendations within each COR. A new addition to this methodology is separation of the Class III recommendations to delineate if the recommendation is determined to be of "no benefit" or is associated with "harm" to the patient. In addition, in view of the increasing number of comparative effectiveness studies, comparator verbs and suggested phrases for writing recommendations for the comparative effectiveness of one treatment or strategy versus another have been added for COR I and IIa, LOE A or B only.

In view of the advances in medical therapy across the spectrum of cardiovascular diseases, the Task Force has designated the term *guideline–directed medical therapy (GDMT)* to represent optimal medical therapy as defined by ACCF/AHA guideline–recommended therapies (primarily Class I). This new term, GDMT, will be used herein and throughout all future guidelines.

Because the ACCF/AHA practice guidelines address patient populations (and healthcare providers) residing in North America, drugs that are not currently available in North America are discussed in the text without a specific COR. For studies performed in large numbers of subjects outside North America, each writing committee reviews the

potential influence of different practice patterns and patient populations on the treatment effect and relevance to the ACCF/AHA target population to determine whether the findings should inform a specific recommendation.

The ACCF/AHA practice guidelines are intended to assist healthcare providers in clinical decision making by describing a range of generally acceptable approaches to the diagnosis, management, and prevention of specific diseases or conditions. The guidelines attempt to define practices that meet the needs of most patients in most circumstances. The ultimate judgment regarding the care of a particular patient must be made by the healthcare provider and patient in light of all the circumstances presented by that patient. As a result, situations may arise for which deviations from these guidelines may be appropriate. Clinical decision making should involve consideration of the quality and availability of expertise in the area where care is provided. When these guidelines are used as the basis for regulatory or payer decisions, the goal should be improvement in quality of care. The Task Force recognizes that situations arise in which additional data are needed to inform patient care more effectively; these areas will be identified within each respective guideline when appropriate.

Prescribed courses of treatment in accordance with these recommendations are effective only if followed. Because lack of patient understanding and adherence may adversely affect outcomes, physicians and other healthcare providers should make every effort to engage the patient's active participation in prescribed medical regimens and lifestyles. In addition, patients should be informed of the risks, benefits, and alternatives to a particular treatment and be involved in shared decision making whenever feasible, particularly for COR IIa and IIb, where the benefit-to-risk ratio may be lower.

The Task Force makes every effort to avoid actual, potential, or perceived conflicts of interest that may arise as a result of industry relationships or personal interests among the members of the writing committee. All writing committee members and peer reviewers of the guideline are required to disclose all such current relationships, as well as those existing 12 months previously. In December 2009, the ACCF and AHA implemented a new policy for relationships with industry and other entities (RWI) that requires the writing committee chair plus a minimum of 50% of the writing committee to have no relevant RWI (Appendix 1 for the ACCF/AHA definition of relevance). These statements are reviewed by the Task Force and all members during each conference call and meeting of the writing committee and are updated as changes occur. All guideline recommendations require a confidential vote by the writing committee and must be approved by a consensus of the voting members. Members are not permitted to write, and must recuse themselves from voting on, any recommendation or section to which their RWI apply. Members who recused themselves from voting are indicated in the list of writing committee members, and section recusals are noted in Appendix 1. Authors' and peer reviewers' RWI pertinent to this guideline are disclosed in Appendixes 1 and 2, respectively.

Additionally, to ensure complete transparency, writing committee members' comprehensive disclosure information—including RWI not pertinent to this document—is available as an online supplement. Comprehensive disclosure information for the Task Force is also available online at www.cardiosource.org/ACC/About-ACC/Leadership/Guidelines-and-Documents-Task-Forces.aspx. The work of the writing committee was supported exclusively by the ACCF and AHA without commercial support. Writing committee members volunteered their time for this activity.

In an effort to maintain relevance at the point of care for practicing physicians, the Task Force continues to oversee an ongoing process improvement initiative. As a result, in response to pilot projects, evidence tables (with references linked to abstracts in PubMed) have been added.

In April 2011, the Institute of Medicine released 2 reports: *Finding What Works in Health Care: Standards for Systematic Reviews* and *Clinical Practice Guidelines We Can Trust* (2,3). It is noteworthy that the ACCF/AHA guidelines are cited as being compliant with many of the proposed standards. A thorough review of these reports and of our current methodology is under way, with further enhancements anticipated.

The recommendations in this guideline are considered current until they are superseded by a focused update or the full-text guideline is revised. Guidelines are official policy of both the ACCF and AHA.

Alice K. Jacobs, MD, FACC, FAHA Chair
ACCF/AHA Task Force on Practice Guidelines

1. Introduction

1.1. Methodology and Evidence Review

Whenever possible, the recommendations listed in this document are evidence based. Articles reviewed in this guideline revision covered evidence from the past 10 years through January 2011, as well as selected other references through April 2011. Searches were limited to studies, reviews, and other evidence conducted in human subjects that were published in English. Key search words included but were not limited to the following: *analgesia*, *anastomotic techniques*, *antiplatelet agents*, *automated proximal clampless anastomosis device*, *asymptomatic ischemia*, *Cardica C-port*, *cost effectiveness*, *depressed left ventricular (LV) function*, *distal anastomotic techniques*, *direct proximal anastomosis on aorta*, *distal anastomotic devices*, *emergency coronary artery bypass graft (CABG) and ST-elevation myocardial infarction (STEMI)*, *heart failure*, *interrupted sutures*, *LV systolic dysfunction, magnetic connectors*, *PAS-Port automated proximal clampless anastomotic device*, *patency*, *proximal connectors*, *renal disease*, *sequential anastomosis*, *sternotomy*, *symmetry connector*, *symptomatic ischemia*, *proximal connectors*, *sequential anastomosis*, *T grafts*, *thoracotomy*, *U-clips*, *Ventrica Magnetic Vascular Port system*, *Y grafts*. Additionally, the committee reviewed documents related to the subject matter previously published by the

ACCF and AHA. References selected and published in this document are representative but not all-inclusive.

To provide clinicians with a comprehensive set of data, whenever deemed appropriate or when published, the absolute risk difference and number needed to treat or harm are provided in the guideline, along with confidence interval (CI) and data related to the relative treatment effects such as odds ratio (OR), relative risk (RR), hazard ratio (HR), or incidence rate ratio.

The focus of these guidelines is the safe, appropriate, and efficacious performance of CABG.

1.2. Organization of the Writing Committee

The committee was composed of acknowledged experts in CABG, interventional cardiology, general cardiology, and cardiovascular anesthesiology. The committee included representatives from the ACCF, AHA, American Association for Thoracic Surgery, Society of Cardiovascular Anesthesiologists, and Society of Thoracic Surgeons (STS).

1.3. Document Review and Approval

This document was reviewed by 2 official reviewers, each nominated by both the ACCF and the AHA, as well as 1 reviewer each from the American Association for Thoracic Surgery, Society of Cardiovascular Anesthesiologists, and STS, as well as members from the ACCF/AHA Task Force on Data Standards, ACCF/AHA Task Force on Performance Measures, ACCF Surgeons' Scientific Council, ACCF Interventional Scientific Council, and Southern Thoracic Surgical Association. All information on reviewers' RWI was distributed to the writing committee and is published in this document (Appendix 2).

This document was approved for publication by the governing bodies of the ACCF and the AHA and endorsed by the American Association for Thoracic Surgery, Society of Cardiovascular Anesthesiologists, and STS.

2. Procedural Considerations

2.1. Intraoperative Considerations

2.1.1. Anesthetic Considerations: Recommendations

CLASS I

1. Anesthetic management directed toward early postoperative extubation and accelerated recovery of low- to medium-risk patients undergoing uncomplicated CABG is recommended (4–6). *(Level of Evidence: B)*
2. Multidisciplinary efforts are indicated to ensure an optimal level of analgesia and patient comfort throughout the perioperative period (7–11). *(Level of Evidence: B)*
3. Efforts are recommended to improve interdisciplinary communication and patient safety in the perioperative environment (e.g., formalized checklist-guided multidisciplinary communication) (12–15). *(Level of Evidence: B)*
4. A fellowship-trained cardiac anesthesiologist (or experienced board-certified practitioner) credentialed in the use of perioperative transesophageal echocardiography (TEE) is recommended to provide or supervise anesthetic care of patients who are considered to be at high risk (16–18). *(Level of Evidence: C)*

CLASS IIa

1. Volatile anesthetic-based regimens can be useful in facilitating early extubation and reducing patient recall (5,19–21). *(Level of Evidence: A)*

CLASS IIb

1. The effectiveness of high thoracic epidural anesthesia/analgesia for routine analgesic use is uncertain (22–25). *(Level of Evidence: B)*

CLASS III: HARM

1. Cyclooxygenase-2 inhibitors are not recommended for pain relief in the postoperative period after CABG (26,27). *(Level of Evidence: B)*
2. Routine use of early extubation strategies in facilities with limited backup for airway emergencies or advanced respiratory support is potentially harmful. *(Level of Evidence: C)*

See Online Data Supplement 1 for additional data on anesthetic considerations.

Anesthetic management of the CABG patient mandates a favorable balance of myocardial oxygen supply and demand to prevent or minimize myocardial injury (Section 2.1.8). Historically, the popularity of several anesthetic techniques for CABG has varied on the basis of their known or potential adverse cardiovascular effects (e.g., cardiovascular depression with high doses of volatile anesthesia, lack of such depression with high-dose opioids, or coronary vasodilation and concern for a "steal" phenomenon with isoflurane) as well as concerns about interactions with preoperative medications (e.g., cardiovascular depression with beta blockers or hypotension with angiotensin-converting enzyme [ACE] inhibitors and angiotensin-receptor blockers [ARBs] [28–30]) (Sections 2.1.8 and 4.5). Independent of these concerns, efforts to improve outcomes and to reduce costs have led to shorter periods of postoperative mechanical ventilation and even, in some patients, to prompt extubation in the operating room ("accelerated recovery protocols" or "fast-track management") (5,31).

High-dose opioid anesthesia with benzodiazepine supplementation was used commonly in CABG patients in the United States in the 1970s and 1980s. Subsequently, it became clear that volatile anesthetics are protective in the setting of myocardial ischemia and reperfusion, and this, in combination with a shift to accelerated recovery or "fast-track" strategies, led to their ubiquitous use. As a result, opioids have been relegated to an adjuvant role (32,33). Despite their widespread use, volatile anesthetics have not been shown to provide a mortality rate advantage when compared with other intravenous regimens (Section 2.1.8).

Optimal anesthesia care in CABG patients should include 1) a careful preoperative evaluation and treatment of modifiable risk factors; 2) proper handling of all medications given preoperatively (Sections 4.1, 4.3, and 4.5); 3) establishment of central venous access and careful cardiovascular monitoring; 4) induction of a state of unconsciousness, analgesia, and immobility; and 5) a smooth transition to the

early postoperative period, with a goal of early extubation, patient mobilization, and hospital discharge. Attention should be directed at preventing or minimizing adverse hemodynamic and hormonal alterations that may induce myocardial ischemia or exert a deleterious effect on myocardial metabolism (as may occur during cardiopulmonary bypass [CPB]) (Section 2.1.8). This requires close interaction between the anesthesiologist and surgeon, particularly when manipulation of the heart or great vessels is likely to induce hemodynamic instability. During on-pump CABG, particular care is required during vascular cannulation and weaning from CPB; with off-pump CABG, the hemodynamic alterations often caused by displacement or verticalization of the heart and application of stabilizer devices on the epicardium, with resultant changes in heart rate, cardiac output, and systemic vascular resistance, should be monitored carefully and managed appropriately.

In the United States, nearly all patients undergoing CABG receive general anesthesia with endotracheal intubation utilizing volatile halogenated general anesthetics with opioid supplementation. Intravenous benzodiazepines often are given as premedication or for induction of anesthesia, along with other agents such as propofol or etomidate. Nondepolarizing neuromuscular-blocking agents, particularly nonvagolytic agents with intermediate duration of action, are preferred to the longer-acting agent, pancuronium. Use of the latter is associated with higher intraoperative heart rates and a higher incidence of residual neuromuscular depression in the early postoperative period, with a resultant delay in extubation (23,34). In addition, low concentrations of volatile anesthetic usually are administered via the venous oxygenator during CPB, facilitating amnesia and reducing systemic vascular resistance.

Outside the United States, alternative anesthetic techniques, particularly total intravenous anesthesia via propofol and opioid infusions with benzodiazepine supplementation with or without high thoracic epidural anesthesia, are commonly used. The use of high thoracic epidural anesthesia exerts salutary effects on the coronary circulation as well as myocardial and pulmonary function, attenuates the stress response, and provides prolonged postoperative analgesia (24,25,35). In the United States, however, concerns about the potential for neuraxial bleeding (particularly in the setting of heparinization, platelet inhibitors, and CPB-induced thrombocytopenia), local anesthetic toxicity, and logistical issues related to the timing of epidural catheter insertion and management have resulted in limited use of these techniques (22). Their selective use in patients with severe pulmonary dysfunction (Section 6.5) or chronic pain syndromes may be considered. Although meta-analyses of randomized controlled trials (RCTs) of high thoracic epidural anesthesia/analgesia in CABG patients (particularly on-pump) have yielded inconsistent results on morbidity and mortality rates, it does appear to reduce time to extubation, pain, and pulmonary complications (36–38). Of interest, although none of the RCTs have reported the occurrence of epidural hematoma or abscess, these entities occur on occasion (38). Finally, the use of other regional anesthetic approaches for postoperative analgesia, such as parasternal block, has been reported (39).

Over the past decade, early extubation strategies ("fast-track" anesthesia) often have been used in low- to medium-risk CABG patients. These strategies allow a shorter time to extubation, a decreased length of intensive care unit (ICU) stay, and variable effects on length of hospital stay (4–6). Immediate extubation in the operating room, with or without markedly accelerated postoperative recovery pathways (e.g., "ultra-fast-tracking," "rapid recovery protocol," "short-stay intensive care") have been used safely, with low rates of reintubation and no influence on quality of life (40–44). Observational data suggest that physician judgment in triaging lower-risk patients to early or immediate extubation works well, with rates of reintubation $<1\%$ (45). Certain factors appear to predict fast-track "failure," including previous cardiac surgery, use of intra-aortic balloon counterpulsation, and possibly advanced patient age.

Provision of adequate perioperative analgesia is important in enhancing patient mobilization, preventing pulmonary complications, and improving the patient's psychological well-being (9,11). The intraoperative use of high-dose morphine (40 mg) may offer superior postoperative pain relief and enhance patient well-being compared with fentanyl (despite similar times to extubation) (46).

The safety of nonsteroidal anti-inflammatory agents for analgesia is controversial, with greater evidence for adverse cardiovascular events with the selective cyclooxygenase-2 inhibitors than the nonselective agents. A 2007 AHA scientific statement presented a stepped-care approach to the management of musculoskeletal pain in patients with or at risk for coronary artery disease (CAD), with the goal of limiting the use of these agents to patients in whom safer therapies fail (47). In patients hospitalized with unstable angina (UA) and non–ST-elevation myocardial infarction (NSTEMI), these agents should be discontinued promptly and reinstituted later according to the stepped-care approach (48).

In the setting of cardiac surgery, nonsteroidal anti-inflammatory agents previously were used for perioperative analgesia. A meta-analysis of 20 trials of patients undergoing thoracic or cardiac surgery, which evaluated studies published before 2005, reported significant reductions in pain scores, with no increase in adverse outcomes (49). Subsequently, 2 RCTs, both studying the oral cyclooxygenase-2 inhibitor valdecoxib and its intravenous prodrug, parecoxib, reported a higher incidence of sternal infections in 1 trial and a significant increase in adverse cardiovascular events in the other (26,27). On the basis of the results of these 2 studies (as well as other nonsurgical reports of increased risk with cyclooxygenase-2–selective agents), the U.S. Food and Drug Administration in 2005 issued a "black box" warning for all nonsteroidal anti-inflammatory agents (except aspirin) immediately after CABG (50). The concurrent administration

of ibuprofen with aspirin has been shown to attenuate the latter's inhibition of platelet aggregation, likely because of competitive inhibition of cyclooxygenase at the platelet-receptor binding site (51).

Observational analyses in patients undergoing noncardiac surgery have shown a significant reduction in perioperative death with the use of checklists, multidisciplinary surgical care, intraoperative time-outs, postsurgical debriefings, and other communication strategies (14,15). Such methodology is being used increasingly in CABG patients (12–14).

In contrast to extensive literature on the role of the surgeon in determining outcomes with CABG, limited data on the influence of the anesthesiologist are available. Of 2 such reports from single centers in the 1980s, 1 suggested that the failure to control heart rate to ≤110 beats per minute was associated with a higher mortality rate, and the other suggested that increasing duration of CPB adversely influenced outcome (52,53). Another observational analysis of data from vascular surgery patients suggested that anesthetic specialization was independently associated with a reduction in mortality rate (54).

To meet the challenges of providing care for the increasingly higher-risk patients undergoing CABG, efforts have been directed at enhancing the experience of trainees, particularly in the use of newer technologies such as TEE. Cardiac anesthesiologists, in collaboration with cardiologists and surgeons, have implemented national training and certification processes for practitioners in the use of perioperative TEE (Section 2.1.7) (164,165). Accreditation of cardiothoracic anesthesia fellowship programs from the Accreditation Council for Graduate Medical Education was initiated in 2004, and efforts are ongoing to obtain formal subspecialty certification (18).

2.1.2. Use of CPB

Several adverse outcomes have been attributed to CPB, including 1) neurological deficits (e.g., stroke, coma, postoperative neurocognitive dysfunction); 2) renal dysfunction; and 3) the Systemic Inflammatory Response Syndrome (SIRS). The SIRS is manifested as generalized systemic inflammation occurring after a major morbid event, such as trauma, infection, or major surgery. It is often particularly apparent after on-pump cardiac surgery, during which surgical trauma, contact of blood with nonphysiological surfaces (e.g., pump tubing, oxygenator surfaces), myocardial ischemia and reperfusion, and hypothermia combine to cause a dramatic release of cytokines (e.g., interleukin [IL] 6 and IL8) and other mediators of inflammation (55). Some investigators have used serum concentrations of S100 beta as a marker of brain injury (56) and have correlated increased serum levels with the number of microemboli exiting the CPB circuit during CABG. In contrast, others have noted the increased incidence of microemboli with on-pump CABG (relative to off-pump CABG) but have failed to show a corresponding worsening of neurocognitive function 1 week to 6 months postoperatively (57,58). Blood retrieved from the operative field during on-pump CABG contains lipid material and particulate matter, which have been implicated as possible causes of postoperative neurocognitive dysfunction. Although a study (59) reported that CPB-associated neurocognitive dysfunction can be mitigated by the routine processing of shed blood with a cell saver before its reinfusion, another study (60) failed to show such an improvement.

It has been suggested that CPB leads to an increased incidence of postoperative renal failure requiring dialysis, but a large RCT comparing on-pump and off-pump CABG showed no difference in its occurrence (61). Of interest, this study failed to show a decreased incidence of postoperative adverse neurological events (stroke, coma, or neurocognitive deficit) in those undergoing off-pump CABG.

The occurrence of SIRS in patients undergoing CPB has led to the development of strategies designed to prevent or to minimize its occurrence. Many reports have focused on the increased serum concentrations of cytokines (e.g., IL-2R, IL-6, IL-8, tumor necrosis factor alpha) and other modulators of inflammation (e.g., P-selectin, sE-selectin, soluble intercellular adhesion molecule-1, plasma endothelial cell adhesion molecule-1, and plasma malondialdehyde), which reflect leukocyte and platelet activation, in triggering the onset of SIRS. A study showed a greater upregulation of neutrophil CD11b expression (a marker of leukocyte activation) in patients who sustained a ≥50% increase in the serum creatinine concentration after CPB, thereby implicating activated neutrophils in the pathophysiology of SIRS and the occurrence of post-CPB renal dysfunction (62). Modulating neutrophil activation to reduce the occurrence of SIRS has been investigated; however, the results have been inconsistent. Preoperative intravenous methylprednisolone (10 mg/kg) caused a reduction in the serum concentrations of many of these cytokines after CPB, but this reduction was not associated with improved hemodynamic variables, diminished blood loss, less use of inotropic agents, shorter duration of ventilation, or shorter ICU length of stay (63). Similarly, the use of intravenous immunoglobulin G in patients with post-CPB SIRS has not been associated with decreased rates of short-term morbidity or 28-day mortality (64).

Other strategies to mitigate the occurrence of SIRS after CPB have been evaluated, including the use of 1) CPB circuits (including oxygenators) coated with materials known to reduce complement and leukocyte activation; 2) CPB tubing that is covalently bonded to heparin; and 3) CPB tubing coated with polyethylene oxide polymer or Poly (2-methoxyethylacrylate). Leukocyte depletion via specialized filters in the CPB circuits has been shown to reduce the plasma concentrations of P-selectin, intercellular adhesion molecule-1, IL-8, plasma endothelial cell adhesion molecule-1, and plasma malondialdehyde after CPB (65).

Finally, closed mini-circuits for CPB have been developed in an attempt to minimize the blood–air interface and blood contact with nonbiological surfaces, both of which

promote cytokine elaboration, but it is uncertain if these maneuvers and techniques have a discernible effect on outcomes after CABG.

2.1.3. Off-Pump CABG Versus Traditional On-Pump CABG

Since the first CABG was performed in the late 1960s, the standard surgical approach has included the use of cardiac arrest coupled with CPB (so-called on-pump CABG), thereby optimizing the conditions for construction of vascular anastomoses to all diseased coronary arteries without cardiac motion or hemodynamic compromise. Such on-pump CABG has become the gold standard and is performed in about 80% of subjects undergoing the procedure in the United States. Despite the excellent results that have been achieved, the use of CPB and the associated manipulation of the ascending aorta are linked with certain perioperative complications, including myonecrosis during aortic occlusion, cerebrovascular accidents, generalized neurocognitive dysfunction, renal dysfunction, and SIRS. In an effort to avoid these complications, off-pump CABG was developed (58,66). Off-pump CABG is performed on the beating heart with the use of stabilizing devices (which minimize cardiac motion); in addition, it incorporates techniques to minimize myocardial ischemia and systemic hemodynamic compromise. As a result, the need for CPB is obviated. This technique does not necessarily decrease the need for manipulation of the ascending aorta during construction of the proximal anastomoses.

To date, the results of several RCTs comparing on-pump and off-pump CABG in various patient populations have been published (61,67,68). In addition, registry data and the results of meta-analyses have been used to assess the relative efficacies of the 2 techniques (69,70). In 2005, an AHA scientific statement comparing the 2 techniques concluded that both procedures usually result in excellent outcomes and that neither technique should be considered superior to the other (71). At the same time, several differences were noted. Off-pump CABG was associated with less bleeding, less renal dysfunction, a shorter length of hospital stay, and less neurocognitive dysfunction. The incidence of perioperative stroke was similar with the 2 techniques. On-pump CABG was noted to be less technically complex and allowed better access to diseased coronary arteries in certain anatomic locations (e.g., those on the lateral LV wall) as well as better long-term graft patency.

In 2009, the results of the largest RCT to date comparing on-pump CABG to off-pump CABG, the ROOBY (Randomized On/Off Bypass) trial, were published, reporting the outcomes for 2,203 patients (99% men) at 18 Veterans Affairs Medical Centers (61). The primary short-term endpoint, a composite of death or complications (reoperation, new mechanical support, cardiac arrest, coma, stroke, or renal failure) within 30 days of surgery, occurred with similar frequency (5.6% for on-pump CABG; 7.0% for off-pump CABG; $p=0.19$). The primary long-term endpoint, a composite of death from any cause, a repeat revascularization procedure, or a nonfatal myocardial infarction (MI) within 1 year of surgery, occurred more often in those undergoing off-pump CABG (9.9%) than in those having on-pump CABG (7.4%; $p=0.04$). Neuropsychological outcomes and resource utilization were similar between the 2 groups. One year after surgery, graft patency was higher in the on-pump group (87.8% versus 82.6%; $p<0.01$). In short, the ROOBY investigators failed to show an advantage of off-pump CABG compared with on-pump CABG in a patient population considered to be at low risk. Instead, use of the on-pump technique was associated with better 1-year composite outcomes and 1-year graft patency rates, with no difference in neuropsychological outcomes or resource utilization.

Although numerous investigators have used single-center registries, the STS database, and meta-analyses in an attempt to identify patient subgroups in whom off-pump CABG is the preferred procedure, even these analyses have reached inconsistent conclusions about off-pump CABG's ability to reduce morbidity and mortality rates (69,72–83). A retrospective cohort study of 14,766 consecutive patients undergoing isolated CABG identified a mortality benefit (OR: 0.45) for off-pump CABG in patients with a predicted risk of mortality >2.5% (82), but a subsequent randomized comparison of off-pump CABG to traditional on-pump CABG in 341 high-risk patients (a Euroscore >5) showed no difference in the composite endpoint of all-cause death, acute MI, stroke, or a required reintervention procedure (78). An analysis of data from the New York State Cardiac Surgery Reporting system did not demonstrate a reduction in mortality rate with off-pump CABG in any patient subgroup, including the elderly (age >80 years) or those with cerebrovascular disease, azotemia, or an extensively calcified ascending aorta (69).

Despite these results, off-pump CABG is the preferred approach by some surgeons who have extensive experience with it and therefore are comfortable with its technical nuances. Recently, published data suggested that the avoidance of aortic manipulation is the most important factor in reducing the risk of neurological complications (84,85). Patients with extensive disease of the ascending aorta pose a special challenge for on-pump CABG; for these patients, cannulation or cross-clamping of the aorta may create an unacceptably high risk of stroke. In such individuals, off-pump CABG in conjunction with avoidance of manipulation of the ascending aorta (including placement of proximal anastomoses) may be beneficial. Surgeons typically prefer an on-pump strategy in patients with hemodynamic compromise because CPB offers support for the systemic circulation. In the end, most surgeons consider either approach to be reasonable for the majority of subjects undergoing CABG.

2.1.4. Bypass Graft Conduit: Recommendations

CLASS I

1. If possible, the left internal mammary artery (LIMA) should be used to bypass the left anterior descending (LAD) artery when bypass of the LAD artery is indicated (86–89). *(Level of Evidence: B)*

CLASS IIa

1. The right internal mammary artery (IMA) is probably indicated to bypass the LAD artery when the LIMA is unavailable or unsuitable as a bypass conduit. *(Level of Evidence: C)*
2. When anatomically and clinically suitable, use of a second IMA to graft the left circumflex or right coronary artery (when critically stenosed and perfusing LV myocardium) is reasonable to improve the likelihood of survival and to decrease reintervention (90–94). *(Level of Evidence: B)*

CLASS IIb

1. Complete arterial revascularization may be reasonable in patients less than or equal to 60 years of age with few or no comorbidities. *(Level of Evidence: C)*
2. Arterial grafting of the right coronary artery may be reasonable when a critical (≥90%) stenosis is present (89,93,95). *(Level of Evidence: B)*
3. Use of a radial artery graft may be reasonable when grafting left-sided coronary arteries with severe stenoses (>70%) and right-sided arteries with critical stenoses (≥90%) that perfuse LV myocardium (96–101). *(Level of Evidence: B)*

CLASS III: HARM

1. An arterial graft should not be used to bypass the right coronary artery with less than a critical stenosis (<90%) (89). *(Level of Evidence: C)*

Arteries (internal mammary, radial, gastroepiploic, and inferior epigastric) or veins (greater and lesser saphenous) may be used as conduits for CABG. The effectiveness of CABG in relieving symptoms and prolonging life is directly related to graft patency. Because arterial and venous grafts have different patency rates and modes of failure, conduit selection is important in determining the long-term efficacy of CABG.

2.1.4.1. SAPHENOUS VEIN GRAFTS

Reversed saphenous vein grafts (SVGs) are commonly used in patients undergoing CABG. Their disadvantage is a declining patency with time: 10% to as many as 25% of them occlude within 1 year of CABG (89,102,103); an additional 1% to 2% occlude each year during the 1 to 5 years after surgery; and 4% to 5% occlude each year between 6 and 10 years postoperatively (104). Therefore, 10 years after CABG, 50% to 60% of SVGs are patent, only half of which have no angiographic evidence of atherosclerosis (104). During SVG harvesting and initial exposure to arterial pressure, the endothelium often is damaged, which, if extensive, may lead to platelet aggregation and graft thrombosis. Platelet adherence to the endothelium begins the process of intimal hyperplasia that later causes SVG atherosclerosis (103,105). After adhering to the intima, the platelets release mitogens that stimulate smooth muscle cell migration, leading to intimal proliferation and hyperplasia. Lipid is incorporated into these areas of intimal hyperplasia, resulting in atherosclerotic plaque formation (106). The perioperative administration of aspirin and dipyridamole improves early (<1 month) and 1-year SVG patency and decreases lipid accumulation in the SVG intima (103, 106,107).

2.1.4.2. INTERNAL MAMMARY ARTERIES

Unlike SVGs, IMAs usually are patent for many years postoperatively (10-year patency >90%) (89,95,102,108–117) because of the fact that <4% of IMAs develop atherosclerosis, and only 1% have atherosclerotic stenoses of hemodynamic significance (118–120). This resistance to the development of atherosclerosis is presumably due to 1) the nearly continuous internal elastic lamina that prevents smooth muscle cell migration and 2) the release of prostacyclin and nitric oxide, potent vasodilators and inhibitors of platelet function, by the endothelium of IMAs (119,121,122).

The disadvantage of using the IMA is that it may spasm and eventually atrophy if used to bypass a coronary artery without a flow-limiting stenosis (89,95,118,123–130). Observational studies suggest an improved survival rate in patients undergoing CABG when the LIMA (rather than an SVG) is used to graft the LAD artery (86–88); this survival benefit is independent of the patient's sex, age, extent of CAD, and LV systolic function (87,88). Apart from improving survival rate, LIMA grafting of the LAD artery reduces the incidence of late MI, hospitalization for cardiac events, need for reoperation, and recurrence of angina (86,88). The LIMA should be used to bypass the LAD artery provided that a contraindication to its use (e.g., emergency surgery, poor LIMA blood flow, subclavian artery stenosis, radiation injury, atherosclerosis) is not present.

Because of the beneficial influence on morbidity and mortality rates of using the IMA for grafting, several centers have advocated bilateral IMA grafting in hopes of further improving CABG results (90,91,94). In fact, numerous observational studies have demonstrated improved morbidity and mortality rates when both IMAs are used. On the other hand, bilateral IMA grafting appears to be associated with an increased incidence of sternal wound infections in patients with diabetes mellitus and those who are obese (body mass index >30 kg/m^2).

2.1.4.3. RADIAL, GASTROEPIPLOIC, AND INFERIOR EPIGASTRIC ARTERIES

Ever since the observation that IMAs are superior to SVGs in decreasing the occurrence of ischemic events and prolonging survival, other arterial conduits, such as the radial, gastroepiploic, and inferior epigastric arteries, have been used in an attempt to improve the results of CABG. Information about these other arterial conduits is sparse in comparison to what is known about IMAs and SVGs, however. The radial artery is a muscular artery that is susceptible to spasm and atrophy when used to graft a coronary artery that is not severely narrowed. Radial artery

graft patency is best when used to graft a left-sided coronary artery with >70% stenosis and worst when it is used to bypass the right coronary artery with a stenosis of only moderate severity (96–100).

The gastroepiploic artery is most often used to bypass the right coronary artery or its branches, although it may be used to bypass the LAD artery if the length of the gastroepiploic artery is adequate. Similar to the radial artery, it is prone to spasm and therefore should only be used to bypass coronary arteries that are severely stenotic (131). The 1-, 5-, and 10-year patency rates of the gastroepiploic artery are reportedly 91%, 80%, and 62%, respectively (132).

The inferior epigastric artery is only 8 to 10 centimeters in length and therefore is usually used as a "Y" or "T" graft connected to another arterial conduit. On occasion it is used as a free graft from the aorta to a high diagonal branch of the LAD artery. Because it is a muscular artery, it is prone to spasm and therefore is best used to bypass a severely stenotic coronary artery. Its reported 1-year patency is about 90% (133,134).

2.1.5. Incisions for Cardiac Access

Although the time-honored incision for CABG is a median sternotomy, surgeons have begun to access the heart via several other approaches in an attempt to 1) reduce the traumatic effects often seen with full median sternotomy, 2) hasten postoperative recovery, and 3) enhance cosmesis. The utility and benefit of these smaller incisions has been evident in subjects undergoing valvular surgery, for which only limited access to the heart is required.

The most minimally invasive access incisions for CABG are seen with robotically assisted totally endoscopic CABG. A study showed that totally endoscopic CABG with robotic technology was associated with improved physical health, shorter hospital stay, and a more rapid return to the activities of daily living compared with traditional techniques. At present, direct comparisons of robotically assisted and conventional CABG are lacking (135).

The use of minimally invasive cardiac access incisions for CABG is limited. The need for adequate exposure of the ascending aorta and all surfaces of the heart to accomplish full revascularization usually precludes the use of minimal access incisions, such as upper sternotomy, lower sternotomy, or anterolateral thoracotomy. Nevertheless, use of limited incisions may increase in the future with the advent of hybrid strategies that use a direct surgical approach (usually for grafting the LAD artery through a small parasternal incision) and percutaneous coronary intervention (PCI) of the other diseased coronary arteries. The benefit of hybrid revascularization and hybrid operating rooms, in which PCI and CABG can be accomplished in one procedure, is yet to be determined. In patients with certain comorbid conditions, such as severe aortic calcification, previous chest irradiation, and obesity in combination with severe diabetes mellitus, full median sternotomy may be problematic (136), and hybrid revascularization may be preferable.

2.1.6. Anastomotic Techniques

At present, most coronary bypass grafts are constructed with hand-sewn suture techniques for the proximal and distal anastomoses, a practice that has resulted in good short- and intermediate-term patency rates. Because surgeons have different preferences with regard to the technical aspects of the procedure, a wide variety of suture configurations is used. Sewing of the proximal and distal anastomoses with a continuous polypropylene suture is commonly done, but techniques with interrupted silk sutures have been used, with similar results for graft patency and adverse events.

Certain clinical scenarios have precipitated an interest in alternative techniques of constructing coronary bypass anastomoses. Some surgeons and patients wish to avoid the potential morbidity and cosmetic results of a median sternotomy, yet the least invasive incisions usually are too small to allow hand-sewn anastomoses. To solve this problem, coronary connector devices have been developed for use with arterial or venous conduits to enable grafting without direct suturing. In addition, these devices have been used in subjects with diseased ascending aortas, in whom a technique that allows construction of a proximal anastomosis with minimal manipulation of the ascending aorta (typically by eliminating the need for aortic cross-clamping) may result in less embolization of debris, thereby reducing the occurrence of adverse neurological outcomes. In this situation, the operation is performed through a median sternotomy, and the proximal anastomoses are created with a connector (or may be hand-sewn with the assistance of a device that provides a bloodless operative field) without partial or complete clamping of the ascending aorta.

2.1.7. Intraoperative TEE: Recommendations

CLASS I

1. Intraoperative TEE should be performed for evaluation of acute, persistent, and life-threatening hemodynamic disturbances that have not responded to treatment (137,138). *(Level of Evidence: B)*
2. Intraoperative TEE should be performed in patients undergoing concomitant valvular surgery (137,139). *(Level of Evidence: B)*

CLASS IIa

1. Intraoperative TEE is reasonable for monitoring of hemodynamic status, ventricular function, regional wall motion, and valvular function in patients undergoing CABG (138,140–145). *(Level of Evidence: B)*

The use of intraoperative TEE in patients undergoing cardiac surgery has increased steadily since its introduction in the late 1980s. Although its utility is considered to be highest in patients undergoing valvular and complex open great-vessel/aortic surgery, it is commonly used in subjects undergoing CABG. TEE is most often used (146), although epicardial and epiaortic imaging, performed under aseptic conditions, allows visualization of imaging planes not possible with TEE (147,148). Specifically, epiaortic

imaging allows visualization of the "blind spot" of the ascending aorta (caused by interposition of the trachea with the esophagus), the site of aortic cannulation for CPB, from which dislodgement of friable atheroma, a major risk factor for perioperative stroke, may occur (Section 5.2.1). In addition, epicardial probes allow imaging when TEE is contraindicated, cannot be performed, or produces inadequate images. It can facilitate the identification of intraventricular thrombi when TEE images are equivocal.

The "2003 ACC/AHA/ASE Guideline Update for the Clinical Application of Echocardiography" based its recommendations on those reported in the 1996 American Society of Anesthesiologists/Society of Cardiovascular Anesthesiologists practice guideline and considered the use of TEE in CABG patients (149). The latter document was updated in 2010 (139). Because of the use of different grading methodologies in the American Society of Anesthesiologists/Society of Cardiovascular Anesthesiologists guideline relative to that of the ACCF/AHA, precise comparisons are difficult. However, it is noted that TEE "should be considered" in subjects undergoing CABG, to confirm and refine the preoperative diagnosis, detect new or unsuspected pathology, adjust the anesthetic and surgical plan accordingly, and assess the results of surgery. The strongest recommendation is given for treatment of acute life-threatening hemodynamic instability that has not responded to conventional therapies.

Observational cohort analyses and case reports have suggested the utility of TEE for diagnosing acute life-threatening hemodynamic or surgical problems in CABG patients, many of which are difficult or impossible to detect or treat without direct imaging. Evaluation of ventricular cross-sectional areas and ejection fraction (EF) and estimation or direct measurement of cardiac output by TEE may facilitate anesthetic, fluid, and inotropic/pressor management. The utility of echocardiography for the evaluation of LV end-diastolic area/volume and its potential superiority over pulmonary artery occlusion or pulmonary artery diastolic pressure, particularly in the early postoperative period, has been reported (150,151) (Section 4.10). In subjects without preoperative transthoracic imaging, intraoperative TEE may provide useful diagnostic information (over and above that detected during cardiac catheterization) on valvular function as well as evidence of pulmonary hypertension, intracardiac shunts, or other complications that may alter the planned surgery.

In patients undergoing CABG, intraoperative TEE is used most often for the detection of regional wall motion abnormalities (possibly caused by myocardial ischemia or infarction) and their effect on LV function. Observational studies have suggested that regional wall motion abnormalities detected with TEE can guide surgical therapy, leading to revision of a failed or inadequate conduit or the placement of additional grafts not originally planned. The presence of new wall motion abnormalities after CPB correlates with adverse perioperative and long-term outcomes (143).

Although the initial hope that an estimation of coronary blood flow with intramyocardial contrast enhancement visualized by TEE would facilitate surgical intervention has not been realized, technical advances in imaging of coronary arteries and grafts may ultimately provide reliable information. At present, the evaluation of graft flow with conventional nonimaging handheld Doppler probes appears adequate (Section 8). Intraoperative evaluation of mitral regurgitation may facilitate detection of myocardial ischemia and provide guidance about the need for mitral valve annuloplasty (Section 6.7). Newer technologies, including nonimaging methods for analyzing systolic and diastolic velocity and direction and timing of regional wall motion (Doppler tissue imaging and speckle tracking), as well as "real-time" 3-dimensional imaging, may facilitate the diagnosis of myocardial ischemia and evaluation of ventricular function. At present, however, their cost-effectiveness has not been determined, and they are too complex for routine use (152–154).

Among different centers, the rate of intraoperative TEE use in CABG patients varies from none to routine; its use is influenced by many factors, such as institutional and practitioner preferences, the healthcare system and reimbursement strategies, tertiary care status, and presence of training programs (155). The efficacy of intraoperative TEE is likely influenced by the presence of 1) LV systolic and diastolic dysfunction, 2) concomitant valvular disease, 3) the planned surgical procedure (on pump versus off pump, primary versus reoperative), 4) the surgical approach (full sternotomy versus partial sternotomy versus endoscopic or robotic), 5) its acuity (elective versus emergency); and 6) physician training and experience (137,138,140–142,144,145,156–163).

The safety of intraoperative TEE in patients undergoing cardiac surgery is uncertain. Retrospective analyses of data from patients undergoing diagnostic upper gastrointestinal endoscopy, nonoperative diagnostic TEE imaging, and intraoperative imaging by skilled operators in high-volume centers demonstrate a low frequency of complications related to insertion or manipulation of the probe (164,165). Nevertheless, minor (primarily pharyngeal injury from probe insertion) and major (esophageal perforation, gastric bleeding, or late mediastinitis) complications are reported (166,167). A more indolent complication is that of acquired dysphagia and possible aspiration postoperatively. Although retrospective analyses of postoperative cardiac surgical patients with clinically manifest esophageal dysfunction have identified TEE use as a risk factor (168–170), such dysfunction also has been reported in subjects in whom TEE was not used (171). Advanced age, prolonged intubation, and neurological injury seem to be risk factors for its development. The significance of the incidental intraoperative detection and repair of a patent foramen ovale, a common occurrence, is controversial (172). A 2009 obser-

vational analysis of 13,092 patients (25% isolated CABG; 29% CABG or other cardiac procedure), of whom 17% had a patent foramen ovale detected by TEE (28% of which were repaired), reported an increase in postoperative stroke in the patients who had patent foramen ovale repair (OR: 2.47; 95% CI: 1.02 to 6.0) with no improvement in long-term outcome (173).

2.1.8. Preconditioning/Management of Myocardial Ischemia: Recommendations

CLASS I

1. Management targeted at optimizing the determinants of coronary arterial perfusion (e.g., heart rate, diastolic or mean arterial pressure, and right ventricular or LV end-diastolic pressure) is recommended to reduce the risk of perioperative myocardial ischemia and infarction (53,174–177). *(Level of Evidence: B)*

CLASS IIa

1. Volatile-based anesthesia can be useful in reducing the risk of perioperative myocardial ischemia and infarction (178–181). *(Level of Evidence: A)*

CLASS IIb

1. The effectiveness of prophylactic pharmacological therapies or controlled reperfusion strategies aimed at inducing preconditioning or attenuating the adverse consequences of myocardial reperfusion injury or surgically induced systemic inflammation is uncertain (182–189). *(Level of Evidence: A)*
2. Mechanical preconditioning might be considered to reduce the risk of perioperative myocardial ischemia and infarction in patients undergoing off-pump CABG (190–192). *(Level of Evidence: B)*
3. Remote ischemic preconditioning strategies using peripheral-extremity occlusion/reperfusion might be considered to attenuate the adverse consequences of myocardial reperfusion injury (193–195). *(Level of Evidence: B)*
4. The effectiveness of postconditioning strategies to attenuate the adverse consequences of myocardial reperfusion injury is uncertain (196,197). *(Level of Evidence: C)*

See Online Data Supplements 2 to 4 for additional data on preconditioning.

Perioperative myocardial injury is associated with adverse outcomes after CABG (198–200), and available data suggest a direct correlation between the amount of myonecrosis and the likelihood of an adverse outcome (198,201–204) (Section 5.2.4).

The etiologies of perioperative myocardial ischemia and infarction and their complications (electrical or mechanical) range from alterations in the determinants of global or regional myocardial oxygen supply and demand to complex biochemical and microanatomic, systemic, or vascular abnormalities, many of which are not amenable to routine diagnostic and therapeutic interventions. Adequate surgical reperfusion is important in determining outcome, even though it may initially induce reperfusion injury. Various studies delineating the major mediators of reperfusion injury have focused attention on the mitochondrial permeability transition pore, the opening of which during reperfusion uncouples oxidative phosphorylation, ultimately leading to cell death (205). Although several pharmacological interventions targeting components of reperfusion injury have been tried, none has been found to be efficacious for this purpose (182,184–189,205–207).

The severity of reperfusion injury is influenced by numerous factors, including 1) the status of the patient's coronary circulation, 2) the presence of active ongoing ischemia or infarction, 3) preexisting medical therapy (Sections 4.3 and 4.5), 4) concurrent use of mechanical assistance to improve coronary perfusion (i.e., intra-aortic balloon counterpulsation), and 5) the surgical approach used (on pump or off pump). CPB with ischemic arrest is known to induce the release of cytokines and chemokines involved in cellular homeostasis, thrombosis, and coagulation; oxidative stress; adhesion of blood cell elements to the endothelium; and neuroendocrine stress responses; all of these may contribute to myocardial injury (208,209). Controlled reperfusion strategies during CPB, involving prolonged reperfusion with warm-blood cardioplegia in conjunction with metabolic enhancers, are rarely used in lieu of more routine methods of preservation (e.g., asystolic arrest, anterograde or retrograde blood cardioplegia during aortic cross-clamping). Several studies suggest that the magnitude of SIRS is greater with on-pump CABG than with off-pump CABG (201,208,210–213).

Initial studies of preconditioning used mechanical occlusion of arterial inflow followed by reperfusion via aortic cross-clamping immediately on institution of bypass or with coronary artery occlusion proximal to the planned distal anastomosis during off-pump CABG (190,191,214–217). Because of concerns of the potential adverse cerebral effects of aortic manipulation, enthusiasm for further study of this technique in on-pump CABG patients is limited (Section 5.2.1). Despite intense interest in the physiology of post-conditioning, few data are available (197). A small 2008 study in patients undergoing valve surgery, which used repeated manipulation of the ascending aorta, reported a reduction in surrogate markers of inflammation and myonecrosis (196). In lieu of techniques utilizing mechanical occlusion, pharmacological conditioning agents are likely to be used. An alternative approach that avoids much (but not all) of the safety concerns related to potential vascular injury is remote preconditioning of arterial inflow to the leg or (more commonly) the arm via blood pressure cuff occlusion (218). Two studies of patients undergoing on-pump CABG at a single center, the first of which used 2 different myocardial protection strategies and the second of which repeated the study with a standardized cold-blood cardioplegia routine, reported similar amounts of troponin release during the 72 hours postoperatively, with no apparent complications (193,195). A larger trial was unable to confirm any benefits of a similar protocol, casting doubt on the utility of this approach (194).

Volatile halogenated anesthetics and opioids have antiischemic or conditioning properties (32,33,219,220), and propofol has antioxidant properties of potential value in

subjects with reperfusion injury (221,222). The salutary properties of volatile anesthetics during myocardial ischemia are well known. Their negative inotropic and chronotropic effects are considered to be beneficial, particularly in the setting of elevated adrenergic tone that is common with surgical stimulation. Although contemporary volatile agents demonstrate some degree of coronary arterial vasodilation (with isoflurane considered the most potent), the role of a "steal phenomena" in the genesis of ischemia is considered to be trivial (33). In comparison to propofol/opioid infusions, volatile agents seem to reduce troponin release, preserve myocardial function, and improve resource utilization (i.e., ICU or hospital lengths of stay) and 1-year outcome (223–227). It is postulated that multiple factors that influence myocardial preservation modulate the potential impact of a specific anesthetic regimen.

Observational analyses have reported an association between elevated perioperative heart rates and adverse outcomes (228,229), but it is difficult to recommend a specific heart rate for all CABG patients. Instead, the heart rate may need to be adjusted up or down to maintain an adequate cardiac output (230,231). Similarly, controversy exists about management of blood pressure in the perioperative period (232), particularly with regard to systolic pressure (233) and pulse pressure (234). Intraoperative hypotension is considered to be a risk factor for adverse outcomes in patients undergoing many types of surgery. Unique to CABG are unavoidable periods of hypotension associated with surgical manipulation, cannulation for CPB, weaning from CPB, or during suspension and stabilization of the heart with off-pump CABG. Minimization of such periods is desirable but is often difficult to achieve, particularly in patients who are unstable hemodynamically.

2.2. Clinical Subsets

2.2.1. CABG in Patients With Acute MI: Recommendations

CLASS I

1. Emergency CABG is recommended in patients with acute MI in whom 1) primary PCI has failed or cannot be performed, 2) coronary anatomy is suitable for CABG, and 3) persistent ischemia of a significant area of myocardium at rest and/or hemodynamic instability refractory to nonsurgical therapy is present (235–239). *(Level of Evidence: B)*
2. Emergency CABG is recommended in patients undergoing surgical repair of a postinfarction mechanical complication of MI, such as ventricular septal rupture, mitral valve insufficiency because of papillary muscle infarction and/or rupture, or free wall rupture (240–244). *(Level of Evidence: B)*
3. Emergency CABG is recommended in patients with cardiogenic shock and who are suitable for CABG irrespective of the time interval from MI to onset of shock and time from MI to CABG (238,245–247). *(Level of Evidence: B)*
4. Emergency CABG is recommended in patients with life-threatening ventricular arrhythmias (believed to be ischemic in origin) in the presence of left main stenosis greater than or equal to 50% and/or 3-vessel CAD (248). *(Level of Evidence: C)*

CLASS IIa

1. The use of CABG is reasonable as a revascularization strategy in patients with multivessel CAD with recurrent angina or MI within the first 48 hours of STEMI presentation as an alternative to a more delayed strategy (235,237,239,249). *(Level of Evidence: B)*
2. Early revascularization with PCI or CABG is reasonable for selected patients greater than 75 years of age with ST-segment elevation or left bundle branch block who are suitable for revascularization irrespective of the time interval from MI to onset of shock (250–254). *(Level of Evidence: B)*

CLASS III: HARM

1. Emergency CABG should not be performed in patients with persistent angina and a small area of viable myocardium who are stable hemodynamically. *(Level of Evidence: C)*
2. Emergency CABG should not be performed in patients with no-reflow (successful epicardial reperfusion with unsuccessful microvascular reperfusion). *(Level of Evidence: C)*

See Online Data Supplement 5 for additional data on CABG in patients with acute myocardial infarction.

With the widespread use of fibrinolytic therapy or primary PCI in subjects with STEMI, emergency CABG is now reserved for those with 1) left main and/or 3-vessel CAD, 2) ongoing ischemia after successful or failed PCI, 3) coronary anatomy not amenable to PCI, 4) a mechanical complication of STEMI (241,255,256), and 5) cardiogenic shock (defined as hypotension [systolic arterial pressure $<$90 mm Hg for $\geq$30 minutes or need for supportive measures to maintain a systolic pressure $\geq$90 mm Hg], evidence of end-organ hypoperfusion, cardiac index $\leq$2.2 L/min/m^2, and pulmonary capillary wedge pressure $\geq$15 mm Hg) (245,247). In the SHOCK (Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock) trial, 36% of patients randomly assigned to early revascularization therapy underwent emergency CABG (245). Although those who underwent emergency CABG were more likely to be diabetic and to have complex coronary anatomy than were those who had PCI, the survival rates of the 2 groups were similar (247). The outcomes of high-risk STEMI patients with cardiogenic shock undergoing emergency CABG suggest that CABG may be preferred to PCI in this patient population when complete revascularization cannot be accomplished with PCI (236,238,246).

The need for emergency CABG in subjects with STEMI is relatively uncommon, ranging from 3.2% to 10.9% (257,258). Of the 1,572 patients enrolled in the DANAMI-2 (Danish Multicenter Randomized Study on Thrombolytic Therapy Versus Acute Coronary Angioplasty in Acute Myocardial Infarction) study, only 50 (3.2%) underwent CABG within 30 days (30 patients initially treated with PCI and 20 given fibrinolysis), and only 3 patients (0.2%) randomly assigned to receive primary PCI underwent emergency CABG (257). Of the 1,100 patients who underwent coronary angiography in the PAMI-2 (Primary Angioplasty in Myocardial Infarction) trial, CABG was performed before hospital discharge in 120 (258).

The in-hospital mortality rate is higher in STEMI patients undergoing emergency CABG than in those undergoing it on a less urgent or a purely elective basis (239,257,259–264). In a study of 1,181 patients undergoing CABG, the in-hospital mortality rate increased as the patients' preoperative status worsened, ranging from 1.2% in those with stable angina to 26% in those with cardiogenic shock (265).

Although patients requiring emergency or urgent CABG after STEMI are at higher risk than those undergoing it electively, the optimal timing of CABG after STEMI is controversial. A retrospective study performed before the widespread availability of fibrinolysis and primary PCI reported an overall in-hospital mortality rate of 5.2% in 440 STEMI patients undergoing CABG as primary reperfusion therapy. Those undergoing CABG ≤6 hours after symptom onset had a lower in-hospital and long-term (10 years) mortality rate than those undergoing CABG >6 hours after symptom onset (237). Other studies have provided conflicting results, because of, at least in part, the lack of clear delineation between STEMI and NSTEMI patients in these large database reports (259,265). In an analysis of 9,476 patients hospitalized with an acute coronary syndrome (ACS) who underwent CABG during the index hospitalization, 1,344 (14%) were STEMI patients with shock or intra-aortic balloon placement preoperatively (264). These individuals had a mortality rate of 4% when CABG was performed on the third hospital day, which was lower than the mortality rates reported when CABG was performed earlier or later during the hospitalization (264). In studies in which the data from STEMI patients were analyzed separately with regard to the optimal timing of CABG, however, the results appear to be different. In 1 analysis of 44,365 patients who underwent CABG after MI (22,984 with STEMI; 21,381 with NSTEMI), the in-hospital mortality rate was similar in the 2 groups undergoing CABG <6 hours after diagnosis (12.5% and 11.5%, respectively), but it was higher in STEMI patients than in NSTEMI patients when CABG was performed 6 to 23 hours after diagnosis (13.6% versus 6.2%; p=0.006) (262). The groups had similar in-hospital mortality rates when CABG was performed at all later time points (1 to 7 days, 8 to 14 days, and ≥15 days after the acute event) (262). Similarly, in a study of 138 subjects with STEMI unresponsive to maximal nonsurgical therapy who underwent emergency CABG, the overall mortality rate was 8.7%, but it varied according to the time interval from symptom onset to time of operation. The mortality rate was 10.8% for patients undergoing CABG within 6 hours of the onset of symptoms, 23.8% in those undergoing CABG 7 to 24 hours after symptom onset, 6.7% in patients undergoing CABG from 1 to 3 days, 4.2% in those who underwent surgery from 4 to 7 days, and 2.4% after 8 days (266). In an analysis of data from 150 patients with STEMI who did not qualify for primary PCI and required CABG, the in-hospital mortality rate increased according to the time interval between symptom onset and surgery (239). The mortality rate was 6.1% for subjects who underwent CABG within 6 hours of pain onset, 50% in those who underwent CABG 7 to 23 hours after pain onset, and 7.1% in those who underwent CABG after 15 days (239). Lastly, in another study, the time interval of 6 hours was also found to be important in STEMI patients requiring CABG. The mean time from symptom onset to CABG was significantly shorter in survivors versus nonsurvivors (5.1±2.7 hours versus 11.4±3.2 hours; p<0.0007) (235). In patients with cardiogenic shock, the benefits of early revascularization were apparent across a wide time interval between 1) MI and the onset of shock and 2) MI and CABG. Therefore, although CABG exerts its most profound salutary effect when it is performed as soon as possible after MI and the appearance of shock, the time window in which it is beneficial is quite broad.

Apart from the timing of CABG, the outcomes of STEMI patients undergoing CABG depend on baseline demographic variables. Those with mechanical complications of STEMI (e.g., ventricular septal rupture or mitral regurgitation caused by papillary muscle rupture) have a high operative mortality rate (240–242,244,255,267). In a study of 641 subjects with ACS, 22 with evolving STEMI and 20 with a mechanical complication of STEMI were referred for emergency CABG; the 30-day mortality rate was 0% in those with evolving STEMI and 25% in those with a mechanical complication of STEMI (268). In those with mechanical complications, several variables were predictive of death, including advanced age, female sex, cardiogenic shock, the use of intra-aortic balloon counterpulsation preoperatively, pulmonary disease, renal insufficiency, and magnitude of elevation of the serum troponin concentration (235,239,263,265,266,269,270).

2.2.2. Life-Threatening Ventricular Arrhythmias: Recommendations

CLASS I

1. CABG is recommended in patients with resuscitated sudden cardiac death or sustained ventricular tachycardia thought to be caused by significant CAD (≥50% stenosis of left main coronary artery and/or ≥70% stenosis of 1, 2, or all 3 epicardial coronary arteries) and resultant myocardial ischemia (248,271,272). *(Level of Evidence: B)*

CLASS III: HARM

1. CABG should not be performed in patients with ventricular tachycardia with scar and no evidence of ischemia. *(Level of Evidence: C)*

See Online Data Supplement 6 for additional data on life-threatening ventricular arrhythmias.

Most studies evaluating the benefits of CABG in patients with ventricular arrhythmias have examined survivors of out-of-hospital cardiac arrest as well as patients with inducible ventricular tachycardia or fibrillation during electrophysiological study (272–274). In general, CABG has been more effective in reducing the occurrence of ventricular fibrillation than of ventricular tachycardia, because the mechanism of the latter is usually reentry with scarred

endocardium rather than ischemia. Observational studies have demonstrated a favorable prognosis of subjects undergoing CABG for ischemic ventricular tachycardia/fibrillation (248).

In survivors of cardiac arrest who have severe but operable CAD, CABG can suppress the appearance of arrhythmias, reduce subsequent episodes of cardiac arrest, and result in a good long-term outcome (271–273). It is particularly effective when an ischemic cause of the arrhythmia can be documented (for instance, when it occurs with exercise) (275). Still, because CABG may not alleviate all the factors that predispose to ventricular arrhythmias, concomitant insertion of an implantable cardioverter-defibrillator is often warranted (276). Similarly, continued inducibility or clinical recurrence of ventricular tachycardia after CABG usually requires an implantable cardioverter-defibrillator implantation.

Patients with depressed LV systolic function, advanced age, female sex, and increased CPB time are at higher risk for life-threatening arrhythmias in the early postoperative period. Given the poor short-term prognosis of those with these arrhythmias, mechanical and ischemic causes should be considered in the postoperative setting (277–279).

2.2.3. Emergency CABG After Failed PCI: Recommendations

CLASS I

1. Emergency CABG is recommended after failed PCI in the presence of ongoing ischemia or threatened occlusion with substantial myocardium at risk (280,281). *(Level of Evidence: B)*
2. Emergency CABG is recommended after failed PCI for hemodynamic compromise in patients without impairment of the coagulation system and without a previous sternotomy (280,282,283). *(Level of Evidence: B)*

CLASS IIa

1. Emergency CABG is reasonable after failed PCI for retrieval of a foreign body (most likely a fractured guidewire or stent) in a crucial anatomic location. *(Level of Evidence: C)*
2. Emergency CABG can be beneficial after failed PCI for hemodynamic compromise in patients with impairment of the coagulation system and without previous sternotomy. *(Level of Evidence: C)*

CLASS IIb

1. Emergency CABG might be considered after failed PCI for hemodynamic compromise in patients with previous sternotomy. *(Level of Evidence: C)*

CLASS III: HARM

1. Emergency CABG should not be performed after failed PCI in the absence of ischemia or threatened occlusion. *(Level of Evidence: C)*
2. Emergency CABG should not be performed after failed PCI if revascularization is impossible because of target anatomy or a no-reflow state. *(Level of Evidence: C)*

See Online Data Supplement 7 for additional data on CABG after failed PCI.

With widespread stent use as well as effective antiplatelet and antithrombotic therapies, emergency CABG after failed PCI is not commonly performed. In a 2009 analysis of data from almost 22,000 patients undergoing PCI at a single center, only 90 (0.4%) required CABG within 24 hours of PCI (281). A similarly low rate (≤0.8%) of emergency CABG after PCI has been reported by others (284–286). The indications for emergency CABG after PCI include 1) acute (or threatened) vessel closure, 2) coronary arterial dissection, 3) coronary arterial perforation (281), and 4) malfunction of PCI equipment (e.g., stent dislodgement, fractured guidewire). Subjects most likely to require emergency CABG after failed PCI are those with evolving STEMI, cardiogenic shock, 3-vessel CAD, or the presence of a type C coronary arterial lesion (defined as >2 cm in length, an excessively tortuous proximal segment, an extremely angulated segment, a total occlusion >3 months in duration, or a degenerated SVG that appears to be friable) (281).

In those in whom emergency CABG for failed PCI is performed, morbidity and mortality rates are increased compared with those undergoing elective CABG (287–289), resulting at least in part from the advanced age of many patients now referred for PCI, some of whom have multiple comorbid conditions and complex coronary anatomy. Several variables have been shown to be associated with increased perioperative morbidity and mortality rates, including 1) depressed LV systolic function (290), 2) recent ACS (290,291), 3) multivessel CAD and complex lesion morphology (291,292), 4) cardiogenic shock (281), 5) advanced patient age (293), 6) absence of angiographic collaterals (293), 7) previous PCI (294), and 8) a prolonged time delay in transfer to the operating room (293). In patients undergoing emergency CABG for failed PCI, an off-pump procedure may be associated with a reduced incidence of renal failure, need for intra-aortic balloon use, and reoperation for bleeding (283,295).

If complete revascularization is achieved with minimal delay in patients undergoing emergency CABG after failed PCI, long-term prognosis is similar to that of subjects undergoing elective CABG (280,282,296). In-hospital morbidity and mortality rates in women (297) and the elderly (298) undergoing emergency CABG for failed PCI are relatively high, but the long-term outcomes in these individuals are comparable to those achieved in men and younger patients.

2.2.4. CABG in Association With Other Cardiac Procedures: Recommendations

CLASS I

1. CABG is recommended in patients undergoing noncoronary cardiac surgery with greater than or equal to 50% luminal diameter narrowing of the left main coronary artery or greater than or equal to 70% luminal diameter narrowing of other major coronary arteries. *(Level of Evidence: C)*

CLASS IIa

1. The use of the LIMA is reasonable to bypass a significantly narrowed LAD artery in patients undergoing noncoronary cardiac surgery. *(Level of Evidence: C)*

2. CABG of moderately diseased coronary arteries (>50% luminal diameter narrowing) is reasonable in patients undergoing noncoronary cardiac surgery. (*Level of Evidence: C*)

3. CAD Revascularization

Recommendations and text in this section are the result of extensive collaborative discussions between the PCI and CABG writing committees, as well as key members of the Stable Ischemic Heart Disease (SIHD) and UA/NSTEMI writing committees. Certain issues, such as older versus more contemporary studies, primary analyses versus subgroup analyses, and prospective versus post hoc analyses, have been carefully weighed in designating COR and LOE; they are addressed in the appropriate corresponding text. The goals of revascularization for patients with CAD are to 1) to improve survival and 2) to relieve symptoms.

Revascularization recommendations in this section are predominantly based on studies of patients with symptomatic SIHD and should be interpreted in this context. As discussed later in this section, recommendations on the type of revascularization are, in general, applicable to patients with UA/NSTEMI. In some cases (e.g., unprotected left main CAD), specific recommendations are made for patients with UA/NSTEMI or STEMI.

Historically, most studies of revascularization have been based on and reported according to angiographic criteria. Most studies have defined a "significant" stenosis as ≥70% diameter narrowing; therefore, for revascularization decisions and recommendations in this section, a "significant" stenosis has been defined as ≥70% diameter narrowing (≥50% for left main CAD). Physiological criteria, such as an assessment of fractional flow reserve, has been used in deciding when revascularization is indicated. Thus, for recommendations on revascularization in this section, coronary stenoses with fractional flow reserve ≤0.80 can also be considered "significant" (299,300).

As noted, the revascularization recommendations have been formulated to address issues related to 1) improved survival and/or 2) improved symptoms. When one method of revascularization is preferred over the other for improved survival, this consideration, in general, takes precedence over improved symptoms. When discussing options for revascularization with the patient, he or she should understand when the procedure is being performed in an attempt to improve symptoms, survival, or both.

Although some results from the SYNTAX (Synergy between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery) study are best characterized as subgroup analyses and "hypothesis generating," SYNTAX nonetheless represents the latest and most comprehensive comparison of contemporary PCI and CABG (301,302). Therefore, the results of SYNTAX have been considered appropriately when formulating our revascularization recommendations. Although the limitations of using the SYNTAX score for certain revascularization recommendations are recognized, the SYNTAX score is a reasonable surrogate for the extent of CAD and its complexity and serves as important information that should be considered when making revascularization decisions. Recommendations that refer to SYNTAX scores use them as surrogates for the extent and complexity of CAD.

Revascularization recommendations to improve survival and symptoms are given in the following text and summarized in Tables 2 and 3. References to studies comparing revascularization with medical therapy are presented when available for each anatomic subgroup.

See Online Data Supplements 8 and 9 for additional data regarding the survival and symptomatic benefits with CABG or PCI for different anatomic subsets.

3.1. Heart Team Approach to Revascularization Decisions: Recommendations

CLASS I

1. A Heart Team approach to revascularization is recommended in patients with unprotected left main or complex CAD (302–304). (*Level of Evidence: C*)

CLASS IIa

1. Calculation of the STS and SYNTAX scores is reasonable in patients with unprotected left main and complex CAD (301,302,305–310). (*Level of Evidence: B*)

One protocol used in RCTs (302–304,311) often involves a multidisciplinary approach referred to as the Heart Team. Composed of an interventional cardiologist and a cardiac surgeon, the Heart Team 1) reviews the patient's medical condition and coronary anatomy, 2) determines that PCI and/or CABG are technically feasible and reasonable, and 3) discusses revascularization options with the patient before a treatment strategy is selected. Support for using a Heart Team approach comes from reports that patients with complex CAD referred specifically for PCI or CABG in concurrent trial registries have lower mortality rates than those randomly assigned to PCI or CABG in controlled trials (303,304).

The SIHD, PCI, and CABG guideline writing committees endorse a Heart Team approach in patients with unprotected left main CAD and/or complex CAD in whom the optimal revascularization strategy is not straightforward. A collaborative assessment of revascularization options, or the decision to treat with GDMT without revascularization, involving an interventional cardiologist, a cardiac surgeon, and (often) the patient's general cardiologist, followed by discussion with the patient about treatment options, is optimal. Particularly in patients with SIHD and unprotected left main and/or complex CAD for whom a revascularization strategy is not straightforward, an approach has been endorsed that involves terminating the procedure after diagnostic coronary angiography is completed; this allows a thorough discussion and affords both the interventional cardiologist and cardiac surgeon the opportunity to discuss

Table 2. Revascularization to Improve Survival Compared With Medical Therapy

Anatomic Setting	COR	LOE	References
UPLM or complex CAD			
CABG and PCI	I—Heart Team approach recommended	C	(302–304)
CABG and PCI	IIa—Calculation of the STS and SYNTAX scores	B	(301,302,305–310)
UPLM*			
CABG	I	B	(312–318)
PCI	IIa—For SIHD when both of the following are present: • 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) • Clinical characteristics that predict a significantly increased risk of adverse surgical outcomes (e.g., STS-predicted risk of operative mortality ≥5%)	B	(301,305,307,311,319–336)
	IIa—For UA/NSTEMI if not a CABG candidate	B	(301,324–327,332,333, 335–337)
	IIa—For STEMI when distal coronary flow is TIMI flow grade <3 and PCI can be performed more rapidly and safely than CABG	C	(321,338,339)
	IIb—For SIHD when *both* of the following are present: • 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) • 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%)	B	(301,305,307,311, 319–336,340)
	III: Harm—For SIHD in patients (versus performing CABG) with unfavorable anatomy for PCI and who are good candidates for CABG	B	(301,305,307,312–320)
3-vessel disease with or without proximal LAD artery disease*			
CABG	I	B	(314,318,341–344)
	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	(320,334,343,359–360)
PCI	IIb—Of uncertain benefit	B	(314,341,343,370).
2-vessel disease with proximal LAD artery disease*			
CABG	I	B	(314,318,341–344)
PCI	IIb—Of uncertain benefit	B	(314,341,343,370)
2-vessel disease without proximal LAD artery disease*			
CABG	IIa—With extensive ischemia	B	(348–351)
	IIb—Of uncertain benefit without extensive ischemia	C	(343)
PCI	IIb—Of uncertain benefit	B	(314,341,343,370)
1-vessel proximal LAD artery disease			
CABG	IIa—With LIMA for long-term benefit	B	(87,88,318,343)
PCI	IIb—Of uncertain benefit	B	(314,341,343,370)
1-vessel disease without proximal LAD artery involvement			
CABG	III: Harm	B	(318,341,348,349, 382–386)
PCI	III: Harm	B	(318,341,348,349, 382–386)
LV dysfunction			
CABG	IIa—EF 35% to 50%	B	(318,352–356)
CABG	IIb—EF <35% without significant left main CAD	B	(318,352–356,371,372)
PCI	Insufficient data		N/A
Survivors of sudden cardiac death with presumed ischemia-mediated VT			
CABG	I	B	(271,345,347)
PCI	I	C	(345)
No anatomic or physiological criteria for revascularization			
CABG	III: Harm	B	(318,341,348,349,382–386)
PCI	III: Harm	B	(318,341,348,349,382–386)

In patients with multivessel disease who also have diabetes, it is reasonable to choose CABG (with LIMA) over PCI (350,362–369) *(Class IIa/LOE: B).

CABG indicates coronary artery bypass graft; CAD, coronary artery disease; COPD, chronic obstructive pulmonary disease; COR, class of recommendation; 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.

Table 3. Revascularization to Improve Symptoms With Significant Anatomic (≥50% Left Main or ≥70% Non–Left Main CAD) or Physiological (FFR≤0.80) Coronary Artery Stenoses

Clinical Setting	COR	LOE	References
≥1 significant stenoses amenable to revascularization and unacceptable angina despite GDMT	I—CABG I—PCI	A	(370,387–396)
≥1 significant stenoses and unacceptable angina in whom GDMT cannot be implemented because of medication contraindications, adverse effects, or patient preferences	IIa—CABG IIa—PCI	C	N/A
Previous CABG with ≥1 significant stenoses associated with ischemia and unacceptable angina despite GDMT	IIa—PCI	C	(374,377,380)
	IIb—CABG	C	(381)
Complex 3-vessel CAD (e.g., SYNTAX score >22) with or without involvement of the proximal LAD artery and a good candidate for CABG	IIa—CABG preferred over PCI	B	(320,343,359–361)
Viable ischemic myocardium that is perfused by coronary arteries that are not amenable to grafting	IIb—TMR as an adjunct to CABG	B	(397–401)
No anatomic or physiologic criteria for revascularization	III: Harm—CABG III: Harm—PCI	C	N/A

CABG indicates coronary artery bypass graft; CAD, coronary artery disease; COR, class of recommendation; FFR, fractional flow reserve; GDMT, guideline-directed medical therapy; LOE, level of evidence; N/A, not applicable; PCI, percutaneous coronary intervention; SYNTAX, Synergy between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and TMR, transmyocardial laser revascularization.

revascularization options with the patient. Because the STS score and the SYNTAX score have been shown to predict adverse outcomes in patients undergoing CABG and PCI, respectively, calculation of these scores is often useful in making revascularization decisions (301,302,305–310).

3.2. Revascularization to Improve Survival: Recommendations

Left Main CAD Revascularization

CLASS I

1. CABG to improve survival is recommended for patients with significant (≥50% diameter stenosis) left main coronary artery stenosis (312–318). *(Level of Evidence: B)*

CLASS IIa

1. PCI to improve survival is reasonable as an alternative to CABG in selected stable patients with significant (≥50% diameter stenosis) unprotected left main CAD with: 1) 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 [≤22], ostial or trunk left main CAD); and 2) clinical characteristics that predict a significantly increased risk of adverse surgical outcomes (e.g., STS-predicted risk of operative mortality ≥5%) (301,305,307,311,319–336). *(Level of Evidence: B)*
2. PCI to improve survival is reasonable in patients with UA/NSTEMI when an unprotected left main coronary artery is the culprit lesion and the patient is not a candidate for CABG (301,324–327,332,333,335–337). *(Level of Evidence: B)*
3. PCI to improve survival is reasonable in patients with acute STEMI when an unprotected left main coronary artery is the culprit lesion, distal coronary flow is less than Thrombolysis In Myocardial Infarction grade 3, and PCI can be performed more rapidly and safely than CABG (321,338,339). *(Level of Evidence: C)*

CLASS IIb

1. PCI to improve survival may be reasonable as an alternative to CABG in selected stable patients with significant (≥50% diameter stenosis) unprotected left main CAD with: 1) anatomic conditions associated with a low to intermediate risk of PCI procedural complications and an intermediate to high likelihood of good long-term outcome (e.g., low–intermediate SYNTAX score of <33, bifurcation left main CAD); and 2) clinical characteristics that predict an increased risk of adverse surgical outcomes (e.g., moderate–severe chronic obstructive pulmonary disease, disability from previous stroke, or previous cardiac surgery; STS-predicted risk of operative mortality >2%) (301,305,307,311,319–336,340). *(Level of Evidence: B)*

CLASS III: HARM

1. PCI to improve survival should not be performed in stable patients with significant (≥50% diameter stenosis) unprotected left main CAD who have unfavorable anatomy for PCI and who are good candidates for CABG (301,305,307,312–320). *(Level of Evidence: B)*

Non–Left Main CAD Revascularization

CLASS I

1. CABG to improve survival is beneficial in patients with significant (≥70% diameter) stenoses in 3 major coronary arteries (with or without involvement of the proximal LAD artery) or in the proximal LAD plus 1 other major coronary artery (314,318,341–344). *(Level of Evidence: B)*
2. CABG or PCI to improve survival is beneficial in survivors of sudden cardiac death with presumed ischemia-mediated ventricular tachycardia caused by significant (≥70% diameter) stenosis in a major coronary artery. *(CABG Level of Evidence: B [271,345,347]; PCI Level of Evidence: C [345])*

CLASS IIa

1. CABG to improve survival is reasonable in patients with significant (≥70% diameter) stenoses in 2 major coronary arteries with severe or extensive myocardial ischemia (e.g., high-risk criteria on stress testing, abnormal intracoronary hemodynamic evaluation, or >20% perfusion defect by myocardial perfusion stress imaging) or target vessels supplying a large area of viable myocardium (348–351). *(Level of Evidence: B)*
2. CABG to improve survival is reasonable in patients with mild-moderate LV systolic dysfunction (EF 35% to 50%) and significant (≥70% diameter stenosis) multivessel CAD or proximal LAD coronary artery stenosis, when viable myocardium is present in the region of intended revascularization (318,352–356). *(Level of Evidence: B)*

3. CABG with a LIMA graft to improve survival is reasonable in patients with significant (≥70% diameter) stenosis in the proximal LAD artery and evidence of extensive ischemia (87,88,318,343). *(Level of Evidence: B)*
4. It is reasonable to choose CABG over PCI to improve survival in patients with complex 3-vessel CAD (e.g., SYNTAX score >22), with or without involvement of the proximal LAD artery, who are good candidates for CABG (320,334,343,359–360). *(Level of Evidence: B)*
5. CABG is probably recommended in preference to PCI to improve survival in patients with multivessel CAD and diabetes mellitus, particularly if a LIMA graft can be anastomosed to the LAD artery (350,362–369). *(Level of Evidence: B)*

CLASS IIb

1. The usefulness of CABG to improve survival is uncertain in patients with significant (≥70%) stenoses in 2 major coronary arteries not involving the proximal LAD artery and without extensive ischemia (343). *(Level of Evidence: C)*
2. The usefulness of PCI to improve survival is uncertain in patients with 2- or 3-vessel CAD (with or without involvement of the proximal LAD artery) or 1-vessel proximal LAD disease (314,341,343,370). *(Level of Evidence: B)*
3. CABG might be considered with the primary or sole intent of improving survival in patients with SIHD with severe LV systolic dysfunction (EF <35%) whether or not viable myocardium is present (318,352–356,371,372). *(Level of Evidence: B)*
4. The usefulness of CABG or PCI to improve survival is uncertain in patients with previous CABG and extensive anterior wall ischemia on noninvasive testing (373–381). *(Level of Evidence: B)*

CLASS III: HARM

1. CABG or PCI should not be performed with the primary or sole intent to improve survival in patients with SIHD with 1 or more coronary stenoses that are not anatomically or functionally significant (e.g., <70% diameter non–left main coronary artery stenosis, fractional flow reserve >0.80, no or only mild ischemia on noninvasive testing), involve only the left circumflex or right coronary artery, or subtend only a small area of viable myocardium (318,341,348,349,382–386). *(Level of Evidence: B)*

3.3. Revascularization to Improve Symptoms: Recommendations

CLASS I

1. CABG or PCI to improve symptoms is beneficial in patients with 1 or more significant (≥70% diameter) coronary artery stenoses amenable to revascularization and unacceptable angina despite GDMT (370,387–396). *(Level of Evidence: A)*

CLASS IIa

1. CABG or PCI to improve symptoms is reasonable in patients with 1 or more significant (≥70% diameter) coronary artery stenoses and unacceptable angina for whom GDMT cannot be implemented because of medication contraindications, adverse effects, or patient preferences. *(Level of Evidence: C)*
2. PCI to improve symptoms is reasonable in patients with previous CABG, 1 or more significant (≥70% diameter) coronary artery stenoses associated with ischemia, and unacceptable angina despite GDMT (374,377,380). *(Level of Evidence: C)*
3. It is reasonable to choose CABG over PCI to improve symptoms in patients with complex 3-vessel CAD (e.g., SYNTAX score >22), with or without involvement of the proximal LAD artery, who are good candidates for CABG (320,334,343,359–360). *(Level of Evidence: B)*

CLASS IIb

1. CABG to improve symptoms might be reasonable for patients with previous CABG, 1 or more significant (≥70% diameter) coronary artery stenoses not amenable to PCI, and unacceptable angina despite GDMT (381). *(Level of Evidence: C)*
2. Transmyocardial laser revascularization (TMR) performed as an adjunct to CABG to improve symptoms may be reasonable in patients with viable ischemic myocardium that is perfused by arteries that are not amenable to grafting (397–401). *(Level of Evidence: B)*

CLASS III: HARM

1. CABG or PCI to improve symptoms should not be performed in patients who do not meet anatomic (≥50% left main or ≥70% non–left main stenosis) or physiological (e.g., abnormal fractional flow reserve) criteria for revascularization. *(Level of Evidence: C)*

3.4. CABG Versus Contemporaneous Medical Therapy

In the 1970s and 1980s, 3 RCTs established the survival benefit of CABG compared with contemporaneous (although minimal by current standards) medical therapy without revascularization in certain subjects with stable angina: the Veterans Affairs Cooperative Study (402), European Coronary Surgery Study (344), and CASS (Coronary Artery Surgery Study) (403). Subsequently, a 1994 meta-analysis of 7 studies that randomized a total of 2,649 patients to medical therapy for CABG (318) showed that CABG offered a survival advantage over medical therapy for patients with left main or 3-vessel CAD. The studies also established that CABG is more effective than medical therapy at relieving anginal symptoms. These studies have been replicated only once during the past decade. In MASS II (Medicine, Angioplasty, or Surgery Study II), patients with multivessel CAD who were treated with CABG were less likely than those treated with medical therapy to have a subsequent MI, need additional revascularization, or experience cardiac death in the 10 years after randomization (392).

Surgical techniques and medical therapy have improved substantially during the intervening years. As a result, if CABG were to be compared with GDMT in RCTs today, the relative benefits for survival and angina relief observed several decades ago might no longer be observed. Conversely, the concurrent administration of GDMT may substantially improve long-term outcomes in patients treated with CABG in comparison with those receiving medical therapy alone. In the BARI 2D (Bypass Angioplasty Revascularization Investigation 2 Diabetes) trial of patients with diabetes mellitus, no significant difference in risk of mortality in the cohort of patients randomized to GDMT plus CABG or GDMT alone was observed, although the study was not powered for this endpoint, excluded patients with significant left main CAD, and included only a small percentage of patients with proximal LAD artery disease or LV ejection fraction (LVEF) <0.50 (404). The PCI and CABG guideline writing committees endorse the performance of the ISCHEMIA (International Study of Comparative Health Effectiveness with Medical and Invasive Approaches) trial,

which will provide contemporary data on the optimal management strategy (medical therapy or revascularization with CABG or PCI) of patients with SIHD, including multivessel CAD, and moderate to severe ischemia.

3.5. PCI Versus Medical Therapy

Although contemporary interventional treatments have lowered the risk of restenosis compared with earlier techniques, meta-analyses have failed to show that the introduction of bare-metal stents (BMS) confers a survival advantage over balloon angioplasty (405–407) or that the use of drug-eluting stents (DES) confers a survival advantage over BMS (407,408).

No study to date has demonstrated that PCI in patients with SIHD improves survival rates (314,341,343,370,404,407,409–412). Neither COURAGE (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation) (370) nor BARI 2D (404), which treated all patients with contemporary optimal medical therapy, demonstrated any survival advantage with PCI, although these trials were not specifically powered for this endpoint. Although 1 large analysis evaluating 17 RCTs of PCI versus medical therapy (including 5 trials of subjects with ACS) found a 20% reduction in death with PCI compared with medical therapy (411), 2 other large analyses did not (407,410). An evaluation of 13 studies reporting the data from 5,442 patients with nonacute CAD showed no advantage of PCI over medical therapy for the individual endpoints of all-cause death, cardiac death or MI, or nonfatal MI (412). Evaluation of 61 trials of PCI conducted over several decades shows that despite improvements in PCI technology and pharmacotherapy, PCI has not been demonstrated to reduce the risk of death or MI in patients without recent ACS (407).

The findings from individual studies and systematic reviews of PCI versus medical therapy can be summarized as follows:

- PCI reduces the incidence of angina (370,387,392,395,396,413).
- PCI has not been demonstrated to improve survival in stable patients (407,409,410).
- PCI may increase the short-term risk of MI (370,409,413,414).
- PCI does not lower the long-term risk of MI (370,404,407,409,410,414).

3.6. CABG Versus PCI

The results of 26 RCTs comparing CABG and PCI have been published: Of these, 9 compared CABG with balloon angioplasty (363,393,415–429), 14 compared CABG with BMS implantation (376,430–447), and 3 compared CABG with DES implantation (302,448,449).

3.6.1. CABG Versus Balloon Angioplasty or BMS

A systematic review of the 22 RCTs comparing CABG with balloon angioplasty or BMS implantation concluded the following (450):

1. Survival was similar for CABG and PCI (with balloon angioplasty or BMS) at 1 year and 5 years. Survival was similar for CABG and PCI in subjects with 1-vessel CAD (including those with disease of the proximal portion of the LAD artery) or multivessel CAD.
2. Incidence of MI was similar at 5 years after randomization.
3. Procedural stroke occurred more commonly with CABG than with PCI (1.2% versus 0.6%).
4. Relief of angina was accomplished more effectively with CABG than with PCI 1 year after randomization and 5 years after randomization.
5. During the first year after randomization, repeat coronary revascularization was performed less often after CABG than after PCI (3.8% versus 26.5%). This was also demonstrated after 5 years of follow-up (9.8% versus 46.1%). This difference was more pronounced with balloon angioplasty than with BMS.

A collaborative analysis of data from 10 RCTs comparing CABG with balloon angioplasty (6 trials) or with BMS implantation (4 trials) (451) permitted subgroup analyses of the data from the 7,812 patients. No difference was noted with regard to mortality rate 5.9 years after randomization or the composite endpoint of death or MI. Repeat revascularization and angina were noted more frequently in those treated with balloon angioplasty or BMS implantation (451). The major new observation of this analysis was that CABG was associated with better outcomes in patients with diabetes mellitus and in those >65 years old. Of interest, the relative outcomes of CABG and PCI were not influenced by other patient characteristics, including the number of diseased coronary arteries.

The aforementioned meta-analysis and systematic review (450,451) comparing CABG and balloon angioplasty or BMS implantation were limited in several ways.

1. Many trials did not report outcomes for other important patient subsets. For example, the available data are insufficient to determine if race, obesity, renal dysfunction, peripheral artery disease (PAD), or previous coronary revascularization affected the comparative outcomes of CABG and PCI.
2. Most of the patients enrolled in these trials were male, and most had 1- or 2-vessel CAD and normal LV systolic function (EF >50%)—subjects known to be unlikely to derive a survival benefit and less likely to experience complications after CABG (318).
3. The patients enrolled in these trials represented only a small fraction (generally <5% to 10%) of those who were screened. For example, most screened patients with

1-vessel CAD and many with 3-vessel CAD were not considered for randomization.

See Online Data Supplements 10 and 11 for additional data comparing CABG with PCI.

3.6.2. CABG Versus DES

Although the results of 9 observational studies comparing CABG and DES implantation have been published (320,452–459), most of them had short (12 to 24 months) follow-up periods. In a meta-analysis of 24,268 patients with multivessel CAD treated with CABG or DES (460), the incidences of death and MI were similar for the 2 procedures, but the frequency with which repeat revascularization was performed was roughly 4 times higher after DES implantation. Only 1 large RCT comparing CABG and DES implantation has been published. The SYNTAX trial randomly assigned 1,800 patients (of a total of 4,337 who were screened) to receive DES or CABG (302,334). Major adverse cardiac events (MACE), a composite of death, stroke, MI, or repeat revascularization during the 3 years after randomization, occurred in 20.2% of CABG patients and 28.0% of those undergoing DES implantation ($p<0.001$). The rates of death and stroke were similar; however, MI (3.6% for CABG; 7.1% for DES) and repeat revascularization (10.7% for CABG; 19.7% for DES) were more likely to occur with DES implantation (334).

In SYNTAX, the extent of CAD was assessed using the SYNTAX score, which is based on the location, severity, and extent of coronary stenoses, with a low score indicating less complicated anatomic CAD. In post hoc analyses, a low score was defined as ≤22; intermediate 23 to 32; and high, ≥33. The occurrence of MACE correlated with the SYNTAX score for DES patients but not for those undergoing CABG. At 12-month follow-up, the primary endpoint was similar for CABG and DES in those with a low SYNTAX score. In contrast, MACE occurred more often after DES implantation than after CABG in those with an intermediate or high SYNTAX score (302). At 3 years of follow-up, the mortality rate was greater in subjects with 3-vessel CAD treated with PCI than in those treated with CABG (6.2% versus 2.9%). The differences in MACE between those treated with PCI or CABG increased with an increasing SYNTAX score (Figure 1) (334).

Although the utility of using a SYNTAX score in everyday clinical practice remains uncertain, it seems reasonable to conclude from SYNTAX and other data that outcomes of patients undergoing PCI or CABG in those with relatively uncomplicated and lesser degrees of CAD are comparable, whereas in those with complex and diffuse CAD, CABG appears to be preferable (334).

See Online Data Supplements 12 and 13 for additional data comparing CABG with DES.

3.7. Left Main CAD

3.7.1. CABG or PCI Versus Medical Therapy for Left Main CAD

CABG confers a survival benefit over medical therapy in patients with left main CAD. Subgroup analyses from RCTs performed 3 decades ago included 91 patients with left main CAD in the Veterans Administration Cooperative Study (316). A meta-analysis of these trials demonstrated a 66% RR reduction in mortality with CABG, with the benefit extending to 10 years (318). The CASS Registry (312) contained data from 1,484 patients with ≥50% left main CAD initially treated surgically or nonsurgically. Median survival duration was 13.3 years in the surgical group and 6.6 years in the medical group. The survival benefit of CABG over medical therapy appeared to extend to 53 asymptomatic patients with left main CAD in the CASS Registry (317). Other therapies that subsequently have been shown to be associated with improved long-term

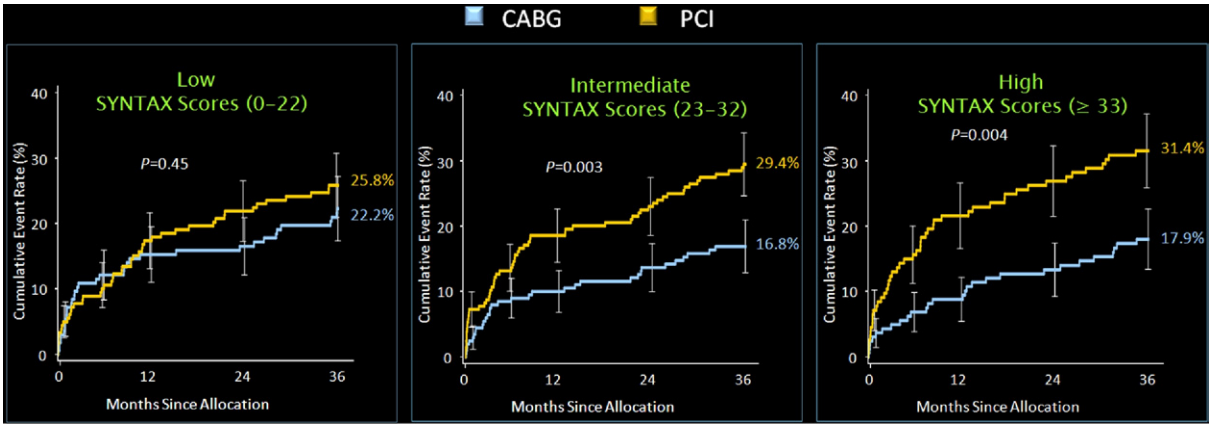

Figure 1. Cumulative Incidence of MACE in Patients With 3-Vessel CAD Based on SYNTAX Score at 3-Year Follow-Up in the SYNTAX Trial Treated With Either CABG or PCI

CABG indicates coronary artery bypass graft; CAD, coronary artery disease; MACE, major adverse cardiovascular event; PCI, percutaneous coronary intervention; and SYNTAX, Synergy between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery. Adapted with permission from Kappetein (334).

outcome, such as the use of aspirin, statins, and IMA grafting, were not widely used in that era.

RCTs and subgroup analyses that compare PCI with medical therapy in patients with "unprotected" left main CAD do not exist.

3.7.2. Studies Comparing PCI Versus CABG for Left Main CAD

Of all subjects undergoing coronary angiography, approximately 4% are found to have left main CAD (463), >80% of whom have significant (≥70% diameter) stenoses in other epicardial coronary arteries.

Published cohort studies have found that major clinical outcomes are similar with PCI or CABG 1 year after revascularization and that mortality rates are similar at 1, 2, and 5 years of follow-up; however, the risk of needing target-vessel revascularization is significantly higher with stenting than with CABG.

In the SYNTAX trial, 45% of screened patients with unprotected left main CAD had complex diseases that prevented randomization; 89% of these underwent CABG (301,302). In addition, 705 of the 1,800 patients who were randomized had revascularization for unprotected left main CAD. The majority of patients with left main CAD and a low SYNTAX score had isolated left main CAD or left main CAD plus 1-vessel CAD; the majority of those with an intermediate score had left main CAD plus 2-vessel CAD; and most of those with a high SYNTAX score had left main CAD plus 3-vessel CAD. At 1 year, rates of all-cause death and MACE were similar for the 2 groups (301). Repeat revascularization rates were higher in the PCI group than the CABG group (11.8% versus 6.5%), but stroke occurred more often in the CABG group (2.7% versus 0.3%). At 3 years of follow-up, the incidence of death in those undergoing left main CAD revascularization with low or intermediate SYNTAX scores (≤32) was 3.7% after PCI and 9.1% after CABG (p=0.03), whereas in those with a high SYNTAX score (≥33) the incidence of death after 3 years was 13.4% after PCI and 7.6% after CABG (p=0.10) (334). Because the primary endpoint of SYNTAX was not met (i.e., noninferiority comparison of CABG and PCI), these subgroup analyses need to be considered in that context.

In the LE MANS (Study of Unprotected Left Main Stenting Versus Bypass Surgery) trial (311), 105 patients with left main CAD were randomized to receive PCI or CABG. Although a low proportion of patients treated with PCI received DES (35%) and a low proportion of patients treated with CABG received IMA grafts (72%), the outcomes at 30 days and 1 year were similar between the groups. In the PRECOMBAT (Premier of Randomized Comparison of Bypass Surgery versus Angioplasty Using Sirolimus-Eluting Stent in Patients with Left Main Coronary Artery Disease) trial of 600 patients with left main disease, the composite endpoint of death, MI, or stroke at 2 years occurred in 4.4% of patients treated with PCI and 4.7% of patients treated with CABG, but ischemia-driven target-vessel revascularization was more often required in the patients treated with PCI (9.0% versus 4.2%) (340).

The results from these 3 RCTs suggest (but do not definitively prove) that major clinical outcomes in *selected* patients with left main CAD are similar with CABG and PCI at 1- to 2-year follow-up, but repeat revascularization rates are higher after PCI than after CABG. RCTs with extended follow-up of ≥5 years are required to provide definitive conclusions about the optimal treatment of left main CAD. In a meta-analysis of 8 cohort studies and 2 RCTs (329), death, MI, and stroke occurred with similar frequency in the PCI- and CABG-treated patients at 1, 2, and 3 years of follow-up. Target-vessel revascularization was performed more often in the PCI group at 1 year (OR: 4.36), 2 years (OR: 4.20), and 3 years (OR: 3.30).

See Online Data Supplements 14 to 19 for additional data comparing PCI with CABG for left main CAD.

3.7.3. Revascularization Considerations for Left Main CAD

Although CABG has been considered the "gold standard" for unprotected left main CAD revascularization, more recently PCI has emerged as a possible alternative mode of revascularization in carefully selected patients. Lesion location is an important determinant when considering PCI for unprotected left main CAD. Stenting of the left main ostium or trunk is more straightforward than treating distal bifurcation or trifurcation stenoses, which generally requires a greater degree of operator experience and expertise (464). In addition, PCI of bifurcation disease is associated with higher restenosis rates than when disease is confined to the ostium or trunk (327,465). Although lesion location influences technical success and long-term outcomes after PCI, location exerts a negligible influence on the success of CABG. In subgroup analyses, patients with left main CAD and a SYNTAX score ≥33 with more complex or extensive CAD had a higher mortality rate with PCI than with CABG (334). Physicians can estimate operative risk for all CABG candidates by using a standard instrument, such as the risk calculator from the STS database. The above considerations are important factors when choosing among revascularization strategies for unprotected left main CAD and have been factored into revascularization recommendations. Use of a Heart Team approach has been recommended in cases in which the choice of revascularization is not straightforward. As discussed in Section 3.9.7, the ability of the patient to tolerate and comply with dual antiplatelet therapy (DAPT) is also an important consideration in revascularization decisions.

The 2005 PCI guidelines (466) recommended routine angiographic follow-up 2 to 6 months after stenting for uprotected left main CAD. However, because angiography has limited ability to predict stent thrombosis and the

results of SYNTAX suggest good intermediate-term results for PCI in subjects with left main CAD, this recommendation was removed in the 2009 STEMI/PCI focused update (467).

Experts have recommended immediate PCI for unprotected left main CAD in the setting of STEMI (339). The impetus for such a strategy is greatest when the left main CAD is the site of the culprit lesion, antegrade coronary flow is diminished [e.g., Thrombolysis In Myocardial Infarction flow grade 0, 1, or 2], the patient is hemodynamically unstable, and it is believed that PCI can be performed more quickly than CABG. When possible, the interventional cardiologist and cardiac surgeon should decide together on the optimal form of revascularization for these subjects, although it is recognized that these patients are usually critically ill and therefore not amenable to a prolonged deliberation or discussion of treatment options.

3.8. Proximal LAD Artery Disease

A cohort study (341) and a meta-analysis (318) from the 1990s suggested that CABG confers a survival advantage over contemporaneous medical therapy for patients with disease in the proximal segment of the LAD artery. Cohort studies and RCTs (318,420,432,433,435,448,468–470) as well as collaborative- and meta-analyses (451,471–473) showed that PCI and CABG result in similar survival rates in these patients.

See Online Data Supplement 20 for additional data regarding proximal LAD artery revascularization.

3.9. Clinical Factors That May Influence the Choice of Revascularization

3.9.1. Diabetes Mellitus

An analysis performed in 2009 of data on 7,812 patients (1,233 with diabetes) in 10 RCTs demonstrated a worse long-term survival rate in patients with diabetes mellitus after balloon angioplasty or BMS implantation than after CABG (451). The BARI 2D trial (404) randomly assigned 2,368 patients with type 2 diabetes and CAD to undergo intensive medical therapy or prompt revascularization with PCI or CABG, according to whichever was thought to be more appropriate. By study design, those with less extensive CAD more often received PCI, whereas those with more extensive CAD were more likely to be treated with CABG. The study was not designed to compare PCI with CABG. At 5-year follow-up, no difference in rates of survival or MACE between the medical therapy group and those treated with revascularization was noted. In the PCI stratum, no significant difference in MACE between medical therapy and revascularization was demonstrated (DES in 35%; BMS in 56%); in the CABG stratum, MACE occurred less often in the revascularization group. One-year follow-up data from the SYNTAX study demonstrated a higher rate of repeat revascularization in patients with diabetes mellitus treated with PCI than with CABG, driven by a tendency for higher repeat revascularization rates in those with higher SYNTAX scores undergoing PCI (364). In summary, in subjects requiring revascularization for multivessel CAD, current evidence supports diabetes mellitus as an important factor when deciding on a revascularization strategy, particularly when complex or extensive CAD is present (Figure 2).

See Online Data Supplements 21 and 22 for additional data regarding diabetes mellitus.

3.9.2. Chronic Kidney Disease

Cardiovascular morbidity and mortality rates are markedly increased in patients with chronic kidney disease (CKD) when compared with age-matched controls without CKD. The mortality rate for patients on hemodialysis is >20% per year, and approximately 50% of deaths among these patients are due to a cardiovascular cause (476,477).

To date, randomized comparisons of coronary revascularization (with CABG or PCI) and medical therapy in patients with CKD have not been reported. Some, but not all, observational studies or subgroup analyses have demonstrated an improved survival rate with revascularization compared with medical therapy in patients with CKD and multivessel CAD (478–480), despite the fact that the incidence of periprocedural complications (e.g., death, MI, stroke, infection, renal failure) is increased in patients with CKD compared with those without renal dysfunction. Some studies have shown that CABG is associated with a greater survival benefit than PCI among patients with severe renal dysfunction (479–485).

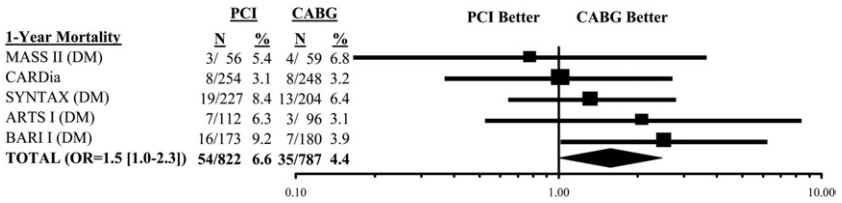

Figure 2. 1-Year Mortality After Revascularization for Multivessel Disease and Diabetes Mellitus

An OR of >1 suggests an advantage of CABG over PCI. ARTS I indicates Arterial Revascularization Therapy Study I (474); BARI I, Bypass Angioplasty Revascularization Investigation I (362); CARDia, Coronary Artery Revascularization in Diabetes (475); CI, confidence interval; DM, diabetes mellitus; MASS II, Medicine, Angioplasty, or Surgery Study II (366); OR, odds ratio; SYNTAX, Synergy between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and W, weighted (364).

3.9.3. Completeness of Revascularization

Most patients undergoing CABG receive complete or nearly complete revascularization, which seems to influence long-term prognosis positively (486). In contrast, complete revascularization is accomplished less often in subjects receiving PCI (e.g., in <70% of patients), but the extent to which the absence of complete initial revascularization influences outcome is less clear. Rates of late survival and survival free of MI appear to be similar in patients with and without complete revascularization after PCI. Nevertheless, the need for subsequent CABG is usually higher in those whose initial revascularization procedure was incomplete (compared with those with complete revascularization) after PCI (487–489).

3.9.4. LV Systolic Dysfunction

Several older studies and a meta-analysis of the data from these studies reported that patients with LV systolic dysfunction (predominantly mild to moderate in severity) had better survival with CABG than with medical therapy alone (318,352–356). For patients with more severe LV systolic dysfunction, however, the evidence that CABG results in better survival compared with medical therapy is lacking. In the STICH (Surgical Treatment for Ischemic Heart Failure) trial of subjects with LVEF <35% with or without viability testing, CABG and GDMT resulted in similar rates of survival (death from any cause, the study's primary outcome) after 5 years of follow-up. For a number of secondary outcomes at this time point, including 1) death from any cause or hospitalization for heart failure, 2) death from any cause or hospitalization for cardiovascular causes, 3) death from any cause or hospitalization for any cause, or 4) death from any cause or revascularization with PCI or CABG, CABG was superior to GDMT. Although the primary outcome (death from any cause) was similar in the 2 treatment groups after an average of 5 years of follow-up, the data suggest the possibility that outcomes would differ if the follow-up were longer in duration; as a result, the study is being continued to provide follow-up for up to 10 years (371,372).

Only very limited data comparing PCI with medical therapy in patients with LV systolic dysfunction are available (356). In several ways, these data are suboptimal, in that many studies compared CABG with balloon angioplasty, many were retrospective, and many were based on cohort or registry data. Some of the studies demonstrated a similar survival rate in patients having CABG and PCI (359,451,490–492), whereas others showed that those undergoing CABG had better outcomes (320). The data that exist at present on revascularization in patients with CAD and LV systolic dysfunction are more robust for CABG than for PCI, although data from contemporary RCTs in this patient population are lacking. Therefore, the choice of revascularization in patients with CAD and LV systolic dysfunction is best based on clinical variables (e.g., coronary anatomy, presence of diabetes mellitus, presence of CKD), magnitude of LV systolic dysfunction, patient preferences, clinical judgment, and consultation between the interventional cardiologist and the cardiac surgeon.

3.9.5. Previous CABG

In patients with recurrent angina after CABG, repeat revascularization is most likely to improve survival in subjects at highest risk, such as those with obstruction of the proximal LAD artery and extensive anterior ischemia (373–381). Patients with ischemia in other locations and those with a patent LIMA to the LAD artery are unlikely to experience a survival benefit from repeat revascularization (380).

Cohort studies comparing PCI and CABG among post-CABG patients report similar rates of mid- and long-term survival after the 2 procedures (373,376–379,381,493). In the patient with previous CABG who is referred for revascularization for medically refractory ischemia, factors that may support the choice of repeat CABG include vessels unsuitable for PCI, number of diseased bypass grafts, availability of the IMA for grafting, chronically occluded coronary arteries, and good distal targets for bypass graft placement. Factors favoring PCI over CABG include limited areas of ischemia causing symptoms, suitable PCI targets, a patent graft to the LAD artery, poor CABG targets, and comorbid conditions.

3.9.6. Unstable Angina/Non–ST-Elevation Myocardial Infarction

The main difference between management of the patient with SIHD and the patient with UA/NSTEMI is that the impetus for revascularization is stronger in the setting of UA/NSTEMI, because myocardial ischemia occurring as part of an ACS is potentially life threatening, and associated anginal symptoms are more likely to be reduced with a revascularization procedure than with GDMT (494–496). Thus, the indications for revascularization are strengthened by the acuity of presentation, the extent of ischemia, and the ability to achieve full revascularization. The choice of revascularization method is generally dictated by the same considerations used to decide on PCI or CABG for patients with SIHD.

3.9.7. DAPT Compliance and Stent Thrombosis: Recommendation

CLASS III: HARM

1. **PCI with coronary stenting (BMS or DES) should not be performed if the patient is not likely to be able to tolerate and comply with DAPT for the appropriate duration of treatment based on the type of stent implanted (497–500). *(Level of Evidence: B)***

The risk of stent thrombosis is increased dramatically in patients who prematurely discontinue DAPT, and stent thrombosis is associated with a mortality rate of 20% to 45% (497). Because the risk of stent thrombosis with BMS is greatest in the first 14 to 30 days, this is the generally

recommended minimum duration of DAPT therapy for these individuals. Consensus in clinical practice is to treat DES patients for at least 12 months with DAPT to avoid late (after 30 days) stent thrombosis (497,501). Therefore, the ability of the patient to tolerate and comply with at least 30 days of DAPT with BMS treatment and at least 12 months of DAPT with DES treatment is an important consideration in deciding whether to use PCI to treat patients with CAD.

3.10. TMR as an Adjunct to CABG

TMR has been used on occasion in patients with severe angina refractory to GDMT in whom complete revascularization cannot be achieved with PCI and/or CABG. Although the mechanism by which TMR might be efficacious in these patients is unknown (502,503), several RCTs of TMR as sole therapy demonstrated a reduction in anginal symptoms compared with intensive medical therapy alone (397–399,504–506). A single randomized multicenter comparison of TMR (with a holmium:YAG laser) plus CABG and CABG alone in subjects in whom some myocardial segments were perfused by arteries considered not amenable to grafting showed a significant reduction in perioperative mortality rate (1.5% versus 7.6%, respectively), and the survival benefit of the TMR–CABG combination was present after 1 year of follow-up (400). At the same time, a large retrospective analysis of data from the STS National Cardiac Database, as well as a study of 169 patients from the Washington Hospital Center who underwent combined TMR–CABG, showed no difference in adjusted mortality rate compared with CABG alone (401,507). In short, a TMR–CABG combination does not appear to improve survival compared with CABG alone. In selected patients, however, such a combination may be superior to CABG alone in relieving angina.

3.11. Hybrid Coronary Revascularization: Recommendations

CLASS IIa

1. Hybrid coronary revascularization (defined as the planned combination of LIMA-to-LAD artery grafting and PCI of ≥1 non-LAD coronary arteries) is reasonable in patients with 1 or more of the following (508–516) *(Level of Evidence: B)*:
   a. Limitations to traditional CABG, such as heavily calcified proximal aorta or poor target vessels for CABG (but amenable to PCI);
   b. Lack of suitable graft conduits;
   c. Unfavorable LAD artery for PCI (i.e., excessive vessel tortuosity or chronic total occlusion).

CLASS IIb

1. Hybrid coronary revascularization (defined as the planned combination of LIMA-to-LAD artery grafting and PCI of ≥1 non-LAD coronary arteries) may be reasonable as an alternative to multivessel PCI or CABG in an attempt to improve the overall risk–benefit ratio of the procedures. *(Level of Evidence: C)*

Hybrid coronary revascularization, defined as the planned combination of LIMA-to-LAD artery grafting and PCI of ≥1 non-LAD coronary arteries (515), is intended to combine the advantages of CABG (i.e., durability of the LIMA graft) and PCI (516). Patients with multivessel CAD (e.g., LAD and ≥1 non-LAD stenoses) and an indication for revascularization are potentially eligible for this approach. Hybrid revascularization is ideal in patients in whom technical or anatomic limitations to CABG or PCI alone may be present and for whom minimizing the invasiveness (and therefore the risk of morbidity and mortality) of surgical intervention is preferred (510) (e.g., patients with severe preexisting comorbidities, recent MI, a lack of suitable graft conduits, a heavily calcified ascending aorta, or a non-LAD coronary artery unsuitable for bypass but amenable to PCI, and situations in which PCI of the LAD artery is not feasible because of excessive tortuosity or chronic total occlusion).

Hybrid coronary revascularization may be performed in a hybrid suite in one operative setting or as a staged procedure (i.e., PCI and CABG performed in 2 different operative suites, separated by hours to 2 days, but typically during the same hospital stay). Because most hospitals lack a hybrid operating room, staged procedures are usually performed. With the staged procedure, CABG before PCI is preferred, because this approach allows the interventional cardiologist to 1) verify the patency of the LIMA-to-LAD artery graft before attempting PCI of other vessels and 2) minimize the risk of perioperative bleeding that would occur if CABG were performed after PCI (i.e., while the patient is receiving DAPT). Because minimally invasive CABG may be associated with lower graft patency rates compared with CABG performed through a midline sternotomy, it seems prudent to angiographically image all grafts performed through a minimally invasive approach to confirm graft patency (510).

To date, no RCTs involving hybrid coronary revascularization have been published. Over the past 10 years, several small, retrospective series of hybrid revascularization using minimally invasive CABG and PCI have reported low mortality rates (0 to 2%) and event-free survival rates of 83% to 92% at 6 to 12 months of follow-up. The few series that have compared the outcomes of hybrid coronary revascularization with standard CABG report similar outcomes at 30 days and 6 months (508–514).

4. Perioperative Management

4.1. Preoperative Antiplatelet Therapy: Recommendations

CLASS I

1. Aspirin (100 mg to 325 mg daily) should be administered to CABG patients preoperatively (517–519). (*Level of Evidence: B*)
2. In patients referred for elective CABG, clopidogrel and ticagrelor should be discontinued for at least 5 days before surgery (520–522) (*Level of Evidence: B*) and prasugrel for at least 7 days *(Level of Evidence: C)* to limit blood transfusions.
3. In patients referred for urgent CABG, clopidogrel and ticagrelor should be discontinued for at least 24 hours to reduce major bleeding complications (521,523–525). *(Level of Evidence: B)*

4. In patients referred for CABG, short-acting intravenous glycoprotein IIb/IIIa inhibitors (eptifibatide or tirofiban) should be discontinued for at least 2 to 4 hours before surgery (526,527) and abciximab for at least 12 hours beforehand (528) to limit blood loss and transfusions. *(Level of Evidence: B)*

CLASS IIb

1. In patients referred for urgent CABG, it may be reasonable to perform surgery less than 5 days after clopidogrel or ticagrelor has been discontinued and less than 7 days after prasugrel has been discontinued. *(Level of Evidence: C)*

Nearly all patients with UA or recent MI in whom CABG is performed will be taking aspirin; CABG can be performed safely in these individuals, with only a modest increase in bleeding risk. Preoperative aspirin use reduces operative morbidity and mortality rates (517,518).

Although the use of thienopyridines (clopidogrel or prasugrel) is associated with improved outcomes in subjects with UA or NSTEMI (305,306), their use is associated with an increase in post-CABG bleeding and need for transfusions (520,522,529–533). The risk of major bleeding complications (i.e., pericardial tamponade or reoperation) is increased when CABG is performed <24 hours after clopidogrel's discontinuation (524,525). Conversely, no increase in bleeding or transfusions is noted when CABG is performed >5 days after clopidogrel has been stopped (529,532). The magnitude of bleeding risk when CABG is performed 1 to 4 days after the discontinuation of clopidogrel is less certain. Although the incidence of life-threatening bleeding does not appear to be significantly increased during this time, an increase in blood transfusions is likely (523,524,529,531). Accordingly, from the perspective of blood conservation, it is reasonable to delay elective CABG for ≥5 days after discontinuing clopidogrel. For patients requiring more urgent CABG, it can be performed >24 hours after clopidogrel has been stopped with little or no increased risk of major bleeding. Approximately two thirds of clopidogrel-treated patients undergo CABG <5 days after clopidogrel discontinuation (529,532), driven largely by concerns for patient stability, resource utilization, patient preference, and the confidence of the surgical team in managing hemostasis. Little experience with CABG in patients treated with prasugrel has been reported. In the TRITON-TIMI 38 (Trial to Assess Improvement in Therapeutic Outcomes by Optimizing Platelet Inhibition With Prasugrel Thrombolysis in Myocardial Infarction) trial, the incidence of CABG-related major bleeding was higher in prasugrel-treated patients than in those on clopidogrel (13.4% versus 3.2%; $p<0.001$) (533). When possible, therefore, CABG should be delayed for ≥7 days after prasugrel is discontinued (533).

Ticagrelor, an oral agent that binds reversibly to the platelet $P2Y_{12}$ receptor, provides faster, more effective, and more consistent inhibition of platelet aggregation and more rapid recovery of platelet function after discontinuation than clopidogrel (534). In the PLATO (Platelet Inhibition and Patient Outcomes) trial, 632 patients in the ticagrelor group and 629 in the clopidogrel group underwent CABG within 7 days of the last dose of study drug (521). Although the study protocol recommended waiting ≥5 days after stopping clopidogrel and 24 to 72 hours after ticagrelor, many patients underwent surgery before the recommended waiting times. The rates of major bleeding (59.3% with ticagrelor, 57.6% with clopidogrel) and transfusion requirements (55.7% with ticagrelor, 56.5% with clopidogrel) were similar. Furthermore, no difference in bleeding was noted between ticagrelor and clopidogrel with respect to time from last dose of study drug, even when CABG was performed 1, 2, or 3 days after discontinuation. On the basis of these data, it does not appear that the more rapid recovery of platelet function seen in ticagrelor pharmacokinetic studies translates to a lower risk of bleeding or less need for transfusion compared with clopidogrel when CABG is performed early (i.e., <5 days) after drug discontinuation.

4.2. Postoperative Antiplatelet Therapy: Recommendations

CLASS I

1. If aspirin (100 mg to 325 mg daily) was not initiated preoperatively, it should be initiated within 6 hours postoperatively and then continued indefinitely to reduce the occurrence of SVG closure and adverse cardiovascular events (519,535,536). *(Level of Evidence: A)*

CLASS IIa

1. For patients undergoing CABG, clopidogrel 75 mg daily is a reasonable alternative in patients who are intolerant of or allergic to aspirin. *(Level of Evidence: C)*

See Online Data Supplement 23 for additional data on postoperative antiplatelet therapy.

Aspirin significantly improves SVG patency rates, particularly during the first postoperative year. Because arterial graft patency rates are high even in the absence of antiplatelet therapy, the administration of such therapy has not shown an improvement. Aspirin administration before CABG offers no improvement in subsequent SVG patency compared with its early postoperative initiation (535). Prospective controlled trials have demonstrated a graft patency benefit when aspirin was started 1, 7, or 24 hours after operation (103,537); in contrast, the benefit of postoperative aspirin on SVG patency was lost when it was initiated >48 hours after surgery (538).

Dosing regimens ranging from 100 mg daily to 325 mg 3 times daily appear to be efficacious (539). As the grafted recipient's coronary arterial luminal diameter increases, SVG patency rates improve, and the relative advantage of aspirin over placebo is reduced (540). Although aspirin doses of <100 mg daily have been used for prevention of adverse events in patients with CAD, they may be less efficacious than higher doses in optimizing SVG patency (541). Enteric-coated aspirin, 75 mg, has been associated with suboptimal inhibition of platelet aggregation in 44% of patients with stable cardiovascular disease, suggesting that soluble aspirin may be preferred if low-dose aspirin is used

(542). When given within 48 hours after CABG, aspirin has been shown to reduce subsequent rates of mortality, MI, stroke, renal failure, and bowel infarction (519).

Although ticlopidine is efficacious at inhibiting platelet aggregation, it offers no advantage over aspirin except as an alternative in the truly aspirin-allergic patient (543). In addition, its use may be associated with potentially life-threatening neutropenia, a rare adverse effect, such that white blood cell counts should be monitored repetitively after initiating it. Dipyridamole and warfarin add nothing to the effect of aspirin on SVG patency (544,545), and use of the latter may be associated with an increased risk for bleeding compared with antiplatelet agents (546).

Clopidogrel is associated with fewer adverse effects than ticlopidine. Severe leukopenia occurs very rarely (546,547). A subset analysis of CABG patients from the CURE (Clopidogrel in Unstable Angina to Prevent Recurrent Ischemic Events) trial suggested that clopidogrel reduced the occurrence of cardiovascular death, MI, and stroke (14.5%) compared with placebo (16.2%). This benefit occurred primarily before surgery, however, and after CABG a difference in primary endpoints between groups was not demonstrable. Clopidogrel was stopped a median of 10 days before surgery and was restarted postoperatively in 75.3% of patients assigned to receive it. All patients received aspirin, 75 mg to 325 mg daily, but the details of aspirin administration in the study groups were not described (530).

4.3. Management of Hyperlipidemia: Recommendations

CLASS I

1. All patients undergoing CABG should receive statin therapy, unless contraindicated (545,548–559). *(Level of Evidence: A)*
2. In patients undergoing CABG, an adequate dose of statin should be used to reduce LDL cholesterol to less than 100 mg/dL and to achieve at least a 30% lowering of LDL cholesterol (548–552). *(Level of Evidence: C)*

CLASS IIa

1. In patients undergoing CABG, it is reasonable to treat with statin therapy to lower the LDL cholesterol to less than 70 mg/dL in very high-risk* patients (549–551,561–563). *(Level of Evidence: C)*
2. For patients undergoing urgent or emergency CABG who are not taking a statin, it is reasonable to initiate high-dose statin therapy immediately (564). *(Level of Evidence: C)*

CLASS III: HARM

1. Discontinuation of statin or other dyslipidemic therapy is not recommended before or after CABG in patients without adverse reactions to therapy (565–567). *(Level of Evidence: B)*

See Online Data Supplement 24 for additional data on management of hyperlipidemia.

*Presence of established cardiovascular disease plus 1) multiple major risk factors (especially diabetes), 2) severe and poorly controlled risk factors (especially continued cigarette smoking), 3) multiple risk factors of the metabolic syndrome (especially high triglycerides ≥200 mg/dL plus non–high-density lipoprotein cholesterol ≥130 mg/dL with low high-density lipoprotein cholesterol [<40 mg/dL]), and 4) acute coronary syndromes.

In patients with CAD, treatment of hyperlipidemia with therapeutic lifestyle changes and medications reduces the risk of nonfatal MI and death. The goal of such therapy is to reduce the LDL cholesterol level to <100 mg/dL (563). Statins are the most commonly prescribed agents for achieving this goal (563).

Studies of lipid-lowering therapy in CABG patients have demonstrated that lowering LDL cholesterol with statins influences post-CABG outcomes, and "aggressive" LDL cholesterol lowering (to 60 to 85 mg/dL) is associated with a reduced rate of graft atherosclerosis and repeat revascularization compared with only "moderate" lowering (130 to 140 mg/dL) (545,556). In the latter study, both groups of subjects initially received lovastatin at different doses (40 mg in the "aggressive" lowering group versus 2.5 mg in the "moderate" group), and cholestyramine was added if LDL cholesterol goals were not met with lovastatin alone. Of note, patients were maintained on therapy for ≥1 year, and as many as 11 years, after CABG.

The PROVE IT TIMI-22 (Pravastatin or Atorvastatin Evaluation and Infection Therapy: Thrombolysis in Myocardial Infarction) trial randomly assigned patients with ACS, a minority of whom had previous CABG, to intensive (LDL cholesterol goal <70 mg/dL) versus standard (LDL cholesterol goal <100 mg/dL) lipid-lowering therapy. The benefit of intensive therapy (a reduction in death, MI, recurrent UA, repeat revascularization, or stroke) was observed within 30 days (561). In the occasional subject who cannot take statins, alternative hypolipidemic agents, such as bile acid sequestrants, niacin, and fibrates, should be considered, in accordance with National Cholesterol Education Program: Adult Treatment Panel III guidelines (563).

4.3.1. Timing of Statin Use and CABG Outcomes

As noted, the benefits of post-CABG LDL lowering with statins have been reported previously, but no prospective studies of the impact of preoperative LDL cholesterol lowering on post-CABG outcomes are available. One small randomized comparison of preoperative placebo and a statin (initiated 1 week before CABG) showed a reduction in elevated perioperative cardiac biomarkers with statin therapy (554). Several nonrandomized, retrospective studies have noted an association between preoperative statin use and reduced rates of postoperative nonfatal MI and death (553,555,557–559). In addition, preoperative statin use has been associated with reduced rates of postoperative atrial fibrillation (AF) (571,572), neurological dysfunction (555, 573,574), renal dysfunction (575), and infection (576). Untreated hyperlipidemic patients have been shown to have a higher risk of post-CABG events than that of treated hyperlipidemic patients and those with normal serum lipid concentrations (567). In patients undergoing CABG who are not on statin therapy or at LDL goal, it seems reasonable to initiate intensive statin therapy preoperatively (i.e., no later than 1 week before surgery).

Postoperatively, statin use should be resumed when the patient is able to take oral medications and should be continued indefinitely. Patients in whom statins were discontinued after CABG have been shown to have a higher mortality rate than those in whom statins were continued postoperatively (566).

4.3.1.1. POTENTIAL ADVERSE EFFECTS OF PERIOPERATIVE STATIN THERAPY

The most common adverse effects reported with statin use are myopathy and hepatotoxicity. Muscle aches have been reported in about 5% of patients treated with statins, although several pooled analyses of RCTs have shown a similar rate of muscle aches with placebo (577). Myositis, defined as muscle pain with a serum creatine kinase >10 times the upper limit of normal, occurs in 0.1% to 0.2% of statin users, and rhabdomyolysis occurs in 0.02% (578,579). In addition, approximately 2% of patients are observed to have elevated liver enzymes (i.e., alanine and aspartate transaminases) in the weeks to months after statin initiation, but no data are available to suggest that these elevations are associated with permanent hepatotoxicity or an increased risk of hepatitis. Nonetheless, the presence of active or chronic liver disease is a contraindication to statin use, and patients initiated on a statin should be monitored for the development of myositis or rhabdomyolosis, either of which would mandate its discontinuation (580).

4.4. Hormonal Manipulation: Recommendations

CLASS I

1. Use of continuous intravenous insulin to achieve and maintain an early postoperative blood glucose concentration less than or equal to 180 mg/dL while avoiding hypoglycemia is indicated to reduce the incidence of adverse events, including deep sternal wound infection, after CABG (581–583). *(Level of Evidence: B)*

CLASS IIb

1. The use of continuous intravenous insulin designed to achieve a target intraoperative blood glucose concentration less than 140 mg/dL has uncertain effectiveness (584–586). *(Level of Evidence: B)*

CLASS III: HARM

1. Postmenopausal hormonal therapy (estrogen/progesterone) should not be administered to women undergoing CABG (587–589). *(Level of Evidence: B)*

4.4.1. Glucose Control

Hyperglycemia often occurs during and after CABG, particularly when CABG is performed on pump. Intraoperative hyperglycemia is associated with an increased morbidity rate in patients with diabetes (590) and with excess mortality in patients with and without diabetes (591). Hyperglycemia during CPB is an independent risk factor for death in patients undergoing cardiac surgery. A retrospective observational study of 409 cardiac surgical patients identified intraoperative hyperglycemia as an independent risk factor for perioperative complications, including death, and calculated a 34% increased likelihood of postoperative complications for every 20-mg/dL increase in blood glucose concentration >100 mg/dL during surgery (592). An RCT of critically ill patients, many of whom had high-risk cardiac surgery, found reduced morbidity and mortality rates in those whose blood glucose was tightly controlled (583), and follow-up of these subjects showed that this benefit persisted for up to 4 years (582).

The Portland Diabetes Project, begun in 1992, was the first large study to elucidate the detrimental effects of hyperglycemia in relation to CABG outcomes. This prospective observational study described the evolution in management of cardiac surgical patients with diabetes mellitus from a strategy of intermittent subcutaneous injections of insulin to one of continuous intravenous insulin infusion with decreasing target glucose concentrations. As this management strategy evolved, the upper target serum glucose concentrations declined from 200 mg/dL to 110 mg/dL, with which significant reductions in operative and cardiac-related death (arrhythmias and acute ventricular failure) were noted (581). In addition, continuous intravenous insulin to maintain a serum glucose concentration of 120 mg/dL to 160 mg/dL resulted in a reduced incidence of deep sternal wound infection (593,594). As a result, most centers now emphasize tight glucose control (target serum glucose concentration ≤180 mg/dL, accomplished with a continuous intravenous insulin infusion) during surgery and until the morning of the third postoperative day.

Whether extremely tight intraoperative glucose control can further reduce morbidity or mortality rate is controversial. A prospective trial from the Mayo Clinic randomly assigned 400 patients to intensive treatment (continuous insulin infusion during surgery) or conventional treatment (insulin given only for a glucose concentration >200 mg/dL) (586). Postoperative ICU management was similar in the 2 groups. Although no difference was noted between groups in a composite endpoint of death, deep sternal wound infection, prolonged ventilation, cardiac arrhythmias, stroke, or renal failure within 30 days of surgery, intensive treatment caused an increased incidence of death and stroke, thereby raising concerns about this intervention (586). In a prospective RCT in 381 CABG patients without diabetes, those with an intraoperative blood glucose concentration >100 mg/dL were assigned to an insulin infusion or no treatment (584). Those receiving insulin had lower intraoperative glucose concentrations, but no difference between groups was observed in the occurrence of new neurological, neuro-ophthalmologic, or neurobehavioral deficits or neurology-related deaths. Of note, no difference in need for inotropic support, hospital length of stay, or operative mortality rate was seen between the groups (584). A retrospective analysis of intraoperative and postoperative ICU glucose concentrations in >4,300 patients undergoing cardiac surgery at the Cleveland Clinic observed that a blood glucose concentration >200 mg/dL in the operating room or ICU was associated with worse outcomes, but intraoperative glucose concentrations ≤140 mg/dL were not associated with improved outcomes compared with severe

hyperglycemia, despite infrequent hypoglycemia. Diabetic status did not influence the effects of hyperglycemia (585). In short, until additional information is available, extremely tight intraoperative glucose control is not recommended.

Although the management of blood glucose before surgery in patients with and without diabetes mellitus is not well studied, an increased incidence of adverse outcomes has been noted in patients with poor preoperative glycemic control (593,595). As a result, most centers now attempt to optimize glucose control before surgery, attempting to achieve a target glucose concentration ≤180 mg/dL with continuous intravenous insulin. Measuring preoperative hemoglobin A1c concentrations may be helpful in assessing the adequacy of preoperative glycemic control and identifying patients at risk for postoperative hyperglycemia (596).

4.4.2. Postmenopausal Hormone Therapy

Postmenopausal hormone therapy was shown previously to reduce the risk of cardiac-related death. However, more contemporary published RCTs have suggested that it may have adverse cardiovascular effects. The Women's Health Initiative randomly assigned >16,000 healthy postmenopausal women to placebo or continuous combined estrogen–progestin therapy. Hormone therapy was discontinued early because of an increased risk of breast cancer in those receiving it. Additionally, subjects receiving it had an increased incidence of cardiac ischemic events (29% increase, mainly nonfatal MI), stroke, and venous thromboembolism (588). A secondary prevention trial, HERS (Heart and Estrogen/Progestin Replacement Study), randomly assigned 2,763 postmenopausal women with known CAD to continuous estrogen/progestin or placebo, after which they were followed up for a mean of 4.1 years (587). No difference in the primary endpoints of nonfatal MI and CAD death was noted, but those receiving hormone therapy had a greater incidence of deep venous thrombosis and other thromboembolic events. This predisposition to thrombosis has raised concerns that hormone therapy may cause adverse events at the time of CABG. A prospective RCT comparing hormone therapy to placebo in postmenopausal women after CABG was initiated in 1998 but was stopped when the Women's Health Initiative trial results were reported (589). Eighty-three subjects were enrolled, and 45 underwent angiographic follow-up at 42 months. Angiographic progression of CAD in nonbypassed coronary arteries was greater in patients receiving hormone therapy, although less progression of disease was observed in SVGs. Postoperative angioplasty was performed in 8 hormone therapy patients and only 1 placebo subject ($p<0.05$). On the basis of these data, it is not recommended that postmenopausal hormone therapy be initiated in women undergoing CABG, and it may be reasonable to discontinue it in those scheduled for elective CABG.

4.4.3. CABG in Patients With Hypothyroidism

Subclinical hypothyroidism (thyroid-stimulating hormone concentration, 4.50 mIU/L to 19.9 mIU/L) occurs commonly in patients with CAD. In a meta-analysis of >55,000 subjects with CAD, those with subclinical hypothyroidism did not have an increase in total deaths, but the CAD mortality rate was increased, particularly in those with thyroid-stimulating hormone concentrations >10 mIU/L (597).

The risks of CABG in hypothyroid patients are poorly defined. A retrospective study of hypothyroid patients undergoing CABG had a higher incidence of heart failure and gastrointestinal complications and a lower incidence of postoperative fever than did members of a matched euthyroid group (598). Patients with subclinical hypothyroidism may be at increased risk for developing AF after CABG (599), and 1 study even suggested that triiodothyronine supplementation in patients undergoing CABG (including those who are euthyroid) decreased the incidence of postoperative AF (600). Conversely, controlled studies of triiodothyronine in subjects undergoing CABG have shown no benefit (601,602). Rarely, patients may develop severe hypothyroidism after CABG, which manifests as lethargy, prolonged required ventilation, and hypotension (603). Thyroid replacement is indicated in these individuals.

4.5. Perioperative Beta Blockers: Recommendations

CLASS I

1. Beta blockers should be administered for at least 24 hours before CABG to all patients without contraindications to reduce the incidence or clinical sequelae of postoperative AF (604–608,608a–608c). *(Level of Evidence: B)*
2. Beta blockers should be reinstituted as soon as possible after CABG in all patients without contraindications to reduce the incidence or clinical sequelae of AF (604–608,608a–608c). *(Level of Evidence: B)*
3. Beta blockers should be prescribed to all CABG patients without contraindications at the time of hospital discharge. *(Level of Evidence: C)*

CLASS IIa

1. Preoperative use of beta blockers in patients without contraindications, particularly in those with an LVEF greater than 30%, can be effective in reducing the risk of in-hospital mortality (609–611). *(Level of Evidence: B)*
2. Beta blockers can be effective in reducing the incidence of perioperative myocardial ischemia (612–615). *(Level of Evidence: B)*
3. Intravenous administration of beta blockers in clinically stable patients unable to take oral medications is reasonable in the early postoperative period (616). *(Level of Evidence: B)*

CLASS IIb

1. The effectiveness of preoperative beta blockers in reducing in-hospital mortality rate in patients with LVEF less than 30% is uncertain (609,617). *(Level of Evidence: B)*

See Online Data Supplement 25 for additional data on beta blockers.

Because beta blockers have been shown to reduce the incidence of postoperative AF in CABG patients who are receiving them preoperatively (604,605,608) (Section 5.2.5), the STS and AHA recommend that they be administered preoperatively to all patients without contraindications and then be continued postoperatively (618,619). Despite this recommendation, uncertainty exists about their efficacy in subjects not receiving them preoperatively; in this patient population, their use appears to lengthen hospital stay and not to reduce the incidence of postoperative AF (604,607). Their efficacy in preventing or treating perioperative myocardial ischemia is supported by the results of observational studies and small RCTs (612–614). Although a meta-analysis of available data did not show an improvement in outcomes with perioperative beta blockers (615), observational analyses suggest that preoperative beta-blocker use is associated with a reduction in perioperative deaths (609–611). Another analysis of data from 629,877 patients reported a mortality rate of 2.8% in those receiving beta blockers versus 3.4% in those not receiving them (609).

Few data are available on the pharmacokinetic disposition of beta blockers in the early postoperative period, when an alteration in gastrointestinal perfusion may adversely affect their absorption after oral administration. An RCT demonstrated a significant reduction in the incidence of postoperative AF when a continuous intravenous infusion of metoprolol was used rather than oral administration (616).

The efficacy of beta-blocker use in CABG patients after hospital discharge is uncertain, as data from 2 RCTs and 1 large detailed observational analysis suggest that they exert no benefit over 2 years postoperatively (621–623). In contrast, some observational analyses have reported that they are, in fact, efficacious in high-risk subgroups (e.g., those with perioperative myocardial ischemia or elderly subjects with heart failure) (624). A contemporary analysis of prescription data from 3,102 Canadian patients, 83% of whom were prescribed a beta blocker at the time of discharge, reported that those receiving beta blockers had a reduced mortality rate during a mean follow-up of 75 months (625). Of note, improved survival was noted in all patient subgroups receiving beta blockers, even including those without perioperative myocardial ischemia or heart failure.

4.6. ACE Inhibitors/ARBs: Recommendations

CLASS I

1. ACE inhibitors and ARBs given before CABG should be reinstituted postoperatively once the patient is stable, unless contraindicated (622,626,627). *(Level of Evidence: B)*
2. ACE inhibitors or ARBs should be initiated postoperatively and continued indefinitely in CABG patients who were not receiving them preoperatively, who are stable, and who have an LVEF less than or equal to 40%, hypertension, diabetes mellitus, or CKD, unless contraindicated (622,627,627a,627b). *(Level of Evidence: A)*

CLASS IIa

1. It is reasonable to initiate ACE inhibitors or ARBs postoperatively and to continue them indefinitely in all CABG patients who were not receiving them preoperatively and are considered to be at low risk (i.e., those with a normal LVEF in whom cardiovascular risk factors are well controlled), unless contraindicated (622,627–630). *(Level of Evidence: B)*

CLASS IIb

1. The safety of the preoperative administration of ACE inhibitors or ARBs in patients on chronic therapy is uncertain (631–636). *(Level of Evidence: B)*
2. The safety of initiating ACE inhibitors or ARBs before hospital discharge is not well established (622,628,630,640). *(Level of Evidence: B)*

See Online Data Supplements 26 and 27 for additional data on ACE inhibitors.

ACE inhibitors and ARBs are known to exert cardiovasculoprotective actions, particularly in subjects with LV systolic dysfunction, hypertension, diabetes mellitus, or chronic renal insufficiency (626). Nonetheless, the safety and effectiveness of preoperative ACE inhibitors and ARBs in patients undergoing cardiac or noncardiac surgery is uncertain (638) because their administration has been associated with intraoperative hypotension as well as a blunted response to pressors and inotropic agents after induction of anesthesia. Of particular concern during cardiac surgery is their reported association with severe hypotension after CPB (so-called vasoplegia syndrome) and postoperative renal dysfunction (631,639).

Although it has been postulated that these agents may protect against the development of postoperative AF, published studies have reached conflicting conclusions in this regard (634,636). The safety and efficacy of ACE inhibitors and ARBs after CABG in previously naïve low- to moderate-risk patients (i.e., subjects without diabetes mellitus or renal insufficiency and with or without asymptomatic moderate LV systolic dysfunction) are uncertain; furthermore, ACE inhibitors and ARBs must be used with caution in these subjects. They should not be instituted in the immediate postoperative period if the systolic arterial pressure is <100 mm Hg or if the patient develops hypotension in the hospital after receiving them. The IMAGINE (Ischemia Management With Accupril Post Bypass Graft via Inhibition of Angiotensin Converting Enzyme) study failed to show a beneficial effect of postoperative ACE inhibitor therapy 3 years after CABG, instead noting an increase in adverse events, particularly recurrent angina in the first 3 months of therapy (630). A subanalysis of the data from patients enrolled in EUROPA (European Trial on the Reduction of Cardiac Events with Perindopril in Stable Coronary Artery Disease) with previous revascularization (CABG or PCI no sooner than 6 months before enrollment) suggested a primary and secondary prevention benefit over a 4.2-year follow-up period; however, an analysis of the data from almost 3,000 patients in the

PREVENT IV (PRoject of Ex-vivo Vein graft ENgineering via Transfection) trial, all of whom were taking either ACE inhibitors or ARBs at the time of hospital discharge, failed to demonstrate a significant reduction in death or MI after 2 years of follow-up in "ideal" candidates (based on ACCF/AHA/HRS guidelines) (HR: 0.87; 95% CI: 0.52 to 1.45; p=NS), whereas significance was achieved in "non-ideal" candidates (HR: 1.64; 95% CI: 1.00 to 2.68; p=0.05) (608,622,628,640).

4.7. Smoking Cessation: Recommendations

CLASS I

1. All smokers should receive in-hospital educational counseling and be offered smoking cessation therapy during CABG hospitalization (642–644). *(Level of Evidence: A)*

CLASS IIb

1. The effectiveness of pharmacological therapy for smoking cessation offered to patients before hospital discharge is uncertain. *(Level of Evidence: C)*

See Online Data Supplement 28 for additional data on smoking cessation.

Smoking cessation after CABG is associated with a substantial reduction in subsequent MACE, including MI and death. Data from the randomized portion of the CASS study showed 10-year survival rates of 82% among the 468 patients who quit smoking after CABG and only 77% in the 312 who continued to smoke (p=0.025) (645). Those who continued to smoke were more likely to have recurrent angina and to require repeat hospitalization. Data from the CASS registry demonstrated 5-year mortality rates of 22% for those who continued to smoke and only 15% for those who successfully quit smoking after CABG (RR: 1.55; 95% CI: 1.29 to 1.85) (646). Similar favorable outcomes with smoking cessation were reported from the MRFIT (Multiple Risk Factor Intervention Trial), in which the impact of smoking cessation on MACE was assessed after 10.5 years of follow-up in 12,866 men; the risk of death was greater among smokers than nonsmokers (RR: 1.57) (647). Notably, the risk of dying from cardiac causes was lower for those who successfully quit than for nonquitters after only 1 year of smoking cessation (RR: 0.63), and it remained so in those who quit for at least the first 3 years of the study (RR: 0.38) (647). The beneficial effects of smoking cessation after CABG seem to be durable during long-term follow-up (i.e., even 30 years postoperatively) (648–650). In fact, smoking cessation was associated with a reduction in mortality rate of greater magnitude than that resulting from any other treatment or intervention after CABG (649). In these long-term follow-up studies, patients who continued to smoke had significantly higher rates of MI, reoperation, and death.

Smoking is a powerful independent predictor of sudden cardiac death in patients with CAD (HR: 2.47; 95% CI: 1.46 to 4.19). It has been associated with accelerated disease and occlusion of SVGs as well as endothelial dysfunction of arterial grafts (651–653). Compared with nonsmokers, subjects who are smoking at the time of CABG more often have pulmonary complications that require prolonged postoperative intubation and a longer ICU stay as well as postoperative infections (654–656). Even smokers who quit just before CABG have fewer postoperative complications than those who continued to smoke (654). As a result, all smokers referred for CABG should be counseled to quit smoking before surgery.

Smoking cessation seems to be especially beneficial for patients hospitalized with ACS who then require CABG (644,657). Independent predictors of continued nonsmoking 1 year after CABG included <3 previous attempts to quit (OR: 7.4; 95% CI: 1.9 to 29.1), >1 week of preoperative nonsmoking (OR: 10.0; 95% CI: 2.0 to 50), a definite intention to quit smoking (OR: 12.0; 95% CI: 2.6 to 55.1), and no difficulty with smoking cessation while in the hospital (OR: 9.6; 95% CI: 1.8 to 52.2) (658). Aggressive smoking cessation intervention directed at patients early after post-CABG discharge appears to be more effective than a conservative approach (642). In a systematic review of 33 trials of smoking cessation, counseling that began during hospitalization and included supportive contacts for >1 month after hospital discharge increased the rates of smoking cessation (OR: 1.65; 95% CI: 1.44 to 1.90), whereas the use of pharmacotherapy did not improve abstinence rates (643). These findings are supported by a 2009 RCT comparing intensive or minimal smoking cessation intervention in patients hospitalized for CABG or acute MI (644). In this trial, the 12-month self-reported rate of abstinence was 62% among patients randomly assigned to the intensive program and 46% among those randomly allocated to the minimal intervention (OR: 2.0; 95% CI: 1.2 to 3.1). Overall, a higher rate of continuous abstinence was observed in patients undergoing CABG than in those who had sustained an MI. Interestingly, the rates of abstinence were lower in subjects who used pharmacotherapy regardless of the intervention group (OR: 0.3; 95% CI: 0.2 to 0.5) (644).

Seven first-line pharmacological treatments are available for smoking cessation therapy, including 5 nicotine-replacement therapies; the antidepressant bupropion; and varenicline, a partial agonist of the $\alpha_4\beta_2$ subtype of the nicotinic acetylcholine receptor (659–661). The data supporting the use and timing of nicotine-replacement therapy after CABG are unclear. One study from a large general practice database reported no increased risk of MI, stroke, or death with nicotine-replacement therapy (662), whereas a retrospective case–control study of critically ill patients reported a higher in-hospital mortality rate in those receiving nicotine replacement (20% versus 7%; p=0.0085). Despite adjusting for the severity of illness, nicotine-replacement therapy was an independent predictor of in-hospital mortality (OR: 24.6; 95% CI: 3.6 to 167.6; p=0.0011) (663). Similarly, in a cohort study of post-CABG patients, nicotine-replacement therapy was shown

to be an independent predictor of in-hospital mortality after adjusting for baseline characteristics (OR: 6.06; 95% CI: 1.65 to 22.21) (663,664). Additional studies are needed to determine the safety of nicotine-replacement therapy in smokers undergoing CABG as well as the optimal time at which to begin such therapy postoperatively.

4.8. Emotional Dysfunction and Psychosocial Considerations: Recommendation

CLASS IIa

1. Cognitive behavior therapy or collaborative care for patients with clinical depression after CABG can be beneficial to reduce objective measures of depression (665–669). *(Level of Evidence: B)*

The negative impact of emotional dysfunction on risk of morbidity and mortality after CABG is well recognized. In a multivariate analysis of elderly patients after CABG, the 2 most important predictors of death were a lack of social participation and a lack of religious strength (670). Social isolation is associated with increased risk of death in patients with CAD (671), and treatment may improve outcomes (672). The most carefully studied mood disorder, depression, occurs commonly after CABG. Several studies have shown that the primary predictor of depression after CABG is its presence before CABG and that only rarely does CABG cause depression in patients who were not depressed beforehand. In 1 report, half the patients who were depressed before CABG were not depressed afterward, and only 9% of subjects who were not depressed before CABG developed depression postoperatively (673). The prevalence of depression at 1 year after CABG was 33%, which is similar to the prevalence in those undergoing other major operations. Patients with stronger perceptions of control of their illness were less likely to be depressed or anxious after CABG (674). No difference in the incidence of mood disturbances was noted when off-pump and on-pump CABG were compared (675).

4.8.1. Effects of Mood Disturbance and Anxiety on CABG Outcomes

Depression is an important risk factor for the development and progression of CAD. In fact, it is a more important predictor of the success of cardiac rehabilitation than many other functional cardiac variables (676). Both the presence of depressive symptoms before CABG and the postoperative worsening of these symptoms correlate with poorer physical and psychosocial functioning and poorer quality of life after CABG (677). In a study of 440 patients who underwent CABG, the effects of both preoperative anxiety and depression (as defined by the Depression Anxiety and Stress Scale) on mortality rate were assessed for a median of 5 years postoperatively (678). Interestingly, preoperative anxiety was associated with a significantly increased risk of death (HR: 1.88; 95% CI: 1.12 to 3.37; $p=0.02$), whereas preoperative depression was not (678). In a multivariate analysis of 817 patients at Duke University Medical Center, severe depression (assessed using the Center for Epidemiological Studies–Depression scale before surgery and 6 months postoperatively (665) was associated with increased risk of death (HR: 2.4; 95% CI: 1.4 to 4.0), as was mild or moderate depression that persisted at 6 months (HR: 2.2; 95% CI: 1.2 to 4.2). In another study of 309 subjects followed up for ≤1 year after CABG, those with diagnostic criteria for a major depressive disorder before discharge were nearly 3 times as likely to have a cardiac event, such as heart failure requiring hospitalization, MI, cardiac arrest, PCI, repeat CABG, or cardiac death (666). Finally, depression after CABG is an important predictor of the recurrence of angina during the first 5 postoperative years (666,673).

4.8.2. Interventions to Treat Depression in CABG Patients

The Bypassing the Blues investigators identified 302 patients who were depressed before CABG and 2 weeks after discharge (668). They were randomly assigned to 8 months of telephone-delivered collaborative care (150 patients) or "usual care" (152 patients). The 2 groups were compared with each other and also to another group of 151 randomly selected nondepressed post-CABG patients. At 8 month follow-up, the collaborative care group showed an improvement in quality of life and physical functioning and were more likely to report a >50% decline in the Hamilton Rating Score for Depression than the usual care group (50.0% versus 29.6%; $p<0.001$). Men were more likely to benefit from the intervention (668,669). In another study, 123 patients who met the Diagnostic and Statistical Manual of Mental Disorders, 4th edition, criteria for major or minor depression within 1 year of CABG were randomly assigned to 12 weeks of cognitive behavior therapy, 12 weeks of supportive stress management, or usual care (667). Both interventions were efficacious for treating depression after CABG, and cognitive behavior therapy had the most durable effects on depression and several secondary psychological outcome variables (667). Thus, both collaborative intervention and cognitive behavior therapy are effective for treating depression in patients after CABG. Given that depression is associated with adverse outcomes after CABG, it is likely that these interventions also may lead to reduced rates of morbidity and mortality.

4.9. Cardiac Rehabilitation: Recommendation

CLASS I

1. Cardiac rehabilitation is recommended for all eligible patients after CABG (679–681,681a–681d). *(Level of Evidence: A)*

See Online Data Supplement 29 for additional data on cardiac rehabilitation.

Cardiac rehabilitation, including early ambulation during hospitalization, outpatient prescriptive exercise training, and education, reduces risk of death in survivors of MI (682–684). Beginning 4 to 8 weeks after CABG, 3-times-weekly education and exercise sessions for 3 months are associated with a 35% increase in exercise tolerance

(p=0.0001), a slight (2%) (p=0.05) increase in high-density lipoprotein cholesterol, and a 6% reduction in body fat (p=0.002) (421). Exercise training is a valuable adjunct to dietary modification of fat and total caloric intake in maximizing the reduction of body fat while minimizing the reduction of lean body mass. Aerobic training improves volume of maximum oxygen consumption at 6 months compared with moderate continuous training (p<0.001) (685).

After hospital discharge, CABG patients were randomly assigned to standard care (n=109) or standard care plus rehabilitation (n=119). At 5 years, the groups were similar in symptoms, medication use, exercise capacity, and depression scores, but rehabilitated patients reported better physical mobility, better perceived health, and better perceived overall life situation. A larger proportion of the rehabilitated patients were working at 3 years, although this difference disappeared with longer follow-up (679). Subjects who sustained an MI followed by CABG had greater improvement in exercise tolerance after rehabilitation than did those who had an MI alone. Improvement was sustained for 2 years (686). Observational studies have reported that cardiac events are reduced with rehabilitation after revascularization (680).

In many CABG patients, initiation of rehabilitation is a substantial hurdle. Medically indigent patients seem to have rehabilitation compliance and benefit rates similar to those of insured or private-paying patients if rehabilitation is initiated promptly and is structured appropriately (687). In addition to contributing to a patient's sense of well-being, participation in cardiac rehabilitation offers an economic benefit. During a 3-year (mean: 21 months) follow-up after CABG or another coronary event, per capita hospitalization charges were $739 lower for rehabilitated patients compared with nonparticipants (688). Post-CABG patients are more likely to resume sexual activity than are survivors of MI. Anticipatory and proactive advice by the physician or surgeon on the safety of resumption of sexual activity as the patient reengages in other daily activities is beneficial (682).

Recommendations for intensive risk-reduction therapies for patients with established coronary and other atherosclerotic vascular disease are detailed in the "AHA/ACCF Secondary Prevention and Risk Reduction Therapy for Patients With Coronary and Other Atherosclerotic Vascular Disease: 2011 Update" (689). This updated guideline includes recommendations on smoking, blood pressure control, lipid management, physical therapy, weight management, type 2 diabetes management, antiplatelet agents and anticoagulants, renin–angiotensin–aldosterone system blockers (ACE inhibitors and ARBs), beta blockers, influenza vaccination, depression, and cardiac rehabilitation.

4.10. Perioperative Monitoring

4.10.1. Electrocardiographic Monitoring: Recommendations

CLASS I

1. Continuous monitoring of the electrocardiogram for arrhythmias should be performed for at least 48 hours in all patients after CABG (606,690,691). *(Level of Evidence: B)*

CLASS IIa

1. Continuous ST-segment monitoring for detection of ischemia is reasonable in the intraoperative period for patients undergoing CABG (53,692–694). *(Level of Evidence: B)*

CLASS IIb

1. Continuous ST-segment monitoring for detection of ischemia may be considered in the early postoperative period after CABG (613, 690,695–698). *(Level of Evidence: B)*

4.10.2. Pulmonary Artery Catheterization: Recommendations

CLASS I

1. Placement of a pulmonary artery catheter (PAC) is indicated, preferably before the induction of anesthesia or surgical incision, in patients in cardiogenic shock undergoing CABG. *(Level of Evidence: C)*

CLASS IIa

1. Placement of a PAC can be useful in the intraoperative or early postoperative period in patients with acute hemodynamic instability (699–704). *(Level of Evidence: B)*

CLASS IIb

1. Placement of a PAC may be reasonable in clinically stable patients undergoing CABG after consideration of baseline patient risk, the planned surgical procedure, and the practice setting (699–704). *(Level of Evidence: B)*

4.10.3. Central Nervous System Monitoring: Recommendations

CLASS IIb

1. The effectiveness of intraoperative monitoring of the processed electroencephalogram to reduce the possibility of adverse recall of clinical events or for detection of cerebral hypoperfusion in CABG patients is uncertain (705–707). *(Level of Evidence: B)*
2. The effectiveness of routine use of intraoperative or early postoperative monitoring of cerebral oxygen saturation via near-infrared spectroscopy to detect cerebral hypoperfusion in patients undergoing CABG is uncertain (708–710). *(Level of Evidence: B)*

See Online Data Supplement 30 for additional data on central nervous system monitoring.

Requirements for basic perioperative monitoring in patients undergoing CABG, including heart rate, blood pressure, peripheral oxygen saturation, and body temperature, are well accepted. Additional intraoperative standards established by the American Society of Anesthesiologists, including the addition of end-tidal carbon dioxide measurement in the intubated patient, are uniformly applied (711). Specialized monitoring of cardiac and cerebral function varies among centers and includes the use of PACs, TEE, or other forms of echocardiography (Section 2.1.7); noninvasive monitors of cardiac output; processed electroencephalographic monitoring; and cerebral oximetry with near-infrared spectroscopy. Given the added expense and potential hazards of such monitors (e.g., pulmonary artery rupture with PAC, false-positive changes with cerebral oximetry or processed electroencephalogram), substantial controversy exists about indications for their use. None of these monitoring methods is routinely recommended.

Electrocardiographic monitoring includes an assessment of heart rate and rhythm as well as the morphology and deviation of the QRS complex and ST segments for evidence of ischemia, infarction, or abnormal conduction (690). Continuous telemetric monitoring of cardiac rate and rhythm is recommended for 48 to 72 hours after surgery in all patients because of the high incidence of post-CABG AF, which most often occurs 2 and 4 days after surgery (606,613,690,691,697,698). In addition, other arrhythmias and conduction abnormalities may occur in patients with ischemia because of incomplete revascularization or in those undergoing concurrent valve replacement.

Uncertainty continues with regard to the utility of PAC in low-risk patients undergoing CABG (712). Several observational studies suggest that such patients can be managed only with monitoring of central venous pressure, with insertion of a PAC held in reserve should the need arise. In fact, it has even been suggested that patients in whom a PAC is placed incur greater resource utilization and more aggressive therapy, which may lead to worse outcomes and higher costs. The reported rates of PAC use range from <10% in a combined private–academic setting to >90% in patients in the Department of Veterans Affairs health system (61,639,701,702,713).

Aside from providing an indirect assessment of left atrial pressure and the presence and severity of pulmonary hypertension, PAC can be used to measure cardiac output (by thermodilution) and to monitor the mixed venous oxygen saturation—information that may be helpful in the management of high-risk patients (712,714). The need for careful consideration of baseline patient risk, the planned procedure, and the patient setting before use of a PAC are outlined in several opinion pieces, consensus documents, the "Practice Guidelines for Pulmonary Artery Catheterization: An Updated Report by the American Society of Anesthesiologists", and the "2009 ACCF/AHA Focused Update on Perioperative Beta Blockade Incorporated Into the ACC/AHA 2007 Guidelines on Perioperative Cardiovascular Evaluation and Care for Noncardiac Surgery" (699,712,714–716). Pulmonary artery perforation or rupture is fatal in >50% of patients in whom it occurs. This complication usually can be avoided by 1) withdrawal of the catheter tip into the main pulmonary artery before initiation of CPB; 2) withdrawal of the catheter into the pulmonary artery before balloon inflation, especially if the pressure tracing suggests damping; and 3) avoiding routine measurement of the pulmonary artery wedge pressure, reserving this maneuver as a specific diagnostic event.

Perioperative monitoring of cerebral function (primarily with an electroencephalogram) has been used in certain high-risk patients, such as those undergoing neurosurgery or carotid vascular surgery (717). In the setting of cardiac surgery, the potentially deleterious effects of CPB on cerebral hypopfusion or embolic events (i.e., air or aortic calcific debris) have been investigated via transcranial Doppler techniques, with a lesser emphasis on the electroencephalogram (in part because of excessive artifact in this setting) (57,718). Although processed electroencephalographic monitors and bifrontal cerebral oximetry have been available for more than 2 decades, controversy remains about their clinical effectiveness (719,720). Processed electroencephalographic monitoring is aimed primarily at assessing the risk of conscious recall of intraoperative events, but it also has been used to gauge the depth of anesthesia, theoretically allowing more precise titration of the anesthetic (721,722). Although a variety of electroencephalographic variables are commonly accepted as markers of cerebral ischemia, the ability of current commercial devices to detect or quantify ischemia is limited (706,707,717,718).

Given the intuitive link between reflectance oximetry (i.e., for peripheral oxygen or mixed venous oxygen saturation) and clinical interventions (i.e., manipulating hemodynamic variables, the fraction of inspired oxygen, etc.), there is considerable interest in the use of bifrontal cerebral oximetry as a measure of brain perfusion (723). Two RCTs in CABG patients suggest that bifrontal cerebral oximetry may be helpful in predicting early perioperative cognitive decline, stroke, noncerebral complications, and ICU and hospital length of stay (709,710). A 2011 observational cohort (1,178 CABG patients) suggested that a patient's preoperative response to breathing oxygen for 2 minutes (Sco_2 ≤50%) is an independent predictor of death at 30 days and 1 year after surgery (724).

5. CABG-Associated Morbidity and Mortality: Occurrence and Prevention

Several comprehensive data registries for CABG have been developed in the United States, the largest being the STS Adult Cardiac Database. For >20 years, these registries have collected data on all aspects of the procedure (306,725,727). A detailed analysis of these data and their correlation to outcomes has facilitated the creation of risk-assessment models that estimate the rates at which various adverse events occur. On the basis of these models, risk-adjusted outcomes for hospitals and surgeons have been calculated and, in some instances, publicly reported.

5.1. Public Reporting of Cardiac Surgery Outcomes: Recommendation

CLASS I

1. Public reporting of cardiac surgery outcomes should use risk-adjusted results based on clinical data (728–735). *(Level of Evidence: B)*

See Online Data Supplement 31 for additional data on public reporting of cardiac surgery outcomes.

To address the need for valid and reliable risk-adjusted outcomes data, cardiac surgery registries were developed by the STS (306,725,727), Veterans Administration (306,736–738), Northern New England Cardiovascular Disease

Study Group (739,740), and the state of New York (741,742). These have been the basis for several performance assessment and improvement strategies, including public report cards (742–744), confidential feedback to participants showing their performance relative to national benchmarks (306,737,745–748), and state or regional collaboratives that identify and disseminate best-practices information (749). Public report cards are the most controversial of these 3 approaches. Although they provide transparency and public accountability, it is unclear if they are the only or best way to improve quality. Reductions in the CABG mortality rate after the publication of such report cards in New York were encouraging (742,750–752), but subsequent studies revealed comparable reductions in other states, regions, and countries that used confidential feedback with or without performance improvement initiatives (752–754). These findings suggest that the common denominator among successful performance improvement strategies is the implementation of a formal quality assessment and feedback program benchmarked against regional or national results (755). The incremental value of public (as opposed to confidential) reporting is controversial.

Although providers fear the potential negative impact of public reporting on referrals and market share, this concern seems to be unfounded (756–765). Even when such impact has been observed, it has generally been modest, transient, and limited to areas populated by more affluent and educated subjects (760–762,766). With implementation of healthcare reform legislation that increases access of consumers and payers to objective data and more easily understood data presentations, the influence of public report cards is likely to increase in the future (762,767–771). As this occurs, it will be important to monitor unintended negative consequences, such as "gaming" of the reporting system (772) and avoidance of high-risk patients (risk aversion), the precise group of patients who are most likely to benefit from aggressive intervention (773–776).

Methodological considerations are important for provider profiling and public reporting. Numerous studies have shown the superiority of clinical over administrative data for these purposes (728–731,733,734). The latter data lack critical clinical variables that are necessary for adequate risk adjustment (732,735), they may confuse comorbidities and complications, and they may contain inaccurate case numbers and mortality rates. Outcomes measures, such as mortality, should always be adjusted for patient severity on admission (i.e., "risk-adjusted" or "risk-standardized") (777–780); otherwise, providers will be hesitant to care for severely ill patients, who are more likely to die from their disease. In addition, if a hospital or surgeon is found to be a low-performing outlier on the basis of unadjusted results, the hospital or surgeon may claim that their patients were sicker. Statistical methodologies should account for small sample sizes and clustered patient observations within institutions, and hierarchical or random-effects models have been advocated by some investigators (743,781–787). Point estimates of outcomes should always be accompanied by measures of statistical uncertainty, such as CIs. The units of analysis and reporting for provider profiling also have implications. Surgeon-level reports are published together with hospital reports in several states, but their smaller sample sizes typically require data aggregation over several years. Surgeon-level reporting may also increase the potential for risk aversion, as the anticipated worse results of the highest-risk patients are not diluted by the larger volume of a hospital or group. Finally, because the distribution of patient severity may vary substantially among providers, direct comparison of the results of one surgeon or hospital with those of another, even by using indirectly risk-standardized results, is often inappropriate (788). Rather, these results should be interpreted as comparisons of a provider's outcomes for his or her specific patient cohort versus what would have been expected had those patients been cared for by an "average" provider in the benchmark population.

Although risk-adjusted mortality rate has been the dominant performance metric in cardiac surgery for 2 decades, other more comprehensive approaches have been advocated (789). The STS CABG composite illustrates one such multidimensional approach, consisting of 11 National Quality Forum–endorsed measures of cardiothoracic surgery performance grouped within 4 domains of care (619,790).

5.1.1. Use of Outcomes or Volume as CABG Quality Measures: Recommendations

CLASS I

1. All cardiac surgery programs should participate in a state, regional, or national clinical data registry and should receive periodic reports of their risk-adjusted outcomes. *(Level of Evidence: C)*

CLASS IIa

1. When credible risk-adjusted outcomes data are not available, volume can be useful as a structural metric of CABG quality (309,751,791–798,800–804,807,818). *(Level of Evidence: B)*

CLASS IIb

1. Affiliation with a high-volume tertiary center might be considered by cardiac surgery programs that perform fewer than 125 CABG procedures annually. *(Level of Evidence: C)*

See Online Data Supplement 32 for additional data on outcomes or volume as CABG quality measures.

Numerous studies have demonstrated an association between hospital or individual practitioner volume and outcome for a variety of surgical procedures and some medical conditions (805–831). CABG was one of the original procedures for which this volume–outcome association was investigated (309,751,791–798,800–804,807,818). The CABG volume–outcome association is generally weaker than that of other procedures, such as esophagectomy or pancreatectomy, which are performed less often. In addition, the results of volume–outcome studies vary substantially according to methodology. The apparent strength of

the volume–outcome association often diminishes with proper risk adjustment based on clinical (as opposed to administrative) data (802,808). It is also weaker in more contemporary studies, presumably because of improved techniques and increasing experience (795,802). Finally, volume–outcome associations appear weaker when hierarchical models are used that properly account for small sample sizes and clustering of observations (832). The impact of CABG volume was studied in an observational cohort of 144,526 patients from 733 hospitals that participated in the STS Adult Cardiac Surgery Database in 2007 (309). In this analysis, a weak association between volume and unadjusted mortality rate was noted (2.6% unadjusted mortality rate for hospitals performing <100 procedures versus 1.7% for hospitals performing ≥450 procedures) (309). Using multivariate hierarchical regression, the largest OR (1.49) was found for the lowest-volume (<100 cases) group versus the highest-volume group. Desirable processes of care (except for use of the IMA) and morbidity rates were not associated with volume. The average STS-CABG composite score for the lowest-volume group (<100 cases per year) was significantly lower than that of the 2 highest-volume groups, but volume explained only 1% of variation in the composite score (619,790).

In general, the best results are achieved most consistently by high-volume surgeons in high-volume hospitals and the worst results by low-volume surgeons in low-volume hospitals (793,794). However, many low-volume programs achieve excellent results, perhaps related to appropriate case selection; effective teamwork among surgeons, nurses, anesthesiologists, perfusionists, and physician assistants; and adoption of best practices derived from larger programs (833,834).

As a quality assessment strategy, participation in a state, regional, or national clinical data registry that provides regular performance feedback reports is highly recommended for all cardiac programs. Random sampling variation is greater at low volumes (309,797,798,803,827,834,835), which complicates performance assessment of smaller programs. Several strategies may be considered to mitigate this measurement issue, including analysis over longer periods of time; appropriate statistical methodologies, such as hierarchical (random-effects) models; composite measures, which effectively increase the number of endpoints; and statistical quality control approaches, such as funnel plots (835) and cumulative sum plots (836–838). Small programs may benefit from direct supervision by a large tertiary center (834). Ultimately, state or national regulatory authorities must decide whether the lower average performance of very small programs and the added difficulty in accurately measuring their performance are outweighed by other considerations, such as the need to maintain cardiac surgery capabilities in rural areas with limited access to referral centers (834).

Volume, a structural quality metric, is an imperfect proxy for direct measurement of outcomes (822,839). Risk-adjusted outcomes based on clinical data are the preferred method of assessing CABG quality except in very low-volume programs, in which performance is generally weakest and small sample size makes accurate assessment of performance difficult.

5.2. Adverse Events

5.2.1. Adverse Cerebral Outcomes

5.2.1.1. STROKE

The incidence of stroke after CABG ranges from 1.4% to 3.8% (840), depending on the patient population and the criteria for diagnosis of stroke. Risk factors for stroke include advanced age, history of stroke, diabetes mellitus, hypertension (841), and female sex (842), with newer research emphasizing the importance of preoperative atherosclerotic disease (including radiographic evidence of previous stroke or aortic atheromatous disease) (843). Although macroembolization and microembolization are major sources of stroke, hypoperfusion (844), perhaps in conjunction with embolization (845), is a risk factor for postoperative stroke. The mortality rate is 10-fold higher among post-CABG patients with stroke than among those without it, and lengths of stay are longer in stroke patients (846).

Although off-pump CABG was introduced in large part to reduce stroke and other adverse neurological outcomes associated with CPB, several RCTs comparing on-pump and off-pump CABG have shown no difference in stroke rates (61,68,78,846a,846b,1069,1259).

See Online Data Supplement 33 for additional data on stroke rates.

5.2.1.1.1. USE OF EPIAORTIC ULTRASOUND IMAGING TO REDUCE STROKE RATES: RECOMMENDATION

CLASS IIa

1. **Routine epiaortic ultrasound scanning is reasonable to evaluate the presence, location, and severity of plaque in the ascending aorta to reduce the incidence of atheroembolic complications (847–849). (*Level of Evidence: B*)**

Identification of an atherosclerotic aorta is believed to be an important step in reducing the risk of stroke after CABG (850). Intraoperative assessment of the ascending aorta for detection of plaque by epiaortic ultrasound imaging is superior to direct palpation and TEE (851,852). Predictors of ascending aortic atherosclerosis include increasing age, hypertension, extracardiac atherosclerosis (peripheral artery and cerebrovascular disease), and elevated serum creatinine concentrations (853–855). Prospective RCTs to evaluate the role of epiaortic scanning in assessing stroke risk have not been reported, but several observational studies reported stroke rates of 0 to 1.4% (847–849,853,856,857) when surgical decision making was guided by the results of epiaortic scanning. Separate guidelines for the use of intraoperative epiaortic ultrasound imaging in cardiac surgery

were endorsed and published in 2008 by the American Society for Echocardiography, Society of Cardiovascular Anesthesiologists, and STS (147).

5.2.1.1.2. THE ROLE OF PREOPERATIVE CAROTID ARTERY NONINVASIVE SCREENING IN CABG PATIENTS: RECOMMENDATIONS

CLASS I

1. A multidisciplinary team approach (consisting of a cardiologist, cardiac surgeon, vascular surgeon, and neurologist) is recommended for patients with clinically significant carotid artery disease for whom CABG is planned. *(Level of Evidence: C)*

CLASS IIa

1. Carotid artery duplex scanning is reasonable in selected patients who are considered to have high-risk features (i.e., age >65 years, left main coronary stenosis, PAD, history of cerebrovascular disease [transient ischemic attack [TIA], stroke, etc.], hypertension, smoking, and diabetes mellitus) (858,859). *(Level of Evidence: C)*
2. In the CABG patient with a previous TIA or stroke and a significant (50% to 99%) carotid artery stenosis, it is reasonable to consider carotid revascularization in conjunction with CABG. In such an individual, the sequence and timing (simultaneous or staged) of carotid intervention and CABG should be determined by the patient's relative magnitudes of cerebral and myocardial dysfunction. *(Level of Evidence: C)*

CLASS IIb

1. In the patient scheduled to undergo CABG who has no history of TIA or stroke, carotid revascularization may be considered in the presence of bilateral severe (70% to 99%) carotid stenoses or a unilateral severe carotid stenosis with a contralateral occlusion. *(Level of Evidence: C)*

Because the presence of extracranial disease of the internal carotid artery is a risk factor for adverse neurological events after CABG (860), one might argue for use of carotid noninvasive scanning (duplex ultrasonography or noninvasive carotid screening) in all patients scheduled for CABG. At issue is the effectiveness of noninvasive carotid screening in identifying carotid artery stenoses of hemodynamic significance. Alternatively, the identification of preoperative risk factors known to be associated with the presence of carotid artery disease could be used to stratify patients into high- and low-risk categories, thereby allowing for a more selective use of noninvasive carotid screening. A retrospective analysis of 1,421 consecutive CABG patients identified the following as risk factors for significant carotid artery disease: age >65 years, presence of a carotid bruit, and a history of cerebrovascular disease (858). In so doing, they reduced preoperative testing by 40%, with only a "negligible" impact on surgical management or neurological outcomes. Similarly, the following risk factors have been identified as predicting the presence of >50% reduction in internal diameter of the internal carotid artery: smoking, diabetes mellitus, hypertension, a previous cerebrovascular event, PAD, left main CAD, and a history of cervical carotid disease (859). All subjects found to have significant carotid disease were noted to have ≥1 of these criteria. In addition, the probability of detecting significant carotid disease increased almost 3 times for each additional criterion that was present. The authors noted that the presence of a single preoperative risk factor increased the sensitivity of the screening test to 100% and increased the specificity to 30%. As a result, they strongly recommend a selective approach to the use of preoperative noninvasive carotid screening, allowing for a decrease in the number of unnecessary tests but exerting little effect on the detection of significant carotid disease.

In patients undergoing carotid endarterectomy, the rates of periprocedural stroke have been reported to be as high as 2.5% in those with asymptomatic carotid stenoses (861) and 5% in those with previous cerebrovascular symptoms (862). In CABG patients with >50% unilateral carotid stenoses in whom carotid endarterectomy is not performed concomitantly with CABG, the peri-CABG stroke rate is reportedly 3%, rising to 5% in those with bilateral carotid artery stenoses and 11% in those with an occluded carotid artery (860). In light of these data, the issue of combined carotid and coronary revascularization (performed simultaneously or in a staged, sequential fashion) as a strategy to reduce the postoperative stroke risk in CABG patients with known carotid artery disease has received substantial attention. The lack of clarity about the optimal approach to the management of such patients is the result of several factors:

- To date, no published randomized, prospective study has addressed this important clinical scenario (863).
- The etiology of postoperative stroke often is multifactorial (e.g., ascending aortic calcifications with resultant atherothrombotic embolization, preexisting carotid artery disease, air or debris cerebral embolization associated with CPB, episodes of transient intraoperative hypotension).
- Many risk factors for stroke coexist in CABG patients.
- The rates for postoperative stroke and death for carotid endarterectomy and for CABG, independent of or in conjunction with one another, vary considerably in different patient populations (e.g., young versus old, male versus female, etc.).
- More than half of all post-CABG strokes occur after uneventful recovery from CABG and are believed to be caused by supraventricular arrhythmias, low cardiac output, or postoperative hypercoagulability (863).
- A substantial proportion of post-CABG strokes occur in patients without significant carotid artery disease or in an anatomic distribution not consistent with a known significant carotid arterial stenosis.

Advances in technologies for carotid and coronary revascularization make the decision-making process for the procedures even more complex. In addition to conventional CABG with CPB, the surgeon may choose an off-pump technique in certain patients (e.g., those with a heavily calcified ascending aorta). Likewise, carotid artery stenting provides an alternative to endarterectomy, which may re-

duce the risk of postoperative stroke. Still, the ultimate impact of such stenting on postoperative stroke rates in CABG patients awaits the results of properly designed trials. At present, carotid artery stenting is reserved for CABG patients in whom a contraindication to open endarterectomy exists.

When combined carotid and coronary revascularization is indicated, an awareness of the stroke and mortality rates for different patient subgroups will help to guide decision making. Several factors favor combined revascularization, including (but not limited to) 1) severe carotid artery disease, 2) unfavorable morphological characteristics of the carotid lesion(s) (e.g., ulcerated lesions), 3) the presence of related symptoms, and 4) a history of TIA or stroke. In those with a history of TIA or stroke who have a significant carotid artery stenosis (50% to 99% in men or 70% to 99% in women), the likelihood of a post-CABG stroke is high; as a result, they are likely to benefit from carotid revascularization (863). Conversely, CABG alone can be performed safely in patients with asymptomatic unilateral carotid stenoses, because a carotid revascularization procedure offers no discernible reduction in the incidence of stroke or death in these individuals. Men with asymptomatic bilateral severe carotid stenoses (50% to 99%) or a unilateral severe stenosis in conjunction with a contralateral carotid artery occlusion may be considered for carotid revascularization in conjunction with CABG. Little evidence exists to suggest that women with asymptomatic carotid artery disease benefit from carotid revascularization in conjunction with CABG (864). Whether the carotid and coronary revascularization procedures are performed simultaneously or in a staged, sequential fashion is usually dictated by the presence or absence of certain clinical variables. In general, synchronous combined procedures are performed only in those with both cerebrovascular symptoms and ACS.

The optimal management of patients with coexisting carotid artery disease and CAD is poorly defined. Several therapeutic approaches can be used, including staged carotid endarterectomy and CABG, simultaneous carotid endarterectomy and CABG, or similar variations that use endovascular stenting as the primary carotid intervention. At present, no prospective RCTs comparing neurological outcomes after these different treatment strategies in patients with coexisting carotid artery disease and CAD have been reported (865).

5.2.1.2. DELIRIUM

The incidence of postoperative delirium after CABG is <10%, similar to that reported after noncardiac surgery (866–868). The risk factors for postoperative delirium are similar for cardiac and noncardiac surgery and include advanced age, preexisting cognitive impairment, and vascular disease (866,868,869). The burden of intraoperative cerebral microemboli does not predict the presence or severity of postoperative delirium (870). The development of postoperative delirium has been linked to functional decline at 1 month, short-term cognitive decline (871), and risk of late mortality (867,872).

5.2.1.3. POSTOPERATIVE COGNITIVE IMPAIRMENT

Short-term cognitive changes occur in some patients after on-pump CABG (873–875). The precise incidence depends on the timing of the postoperative assessment and the choice of criteria for cognitive decline (876,877). Similar short-term cognitive changes also are noted in elderly patients receiving general anesthesia for noncardiac surgery (878–880). Risk factors for short-term postoperative cognitive decline include preexisting risk factors for cerebrovascular disease (881), preexisting central nervous system disease (882), and preexisting cognitive impairment (75). Up to 30% of candidates for CABG have been shown to have cognitive impairment before surgery (75). A few studies have reported a lower incidence of short-term cognitive decline after off-pump CABG than on-pump CABG (883), but most studies have shown no difference in cognitive outcomes between them (884). Studies with appropriate comparison groups have demonstrated that most patients do not suffer cognitive decline after CABG (885,886). For those who do, the postoperative cognitive changes are generally mild, and for most patients, they resolve within 3 months of surgery (887).

Long-term cognitive decline after CABG has been reported (888,889), but other studies have shown that a similar degree of late cognitive decline occurs in comparison groups of demographically similar patients with CAD but without surgery, suggesting that the late decline is not related to the use of CPB (890). An RCT comparing late cognitive outcomes after on-pump and off-pump CABG has reported no difference between them (891).

See Online Data Supplement 34 for additional data on the role of perioperative cognitive impairment.

5.2.2. Mediastinitis/Perioperative Infection: Recommendations

CLASS I

1. Preoperative antibiotics should be administered to all patients to reduce the risk of postoperative infection (892–897). *(Level of Evidence: A)*
2. A first- or second-generation cephalosporin is recommended for prophylaxis in patients without methicillin-resistant *Staphylococcus aureus* colonization (897–905). *(Level of Evidence: A)*
3. Vancomycin alone or in combination with other antibiotics to achieve broader coverage is recommended for prophylaxis in patients with proven or suspected methicillin-resistant *S. aureus* colonization (900,906–908). *(Level of Evidence: B)*
4. A deep sternal wound infection should be treated with aggressive surgical debridement in the absence of complicating circumstances. Primary or secondary closure with muscle or omental flap is recommended (909–911). Vacuum therapy in conjunction with early and aggressive debridement is an effective adjunctive therapy (912–921). *(Level of Evidence: B)*

5. Use of a continuous intravenous insulin protocol to achieve and maintain an early postoperative blood glucose concentration less than or equal to 180 mg/dL while avoiding hypoglycemia is indicated to reduce the risk of deep sternal wound infection (583,586,590,591,922,923). *(Level of Evidence: B)*

CLASS IIa

1. When blood transfusions are needed, leukocyte-filtered blood can be useful to reduce the rate of overall perioperative infection and in-hospital death (924–927). *(Level of Evidence: B)*
2. The use of intranasal mupirocin is reasonable in nasal carriers of *S. aureus* (928,929). *(Level of Evidence: A)*
3. The routine use of intranasal mupirocin is reasonable in patients who are not carriers of *S. aureus,* unless an allergy exists. *(Level of Evidence: C)*

CLASS IIb

1. The use of bilateral IMAs in patients with diabetes mellitus is associated with an increased risk of deep sternal wound infection, but it may be reasonable when the overall benefit to the patient outweighs this increased risk. *(Level of Evidence: C)*

See Online Data Supplements 35 and 36 for additional data on mediastinitis and perioperative infection.

Nosocomial infections occur in 10% to 20% of cardiac surgery patients. To prevent surgical site infections in CABG patients, a multimodality approach involving several perioperative interventions must be considered. Preoperative interventions include screening and decolonization of patients with methicillin-resistant and methicillin-sensitive *S. aureus* colonization and adequate preoperative preparation of the patient. Nasal carriage of *S. aureus* is a well-defined risk factor for subsequent infection. In proven nasal carriers of *S. aureus,* intranasal mupirocin reduces the rate of nosocomial *S. aureus* infection, but it does not reduce the rate of surgical site infection with *S. aureus* (928,929). Preoperative patient bathing, the use of topical antiseptic skin cleansers (chlorhexidine gluconate) (930–932), and proper hair removal techniques (using electric clippers or depilatories rather than razors) (933–937) are important measures with which to prepare the patient for surgery.

Intraoperative techniques to decrease infection include strict adherence to sterile technique, minimization of operating room traffic, less use of flash sterilization of surgical instruments, minimization of electrocautery (933,936) and bone wax (938), use of double-gloving (938–943), and shorter operative times. Identification of patients at high risk for preoperative infection allows the clinician to maximize prevention strategies. Superficial wound infection occurs in 2% to 6% of patients after cardiac surgery (656,944–946), and deep sternal wound infection occurs in 0.45% to 5%, with a mortality rate of 10% and 47% (947–953).

The etiology of deep sternal wound infection is multifactorial. Risk factors for deep sternal wound infection are diabetes mellitus (25,27,28), obesity (body mass index >30 kg/m^2) (947,949,950,953,954), chronic obstructive pulmonary disease (950), prolonged CPB time, reoperation, prolonged intubation time, and surgical reexploration (945,947,955). Potentially modifiable risk factors are smoking cessation, optimized nutritional status, adequate preoperative glycemic status (with hemoglobin A1c <6.9%), and weight loss. The use of bilateral IMAs has been a subject of investigation as a risk factor for deep sternal wound infection. Each IMA provides sternal branches, which provide 90% of the blood supply to each hemi-sternum. As a result, IMA harvesting can compromise sternal wound healing. Although no RCTs assessing the risk of deep sternal wound infection after bilateral IMA grafting have been reported, the use of bilateral IMAs in patients with diabetes and those with other risk factors for surgical site infection increases the incidence of deep sternal wound infection (956,957). Skeletonization of the IMA may be associated with a beneficial reduction in the incidence of sternal wound complications, more evident in patients with diabetes mellitus (958).

Transfusion of homologous blood is a risk factor for adverse outcomes after cardiac surgery. Blood transfusions after CABG are correlated in a dose-related fashion to an increased risk of transfusion-related infection, postoperative infection, postoperative morbidity, and early and late death (959–962). In addition, they have been associated with a higher incidence of sternal wound infections (949,963,964). In a retrospective analysis of 15,592 cardiovascular patients, the risk of septicemia/bacteremia and superficial and deep sternal wound infections increased incrementally with each unit of blood transfused (961). The leukocytes that are present in packed red blood cells induce the immunomodulatory effects associated with blood transfusions. Allogenic transfusions of blood containing leukocytes induce higher concentrations of proinflammatory mediators (such as interleukins 6 and 10) than does the transfusion of leukocyte-depleted blood (924–927,965). In patients undergoing cardiac surgery, RCTs have shown that those receiving leukocyte-filtered blood have lower rates of perioperative infection and in-hospital death than those receiving non–leukocyte-filtered blood (924–927). An RCT showed that those receiving leukocyte-depleted blood had a reduced rate of infection (17.9% versus 23.5%; p=0.04) and 60-day mortality (transfused/nonfiltered patient mortality rate, 7.8%; transfused/filtered at the time of donation, 3.6%; and transfused/filtered at the time of transfusion, 3.3% [p=0.019]) (927). Leukodepletion can be accomplished by the blood bank at the time of donation or at the bedside at the time of transfusion (with the use of an inexpensive in-line transfusion filter). Preoperative antibiotics reduce the risk of postoperative infection 5-fold (892). Interest has grown in administering antibiotic prophylaxis as a single dose rather than as a multiple-dosing regimen for 24 to 48 hours, because single-dose antibiotic prophylaxis reduces the duration of prophylaxis, its cost, and the likelihood of antimicrobial resistance.

Staphylococcus coagulase–negative epidermidis or *S. aureus* (including methicillin-resistant *S. aureus*) account for 50% of surgical site infections. Other organisms that are often

involved are *Corynebacterium* and enteric gram-negative bacilli (966–968). Antibiotic prophylaxis against these organisms should be initiated 30 to 60 minutes before surgery, usually at the time of anesthetic induction, except for vancomycin, which should be started 2 hours before surgery and infused slowly to avoid the release of histamine (903,969,970). In patients without methicillin-resistant *S. aureus* colonization, a cephalosporin (cefazolin, 1 g given intravenously every 6 hours, or cefuroxime, 1.5 g given intravenously every 12 hours) is the agent of choice for standard CABG (897–905). Antibiotic redosing is performed if the operation lasts >3 hours (970). Vancomycin is reserved for the patient who is allergic to cephalosporins or has known or presumed methicillin-resistant *S. aureus* colonization (900,906–908).

The incidence of deep sternal wound infection has decreased over the past 15 years despite an increased risk profile of patients undergoing cardiac surgery (i.e., increased comorbidities, obesity, diabetes mellitus, and advanced age) (971). Several options are available for the treatment of deep sternal wound infection. The main treatment is surgical debridement with primary or delayed reconstruction with vascularized soft tissue (pectoral muscle or omentum) (909–912,972). Conventional treatment with pectoralis flap muscle or omentum is associated with procedure-related morbidities, such as destabilization of the thoracic cage, surgical trauma, and potential failure of the flap. In current practice, the vacuum-assisted closure system is often used in the treatment of mediastinitis (913). With it, local negative pressure is applied to the open wound, accelerating granulation tissue formation and increasing blood supply. Such vacuum-assisted closure therapy, which is less invasive than conventional surgical treatment, has been used as standalone therapy, as a bridge to flap advancement, or as sternal preconditioning and preservation followed by titanium plate sternal osteosynthesis (913,914,973). Although several studies have suggested that vacuum-assisted closure therapy can be a successful alternative to conventional standard therapy (913–921,973), the data are from single-center retrospective studies of patients with heterogeneous disease processes. As a result, it seems reasonable to suggest that both conventional and vacuum-assisted closure therapy can be used in the treatment of mediastinitis.

5.2.3. Renal Dysfunction: Recommendations

CLASS IIb

1. In patients with preoperative renal dysfunction (creatinine clearance <60 mL/min), off-pump CABG may be reasonable to reduce the risk of acute kidney injury (AKI) (974–978). *(Level of Evidence: B)*
2. In patients with preexisting renal dysfunction undergoing on-pump CABG, maintenance of a perioperative hematocrit greater than 19% and mean arterial pressure greater than 60 mm Hg may be reasonable. *(Level of Evidence: C)*
3. In patients with preexisting renal dysfunction, a delay of surgery after coronary angiography may be reasonable until the effect of radiographic contrast material on renal function is assessed (979–981). *(Level of Evidence: B)*
4. The effectiveness of pharmacological agents to provide renal protection during cardiac surgery is uncertain (982–1004). *(Level of Evidence: B)*

See Online Data Supplements 37 to 39 for additional data on CABG and renal dysfunction.

Depending on the definition used, the incidence of AKI (defined in various studies as an increase in serum creatinine concentration and/or decrease in calculated glomerular filtration rate of a certain magnitude) after isolated CABG is 2% to 3%, and the incidence of AKI requiring dialysis is 1% (1005). Risks factors for developing AKI after CABG are preoperative renal dysfunction, LV systolic dysfunction, PAD, advanced age, race, female sex, type of surgery, diabetes mellitus requiring insulin, emergency surgery, preoperative intraaortic balloon support, and congestive heart failure or shock (1005–1013).

The pathogenesis of postoperative AKI is usually multifactorial. The identification and effective management of modifiable variables can minimize its occurrence. CPB can lead to renal dysfunction if renal perfusion is not adequately maintained. In addition, CPB leads to a systemic inflammatory response, with the release of 1) inflammatory cytokines (e.g., kallikrein, bradykinin), 2) catecholamines, and 3) other hormones (e.g., renin, aldosterone, angiotensin II, vasopressin), all of which influence renal function. The effects of hypothermia during CPB on renal function are uncertain. Two RCTs (1014,1015) showed no effect of CPB temperature on renal function in patients undergoing CABG, whereas a 2010 observational study (1016) of 1,072 subjects identified a relationship between a CPB temperature <27°C and the development of AKI (OR: 1.66; 95% CI: 1.16 to 2.39; p=0.005). Although off-pump CABG may theoretically avoid CPB-related renal injury, the cardiac manipulation that is often required to obtain adequate exposure may cause transient decreases in cardiac output, increased peripheral vasoconstriction, and decreased renal perfusion (1017). A meta-analysis of 6 RCTs and 16 observational studies (encompassing data from 27,806 patients) suggested a modest beneficial effect of off-pump CABG in reducing the incidence of AKI but no advantage in reducing the incidence of AKI–dialysis (977). These findings were confirmed by another published RCT of 2,203 patients, in which the incidence of AKI–dialysis was similar among those undergoing off-pump and on-pump CABG (0.8% for off pump; 0.9% for on pump; p=0.82) (61). Considering the low (approximately 1%) incidence of AKI–dialysis in subjects undergoing CABG, available RCTs are underpowered to detect a difference in outcome. In patients with renal dysfunction preoperatively, it might be reasonable to perform off-pump CABG to reduce the risk of AKI (974–976,978,996). During CPB, hemodilution is induced to reduce blood viscosity and plasma oncotic

pressure to improve regional blood flow in the setting of hypothermia and hypoperfusion. However, an excessively low hematocrit on CPB is associated with increased adverse events and in-hospital deaths (1018). In patients undergoing isolated CABG, it has been reported that the mortality rate of patients with a single hematocrit value <19% was twice that of those with a hematocrit of 25% (1019). On the basis of these data, a hematocrit <19% on CPB should be avoided.

No drugs have been identified that prevent or alleviate CABG-associated AKI. N-acetylcysteine reduces proinflammatory cytokine release, oxygen free radical generation, and reperfusion injury, but a review of 10 RCTs containing data from 1,163 patients (982) showed that it did not reduce the incidence of AKI and AKI–dialysis (987). In several RCTs, atrial natriuretic peptide was shown to reduce peak postoperative serum creatinine concentrations, increase urine output, and reduce the need for dialysis in individuals with normal renal function preoperatively, but it did not prevent AKI–dialysis in patients with preexisting renal dysfunction (996).

Fenoldopam, a selective dopamine D_1 receptor agonist that causes vasodilatation and increases renal cortical and outer medullary blood flow, seems to exert protective renal effects in critically ill patients (994,995). A meta-analysis of the data from 1,059 patients reported in 13 randomized and case-matched studies showed that fenoldopam exerts a beneficial effect on renal function. Compared with standard therapy, fenoldopam reduced the need for renal replacement therapy (5.7% versus 13.4%; OR: 0.37; 95% CI: 0.23 to 0.59; $p<0.001$) and lowered the peak value for serum creatinine concentration. Nevertheless, this beneficial effect was counterbalanced by an increased rate of hypotension and vasopressor requirements (15% versus 10.2%; OR: 1.94; 95% CI: 1.1.9 to 3.16; $p=0.008$). Dopamine at low doses increases renal blood flow and blocks the tubular reabsorption of sodium. A meta-analysis on the use of low-dose dopamine reported that it increased urine output and improved serum creatinine concentrations without influencing the need for renal replacement therapy or the rates of adverse events or death (990).

Diltiazem and mannitol have been used to prevent AKI after cardiac surgery (988). Diltiazem may inhibit the inflammatory response that occurs with CPB (992), whereas mannitol produces an osmotic diuresis (1000). The role of mannitol in preventing AKI is unclear (983,1004). Diltiazem does not prevent renal dysfunction (983). Contrast-induced nephropathy is a common cause of AKI. It is usually self-limited and manifests its peak effect 3 to 5 days after the administration of contrast material. In patients with preoperative renal dysfunction, it is reasonable to delay surgery for several days after coronary angiography to reduce the incidence of AKI (979–981).

5.2.4. Perioperative Myocardial Dysfunction: Recommendations

CLASS IIa

1. In the absence of severe, symptomatic aorto-iliac occlusive disease or PAD, the insertion of an intraaortic balloon is reasonable to reduce mortality rate in CABG patients who are considered to be at high risk (e.g., those who are undergoing reoperation or have LVEF <30% or left main CAD) (1021–1026). *(Level of Evidence: B)*
2. Measurement of biomarkers of myonecrosis (e.g., creatine kinase-MB, troponin) is reasonable in the first 24 hours after CABG (200). *(Level of Evidence: B)*

Intraaortic balloon counterpulsation is an established mechanical cardiac support procedure that has been demonstrated to increase cardiac output and to improve coronary blood flow (1025,1026). In several RCTs, its preoperative initiation and perioperative use have been shown to reduce the mortality rate in CABG patients who are considered to be at high risk (i.e., those undergoing repeat CABG, those with an LVEF <30%, or those with left main CAD) (1022–1024) despite its known associated vascular complications (1021). In contrast, its routine use in subjects who are not thought to be high risk has not been demonstrated (1027).

Some myocyte necrosis often occurs during and immediately after CABG, caused by cardiac manipulation, inadequate myocardial protection, intraoperative defibrillation, or acute graft failure. A determination of the frequency and magnitude with which postoperative myonecrosis occurs has been difficult. In 2007, the European Society of Cardiology/ACCF/AHA/World Heart Federation Task Force for the Redefinition of Myocardial Infarction stated, "[B]iomarker values more than 5 times the 99th percentile of the normal reference range during the first 72 h following CABG, when associated with the appearance of new pathological Q-waves or new [left bundle branch block], or angiographically documented new graft or native coronary artery occlusion, or imaging evidence of new loss of viable myocardium should be considered as diagnostic of a CABG-related myocardial infarction (type 5 myocardial infarction)" (203, p. 2183). Until 2000, the conventional biomarker for myonecrosis was creatine kinase-MB, but at present cardiac-specific troponin is the preferred indicator of myonecrosis (198,200). The higher the serum concentrations of biomarkers after CABG, the greater the amount of myonecrosis and, therefore, the greater the likelihood of an adverse outcome.

Published data from the PREVENT IV trial suggest, first, that serum biomarkers for myonecrosis are elevated postoperatively even in roughly 10% of CABG subjects who are considered to be low risk for the procedure and, second, that short-term (30-day) and long-term (2-year) outcomes were worse in these patients than in those without a postoperative biomarker elevation. Similarly, a direct correlation has been noted between the presence and magnitude

of biomarker elevations postoperatively and both intermediate- and long-term risk of death (1028).

5.2.4.1. TRANSFUSION: RECOMMENDATION

CLASS I

1. **Aggressive attempts at blood conservation are indicated to limit hemodilutional anemia and the need for intraoperative and perioperative allogeneic red blood cell transfusion in CABG patients (1029–1032). *(Level of Evidence: B)***

Numerous large observational studies have identified perioperative allogeneic red blood cell transfusion(s) as an independent risk factor for adverse outcomes, including death (1029–1032). A prospective observational study of 8,004 patients demonstrated that the transfusion of allogeneic red blood cells in CABG patients was associated with an increased risk of low-output heart failure irrespective of the extent of hemodilutional anemia (1030). An adverse outcome may be caused by immunomodulation (known to occur with red blood cell transfusion), initiation of a systemic inflammatory response and its associated direct negative myocardial effects, reduced red blood cell capacity for adequate oxygen delivery (1031,1032) (diphosphoglycerate function in "banked" blood may cause tissue hypoxia), and changes in red blood cell morphology of transfused blood. Regardless of etiology, myocardial depression is observed consistently after allogeneic red blood cell transfusion, and this effect appears to be dose dependent. Even risk-adjusted survival rates after CABG in patients transfused with allogeneic red blood cells are reduced (1029–1032).

5.2.5. Perioperative Dysrhythmias: Recommendations

CLASS I

1. **Beta blockers should be administered for at least 24 hours before CABG to all patients without contraindications to reduce the incidence or clinical sequelae of postoperative AF (604–608,608a–608c). *(Level of Evidence: B)***
2. **Beta blockers should be reinstituted as soon as possible after CABG in all patients without contraindications to reduce the incidence or clinical sequelae of AF (604–608,608a–608c). *(Level of Evidence: B)***

CLASS IIa

1. **Preoperative administration of amiodarone to reduce the incidence of postoperative AF is reasonable for patients at high risk for postoperative AF who have contraindications to beta blockers (1036). *(Level of Evidence: B)***
2. **Digoxin and nondihydropyridine calcium channel blockers can be useful to control the ventricular rate in the setting of AF but are not indicated for prophylaxis (606,1037–1041). *(Level of Evidence: B)***

AF immediately after CABG, occurring in 20% to 50% of patients, is often difficult to manage and is associated with a substantially increased risk of morbidity (particularly disabling embolic events) and mortality. A prospective observational study of 1,878 consecutive subjects undergoing CABG noted that post-CABG AF was associated with a 4-fold increased risk of disabling embolic stroke and a 3-fold increased risk of cardiac-related death (607).

The incidence of postoperative AF is increased in the presence of advanced patient age, male sex, PAD, chronic lung disease, concomitant valvular heart disease, left atrial enlargement, previous cardiac surgery, preoperative atrial tachyarrhythmias, pericarditis, and elevated postoperative adrenergic tone. However, many subjects have none of these factors, yet they develop AF in the immediate postoperative period. Postoperative AF almost always occurs within 5 days postoperatively, with a peak incidence on the second postoperative day (608). Numerous trials have assessed the efficacy of various pharmacologic agents in preventing post-CABG AF, including beta-adrenergic-blockers, various antiarrhythmic agents, glucocorticosteroids, hormonal agents (e.g., triiodothyronine), and even statins. Preoperative and postoperative beta blockers (or possibly amiodarone) are most effective at reducing its incidence, with several RCTs showing that they effectively accomplish this goal. In contrast, glucocorticosteroids, hormonal agents, and statins are not effective at decreasing its occurrence (604–606,608b,608c,1042). In subjects without pre-CABG AF, post-CABG AF usually resolves spontaneously within 6 weeks of surgery. As a result, the preferred management strategy of post-CABG AF in such patients often consists of control of the ventricular rate (with beta blockers) in anticipation of spontaneous reversion to sinus rhythm within a few weeks. In addition, if the patient is considered to be at risk for a thromboembolic event while in AF, anticoagulation (with heparin and then warfarin) is warranted. For a more detailed description of the management of subjects with postoperative AF, the reader is referred to the 2011 ACCF/AHA/HRS guidelines for the Management of Patients with Atrial Fibrillation (608).

5.2.6. Perioperative Bleeding/Transfusion: Recommendations

CLASS I

1. **Lysine analogues are useful intraoperatively and postoperatively in patients undergoing on-pump CABG to reduce perioperative blood loss and transfusion requirements (1044–1051). *(Level of Evidence: A)***
2. **A multimodal approach with transfusion algorithms, point-of-care testing, and a focused blood conservation strategy should be used to limit the number of transfusions (1052–1057). *(Level of Evidence: A)***
3. **In patients taking thienopyridines (clopidogrel or prasugrel) or ticagrelor in whom elective CABG is planned, clopidogrel and ticagrelor should be withheld for at least 5 days (520,521,523,524, 531,1058–1063) *(Level of Evidence: B)* and prasugrel for at least 7 days (533) *(Level of Evidence: C)* before surgery.**
4. **It is recommended that surgery be delayed after the administration of streptokinase, urokinase, and tissue-type plasminogen activators until hemostatic capacity is restored, if possible. The timing of recommended delay should be guided by the pharmacodynamic half-life of the involved agent. *(Level of Evidence: C)***
5. **Tirofiban or eptifibatide should be discontinued at least 2 to 4 hours before CABG and abciximab at least 12 hours before CABG (526–528,1049,1050,1064–1068). *(Level of Evidence: B)***

CLASS IIa

1. It is reasonable to consider off-pump CABG to reduce perioperative bleeding and allogeneic blood transfusion (67,1069–1074). *(Level of Evidence: A)*

See Online Data Supplements 40 to 42 for additional data on bleeding/transfusion.

Approximately 10% of allogeneic blood transfusions in the United States are given to subjects undergoing cardiac surgery (1075). Allogeneic transfusion carries the risks of transfusion reactions, air-borne infections, and increased hospital costs. In patients undergoing isolated CABG, transfusions are associated with reduced long-term survival and worse quality of life (1029,1076).

About 10% to 20% of the cardiac patients who are transfused receive roughly 80% of the transfusions that are administered (1075,1078). These high-risk patients often can be identified preoperatively to facilitate measures directed at blood conservation. Several reports have identified risk factors for blood transfusions (1079–1082), including advanced age, preoperative anemia, small body size, reoperative CABG, priority of operation, duration of CPB, presence of preoperative coagulopathy, and preoperative antithrombotic therapy (1080,1083–1088). A multimodal approach that includes transfusion algorithms, point-of-care testing, and a focused blood conservation strategy can limit the percentage of patients requiring transfusion and the amount of blood transfusions per patient (1052–1057).

About 60% to 70% of CABG patients are taking aspirin at the time of the procedure (536,1089,1090). Although aspirin increases perioperative blood loss and blood transfusion requirements (1091–1098), the amount of blood loss can be minimized by avoiding CPB (1099) and by using blood conservation techniques. In a meta-analysis of data from 805 patients (1100), doses of preoperative aspirin >325 mg were associated with increased bleeding (mean difference, 230 mL), whereas those who received <325 mg preoperatively did not have a significant increase in blood loss (mean difference: 65.3 mL; 95% CI: 20.2 to 150.8; p=0.134).

Some subjects undergoing CABG are receiving DAPT. Multiple studies have shown that the preoperative use of aspirin and clopidogrel is associated with increased perioperative bleeding, transfusions, and required reexploration for bleeding (522–524,531,1058–1062,1101–1107). In a study of 350 CABG patients at 14 centers, the risk of reexploration for bleeding was increased 3-fold in patients who were exposed to clopidogrel within 5 days of surgery; half of these patients required transfusions (520). In patients taking clopidogrel in whom elective CABG is planned, the drug should be withheld for 5 to 7 days before surgery. In subjects taking DAPT because of previous placement of a DES, clopidogrel can be stopped 1 year after the most recent DES placement. If CABG cannot be postponed, some operators have suggested that the patient be hospitalized for conversion of thienopyridine therapy to short-acting glycoprotein IIb/IIIa inhibitors for several days before surgery (497,1063,1108,1109); however, no data are available demonstrating the efficacy of such a management strategy. Streptokinase, urokinase, and tissue-type plasminogen activator should be stopped before CABG; in these individuals, the timing of CABG depends on the pharmacodynamic half-life of the agent involved (1110).

The use of unfractionated heparin has not been associated with increased perioperative blood loss; it can be continued until a few hours before CABG. Low-molecular-weight heparin can be administered safely ≤12 hours preoperatively and does not result in excessive perioperative blood loss (1064–1068). Lysine analogues, such as epsilon-aminocaproic acid and tranexamic acid, inhibit fibrinolysis by binding to the plasminogen molecule. Several trials have shown that both epsilon-aminocaproic acid and tranexamic acid reduce blood loss and blood transfusions during cardiac surgery, but they do not reduce the rate of reexploration for bleeding (1044–1051). Both drugs appear to be safe and do not increase the risk of death (1111).

Erythropoietin is a glycoprotein hormone that stimulates red blood cell production. Recombinant human erythropoietin is used in combination with iron supplementation to treat anemic patients (hemoglobin levels <13 g/dL) with renal failure and those undergoing chemotherapy. The use of erythropoietin in cardiac surgery has been studied in 12 RCTs and has been shown to be associated with significant risk reduction in allogeneic blood transfusion after cardiac surgery (1112–1122). However, the data from the RCTs are heterogeneous, with different doses of erythropoietin administered for 1 to 3 weeks preoperatively; as a result, further studies are needed to define more precisely the patient subgroups who may benefit from this therapy (1123). In patients who refuse blood transfusions during cardiac surgery, a short-term course of preoperative erythropoietin, to produce a high hematocrit preoperatively, may be administered (1124,1125). Alternatively, autologous blood donation may be used, which consists of extracting 1 to 3 units during the 30 days preoperatively and then reinfusing it during or postoperatively. However, such a practice is uncommon because of the increased risk of hemodynamic instability.

Off-pump CABG may avoid CPB-related coagulopathy caused by exposure of blood to artificial surfaces, mechanical trauma, alterations in temperature, and hemodilution. Some evidence suggests that off-pump CABG is associated with less bleeding and fewer blood transfusions (67,1069–1074).

6. Specific Patient Subsets

6.1. Elderly

The term "elderly" in CABG patients is usually defined as ≥80 years of age. Compared with younger subjects, the elderly are more likely to have severe (left main or multivessel) CAD, LV systolic dysfunction, concomitant valvular

disease, and previous sternotomy. In addition, they often have comorbid conditions, such as diabetes mellitus, hypertension, chronic obstructive pulmonary disease, PAD, and azotemia. As a result, the elderly have a higher perioperative risk of morbidity and mortality than do younger patients receiving CABG. The operative mortality rate among the elderly ranges from 2.6% (in a population >75 years of age) to 11% (in a population >80 years of age undergoing urgent or emergency surgery) (298,1126). Retrospective studies have observed a substantially higher in-hospital mortality rate among octogenarians than among younger patients (1127–1130). A report from the National Cardiovascular Network of outcomes in 67,764 patients undergoing cardiac surgery, of whom 4,743 were octogenarians, showed that the in-hospital mortality rate for the octogenarians was substantially higher (3.0% versus 8.1%; $p<0.001$) (1127).

Several retrospective studies of patients undergoing CABG have reported a higher incidence of neurological complications, renal failure, respiratory failure, and gastrointestinal complications among octogenarians than among younger subjects (298,1127,1128). In addition, the elderly have longer lengths of stay and are less likely to be discharged home. An analysis of the New York State Department of Health Cardiac Reporting System registry revealed that length of stay after CABG was 8.5 days in patients <50 years of age and 14.1 days in those >80 years of age, with discharge-to-home rates of 96% and 52%, respectively (1126).

Despite higher rates of in-hospital morbidity and mortality, the majority of octogenarians achieve functional improvement after CABG. Two studies of patients ≥80 years of age demonstrated improvements in quality of life, as assessed by the Seattle Angina Questionnaire (1131,1132). In 1 of these, angina relief and quality-of-life improvement scores after CABG did not differ between patients >75 and ≤75 years of age (1126). Of 136 octogenarians who underwent CABG, 81% felt that they were left with little or no disability in their daily activities, and 93% reported substantial symptomatic improvement an average of 2.1 years postoperatively (1131).

6.2. Women

Data on the influence of sex on CABG outcomes are limited. The BARI (Bypass Angioplasty Revascularization Investigation) study compared the outcomes of 1,829 patients with multivessel CAD randomly assigned to receive CABG or PCI; 27% were women (1133). Most information on the efficacy of CABG comes from studies done primarily in men, with extrapolation of the results to women. Although long-term outcomes with CABG in women are similar to or even better than those in men, women have higher rates of periprocedural morbidity and mortality (1133–1139). Several hypotheses have been suggested to explain this increased morbidity and mortality, including older age at presentation, more frequent need for urgent revascularization, more comorbid conditions, smaller body surface area and coronary arterial dimensions, and increased risk of bleeding. The fact that women on average are older than men at the time of CABG is thought, at least in part, to be due to the loss of the protective effects of estrogen with menopause (1134,1138,1140–1148). In studies of age-matched men and women undergoing CABG, in-hospital mortality rates were similar, even among the elderly (≥70 years of age) (1149,1150).

In addition to being older, women undergoing CABG are more likely than men to have ACS and cardiogenic shock (1140) and, therefore, to require urgent revascularization (1138,1141–1143,1146,1148). Sex disparity in the diagnosis and treatment of CAD may contribute to the more complex and delayed presentations in women compared with men (1151). In comparison to men, women are less likely to be referred for coronary angiography and revascularization and are more likely to have refractory ischemia and repeated hospitalizations (1152).

Compared with men undergoing CABG, women have more comorbid conditions, including diabetes mellitus, hypertension, hyperlipidemia, chronic renal insufficiency, chronic obstructive pulmonary disease, and concomitant valvular disease (1153). In some studies, no significant difference in outcomes between women and men undergoing CABG was noted when the data were adjusted for age and comorbidities (1136–1138,1154–1156), whereas in others, female sex remained an independent predictor of a worse outcome (1141,1157,1158). In a systematic review of sex differences and mortality after CABG, early mortality differences were reduced but not eliminated after adjustment for comorbidities, procedural characteristics, and body habitus (1139). Some investigators have shown that smaller body surface area, a surrogate for coronary arterial size, is associated with higher risk of perioperative mortality, whereas others have not (1140).

Women use more hospital resources in the perioperative period than do men, including intra-aortic balloon counterpulsation (1137), vasopressors, mechanical ventilation, dialysis, and blood products (1154,1159), all of which are associated with higher mortality rates (1146,1160,1161). Women are more likely to have wound complications and longer ICU and hospital stays (1162–1165). Lastly, the operative procedure itself appears to be different in women than in men, in that women are less likely to be completely revascularized (1166,1167) and less likely to have IMA grafting, especially bilateral (1168), even though bilateral IMA grafting in women is associated with low rates of in-hospital morbidity and mortality (1169).

6.3. Patients With Diabetes Mellitus

The prevalence of diabetes mellitus in CABG patients has increased markedly over the past 30 years. In the late 1970s, only 10% to 15% of CABG patients had diabetes (1170); by 2005, the incidence had risen to 35% (308). Patients with diabetes, especially those who are insulin dependent, have higher rates of perioperative morbidity and mortality and a

reduced long-term survival rate than those without diabetes (308,1171,1172). In the STS Registry, patients with diabetes on oral therapy had an adjusted OR of 1.15 for death within 30 days of CABG (95% CI: 1.09 to 1.21) as well as a greater likelihood of stroke, renal failure, and deep sternal wound infection than those without diabetes (308). For subjects receiving insulin, the adjusted OR for death within 30 days was 1.50 (95% CI: 1.42 to 1.58), and the risks for other complications were correspondingly higher. The poorer short-term outcome in patients with diabetes is only partly explained by a greater frequency of other comorbid conditions, such as obesity, hypertension, renal insufficiency, PAD, and cerebrovascular disease. The reduced long-term survival rate after CABG in patients with diabetes is likely due to a combination of more rapid progression of atherosclerosis, a lower long-term patency rate of SVGs (1173), and a greater burden of comorbid conditions. As in patients without diabetes, long-term outcome after CABG is better when an IMA is used as a conduit than when CABG is performed with only SVGs (362).

A subgroup analysis of data from the BARI trial suggested that patients with diabetes who underwent CABG with 1 arterial conduit had improved survival compared with those who underwent PCI (516). Several subsequent observational and cohort studies also showed that CABG results in better long-term outcome in patients with diabetes and multivessel CAD compared with balloon angioplasty or BMS implantation (361,451,1174). A meta-analysis of 10 RCTs comparing CABG with balloon angioplasty (n=6) or BMS implantation (n=4) concluded that the mortality rate was substantially lower in patients with diabetes undergoing CABG (451).

Little information is available about CABG versus PCI with DES in patients with diabetes mellitus. The results of CARDia (Coronary Artery Revascularisation in Diabetes), the first RCT comparing CABG and PCI in a population consisting entirely of subjects with diabetes, suggested that PCI with DES (used in 69% of the PCI patients) and CABG achieved similar outcomes (475). Of the 1,800 subjects enrolled in the SYNTAX trial, which compared CABG and PCI with paclitaxel-eluting stents, 452 had medically treated diabetes (364). At 1-year follow-up, the 2 treatments exerted a similar effect on survival, MI, and the composite endpoint of death, MI, or stroke. As in the entire SYNTAX cohort, patients with diabetes randomly assigned to receive PCI had a higher rate of repeat revascularization (20.3% after PCI versus 6.4% after CABG; $p<0.001$), and those with highly complex lesions (i.e., SYNTAX score $\geq$33) had a higher mortality rate with PCI (13.5% versus 4.1%; $p=0.04$). The FREEDOM (Future Revascularization Evaluation in patients with Diabetes mellitus: Optimal management of Multivessel disease) trial, an ongoing randomized comparison of CABG and PCI with DES in 1,900 patients with diabetes and multivessel CAD, should shed further light on the preferred therapy for these patients (1175).

Few comparisons of CABG and contemporary medical therapy in patients with diabetes mellitus are of sufficient size to allow meaningful conclusions. The largest such trial, BARI 2D, randomly assigned 2,368 patients with type 2 diabetes mellitus to revascularization plus intensive medical therapy or intensive medical therapy alone (404,1176), with patients in the medical therapy group to undergo revascularization during follow-up only if such therapy were clinically indicated by the progression of angina or the development of an ACS or severe ischemia. The planned method of revascularization, PCI or CABG, was determined before randomization by the treating physicians. No significant difference in primary endpoints was evident between the PCI group and the medical therapy group. No difference in survival rate between those undergoing CABG and those receiving only medical therapy was noted. Acute MI occurred less often in those assigned to CABG plus intensive medical therapy than in those given intensive medical therapy alone (10% versus 17.6%; $p=0.003$), and the composite endpoints of death or MI (21.1% versus 29.2%; $p=0.01$) and cardiac death or MI also occurred less often (1176). Compared to those selected for PCI, the CABG patients had more 3-vessel CAD (52% versus 20%), more totally occluded arteries (61% versus 32%), more proximal LAD artery stenoses >50% (19% versus 10%), and a higher myocardial jeopardy score.

Elevated fasting blood glucose concentrations before CABG and persistently elevated glucose concentrations afterward are associated with increased risk of morbidity and mortality (592,1177,1178). The complications most closely linked to postoperative hyperglycemia are infections, including deep sternal wound infection and mediastinitis. Achieving glycemic control perioperatively in patients with diabetes decreases this risk (581,593). Because the risk of deep sternal wound infection in patients with diabetes is increased when both IMAs are harvested and used, bilateral IMA grafting is not recommended in this patient cohort unless the overall benefit to the patient outweighs this increased risk (957).

6.4. Anomalous Coronary Arteries: Recommendations

CLASS I

1. Coronary revascularization should be performed in patients with:
   a. A left main coronary artery that arises anomalously and then courses between the aorta and pulmonary artery (1179–1181). *(Level of Evidence: B)*
   b. A right coronary artery that arises anomalously and then courses between the aorta and pulmonary artery with evidence of myocardial ischemia (1179–1182). *(Level of Evidence: B)*

CLASS IIb

1. Coronary revascularization may be reasonable in patients with a LAD coronary artery that arises anomalously and then courses between the aorta and pulmonary artery. *(Level of Evidence: C)*

Several variations and anatomic courses of anomalous coronary arteries have been described, some benign and others

associated with sudden cardiac death. The most life-threatening variants involve anomalous origin of the left main coronary artery from the right sinus of Valsalva or of the right coronary artery from the left sinus of Valsalva, after which the anomalous artery travels to its normal area of perfusion between the ascending aorta and the main pulmonary artery. In a review of consecutive echocardiograms in 2,388 asymptomatic children and young adolescents, the incidence of anomalous coronary arteries arising from the opposite sinus of Valsalva was 0.17% (1183). Anomalous coronary arteries (particularly those traversing between the aorta and the main pulmonary artery) are associated with exercise-related sudden death in young (≤35 years of age) athletes (1184–1190). A consecutive series of 27 young athletes with sudden death who were found to have such anomalous coronary arteries at autopsy had inducible myocardial ischemia and complained of cardiac symptoms before their demise (1179). Isolated case reports of other coronary arterial anomalies in subjects with syncope or sudden death emphasize the need for careful anatomic and functional evaluation of all individuals with anomalous coronary arteries (1191–1194). The method of revascularization employed in adults with anomalous coronary arteries has been 1) CABG or, more recently, 2) PCI with stenting (1195). When CABG is employed, consideration should be given to the presence of competitive flow in the native coronary circulation (1196). In children and some adults, an unroofing procedure or coronary arterial reimplantation may provide the best long term results (1197,1198). The risk associated with these coronary anomalies if they are left untreated and the existing operative experience make corrective surgery reasonable in these individuals (1180).

6.5. Patients With Chronic Obstructive Pulmonary Disease/Respiratory Insufficiency: Recommendations

CLASS IIa

1. Preoperative intensive inspiratory muscle training is reasonable to reduce the incidence of pulmonary complications in patients at high risk for respiratory complications after CABG (1199). *(Level of Evidence: B)*

CLASS IIb

1. After CABG, noninvasive positive pressure ventilation may be reasonable to improve pulmonary mechanics and to reduce the need for reintubation (1200,1201). *(Level of Evidence: B)*
2. High thoracic epidural analgesia may be considered to improve lung function after CABG (37,1202). *(Level of Evidence: B)*

See Online Data Supplement 43 for additional data on patients with chronic obstructive pulmonary disease/respiratory insufficiency.

In the STS Adult Cardiac Database predictive algorithms, the presence of chronic obstructive pulmonary disease preoperatively was an independent predictor of mortality, the need for prolonged postoperative ventilator support, and renal failure (1203). Furthermore, most rehospitalizations following CABG are related to pulmonary dysfunction and/or infection or volume overload. The incidence of complications increases with patient age and the severity of chronic obstructive pulmonary disease, as measured with pulmonary function testing (1204,1205). None of these studies, however, address the relative risks and benefits of CABG in subjects with chronic obstructive pulmonary disease, thereby precluding a specific recommendation regarding the performance of CABG in these patients. In preparation for CABG, optimizing pulmonary function is imperative (1206). An RCT of 279 patients (1199) showed that preoperative respiratory muscle training reduced postoperative pulmonary complications (including pneumonia) and length of stay in patients at high risk for such complications after CABG. Such muscle training is indicated in all patients before CABG, especially those with impaired baseline pulmonary function.

Two prospective RCTs have shown that prophylactic nasal continuous positive airway pressure after CABG improves pulmonary function and offers protection from postoperative pulmonary complications (1200,1201). However, the applicability of these results to patients with impaired pulmonary function is uncertain, because those with severe underlying lung disease and other comorbid conditions were not enrolled. Although noninvasive positive pressure ventilation may be useful in subjects with borderline pulmonary function postoperatively, its overuse should be avoided, because it may cause gastric distention, thereby increasing the risk of vomiting and aspiration. Improved lung function has been achieved with the use of high thoracic epidural anesthesia in patients undergoing CABG (36,37), but its application has been limited by concerns about paraspinal and epidural hemorrhage related to epidural catheter insertion.

Despite some evidence that oral corticosteroids improve pulmonary function after cardiac surgery (1207,1208), their use has not been adopted widely in subjects undergoing CABG. Finally, a consistent reduction in postoperative pulmonary complications has not been shown when off-pump (as opposed to on-pump) CABG is performed (1209).

6.6. Patients With End-Stage Renal Disease on Dialysis: Recommendations

CLASS IIb

1. CABG to improve survival rate may be reasonable in patients with end-stage renal disease undergoing CABG for left main coronary artery stenosis of greater than or equal to 50% (479). *(Level of Evidence: C)*
2. CABG to improve survival rate or to relieve angina despite GDMT may be reasonable for patients with end-stage renal disease with significant stenoses (≥70%) in 3 major vessels or in the proximal LAD artery plus 1 other major vessel, regardless of LV systolic function (1210). *(Level of Evidence: B)*

CLASS III: HARM

1. CABG should not be performed in patients with end-stage renal disease whose life expectancy is limited by noncardiac issues. *(Level of Evidence: C)*

Rates of cardiovascular morbidity and mortality are increased in patients with CKD compared with age-matched controls without CKD, and the magnitude of the increase is directly related to the severity of CKD. About half of those on maintenance dialysis die from a cardiovascular cause (476). At present, the prevalence of CKD in the general population of the United States is estimated to be 13%, with approximately 5.8% of these having Stage III–V disease (i.e., glomerular filtration rate <60 mL/min/1.73 m^2) (1211). In 2009, >525,000 Americans were receiving maintenance hemodialysis (1212).

To date, randomized comparisons of CABG and medical therapy in patients with CKD (irrespective of its severity) have not been reported. Observational studies have demonstrated an improved survival rate with CABG (compared with medical therapy) in patients with CKD and multivessel CAD (57,479). At the same time, these observational studies as well as other registries have demonstrated a markedly reduced long-term survival rate in patients with CKD undergoing CABG compared with nondialysis CABG patients (1213–1216), with the magnitude of the decrease directly related to the severity of CKD. In these reports, subjects with CKD undergoing CABG had an increased incidence of periprocedural complications, including mediastinitis, need for blood transfusion, prolonged ventilation, reoperation, stroke, and increased length of hospital stay (1210).

6.7. Patients With Concomitant Valvular Disease: Recommendations

CLASS I

1. Patients undergoing CABG who have at least moderate aortic stenosis should have concomitant aortic valve replacement (1217–1220). *(Level of Evidence: B)*
2. Patients undergoing CABG who have severe ischemic mitral valve regurgitation not likely to resolve with revascularization should have concomitant mitral valve repair or replacement at the time of CABG (1221–1226). *(Level of Evidence: B)*

CLASS IIa

1. In patients undergoing CABG who have moderate ischemic mitral valve regurgitation not likely to resolve with revascularization, concomitant mitral valve repair or replacement at the time of CABG is reasonable (1221–1226). *(Level of Evidence: B)*

CLASS IIb

1. Patients undergoing CABG who have mild aortic stenosis may be considered for concomitant aortic valve replacement when evidence (e.g., moderate–severe leaflet calcification) suggests that progression of the aortic stenosis may be rapid and the risk of the combined procedure is acceptable. *(Level of Evidence: C)*

6.8. Patients With Previous Cardiac Surgery: Recommendation

CLASS IIa

1. In patients with a patent LIMA to the LAD artery and ischemia in the distribution of the right or left circumflex coronary arteries, it is reasonable to recommend reoperative CABG to treat angina if GDMT has failed and the coronary stenoses are not amenable to PCI (380,1227). *(Level of Evidence: B)*

6.8.1. Indications for Repeat CABG

RCTs comparing medical therapy to CABG in subjects with SIHD demonstrated that those with specific angiographic findings, such as left main disease, 3-vessel disease, and 2-vessel disease that includes the proximal LAD artery, derive a survival benefit from CABG (318). At the same time, it is unknown if CABG provides a survival benefit compared with medical therapy in patients with these anatomic findings who have had previous CABG. It is logical to assume that subjects with previous CABG and these anatomic findings would, in fact, derive a survival benefit from repeat CABG provided that CABG could be performed with an acceptable risk. The importance of recurrent MI in the distribution of the LAD artery has been shown to be associated with a poor prognosis in patients with previous CABG. The long-term outcomes of 723 patients with diseased SVGs who did not undergo reoperation or PCI within 1 year of angiography were reviewed (1228). A stenosis of a graft to the LAD artery was associated with decreased rates of survival, reoperation-free survival, and event-free survival. On the basis of these data, these authors suggest that a >50% stenosis in a graft to the LAD artery is an indication for reoperation. In contrast, patients without ischemia in the LAD artery distribution do not derive a survival benefit from repeat CABG. In an observational study from the Cleveland Clinic, the survival rate of 4,640 patients with patent LIMA grafts to the LAD artery and ischemia in the distribution of the right and/or left circumflex arteries who were treated with repeat CABG, PCI, or medical therapy was examined (380). No improvement in survival was observed in either revascularization group compared with those treated medically.

6.8.2. Operative Risk

Because of the technical difficulty of repeat CABG and the high risk profiles of these patients, reoperative CABG is associated with higher rates of morbidity and mortality than is primary CABG (945,1229–1235). With advances in surgical techniques, some groups have reported a decline in mortality rate for patients undergoing repeat CABG (1233,1236). An observational study suggested that the higher operative risk with reoperation is related to the higher patient risk profiles and not to the technical challenges of the operation itself, thereby suggesting that improvements in surgical techniques have neutralized the risk associated with the complexity of repeat CABG (1233), but others continue to suggest that technical issues are still important in causing the higher mortality rate in these individuals.

6.8.3. Long-Term Outcomes

The survival rate after repeat CABG is lower than that after primary CABG. A multicenter study from Australia re-

ported 1, 3, 5, and 6 year survival rates in reoperative CABG patients of 93.1%, 90.5%, 85.9%, and 80.5%, respectively (1235)—survival results that were significantly lower than those observed after primary CABG. However, after adjusting for differences in risk profiles between primary and reoperative CABG patients, no difference in long-term survival rate was apparent. The variables associated with decreased late survival rate included advanced age, hypertension, elevated serum cholesterol, diabetes mellitus, PAD, renal failure, left main CAD, LV systolic dysfunction, and emergency status (1235).

Compared with primary CABG, repeat CABG is less successful at relieving angina (1237,1238), although a 2004 quality-of-life analysis reported that repeat CABG was as effective as primary CABG in relieving angina and improving functional capacity and quality of life (1239).

6.9. Patients With Previous Stroke

Patients with a previous stroke or TIA are at higher risk for a perioperative stroke during CABG than those without such a history. A meta-analysis of the data from several studies observed a perioperative stroke risk of 8.5% in patients with previous stroke (compared with 2.2% in those without a previous neurological event) ($p<0.0001$) (860). When subjects with a history of stroke or TIA were analyzed separately (i.e., stroke only or TIA only), the increased perioperative risk in comparison with neurologically asymptomatic patients was present in both groups. In a multivariate logistic regression analysis of 16,194 cardiac surgery patients, a history of cerebrovascular disease was identified as an independent predictor of perioperative stroke (1240). The STS National Cardiac Surgery Database demonstrated an increased risk of perioperative death, perioperative stroke, and prolonged length of stay in patients with a history of stroke who underwent isolated CABG from 2002 to 2006 (308).

6.10. Patients With PAD

CAD and PAD, generally defined as atherosclerotic disease of the aorta, its visceral arterial branches (renal and mesenteric), and the arteries of the lower extremities, often coexist. The presence of PAD is an independent predictor of early (1241) and late death in CABG patients. In the STS National Cardiac Surgery Database, 774,881 patients underwent isolated CABG over a 5-year period, of whom 15.5% had PAD. The presence of PAD was an independent risk factor for in-hospital death or death within 30 days of CABG. In addition, PAD was an independent risk factor for perioperative stroke and subsequent need for post-CABG limb revascularization or amputation. Potential but unproven explanations for the adverse effects of PAD on long-term survival after CABG include: 1) The presence of PAD may lead to vascular events (i.e., cerebrovascular events) that adversely affect post-CABG survival; 2) PAD may be a marker for more severe CAD, which may lead to an increased rate of post-CABG death from cardiac causes despite revascularization; and 3) PAD may contribute to noncardiovascular death in the long term. Revascularization of PAD before CABG is not known to improve post-CABG outcomes.

7. Economic Issues

7.1. Cost-Effectiveness of CABG and PCI

In the United States, it is estimated that the annual hospital costs of CABG are approximately $10 billion (1242). Despite the increasing risk profile of CABG candidates, it nonetheless is becoming more cost-effective. Hospital charges from the Nationwide Inpatient Sample of nearly 5.5 million patients who had isolated CABG in the United States from 1988 to 2005 were examined (1243). A decrease in risk-adjusted mortality rate, from 6.2% to 2.1% ($p<0.0001$), was noted. When hospital costs were corrected for inflation, they declined from $26,210 in 1988 to $19,196 in 2005 ($1,988) ($p<0.0001$).

Several factors tend to increase the cost of CABG, including advanced patient age, female sex, African-American ethnicity, postoperative complications, longer hospital stay, and multiple comorbidities, particularly CKD (1244–1247). The National Health Service Foundation Trust in Britain found that patients >75 years of age undergoing CABG had higher rates of postoperative complications and greater resource utilization than their younger counterparts (1244). Similarly, the Maryland Health Services Cost Review Commission reported an increased total cost and length of hospital stay with increasing age in patients undergoing CABG (1245). The same phenomenon was not present with PCI until the patients were >80 years old. In an examination of data from 12,016 subjects undergoing CABG in New York State in 2003, it was determined that older age, female sex, and African-American ethnicity were associated with higher costs (1247). Clinical characteristics, such as a lower LVEF, number of diseased vessels, previous open-heart operations, and numerous comorbidities, further increased costs. Larger hospitals were associated with higher CABG discharge costs, whereas costs significantly decreased with higher CABG volumes.

Not surprisingly, perioperative complications lead to increased costs. An examination of the Medicare Provider Analysis and Review file of data from 114,223 Medicare beneficiaries who survived CABG in 2005 showed the mean cost of hospitalization associated with CABG to be $32,201 ± $23,059 for a mean length of stay of 9.9 ± 7.8 days. Those with complications (13.6% of patients) consumed significantly more hospital resources (incremental cost, $15,468) and had a longer length of stay (average additional stay, 1.3 days) (1246).

Evidence for the role of off-pump versus on-pump CABG in decreasing costs is conflicting. In a randomized study comparing off-pump and on-pump CABG, the mean total hospitalization cost per patient was $2,272 less for

off-pump CABG at hospital discharge and $1,955 less at 1 year (1248). Another study of 6,665 patients who underwent CABG between 1999 and 2005 determined that off-pump CABG provided a small short-term gain (1249), although off-pump patients had increased long-term risks of repeat revascularization and major vascular events, especially if they were considered to be high risk. In the long run, in fact, off-pump patients utilized more resources.

7.1.1. Cost-Effectiveness of CABG Versus PCI

Medical costs and quality of life were examined 10 to 12 years after patients were randomly assigned to receive angioplasty or CABG in the BARI trial (1250). Although CABG costs initially were 53% higher, the gap closed to <5% by the end of 2 years. After 12 years, the average cost was $123,000 in CABG patients and $120,000 for PCI patients. Cumulative costs were significantly higher among patients with diabetes mellitus, heart failure, and comorbid conditions, and they were higher in women. CABG was deemed to be as cost-effective as PCI in patients with multivessel CAD.

The cost of coronary artery revascularization in 6,218 patients with and without CKD whose data were available in the Duke database was examined (1251). CABG was an economically attractive alternative to PCI or medical therapy for all patients with left main or 3-vessel CAD without concomitant CKD as well as those with 2-vessel CAD with concomitant CKD. For subjects with 3-vessel CAD and concomitant CKD, 2-vessel CAD without CKD, and 1-vessel CAD regardless of renal function, medical therapy was an economically attractive strategy compared with CABG or PCI. This analysis concluded that CABG is most economically attractive compared with PCI and medical therapy in patients to whom it confers the greatest survival advantage and for whom the cost of alternative treatments is greatest (i.e., those with the most severe CAD). Although CABG was more expensive than medical therapy for all patients, the survival benefits associated with it were of such magnitude in some subjects that it was economically attractive.

The cost-effectiveness of CABG and PCI in high-risk patients was analyzed in the AWESOME (Angina With Extremely Serious Operative Mortality Evaluation) study (446), in which costs were assessed at 3 and 5 years. After 3 years, the average total cost was $63,896 for PCI and $84,364 for CABG, a difference of $20,468. After 5 years, the average total cost was $81,790 for PCI and $100,522 for CABG, a difference of $18,732. The authors concluded that PCI was less costly and at least as effective for urgent revascularization in high-risk patients with medically refractory angina.

7.1.2. CABG Versus PCI With DES

The use of DES for PCI will require a reassessment of cost-effectiveness. Although the initial procedure is considerably more expensive than the use of balloon angioplasty or BMS, equaling the cost of CABG in many patients with multivessel CAD, the cost of reintervention for restenosis may be reduced. The cost-effectiveness will depend on the pricing of stents, utilization rates of the more expensive stents, and efficacy. In a 2010 study from Japan comparing the total costs at 2 years of CABG and DES implantation in patients with left main CAD, the total costs were significantly lower for those undergoing CABG than for those receiving a DES (1252).

8. Future Research Directions

With improvements in percutaneous techniques and medical therapy, on-pump CABG and off-pump CABG will increasingly be reserved for patients with extensive CAD, many of whom have had previous PCI. The future of CABG will be directed at improving its results in high-risk patients and making CABG less invasive for elective revascularization. Minimally invasive techniques, with the use of robotics and anastomotic connectors, intraoperative imaging, hybrid procedures, and protein and gene therapy, appear promising. Robotic technology in minimally invasive CABG leads to less traumatic harvesting of the LIMA for minimally invasive direct coronary artery bypass procedures compared with nonrobotic techniques (1253). The ultimate goal of robotic CABG is totally endoscopic CABG, but its use has been limited, at least partly because of a substantial learning curve, cost considerations, and few data demonstrating noninferior graft patency and outcomes compared with standard CABG.

Anastomotic connectors may enable more routine application of totally endoscopic anastomoses in subjects undergoing minimally invasive CABG. Because hand-sewn anastomoses are technically challenging when performed endoscopically, consideration has been given to the concept of anatomic connectors to facilitate more reproducible and less technically demanding procedures and ultimately to allow widespread use. Both proximal and distal connectors may be used. Several options are being developed, some only available outside the United States, and the evidence base supporting their use is evolving (1254). The PAS-Port proximal device has been associated with acceptable outcomes. In two prospective studies, its angiographic graft patency 9 months after CABG was similar to that of hand-sewn anastomoses (1255,1256). With this device, the proximal anastomoses must be constructed before the distal ones. At present, only 1 distal device, the Cardica C-Port, has been approved for use in the United States. The prospective studies (1257,1258) demonstrated a 6-month overall patency of 96% in 102 subjects. These devices increase the cost of the operation.

Over the past 20 years, the patency rate of all graft types has improved gradually, so that the present failure rate of LIMA grafts at 1 year is about 8% and of SVGs roughly 20% (1259). Many patients being referred for CABG nowadays have far advanced CAD, which is often diffuse

and exhibits poor vessel runoff. Technical issues at the time of surgery may influence graft patency, and intraoperative imaging may help to delineate technical from nontechnical issues. Because coronary angiography is rarely available intraoperatively, other techniques have been developed to assess graft integrity at this time, most often the transit-time flow and intraoperative fluorescence imaging. The transit-time flow is a quantitative volume-flow technique that cannot define the severity of graft stenosis or discriminate between the influence of the graft conduit and the coronary arteriolar bed on the mean graft flow. Intraoperative fluorescence imaging, which is based on the fluorescent properties of indocyanine green, provides a "semiquantitative" assessment of graft patency with images that provide some details about the quality of coronary anastomoses (1260). Although both methods are valuable in assessing graft patency, neither is sufficiently sensitive or specific to allow identification of more subtle abnormalities (1260). It is hoped that such imaging may help to reduce the occurrence of technical errors.

The hybrid suite can be used as an operating room and a catheterization laboratory. It allows the performance of an angiogram after CABG so that one can identify abnormal grafts, providing the opportunity to revise them (with PCI or surgery) before leaving the operating room. Until completion angiography becomes more routine (in a hybrid suite), cardiac surgeons must rely on reasonably accurate, albeit imperfect, methods to identify problems with a recently implanted graft.

8.1. Hybrid CABG/PCI

Advances in surgical techniques and the introduction of DES have provided a platform for a "hybrid revascularization strategy" that combines grafting the LAD artery with the LIMA and stenting the non-LAD arteries with DES (instead of bypassing them with SVGs). Although preliminary data (1261) have indicated that a hybrid strategy may be a reasonable alternative in some patients with multivessel CAD, its real effect will not be known until results of RCTs are available (1261). The primary purpose of performing hybrid CABG is to decrease the morbidity rate of traditional CABG in high-risk patients. Although hybrid revascularization is most often performed in a staged fashion, a simultaneous hybrid procedure can be performed in a hybrid suite, offering several potential advantages, including improving the efficiency and cost-effectiveness of therapy as well as condensing therapy into 1 patient encounter. If a staged approach is chosen, minimally invasive CABG performed first, followed days later by PCI, is probably preferable, so as to enable surgery without the unwanted effects of antiplatelet therapy as well as to enable complete angiography of the LIMA graft at the time of PCI. The major disadvantage of this approach is that if complications occur with PCI, a third procedure may be necessary. Even with a hybrid suite, one of the most substantive barriers to simultaneous minimally invasive CABG and PCI is the management of antiplatelet therapy. The role of hybrid CABG–PCI compared with sole PCI and sole conventional CABG awaits the results of the ongoing observational study of hybrid coronary revascularization by the National Heart, Lung, and Blood Institute.

8.2. Protein and Gene Therapy

Several proteins, such as vascular endothelial growth factor, acidic fibroblast growth factor, and basic fibroblast growth factor, induce angiogenesis (1262); as a result, interest has grown in using these substances to stimulate myocardial perfusion. One RCT found that patients who were given 100 mcg of basic fibroblast growth factor became angina free, and nuclear perfusion testing appeared to show improved perfusion (1262). Another RCT has suggested that the intracoronary injection of high-dose angiogenic molecules yields improvement in symptoms, exercise time, functional capacity, and myocardial perfusion (1263). Alternatively, gene therapy may be used to induce angiogenesis, but conceptual concerns with intravascular gene therapy, such as peripheral uptake into nontarget tissues and subsequent unintended effects, have been raised.

8.3. Teaching CABG to the Next Generation: Use of Surgical Simulators

Over the past decade, pressure on hospitals and physicians to ensure high quality and safety has increased. Public reporting of outcomes, common in many states, has been endorsed by the STS. In addition, healthcare reform has placed great emphasis on the efficiency of care. These factors, coupled with the increased complexity of patients referred for CABG, the decreased number of qualified physicians specializing in cardiac surgery, and the restrictions on resident work hours, make the teaching of surgical techniques to the next generation a substantial challenge.

Given the success of simulator training of airline and military personnel, it has the potential to have a major impact on surgical training paradigms. With surgical simulators, a trainee's first distal anastomosis in an actual patient will occur only after mastering the technique on a simulator (1264). The mastery of basic skills will allow the trainee to focus on more complex tasks as well as to understand the conduct of the operation more thoroughly and quickly. The fundamentals of simulator training are based on the learning principle of "deliberate practice," in which an individual practices a finite task until it is mastered. Still, before this method of training can be incorporated into a formal curriculum, several issues must be addressed. Trainees must have adequate supervision and instruction to ensure appropriate technique, which will require that attending surgeons have time away from clinical and academic duties to provide simulator training. This poses a considerable challenge under current reimbursement requirements, and a reimbursement system that provides an incentive to active surgeons to teach residents in the simulation laboratory will be required. As an alternative,

training programs may opt to hire recently retired surgeons to teach in the simulation laboratory. Finally, simulators must become more robust, with perhaps computer-enhanced clinical scenarios, before the residents who train on them are qualified to care for patients.

Staff

American College of Cardiology Foundation
David R. Holmes, Jr., MD, FACC, President
John C. Lewin, MD, Chief Executive Officer
Janet Wright, MD, FACC, Senior Vice President, Science and Quality
Charlene May, Senior Director, Science and Clinical Policy
Erin A. Barrett, MPS, Senior Specialist, Science and Clinical Policy

American College of Cardiology Foundation/ American Heart Association
Lisa Bradfield, CAE, Director, Science and Clinical Policy
Debjani Mukherjee, MPH, Associate Director, Evidence-Based Medicine
Sue Keller, BSN, MPH, Senior Specialist, Evidence-Based Medicine
Maria Koinis, Specialist, Science and Clinical Policy
Jesse M. Welsh, Specialist, Science and Clinical Policy

American Heart Association
Ralph L. Sacco, MS, MD, FAAN, FAHA, President
Nancy Brown, Chief Executive Officer
Rose Marie Robertson, MD, FAHA, Chief Science Officer
Gayle R. Whitman, PhD, RN, FAHA, FAAN, Senior Vice President, Office of Science Operations
Cheryl L. Perkins, MD, RPh, Science and Medicine Advisor, Office of Science Operations

REFERENCES

1. ACCF/AHA Task Force on Practice Guidelines. Methodologies and Policies from the ACCF/AHA Task Force on Practice Guideline. Available at http://assets.cardiosource.com/Methodology_Manual_for_ACC_AHA_Writing_Committees.pdf and http://circ.ahajournals.org/site/manual/index.xhtml. Accessed July 1, 2011.
2. Institute of Medicine. Finding What Works in Health Care: Standards for Systematic Reviews. Washington, DC: The National Academies Press, 2011.
3. Institute of Medicine. Clinical Practice Guidelines We Can Trust. Washington, DC: The National Academies Press, 2011.
4. Hawkes CA, Dhileepan S, Foxcroft D. Early extubation for adult cardiac surgical patients. Cochrane Database Syst Rev. 2003; CD003587–10.1002/14651858.CD003587.
5. Myles PS, Daly DJ, Djaiani G, et al. A systematic review of the safety and effectiveness of fast-track cardiac anesthesia. Anesthesiology. 2003;99:982–7.
6. van Mastrigt GA, Maessen JG, Heijmans J, et al. Does fast-track treatment lead to a decrease of intensive care unit and hospital length of stay in coronary artery bypass patients? A meta-regression of randomized clinical trials. Crit Care Med. 2006;34:1624–34.
7. Bainbridge D, Martin JE, Cheng DC. Patient-controlled versus nurse-controlled analgesia after cardiac surgery—a meta-analysis. Can J Anaesth. 2006;53:492–9.
8. Brennan F, Carr DB, Cousins M. Pain management: a fundamental human right. Anesth Analg. 2007;105:205–21.
9. Lahtinen P, Kokki H, Hynynen M. Pain after cardiac surgery: a prospective cohort study of 1–year incidence and intensity. Anesthesiology. 2006;105:794–800.
10. Serfontein L. Awareness in cardiac anesthesia. Curr Opin Anaesthesiol. 2010;23:103–8.
11. Taillefer M-C, Carrier M, Belisle S, et al. Prevalence, characteristics, and predictors of chronic nonanginal postoperative pain after a cardiac operation: a cross-sectional study. J Thorac Cardiovasc Surg. 2006;131:1274–80.
12. Martinez EA, Marsteller JA, Thompson DA, et al. The Society of Cardiovascular Anesthesiologists' FOCUS initiative: locating Errors through Networked Surveillance (LENS) project vision. Anesth Analg. 2010;110:307–11.
13. Wadhera RK, Parker SH, Burkhart HM, et al. Is the "sterile cockpit" concept applicable to cardiovascular surgery critical intervals or critical events? The impact of protocol-driven communication during cardiopulmonary bypass. J Thorac Cardiovasc Surg. 2010;139:312–9.
14. Neily J, Mills PD, Young-Xu Y, et al. Association between implementation of a medical team training program and surgical mortality. JAMA. 2010;304:1693–700.
15. Haynes AB, Weiser TG, Berry WR, et al. A surgical safety checklist to reduce morbidity and mortality in a global population. N Engl J Med. 2009;360:491–9.
16. Cahalan MK, Stewart W, Pearlman A, et al. American Society of Echocardiography and Society of Cardiovascular Anesthesiologists task force guidelines for training in perioperative echocardiography. J Am Soc Echocardiogr. 2002;15:647–52.
17. Mathew JP, Glas K, Troianos CA, et al. American Society of Echocardiography/Society of Cardiovascular Anesthesiologists recommendations and guidelines for continuous quality improvement in perioperative echocardiography. J Am Soc Echocardiogr. 2006; 19:1303–13.
18. Thys DM. Cardiac anesthesia: thirty years later—the second annual Arthur E. Weyman lecture. Anesth Analg. 2009;109:1782–90.
19. Dowd NP, Cheng DC, Karski JM, et al. Intraoperative awareness in fast-track cardiac anesthesia. Anesthesiology. 1998;89:1068–73.
20. Groesdonk HV, Pietzner J, Borger MA, et al. The incidence of intraoperative awareness in cardiac surgery fast-track treatment. J Cardiothorac Vasc Anesth. 2010;24:785–9.
21. Cheng DC, Karski J, Peniston C, et al. Early tracheal extubation after coronary artery bypass graft surgery reduces costs and improves resource use: a prospective, randomized, controlled trial. Anesthesiology. 1996;85:1300–10.
22. Horlocker TT, Wedel DJ, Rowlingson JC, et al. Regional anesthesia in the patient receiving antithrombotic or thrombolytic therapy: American Society of Regional Anesthesia and Pain Medicine Evidence-Based Guidelines (Third Edition). Reg Anesth Pain Med. 2010;35:64–101.
23. Murphy GS, Szokol JW, Marymont JH, et al. Recovery of neuromuscular function after cardiac surgery: pancuronium versus rocuronium. Anesth Analg. 2003;96:1301–7.
24. Nygard E, Kofoed KF, Freiberg J, et al. Effects of high thoracic epidural analgesia on myocardial blood flow in patients with ischemic heart disease. Circulation. 2005;111:2165–70.
25. Tenenbein PK, Debrouwere R, Maguire D, et al. Thoracic epidural analgesia improves pulmonary function in patients undergoing cardiac surgery. Can J Anaesth. 2008;55:344–50.
26. Nussmeier NA, Whelton AA, Brown MT, et al. Complications of the COX-2 inhibitors parecoxib and valdecoxib after cardiac surgery. N Engl J Med. 2005;352:1081–91.
27. Ott E, Nussmeier NA, Duke PC, et al. Efficacy and safety of the cyclooxygenase 2 inhibitors parecoxib and valdecoxib in patients undergoing coronary artery bypass surgery. J Thorac Cardiovasc Surg. 2003;125:1481–92.
28. Lowenstein E, Hallowell P, Levine FH, et al. Cardiovascular response to large doses of intravenous morphine in man. N Engl J Med. 1969;281:1389–93.
29. Reiz S, Balfors E, Sorensen MB, et al. Isoflurane—a powerful coronary vasodilator in patients with coronary artery disease. Anesthesiology. 1983;59:91–7.
30. Slogoff S, Keats AS, Ott E. Preoperative propranolol therapy and aortocoronary bypass operation. JAMA. 1978;240:1487–90.

31. London MJ, Shroyer AL, Grover FL. Fast tracking into the new millennium: an evolving paradigm. Anesthesiology. 1999;91:911–5.
32. Frassdorf J, De Hert S, Schlack W. Anaesthesia and myocardial ischaemia/reperfusion injury. Br J Anaesth. 2009;103:89–98.
33. Tanaka K, Ludwig LM, Kersten JR, et al. Mechanisms of cardioprotection by volatile anesthetics. Anesthesiology. 2004;100:707–21.
34. Butterworth J, James R, Prielipp RC, et al., CABG Clinical Benchmarking Data Base Participants. Do shorter-acting neuromuscular blocking drugs or opioids associate with reduced intensive care unit or hospital lengths of stay after coronary artery bypass grafting? Anesthesiology. 1998;88:1437–46.
35. Berendes E, Schmidt C, Van Aken H, et al. Reversible cardiac sympathectomy by high thoracic epidural anesthesia improves regional left ventricular function in patients undergoing coronary artery bypass grafting: a randomized trial. Arch Surg. 2003;138:1283–90.
36. Bignami E, Landoni G, Biondi-Zoccai GG, et al. Epidural analgesia improves outcome in cardiac surgery: a meta-analysis of randomized controlled trials. J Cardiothorac Vasc Anesth. 2010;24:586–97.
37. Liu SS, Block BM, Wu CL. Effects of perioperative central neuraxial analgesia on outcome after coronary artery bypass surgery: a meta-analysis. Anesthesiology. 2004;101:153–61.
38. Svircevic V, van Dijk D, Nierich A, et al. Meta-analysis of thoracic epidural anesthesia versus general anesthesia for cardiac surgery. Anesthesiology. 2010;114:271–82.
39. McDonald SB, Jacobsohn E, Kopacz DJ, et al. Parasternal block and local anesthetic infiltration with levobupivacaine after cardiac surgery with desflurane: the effect on postoperative pain, pulmonary function, and tracheal extubation times. Anesth Analg. 2005;100:25–32.
40. Horswell JL, Herbert MA, Prince SL, et al. Routine immediate extubation after off-pump coronary artery bypass surgery: 514 consecutive patients. J Cardiothorac Vasc Anesth. 2005;19:282–7.
41. Royse CF, Royse AG, Soeding PF. Routine immediate extubation after cardiac operation: a review of our first 100 patients. Ann Thorac Surg. 1999;68:1326–9.
42. Straka Z, Brucek P, Vanek T, et al. Routine immediate extubation for off-pump coronary artery bypass grafting without thoracic epidural analgesia. Ann Thorac Surg. 2002;74:1544–7.
43. van Mastrigt GA, Heijmans J, Severens JL, et al. Short-stay intensive care after coronary artery bypass surgery: randomized clinical trial on safety and cost-effectiveness. Crit Care Med. 2006;34:65–75.
44. van Mastrigt GA, Joore MA, Nieman FH, et al. Health-related quality of life after fast-track treatment results from a randomized controlled clinical equivalence trial. Qual Life Res. 2010;19:631–42.
45. Chamchad D, Horrow JC, Nachamchik L, et al. The impact of immediate extubation in the operating room after cardiac surgery on intensive care and hospital lengths of stay. J Cardiothorac Vasc Anesth. 2010;24:780–4.
46. Murphy GS, Szokol JW, Marymont JH, et al. Morphine-based cardiac anesthesia provides superior early recovery compared with fentanyl in elective cardiac surgery patients. Anesth Analg. 2009;109:311–9.
47. Antman EM, Bennett JS, Daugherty A, et al. Use of nonsteroidal antiinflammatory drugs: an update for clinicians: a scientific statement from the American Heart Association. Circulation. 2007;115:1634–42.
48. Wright RS, Anderson JL, Adams CD, et al. 2011 ACCF/AHA focused update incorporated into the ACC/AHA 2007 guidelines for the management of patients with unstable angina/non–ST-elevation myocardial infarction: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol. 2011;57:e215–367.
49. Bainbridge D, Cheng DC, Martin JE, et al. NSAID-analgesia, pain control and morbidity in cardiothoracic surgery. Can J Anaesth. 2006;53:46–59.
50. AstraZeneca. Brilinta REMS document. NDA 22-433. Reference ID: 2976456. Available at: http://www.fda.gov/downloads/Drugs/DrugSafety/PostmarketDrugSafetyInformationforPatientsandProviders/UCM264004.pdf. [Package insert]. Accessed August 16, 2011.
51. Gengo FM, Rubin L, Robson M, et al. Effects of ibuprofen on the magnitude and duration of aspirin's inhibition of platelet aggregation: clinical consequences in stroke prophylaxis. J Clin Pharmacol. 2008;48:117–22.
52. Merry AF, Ramage MC, Whitlock RM, et al. First-time coronary artery bypass grafting: the anaesthetist as a risk factor. Br J Anaesth. 1992;68:6–12.
53. Slogoff S, Keats AS. Does perioperative myocardial ischemia lead to postoperative myocardial infarction? Anesthesiology. 1985;62:107–14.
54. Walsh SR, Bhutta H, Tang TY, et al. Anaesthetic specialisation leads to improved early- and medium-term survival following major vascular surgery. Eur J Vasc Endovasc Surg. 2010;39:719–25.
55. Hirai S. Systemic inflammatory response syndrome after cardiac surgery under cardiopulmonary bypass. Ann Thorac Cardiovasc Surg. 2003;9:365–70.
56. Groom RC, Quinn RD, Lennon P, et al. Microemboli from cardiopulmonary bypass are associated with a serum marker of brain injury. J Extra Corpor Technol. 2010;42:40–4.
57. Liu YH, Wang DX, Li LH, et al. The effects of cardiopulmonary bypass on the number of cerebral microemboli and the incidence of cognitive dysfunction after coronary artery bypass graft surgery. Anesth Analg. 2009;109:1013–22.
58. Motallebzadeh R, Bland JM, Markus HS, et al. Neurocognitive function and cerebral emboli: randomized study of on-pump versus off-pump coronary artery bypass surgery. Ann Thorac Surg. 2007;83:475–82.
59. Djaiani G, Fedorko L, Borger MA, et al. Continuous-flow cell saver reduces cognitive decline in elderly patients after coronary bypass surgery. Circulation. 2007;116:1888–95.
60. Rubens FD, Boodhwani M, Mesana T, et al. The cardiotomy trial: a randomized, double-blind study to assess the effect of processing of shed blood during cardiopulmonary bypass on transfusion and neurocognitive function. Circulation. 2007;116:I89–97.
61. Shroyer AL, Grover FL, Hattler B, et al. On-pump versus off-pump coronary-artery bypass surgery. N Engl J Med. 2009;361:1827–37.
62. Rinder CS, Fontes M, Mathew JP, et al. Neutrophil CD11b upregulation during cardiopulmonary bypass is associated with postoperative renal injury. Ann Thorac Surg. 2003;75:899–905.
63. Schurr UP, Zund G, Hoerstrup SP, et al. Preoperative administration of steroids: influence on adhesion molecules and cytokines after cardiopulmonary bypass. Ann Thorac Surg. 2001;72:1316–20.
64. Werdan K, Pilz G, Muller-Werdan U, et al. Immunoglobulin G treatment of postcardiac surgery patients with score-identified severe systemic inflammatory response syndrome—the ESSICS study. CritCare Med. 2008;36:716–23.
65. Chen YF, Tsai WC, Lin CC, et al. Effect of leukocyte depletion on endothelial cell activation and transendothelial migration of leukocytes during cardiopulmonary bypass. Ann Thorac Surg. 2004;78:634–42.
66. Nesher N, Frolkis I, Vardi M, et al. Higher levels of serum cytokines and myocardial tissue markers during on-pump versus off-pump coronary artery bypass surgery. J Card Surg. 2006;21:395–402.
67. Khan NE, De Souza A, Mister R, et al. A randomized comparison of off-pump and on-pump multivessel coronary-artery bypass surgery. N Engl J Med. 2004;350:21–8.
68. Nathoe HM, van Dijk D, The Octopus Study Group, et al. A comparison of on-pump and off-pump coronary bypass surgery in low-risk patients. N Engl J Med. 2003;348:394–402.
69. Hannan EL, Wu C, Smith CR, et al. Off-pump versus on-pump coronary artery bypass graft surgery: differences in short-term outcomes and in long-term mortality and need for subsequent revascularization. Circulation. 2007;116:1145–52.
70. Kuss O, von SB, Borgermann J. Off-pump versus on-pump coronary artery bypass grafting: a systematic review and meta-analysis of propensity score analyses. J Thorac Cardiovasc Surg. 2010;140:829–35, e1–13.
71. Sellke FW, DiMaio JM, Caplan LR, et al. Comparing on-pump and off-pump coronary artery bypass grafting: numerous studies but few conclusions: a scientific statement from the American Heart Association Council on Cardiovascular Surgery and Anesthesia in collaboration with the Interdisciplinary Working Group on Quality of Care and Outcomes Research. Circulation. 2005;111:2858–64.

72. Athanasiou T, Al-Ruzzeh S, Kumar P, et al. Off-pump myocardial revascularization is associated with less incidence of stroke in elderly patients. Ann Thorac Surg. 2004;77:745–53.
73. Eifert S, Kilian E, Beiras-Fernandez A, et al. Early and mid term mortality after coronary artery bypass grafting in women depends on the surgical protocol: retrospective analysis of 3441 on- and off-pump coronary artery bypass grafting procedures. J Cardiothorac Surg. 2010;5:90. Abstract.
74. Jensen BO, Hughes P, Rasmussen LS, et al. Cognitive outcomes in elderly high-risk patients after off-pump versus conventional coronary artery bypass grafting: a randomized trial. Circulation. 2006; 113:2790–5.
75. Jensen BO, Rasmussen LS, Steinbruchel DA. Cognitive outcomes in elderly high-risk patients 1 year after off-pump versus on-pump coronary artery bypass grafting. A randomized trial. Eur J Cardiothorac Surg. 2008;34:1016–21.
76. Li Y, Zheng Z, Hu S. Early and long-term outcomes in the elderly: comparison between off-pump and on-pump techniques in 1191 patients undergoing coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2008;136:657–64.
77. Mack MJ, Brown P, Houser F, et al. On-pump versus off-pump coronary artery bypass surgery in a matched sample of women: a comparison of outcomes. Circulation. 2004;110:II1–6.
78. Moller CH, Perko MJ, Lund JT, et al. No major differences in 30–day outcomes in high-risk patients randomized to off-pump versus on-pump coronary bypass surgery: the best bypass surgery trial. Circulation. 2010;121:498–504.
79. Panesar SS, Athanasiou T, Nair S, et al. Early outcomes in the elderly: a meta-analysis of 4921 patients undergoing coronary artery bypass grafting—comparison between off-pump and on-pump techniques. Heart. 2006;92:1808–16.
80. Puskas JD, Edwards FH, Pappas PA, et al. Off-pump techniques benefit men and women and narrow the disparity in mortality after coronary bypass grafting. Ann Thorac Surg. 2007;84:1447–54.
81. Puskas JD, Kilgo PD, Kutner M, et al. Off-pump techniques disproportionately benefit women and narrow the gender disparity in outcomes after coronary artery bypass surgery. Circulation. 2007;116:I192–9.
82. Puskas JD, Thourani VH, Kilgo P, et al. Off-pump coronary artery bypass disproportionately benefits high-risk patients. Ann Thorac Surg. 2009;88:1142–7.
83. Sharony R, Bizekis CS, Kanchuger M, et al. Off-pump coronary artery bypass grafting reduces mortality and stroke in patients with atheromatous aortas: a case control study. Circulation. 2003;108 Suppl 1:II15–20.
84. Misfeld M, Potger K, Ross DE, et al. "Anaortic" off-pump coronary artery bypass grafting significantly reduces neurological complications compared to off-pump and conventional on-pump surgery with aortic manipulation. Thorac Cardiovasc Surg. 2010;58:408–14.
85. Lev-Ran O, Loberman D, Matsa M, et al. Reduced strokes in the elderly: the benefits of untouched aorta off-pump coronary surgery. Ann Thorac Surg. 2004;77:102–7.
86. Boylan MJ, Lytle BW, Loop FD, et al. Surgical treatment of isolated left anterior descending coronary stenosis: comparison of left internal mammary artery and venous autograft at 18 to 20 years of follow-up. J Thorac Cardiovasc Surg. 1994;107:657–62.
87. Cameron A, Davis KB, Green G, et al. Coronary bypass surgery with internal-thoracic-artery grafts: effects on survival over a 15–year period. N Engl J Med. 1996;334:216–9.
88. Loop FD, Lytle BW, Cosgrove DM, et al. Influence of the internal-mammary-artery graft on 10–year survival and other cardiac events. N Engl J Med. 1986;314:1–6.
89. Sabik JFI, Lytle BW, Blackstone EH, et al. Comparison of saphenous vein and internal thoracic artery graft patency by coronary system. Ann Thorac Surg. 2005;79:544–51.
90. Lytle BW, Blackstone EH, Loop FD, et al. Two internal thoracic artery grafts are better than one. J Thorac Cardiovasc Surg. 1999;117:855–72.
91. Lytle BW, Blackstone EH, Sabik JF, et al. The effect of bilateral internal thoracic artery grafting on survival during 20 postoperative years. Ann Thorac Surg. 2004;78:2005–12.
92. Sabik JFI, Blackstone EH, Gillinov AM, et al. Influence of patient characteristics and arterial grafts on freedom from coronary reoperation. J Thorac Cardiovasc Surg. 2006;131:90–8.
93. Sabik JFI, Stockins A, Nowicki ER, et al. Does location of the second internal thoracic artery graft influence outcome of coronary artery bypass grafting? Circulation. 2008;118 Suppl:S210–5.
94. Stevens LM, Carrier M, Perrault LP, et al. Single versus bilateral internal thoracic artery grafts with concomitant saphenous vein grafts for multivessel coronary artery bypass grafting: effects on mortality and event-free survival. J Thorac Cardiovasc Surg. 2004; 127:1408–15.
95. Sabik JFI, Lytle BW, Blackstone EH, et al. Does competitive flow reduce internal thoracic artery graft patency? Ann Thorac Surg. 2003;76:1490–6.
96. Acar C, Ramsheyi A, Pagny JY, et al. The radial artery for coronary artery bypass grafting: clinical and angiographic results at five years. J Thorac Cardiovasc Surg. 1998;116:981–9.
97. Maniar HS, Sundt TM, Barner HB, et al. Effect of target stenosis and location on radial artery graft patency. J Thorac Cardiovasc Surg. 2002;123:45–52.
98. Moran SV, Baeza R, Guarda E, et al. Predictors of radial artery patency for coronary bypass operations. Ann Thorac Surg. 2001;72: 1552–6.
99. Possati G, Gaudino M, Alessandrini F, et al. Midterm clinical and angiographic results of radial artery grafts used for myocardial revascularization. J Thorac Cardiovasc Surg. 1998;116:1015–21.
100. Royse AG, Royse CF, Tatoulis J, et al. Postoperative radial artery angiography for coronary artery bypass surgery. Eur J Cardiothorac Surg. 2000;17:294–304.
101. Desai ND, Cohen EA, Naylor CD, et al. A randomized comparison of radial-artery and saphenous-vein coronary bypass grafts. N Engl J Med. 2004;351:2302–9.
102. FitzGibbon GM, Kafka HP, Leach AJ, et al. Coronary bypass graft fate and patient outcome: angiographic follow-up of 5,065 grafts related to survival and reoperation in 1,388 patients during 25 years. J Am Coll Cardiol. 1996;28:616–26.
103. Chesebro JH, Fuster V, Elveback LR, et al. Effect of dipyridamole and aspirin on late vein-graft patency after coronary bypass operations. N Engl J Med. 1984;310:209–14.
104. Bourassa MG, Fisher LD, Campeau L, et al. Long-term fate of bypass grafts: the Coronary Artery Surgery Study (CASS) and Montreal Heart Institute experiences. Circulation. 1985;72:V71–8.
105. Fuster V, Dewanjee MK, Kaye MP, et al. Noninvasive radioisotopic technique for detection of platelet deposition in coronary artery bypass grafts in dogs and its reduction with platelet inhibitors. Circulation. 1979;60:1508–12.
106. Chesebro JH, Clements IP, Fuster V, et al. A platelet-inhibitor-drug trial in coronary-artery bypass operations: benefit of perioperative dipyridamole and aspirin therapy on early postoperative vein-graft patency. N Engl J Med. 1982;307:73–8.
107. Metke MP, Lie JT, Fuster V, et al. Reduction of intimal thickening in canine coronary bypass vein grafts with dipyridamole and aspirin. Am J Cardiol. 1979;43:1144–8.
108. Tector AJ, Kress DC, Downey FX, et al. Complete revascularization with internal thoracic artery grafts. Semin Thorac Cardiovasc Surg. 1996;8:29–41.
109. FitzGibbon GM, Kafka HP, Leach AJ, et al. Interventions for coronary stenosis—a Canadian experience of 30 revolutionary years. Can J Cardiol. 1996;12:893–900.
110. Grondin CM, Campeau L, Lesperance J, et al. Comparison of late changes in internal mammary artery and saphenous vein grafts in two consecutive series of patients 10 years after operation. Circulation. 1984;70:I208–12.
111. Barner HB, Standeven JW, Reese J. Twelve-year experience with internal mammary artery for coronary artery bypass. J Thorac Cardiovasc Surg. 1985;90:668–75.
112. Fiore AC, Naunheim KS, Dean P, et al. Results of internal thoracic artery grafting over 15 years: single versus double grafts. Ann Thorac Surg. 1990;49:202–8.
113. Pick AW, Orszulak TA, Anderson BJ, et al. Single versus bilateral internal mammary artery grafts: 10–year outcome analysis. Ann Thorac Surg. 1997;64:599–605.
114. Galbut DL, Traad EA, Dorman MJ, et al. Seventeen-year experience with bilateral internal mammary artery grafts. Ann Thorac Surg. 1990;49:195–201.
115. Lytle BW, Loop FD, Thurer RL, et al. Isolated left anterior descending coronary atherosclerosis: long-term comparison of in-

ternal mammary artery and venous autografts. Circulation. 1980;61:869–74.
116. Bjork VO, Ivert T, Landou C. Angiographic changes in internal mammary artery and saphenous vein grafts, two weeks, one year and five years after coronary bypass surgery. Scand J Thorac Cardiovasc Surg. 1981;15:23–30.
117. Barner HB, Barnett MG. Fifteen- to twenty-one-year angiographic assessment of internal thoracic artery as a bypass conduit. Ann Thorac Surg. 1994;57:1526–8.
118. Barner HB. Double internal mammary-coronary artery bypass. Arch Surg. 1974;109:627–30.
119. Sims FH. A comparison of coronary and internal mammary arteries and implications of the results in the etiology of arteriosclerosis. Am Heart J. 1983;105:560–6.
120. Sisto T, Isola J. Incidence of atherosclerosis in the internal mammary artery. Ann Thorac Surg. 1989;47:884–6.
121. Pearson PJ, Evora PR, Schaff HV. Bioassay of EDRF from internal mammary arteries: implications for early and late bypass graft patency. Ann Thorac Surg. 1992;54:1078–84.
122. Luscher TF, Diederich D, Siebenmann R, et al. Difference between endothelium-dependent relaxation in arterial and in venous coronary bypass grafts. N Engl J Med. 1988;319:462–7.
123. Ivert T, Huttunen K, Landou C, et al. Angiographic studies of internal mammary artery grafts 11 years after coronary artery bypass grafting. J Thorac Cardiovasc Surg. 1988;96:1–12.
124. Geha AS, Baue AE. Early and lage results of coronary revascularization with saphenous vein and internal mammary artery grafts. Am J Surg. 1979;137:456–63.
125. Hashimoto H, Isshiki T, Ikari Y, et al. Effects of competitive blood flow on arterial graft patency and diameter. Medium-term postoperative follow-up. J Thorac Cardiovasc Surg. 1996;111:399–407.
126. Seki T, Kitamura S, Kawachi K, et al. A quantitative study of postoperative luminal narrowing of the internal thoracic artery graft in coronary artery bypass surgery. J Thorac Cardiovasc Surg. 1992;104:1532–8.
127. Pagni S, Storey J, Ballen J, et al. ITA versus SVG: a comparison of instantaneous pressure and flow dynamics during competitive flow. Eur J Cardiothorac Surg. 1997;11:1086–92.
128. Shimizu T, Hirayama T, Suesada H, et al. Effect of flow competition on internal thoracic artery graft: postoperative velocimetric and angiographic study. J Thorac Cardiovasc Surg. 2000;120:459–65.
129. Pagni S, Storey J, Ballen J, et al. Factors affecting internal mammary artery graft survival: how is competitive flow from a patent native coronary vessel a risk factor? J Surg Res. 1997;71:172–8.
130. Nasu M, Akasaka T, Okazaki T, et al. Postoperative flow characteristics of left internal thoracic artery grafts. Ann Thorac Surg. 1995;59:154–61.
131. Glineur D, D'hoore W, El Khoury G, et al. Angiographic predictors of 6–month patency of bypass grafts implanted to the right coronary artery a prospective randomized comparison of gastroepiploic artery and saphenous vein grafts. J Am Coll Cardiol. 2008;51:120–5.
132. Suma H, Isomura T, Horii T, et al. Late angiographic result of using the right gastroepiploic artery as a graft. J Thorac Cardiovasc Surg. 2000;120:496–8.
133. Gurne O, Buche M, Chenu P, et al. Quantitative angiographic follow-up study of the free inferior epigastric coronary bypass graft. Circulation. 1994;90:II148–54.
134. Buche M, Schroeder E, Gurne O, et al. Coronary artery bypass grafting with the inferior epigastric artery. Midterm clinical and angiographic results. J Thorac Cardiovasc Surg. 1995;109:553–9.
135. Bonaros N, Schachner T, Wiedemann D, et al. Quality of life improvement after robotically assisted coronary artery bypass grafting. Cardiology. 2009;114:59–66.
136. Svensson LG, Atik FA, Cosgrove DM, et al. Minimally invasive versus conventional mitral valve surgery: a propensity-matched comparison. J Thorac Cardiovasc Surg. 2010;139:926–32.
137. Eltzschig HK, Rosenberger P, Loffler M, et al. Impact of intraoperative transesophageal echocardiography on surgical decisions in 12,566 patients undergoing cardiac surgery. Ann Thorac Surg. 2008;85:845–52.
138. Savage RM, Lytle BW, Aronson S, et al. Intraoperative echocardiography is indicated in high-risk coronary artery bypass grafting. Ann Thorac Surg. 1997;64:368–73.
139. Practice guidelines for perioperative transesophageal echocardiography. An updated report by the American Society of Anesthesiologists and the Society of Cardiovascular Anesthesiologists Task Force on Transesophageal Echocardiography. Anesthesiology. 2010;112:1084–96.
140. Bergquist BD, Bellows WH, Leung JM. Transesophageal echocardiography in myocardial revascularization: II. Influence on intraoperative decision making. Anesth Analg. 1996;82:1139–45.
141. Moises VA, Mesquita CB, Campos O, et al. Importance of intraoperative transesophageal echocardiography during coronary artery surgery without cardiopulmonary bypass. J Am Soc Echocardiogr. 1998;11:1139–44.
142. Qaddoura FE, Abel MD, Mecklenburg KL, et al. Role of intraoperative transesophageal echocardiography in patients having coronary artery bypass graft surgery. Ann Thorac Surg. 2004;78:1586–90.
143. Swaminathan M, Morris RW, De Meyts DD, et al. Deterioration of regional wall motion immediately after coronary artery bypass graft surgery is associated with long-term major adverse cardiac events. Anesthesiology. 2007;107:739–45.
144. Wang J, Filipovic M, Rudzitis A, et al. Transesophageal echocardiography for monitoring segmental wall motion during off-pump coronary artery bypass surgery. Anesth Analg. 2004;99:965–73.
145. Zimarino M, Gallina S, Di Fulvio M., et al. Intraoperative ischemia and long-term events after minimally invasive coronary surgery. Ann Thorac Surg. 2004;78:135–41.
146. Shanewise JS, Cheung AT, Aronson S, et al. ASE/SCA guidelines for performing a comprehensive intraoperative multiplane transesophageal echocardiography examination: recommendations of the American Society of Echocardiography Council for Intraoperative Echocardiography and the Society of Cardiovascular Anesthesiologists Task Force for Certification in Perioperative Transesophageal Echocardiography. Anesth Analg. 1999;89:870–84.
147. Glas KE, Swaminathan M, Reeves ST, et al. Guidelines for the performance of a comprehensive intraoperative epiaortic ultrasonographic examination: recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. Anesth Analg. 2008;106:1376–84.
148. Reeves ST, Glas KE, Eltzschig H, et al. Guidelines for performing a comprehensive epicardial echocardiography examination: recommendations of the American Society of Echocardiography and the Society of Cardiovascular Anesthesiologists. J Am Soc Echocardiogr. 2007;20:427–37.
149. Cheitlin MD, Armstrong WF, Aurigemma GP, et al. ACC/AHA/ASE 2003 guideline update for the clinical application of echocardiography—summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (ACC/AHA/ASE Committee to Update the 1997 Guidelines for the Clinical Application of Echocardiography). J Am Coll Cardiol. 2003;42:954–70.
150. Cheung AT, Savino JS, Weiss SJ, et al. Echocardiographic and hemodynamic indexes of left ventricular preload in patients with normal and abnormal ventricular function. Anesthesiology. 1994;81:376–87.
151. Fontes ML, Bellows W, Ngo L, et al. Assessment of ventricular function in critically ill patients: limitations of pulmonary artery catheterization. Institutions of the McSPI Research Group. J Cardiothorac Vasc Anesth. 1999;13:521–7.
152. Geyer H, Caracciolo G, Abe H, et al. Assessment of myocardial mechanics using speckle tracking echocardiography: fundamentals and clinical applications [published correction appears in J Am Soc Echocardiogr. 2010;23:734]. J Am Soc Echocardiogr. 2010;23:351–369.
153. Jenkins C, Moir S, Chan J, et al. Left ventricular volume measurement with echocardiography: a comparison of left ventricular opacification, three-dimensional echocardiography, or both with magnetic resonance imaging. Eur Heart J. 2009;30:98–106.
154. Skubas N. Intraoperative Doppler tissue imaging is a valuable addition to cardiac anesthesiologists' armamentarium: a core review. Anesth Analg. 2009;108:48–66.
155. Jacka MJ, Cohen MM, To T, et al. The use of and preferences for the transesophageal echocardiogram and pulmonary artery catheter among cardiovascular anesthesiologists. Anesth Analg. 2002;94:1065–71.

156. Argenziano M, Katz M, Bonatti J, et al. Results of the prospective multicenter trial of robotically assisted totally endoscopic coronary artery bypass grafting. Ann Thorac Surg. 2006;81:1666–74.
157. Bonatti J, Schachner T, Bonaros N, et al. Technical challenges in totally endoscopic robotic coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2006;131:146–53.
158. Chaney MA, Durazo-Arvizu RA, Fluder EM, et al. Port-access minimally invasive cardiac surgery increases surgical complexity, increases operating room time, and facilitates early postoperative hospital discharge. Anesthesiology. 2000;92:1637–45.
159. Gurbuz AT, Hecht ML, Arslan AH. Intraoperative transesophageal echocardiography modifies strategy in off-pump coronary artery bypass grafting. Ann Thorac Surg. 2007;83:1035–40.
160. Kato M, Nakashima Y, Levine J, et al. Does transesophageal echocardiography improve postoperative outcome in patients undergoing coronary artery bypass surgery? J Cardiothorac Vasc Anesth. 1993;7:285–9.
161. Kihara C, Murata K, Wada Y, et al. Impact of intraoperative transesophageal echocardiography in cardiac and thoracic aortic surgery: Experience in 1011 cases. J Cardiol. 2009;54:282–8.
162. Mierdl S, Byhahn C, Dogan S, et al. Segmental wall motion abnormalities during telerobotic totally endoscopic coronary artery bypass grafting. Anesth Analg. 2002;94:774–80.
163. Turner WF Jr., Sloan JH. Robotic-assisted coronary artery bypass on a beating heart: initial experience and implications for the future. Ann Thorac Surg. 2006;82:790–4.
164. Kallmeyer IJ, Collard CD, Fox JA, et al. The safety of intraoperative transesophageal echocardiography: a case series of 7200 cardiac surgical patients. Anesth Analg. 2001;92:1126–30.
165. Min JK, Spencer KT, Furlong KT, et al. Clinical features of complications from transesophageal echocardiography: a single-center case series of 10,000 consecutive examinations. J Am Soc Echocardiogr. 2005;18:925–9.
166. Augoustides JG, Hosalkar HH, Milas BL, et al. Upper gastrointestinal injuries related to perioperative transesophageal echocardiography: index case, literature review, classification proposal, and call for a registry. J Cardiothorac Vasc Anesth. 2006;20:379–84.
167. Ramadan AS, Stefanidis C, Ngatchou W, et al. Esophageal stents for iatrogenic esophageal perforations during cardiac surgery. Ann Thorac Surg. 2007;84:1034–6.
168. Hogue CW Jr., Lappas GD, Creswell LL, et al. Swallowing dysfunction after cardiac operations. Associated adverse outcomes and risk factors including intraoperative transesophageal echocardiography. J Thorac Cardiovasc Surg. 1995;110:517–22.
169. Partik BL, Scharitzer M, Schueller G, et al. Videofluoroscopy of swallowing abnormalities in 22 symptomatic patients after cardiovascular surgery. Am J Roentgenol. 2003;180:987–92.
170. Rousou JA, Tighe DA, Garb JL, et al. Risk of dysphagia after transesophageal echocardiography during cardiac operations. Ann Thorac Surg. 2000;69:486–9.
171. Harrington OB, Duckworth JK, Starnes CL, et al. Silent aspiration after coronary artery bypass grafting. Ann Thorac Surg. 1998;65:1599–603.
172. Sukernik MR, Bennett-Guerrero E. The incidental finding of a patent foramen ovale during cardiac surgery: should it always be repaired? A core review. Anesth Analg. 2007;105:602–10.
173. Krasuski RA, Hart SA, Allen D, et al. Prevalence and repair of intraoperatively diagnosed patent foramen ovale and association with perioperative outcomes and long-term survival. JAMA. 2009;302:290–7.
174. Dyub AM, Whitlock RP, Abouzahr LL, et al. Preoperative intra-aortic balloon pump in patients undergoing coronary bypass surgery: a systematic review and meta-analysis. J Card Surg. 2008;23:79–86.
175. Heusch G. Heart rate in the pathophysiology of coronary blood flow and myocardial ischaemia: benefit from selective bradycardic agents. Br J Pharmacol. 2008;153:1589–601.
176. Gibbons RJ, Balady GJ, Bricker JT, et al. ACC/AHA 2002 guideline update for exercise testing: summary article: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1997 Exercise Testing Guidelines) [published correction appears in J Am Coll Cardiol. 2006;48:1731]. J Am Coll Cardiol. 2002;40:1531–40.
177. Lavana JD, Fraser JF, Smith SE, et al. Influence of timing of intraaortic balloon placement in cardiac surgical patients. J Thorac Cardiovasc Surg. 2010;140:80–5.
178. Landoni G, Biondi-Zoccai GG, Zangrillo A, et al. Desflurane and sevoflurane in cardiac surgery: a meta-analysis of randomized clinical trials. J Cardiothorac Vasc Anesth. 2007;21:502–11.
179. Lucchinetti E, Hofer C, Bestmann L, et al. Gene regulatory control of myocardial energy metabolism predicts postoperative cardiac function in patients undergoing off-pump coronary artery bypass graft surgery: inhalational versus intravenous anesthetics. Anesthesiology. 2007;106:444–57.
180. Yao YT, Li LH. Sevoflurane versus propofol for myocardial protection in patients undergoing coronary artery bypass grafting surgery: a meta-analysis of randomized controlled trials. Chin Med Sci J. 2009;24:133–41.
181. Yu CH, Beattie WS. The effects of volatile anesthetics on cardiac ischemic complications and mortality in CABG: a meta-analysis. Can J Anaesth. 2006;53:906–18.
182. Rabi D, Clement F, McAlister F, et al. Effect of perioperative glucose-insulin-potassium infusions on mortality and atrial fibrillation after coronary artery bypass grafting: a systematic review and meta-analysis. Can J Cardiol. 2010;26:178–84.
183. Buckberg GD. Controlled reperfusion after ischemia may be the unifying recovery denominator. J Thorac Cardiovasc Surg. 2010;140:12–8.
184. Alexander JH, Emery R Jr., Carrier M, et al. Efficacy and safety of pyridoxal 5'-phosphate (MC-1) in high-risk patients undergoing coronary artery bypass graft surgery: the MEND-CABG II randomized clinical trial. JAMA. 2008;299:1777–87.
185. Mangano DT. Effects of acadesine on myocardial infarction, stroke, and death following surgery: a meta-analysis of the 5 international randomized trials: the Multicenter Study of Perioperative Ischemia (McSPI) Research Group. JAMA. 1997;277:325–32.
186. Mangano DT, Miao Y, Tudor IC, et al. Post-reperfusion myocardial infarction: long-term survival improvement using adenosine regulation with acadesine. J Am Coll Cardiol. 2006;48:206–14.
187. Shernan SK, Fitch JC, Nussmeier NA, et al. Impact of pexelizumab, an anti-C5 complement antibody, on total mortality and adverse cardiovascular outcomes in cardiac surgical patients undergoing cardiopulmonary bypass. Ann Thorac Surg. 2004;77:942–9.
188. Smith PK, Shernan SK, Chen JC, et al. Effects of C5 complement inhibitor pexelizumab on outcome in high-risk coronary artery bypass grafting: Combined results from the PRIMO-CABG I and II trials. J Thorac Cardiovasc Surg. 2010;142:89–98.
189. Testa L, Van Gaal WJ, Bhindi R, et al. Pexelizumab in ischemic heart disease: a systematic review and meta-analysis on 15,196 patients. J Thorac Cardiovasc Surg. 2008;136:884–93.
190. Laurikka J, Wu ZK, Iisalo P, et al. Regional ischemic preconditioning enhances myocardial performance in off-pump coronary artery bypass grafting. Chest. 2002;121:1183–9.
191. Penttila HJ, Lepojarvi MV, Kaukoranta PK, et al. Ischemic preconditioning does not improve myocardial preservation during off-pump multivessel coronary operation. Ann Thorac Surg. 2003;75:1246–52.
192. Walsh SR, Tang TY, Kullar P, et al. Ischaemic preconditioning during cardiac surgery: systematic review and meta-analysis of perioperative outcomes in randomised clinical trials. Eur J Cardiothorac Surg. 2008;34:985–94.
193. Hausenloy DJ, Mwamure PK, Venugopal V, et al. Effect of remote ischaemic preconditioning on myocardial injury in patients undergoing coronary artery bypass graft surgery: a randomised controlled trial. Lancet. 2007;370:575–9.
194. Rahman IA, Mascaro JG, Steeds RP, et al. Remote ischemic preconditioning in human coronary artery bypass surgery: from promise to disappointment? Circulation. 2010;122 Suppl:S53–9.
195. Venugopal V, Hausenloy DJ, Ludman A, et al. Remote ischaemic preconditioning reduces myocardial injury in patients undergoing cardiac surgery with cold-blood cardioplegia: a randomised controlled trial. Heart. 2009;95:1567–71.
196. Luo W, Li B, Chen R, et al. Effect of ischemic postconditioning in adult valve replacement. Eur J Cardiothorac Surg. 2008;33:203–8.
197. Ovize M, Baxter GF, Di Lisa F, et al. Postconditioning and protection from reperfusion injury: where do we stand? Position paper

from the Working Group of Cellular Biology of the Heart of the European Society of Cardiology. Cardiovasc Res. 2010;87:406–23.
198. Mohammed AA, Agnihotri AK, van Kimmenade RR, et al. Prospective, comprehensive assessment of cardiac troponin T testing after coronary artery bypass graft surgery. Circulation. 2009;120: 843–50.
199. Ramsay J, Shernan S, Fitch J, et al. Increased creatine kinase MB level predicts postoperative mortality after cardiac surgery independent of new Q waves. J Thorac Cardiovasc Surg. 2005;129:300–6.
200. Yau JM, Alexander JH, Hafley G, et al. Impact of perioperative myocardial infarction on angiographic and clinical outcomes following coronary artery bypass grafting (from PRoject of Ex-vivo Vein graft ENgineering via Transfection [PREVENT] IV). Am J Cardiol. 2008;102:546–51.
201. Chowdhury UK, Malik V, Yadav R, et al. Myocardial injury in coronary artery bypass grafting: on-pump versus off-pump comparison by measuring high-sensitivity C-reactive protein, cardiac troponin I, heart-type fatty acid-binding protein, creatine kinase-MB, and myoglobin release. J Thorac Cardiovasc Surg. 2008;135:1110–9,9.
202. Rahimi K, Banning AP, Cheng AS, et al. Prognostic value of coronary revascularisation-related myocardial injury: a cardiac magnetic resonance imaging study. Heart. 2009;95:1937–43.
203. Thygesen K, Alpert JS, White HD. Universal definition of myocardial infarction. J Am Coll Cardiol. 2007;50:2173–95.
204. Venge P, Johnston N, Lindahl B, et al. Normal plasma levels of cardiac troponin I measured by the high-sensitivity cardiac troponin I access prototype assay and the impact on the diagnosis of myocardial ischemia. J Am Coll Cardiol. 2009;54:1165–72.
205. Yellon DM, Hausenloy DJ. Myocardial reperfusion injury. N Engl J Med. 2007;357:1121–35.
206. Mentzer RM Jr., Bartels C, Bolli R, et al. Sodium-hydrogen exchange inhibition by cariporide to reduce the risk of ischemic cardiac events in patients undergoing coronary artery bypass grafting: results of the Expedition study. Ann Thorac Surg. 2008;85: 1261–70.
207. Turer AT, Hill JA. Pathogenesis of myocardial ischemia-reperfusion injury and rationale for therapy. Am J Cardiol. 2010; 106:360–8.
208. Ghorbel MT, Cherif M, Mokhtari A, et al. Off-pump coronary artery bypass surgery is associated with fewer gene expression changes in the human myocardium in comparison with on-pump surgery. Physiol Genomics. 2010;42:67–75.
209. Podgoreanu MV, Schwinn DA. New paradigms in cardiovascular medicine: emerging technologies and practices: perioperative genomics. J Am Coll Cardiol. 2005;46:1965–77.
210. Castellheim A, Hoel TN, Videm V, et al. Biomarker profile in off-pump and on-pump coronary artery bypass grafting surgery in low-risk patients. Ann Thorac Surg. 2008;85:1994–2002.
211. Parolari A, Camera M, Alamanni F, et al. Systemic inflammation after on-pump and off-pump coronary bypass surgery: a one-month follow-up. Ann Thorac Surg. 2007;84:823–8.
212. Paulitsch FS, Schneider D, Sobel BE, et al. Hemostatic changes and clinical sequelae after on-pump compared with off-pump coronary artery bypass surgery: a prospective randomized study. Coron Artery Dis. 2009;20:100–5.
213. Serrano CV Jr., Souza JA, Lopes NH, et al. Reduced expression of systemic proinflammatory and myocardial biomarkers after off-pump versus on-pump coronary artery bypass surgery: a prospective randomized study. J Crit Care. 2010;25:305–12.
214. Ghosh S, Galinanes M. Protection of the human heart with ischemic preconditioning during cardiac surgery: role of cardiopulmonary bypass. J Thorac Cardiovasc Surg. 2003;126:133–42.
215. Jenkins DP, Pugsley WB, Alkhulaifi AM, et al. Ischaemic preconditioning reduces troponin T release in patients undergoing coronary artery bypass surgery. Heart. 1997;77:314–8.
216. Loubani M, Ghosh S, Galinanes M. The aging human myocardium: tolerance to ischemia and responsiveness to ischemic preconditioning. J Thorac Cardiovasc Surg. 2003;126:143–7.
217. Wu ZK, Iivainen T, Pehkonen E, et al. Ischemic preconditioning suppresses ventricular tachyarrhythmias after myocardial revascularization. Circulation. 2002;106:3091–6.
218. Walsh SR, Tang T, Sadat U, et al. Cardioprotection by remote ischaemic preconditioning. Br J Anaesth. 2007;99:611–6.
219. Murphy GS, Szokol JW, Marymont JH, et al. Opioids and cardioprotection: the impact of morphine and fentanyl on recovery of ventricular function after cardiopulmonary bypass. J Cardiothorac Vasc Anesth. 2006;20:493–502.
220. Peart JN, Gross GJ. Cardioprotective effects of acute and chronic opioid treatment are mediated via different signaling pathways. Am J Physiol Heart Circ Physiol. 2006;291:H1746–53.
221. Wang B, Shravah J, Luo H, et al. Propofol protects against hydrogen peroxide-induced injury in cardiac H9c2 cells via Akt activation and Bcl-2 up-regulation. Biochem Biophys Res Commun. 2009;389:105–11.
222. Xia Z, Huang Z, Ansley DM. Large-dose propofol during cardiopulmonary bypass decreases biochemical markers of myocardial injury in coronary surgery patients: a comparison with isoflurane. Anesth Analg. 2006;103:527–32.
223. De Hert SG, ten Broecke PW, Mertens E, et al. Sevoflurane but not propofol preserves myocardial function in coronary surgery patients. Anesthesiology. 2002;97:42–9.
224. De Hert SG, Van der Linden PJ, Cromheecke S, et al. Cardioprotective properties of sevoflurane in patients undergoing coronary surgery with cardiopulmonary bypass are related to the modalities of its administration. Anesthesiology. 2004;101:299–310.
225. De Hert SG, Van der Linden PJ, Cromheecke S, et al. Choice of primary anesthetic regimen can influence intensive care unit length of stay after coronary surgery with cardiopulmonary bypass. Anesthesiology. 2004;101:9–20.
226. Garcia C, Julier K, Bestmann L, et al. Preconditioning with sevoflurane decreases PECAM-1 expression and improves one-year cardiovascular outcome in coronary artery bypass graft surgery. Br J Anaesth. 2005;94:159–65.
227. Julier K, da Silva R, Garcia C, et al. Preconditioning by sevoflurane decreases biochemical markers for myocardial and renal dysfunction in coronary artery bypass graft surgery: a double-blinded, placebo-controlled, multicenter study. Anesthesiology. 2003;98:1315–27.
228. Fillinger MP, Surgenor SD, Hartman GS, et al. The association between heart rate and in-hospital mortality after coronary artery bypass graft surgery. Anesth Analg. 2002;95:1483–8.
229. Fox K, Ford I, Steg PG, et al. Heart rate as a prognostic risk factor in patients with coronary artery disease and left-ventricular systolic dysfunction (BEAUTIFUL): a subgroup analysis of a randomised controlled trial. Lancet. 2008;372:817–21.
230. Breisblatt WM, Stein KL, Wolfe CJ, et al. Acute myocardial dysfunction and recovery: a common occurrence after coronary bypass surgery. J Am Coll Cardiol. 1990;15:1261–9.
231. Ekery DL, Davidoff R, Orlandi QG, et al. Imaging and diagnostic testing: diastolic dysfunction after coronary artery bypass grafting: a frequent finding of clinical significance not influenced by intravenous calcium. Am Heart J. 2003;145:896–902.
232. Bijker JB, van Klei WA, Kappen TH, et al. Incidence of intraoperative hypotension as a function of the chosen definition: literature definitions applied to a retrospective cohort using automated data collection. Anesthesiology. 2007;107:213–20.
233. Aronson S, Stafford-Smith M, Phillips-Bute B, et al. Intraoperative systolic blood pressure variability predicts 30-day mortality in aortocoronary bypass surgery patients. Anesthesiology. 2010;113: 305–12.
234. Nikolov NM, Fontes ML, White WD, et al. Pulse pressure and long-term survival after coronary artery bypass graft surgery. Anesth Analg. 2010;110:335–40.
235. Alexiou K, Kappert U, Staroske A, et al. Coronary surgery for acute coronary syndrome: which determinants of outcome remain? Clin Res Cardiol. 2008;97:601–8.
236. Chiu FC, Chang SN, Lin JW, et al. Coronary artery bypass graft surgery provides better survival in patients with acute coronary syndrome or ST-segment elevation myocardial infarction experiencing cardiogenic shock after percutaneous coronary intervention: a propensity score analysis. J Thorac Cardiovasc Surg. 2009;138: 1326–30.
237. DeWood MA, Spores J, Berg R Jr., et al. Acute myocardial infarction: a decade of experience with surgical reperfusion in 701 patients. Circulation. 1983;68:II8–16.
238. Donatelli F, Benussi S, Triggiani M, et al. Surgical treatment for life-threatening acute myocardial infarction: a prospective protocol. Eur J Cardiothorac Surg. 1997;11:228–33.

239. Filizcan U, Kurc E, Cetemen S, et al. Mortality predictors in ST-elevated myocardial infarction patients undergoing coronary artery bypass grafting. Angiology. 2011;62:68–73.
240. Chevalier P, Burri H, Fahrat F, et al. Perioperative outcome and long-term survival of surgery for acute post-infarction mitral regurgitation. Eur J Cardiothorac Surg. 2004;26:330–5.
241. Lemery R, Smith HC, Giuliani ER, et al. Prognosis in rupture of the ventricular septum after acute myocardial infarction and role of early surgical intervention. Am J Cardiol. 1992;70:147–51.
242. Russo A, Suri RM, Grigioni F, et al. Clinical outcome after surgical correction of mitral regurgitation due to papillary muscle rupture. Circulation. 2008;118:1528–34.
243. Shamshad F, Kenchaiah S, Finn PV, et al. Fatal myocardial rupture after acute myocardial infarction complicated by heart failure, left ventricular dysfunction, or both: the VALsartan In Acute myocardial iNfarcTion Trial (VALIANT). Am Heart J. 2010;160:145–51.
244. Tavakoli R, Weber A, Brunner-La Rocca H, et al. Results of surgery for irreversible moderate to severe mitral valve regurgitation secondary to myocardial infarction. Eur J Cardiothorac Surg. 2002;21:818–24.
245. Hochman JS, Sleeper LA, Webb JG, et al. Early revascularization in acute myocardial infarction complicated by cardiogenic shock: SHOCK Investigators: Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock. N Engl J Med. 1999; 341:625–34.
246. Mehta RH, Lopes RD, Ballotta A, et al. Percutaneous coronary intervention or coronary artery bypass surgery for cardiogenic shock and multivessel coronary artery disease? Am Heart J. 2010;159: 141–7.
247. White HD, Assmann SF, Sanborn TA, et al. Comparison of percutaneous coronary intervention and coronary artery bypass grafting after acute myocardial infarction complicated by cardiogenic shock: results from the Should We Emergently Revascularize Occluded Coronaries for Cardiogenic Shock (SHOCK) trial. Circulation. 2005;112:1992–2001.
248. Ngaage DL, Cale AR, Cowen ME, et al. Early and late survival after surgical revascularization for ischemic ventricular fibrillation/ tachycardia. Ann Thorac Surg. 2008;85:1278–81.
249. Parikh SV, de Lemos JA, Jessen ME, et al. Timing of in-hospital coronary artery bypass graft surgery for non-ST-segment elevation myocardial infarction patients results from the National Cardiovascular Data Registry ACTION Registry-GWTG (Acute Coronary Treatment and Intervention Outcomes Network Registry-Get With The Guidelines). J Am Coll Cardiol Intv. 2010;3:419–27.
250. Lim HS, Farouque O, Andrianopoulos N, et al. Survival of elderly patients undergoing percutaneous coronary intervention for acute myocardial infarction complicated by cardiogenic shock. J Am Coll Cardiol Intv. 2009;2:146–52.
251. Amin AP, Nathan S, Prodduturi P, et al. Survival benefit from early revascularization in elderly patients with cardiogenic shock after acute myocardial infarction: a cohort study. J Invasive Cardiol. 2009;21:305–12.
252. Migliorini A, Moschi G, Valenti R, et al. Routine percutaneous coronary intervention in elderly patients with cardiogenic shock complicating acute myocardial infarction. Am Heart J. 2006;152: 903–8.
253. Hochman JS, Buller CE, Sleeper LA, et al. Cardiogenic shock complicating acute myocardial infarction—etiologies, management and outcome: a report from the SHOCK Trial Registry: SHould we emergently revascularize Occluded Coronaries for cardiogenic shocK? J Am Coll Cardiol. 2000;36:1063–70.
254. Dzavik V, Sleeper LA, Cocke TP, et al. Early revascularization is associated with improved survival in elderly patients with acute myocardial infarction complicated by cardiogenic shock: a report from the SHOCK Trial Registry. Eur Heart J. 2003;24:828–37.
255. Coskun KO, Coskun ST, Popov AF, et al. Experiences with surgical treatment of ventricle septal defect as a post infarction complication. J Cardiothorac Surg. 2009;4:3.
256. Oliva PB, Hammill SC, Edwards WD. Cardiac rupture, a clinically predictable complication of acute myocardial infarction: report of 70 cases with clinicopathologic correlations. J Am Coll Cardiol. 1993; 22:720–6.
257. Kjaergard H, Nielsen PH, Andreasen JJ, et al. Coronary artery bypass grafting within 30 days after treatment of acute myocardial infarctions with angioplasty or fibrinolysis—a surgical substudy of DANAMI-2. Scand Cardiovasc J. 2004;38:143–6.
258. Stone GW, Brodie BR, Griffin JJ, et al. Role of cardiac surgery in the hospital phase management of patients treated with primary angioplasty for acute myocardial infarction. Am J Cardiol. 2000;85: 1292–6.
259. Creswell LL, Moulton MJ, Cox JL, et al. Revascularization after acute myocardial infarction. Ann Thorac Surg. 1995;60:19–26.
260. Kamohara K, Yoshikai M, Yunoki J, et al. Surgical revascularization for acute coronary syndrome: comparative surgical and long-term results. Jpn J Thorac Cardiovasc Surg. 2006;54:95–102.
261. Kjaergard HK, Nielsen PH, Andreasen JJ, et al. Coronary artery bypass grafting within the first year after treatment of large acute myocardial infarctions with angioplasty or fibrinolysis. Scand Cardiovasc J. 2006;40:25–8.
262. Lee DC, Oz MC, Weinberg AD, et al. Optimal timing of revascularization: transmural versus nontransmural acute myocardial infarction. Ann Thorac Surg. 2001;71:1197–202.
263. Wasvary H, Shannon F, Bassett J, et al. Timing of coronary artery bypass grafting after acute myocardial infarction. Am Surg. 1997; 63:710–5.
264. Weiss ES, Chang DD, Joyce DL, et al. Optimal timing of coronary artery bypass after acute myocardial infarction: a review of California discharge data. J Thorac Cardiovasc Surg. 2008;135:503–11, e1–3.
265. Lee JH, Murrell HK, Strony J, et al. Risk analysis of coronary bypass surgery after acute myocardial infarction. Surgery. 1997;122:675–80.
266. Thielmann M, Neuhauser M, Marr A, et al. Predictors and outcomes of coronary artery bypass grafting in ST elevation myocardial infarction. Ann Thorac Surg. 2007;84:17–24.
267. Purcaro A, Costantini C, Ciampani N, et al. Diagnostic criteria and management of subacute ventricular free wall rupture complicating acute myocardial infarction. Am J Cardiol. 1997;80:397–405.
268. von Segesser LK, Popp J, Amann FW, et al. Surgical revascularization in acute myocardial infarction. Eur J Cardiothorac Surg. 1994;8:363–8.
269. Danner BC, Didilis VN, Stojanovic T, et al. A three-group model to predict mortality in emergent coronary artery bypass graft surgery. Ann Thorac Surg. 2009;88:1433–9.
270. Thielmann M, Massoudy P, Neuhauser M, et al. Prognostic value of preoperative cardiac troponin I in patients undergoing emergency coronary artery bypass surgery with non-ST-elevation or ST-elevation acute coronary syndromes. Circulation. 2006;114:I448–53.
271. Every NR, Fahrenbruch CE, Hallstrom AP, et al. Influence of coronary bypass surgery on subsequent outcome of patients resuscitated from out of hospital cardiac arrest. J Am Coll Cardiol. 1992;19:1435–9.
272. Kelly P, Ruskin JN, Vlahakes GJ, et al. Surgical coronary revascularization in survivors of prehospital cardiac arrest: its effect on inducible ventricular arrhythmias and long-term survival. J Am Coll Cardiol. 1990;15:267–73.
273. Autschbach R, Falk V, Gonska BD, et al. The effect of coronary bypass graft surgery for the prevention of sudden cardiac death: recurrent episodes after ICD implantation and review of literature. Pacing Clin Electrophysiol. 1994;17:552–8.
274. Cook JR, Rizo-Patron C, Curtis AB, et al. Effect of surgical revascularization in patients with coronary artery disease and ventricular tachycardia or fibrillation in the Antiarrhythmics Versus Implantable Defibrillators (AVID) Registry. Am Heart J. 2002;143: 821–6.
275. Berntsen RF, Gunnes P, Lie M, et al. Surgical revascularization in the treatment of ventricular tachycardia and fibrillation exposed by exercise-induced ischaemia. Eur Heart J. 1993;14:1297–303.
276. Daoud EG, Niebauer M, Kou WH, et al. Incidence of implantable defibrillator discharges after coronary revascularization in survivors of ischemic sudden cardiac death. Am Heart J. 1995;130:277–80.
277. Budeus M, Feindt P, Gams E, et al. Risk factors of ventricular tachyarrhythmias after coronary artery bypass grafting. Int J Cardiol. 2006;113:201–8.
278. Yeung-Lai-Wah JA, Qi A, McNeill E, et al. New-onset sustained ventricular tachycardia and fibrillation early after cardiac operations. Ann Thorac Surg. 2004;77:2083–8.
279. Pires LA, Hafley GE, Lee KL, et al. Prognostic significance of nonsustained ventricular tachycardia identified postoperatively after

coronary artery bypass surgery in patients with left ventricular dysfunction. J Cardiovasc Electrophysiol. 2002;13:757–63.
280. Barakate MS, Bannon PG, Hughes CF, et al. Emergency surgery after unsuccessful coronary angioplasty: a review of 15 years' experience. Ann Thorac Surg. 2003;75:1400–5.
281. Roy P, de Labriolle A, Hanna N, et al. Requirement for emergent coronary artery bypass surgery following percutaneous coronary intervention in the stent era. Am J Cardiol. 2009;103:950–3.
282. Craver JM, Weintraub WS, Jones EL, et al. Emergency coronary artery bypass surgery for failed percutaneous coronary angioplasty: a 10–year experience. Ann Surg. 1992;215:425–33.
283. Stamou SC, Hill PC, Haile E, et al. Clinical outcomes of nonelective coronary revascularization with and without cardiopulmonary bypass. J Thorac Cardiovasc Surg. 2006;131:28–33.
284. Frutkin AD, Mehta SK, Patel T, et al. Outcomes of 1,090 consecutive, elective, nonselected percutaneous coronary interventions at a community hospital without onsite cardiac surgery. Am J Cardiol. 2008;101:53–7.
285. Singh M, Gersh BJ, Lennon RJ, et al. Outcomes of a system-wide protocol for elective and nonelective coronary angioplasty at sites without on-site surgery: the Mayo Clinic experience. Mayo Clin Proc. 2009;84:501–8.
286. Ting HH, Raveendran G, Lennon RJ, et al. A total of 1,007 percutaneous coronary interventions without onsite cardiac surgery: acute and long-term outcomes. J Am Coll Cardiol. 2006;47:1713–21.
287. Andreasen JJ, Mortensen PE, Andersen LI, et al. Emergency coronary artery bypass surgery after failed percutaneous transluminal coronary angioplasty. Scand Cardiovasc J. 2000;34:242–6.
288. Berger PB, Stensrud PE, Daly RC, et al. Time to reperfusion and other procedural characteristics of emergency coronary artery bypass surgery after unsuccessful coronary angioplasty. Am J Cardiol. 1995;76:565–9.
289. Carey JA, Davies SW, Balcon R, et al. Emergency surgical revascularisation for coronary angioplasty complications. Br Heart J. 1994;72:428–35.
290. Hake U, Iversen S, Jakob HG, et al. Influence of incremental preoperative risk factors on the perioperative outcome of patients undergoing emergency versus urgent coronary artery bypass grafting. Eur J Cardiothorac Surg. 1989;3:162–8.
291. Talley JD, Weintraub WS, Roubin GS, et al. Failed elective percutaneous transluminal coronary angioplasty requiring coronary artery bypass surgery. In-hospital and late clinical outcome at 5 years. Circulation. 1990;82:1203–13.
292. Wang N, Gundry SR, Van Arsdell G, et al. Percutaneous transluminal coronary angioplasty failures in patients with multivessel disease. Is there an increased risk? J Thorac Cardiovasc Surg. 1995;110:214–21.
293. Klepzig H Jr., Kober G, Satter P, et al. Analysis of 100 emergency aortocoronary bypass operations after percutaneous transluminal coronary angioplasty: which patients are at risk for large infarctions? Eur Heart J. 1991;12:946–51.
294. Bonaros N, Hennerbichler D, Friedrich G, et al. Increased mortality and perioperative complications in patients with previous elective percutaneous coronary interventions undergoing coronary artery bypass surgery. J Thorac Cardiovasc Surg. 2009;137:846–52.
295. Karthik S, Musleh G, Grayson AD, et al. Effect of avoiding cardiopulmonary bypass in non-elective coronary artery bypass surgery: a propensity score analysis. Eur J Cardiothorac Surg. 2003;24:66–71.
296. Ladowski JS, Dillon TA, Deschner WP, et al. Durability of emergency coronary artery bypass for complications of failed angioplasty. Cardiovasc Surg. 1996;4:23–7.
297. Reinecke H, Roeder N, Schmid C, et al. Outcome of women is impaired in patients undergoing emergency coronary artery bypass grafting for failed PTCA. Z Kardiol. 2001;90:729–36.
298. Ghanta RK, Shekar PS, McGurk S, et al. Nonelective cardiac surgery in the elderly: is it justified? J Thorac Cardiovasc Surg. 2010;140:103–9 e1.
299. Beller GA, Ragosta M. Decision making in multivessel coronary disease: the need for physiological lesion assessment. J Am Coll Cardiol Intv. 2010;3:315–7.
300. Tonino PA, Fearon WF, De Bruyne B, et al. Angiographic versus functional severity of coronary artery stenoses in the FAME study fractional flow reserve versus angiography in multivessel evaluation. J Am Coll Cardiol. 2010;55:2816–21.
301. Morice MC, Serruys PW, Kappetein AP, et al. Outcomes in patients with de novo left main disease treated with either percutaneous coronary intervention using paclitaxel-eluting stents or coronary artery bypass graft treatment in the Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery (SYNTAX) trial. Circulation. 2010;121:2645–53.
302. Serruys PW, Morice MC, Kappetein AP, et al. Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. N Engl J Med. 2009;360:961–72.
303. Feit F, Brooks MM, Sopko G, et al., BARI Investigators. Long-term clinical outcome in the Bypass Angioplasty Revascularization Investigation Registry: comparison with the randomized trial. Circulation. 2000;101:2795–802.
304. King SBI, Barnhart HX, Kosinski AS, et al. Angioplasty or surgery for multivessel coronary artery disease: comparison of eligible registry and randomized patients in the EAST trial and influence of treatment selection on outcomes: Emory Angioplasty versus Surgery Trial Investigators. Am J Cardiol. 1997;79:1453–9.
305. Chakravarty T, Buch MH, Naik H, et al. Predictive accuracy of SYNTAX score for predicting long-term outcomes of unprotected left main coronary artery revascularization. Am J Cardiol. 2011;107:360–6.
306. Grover FL, Shroyer AL, Hammermeister K, et al. A decade's experience with quality improvement in cardiac surgery using the Veterans Affairs and Society of Thoracic Surgeons national databases. Ann Surg. 2001;234:464–72.
307. Kim YH, Park DW, Kim WJ, et al. Validation of SYNTAX (Synergy between PCI with TAXUS and Cardiac Surgery) score for prediction of outcomes after unprotected left main coronary revascularization. J Am Coll Cardiol Intv. 2010;3:612–23.
308. Shahian DM, O'Brien SM, Filardo G, et al. The Society of Thoracic Surgeons 2008 cardiac surgery risk models: part 1–coronary artery bypass grafting surgery. Ann Thorac Surg. 2009;88 1 Suppl:S2–22.
309. Shahian DM, O'Brien SM, Normand SL, et al. Association of hospital coronary artery bypass volume with processes of care, mortality, morbidity, and the Society of Thoracic Surgeons composite quality score. J Thorac Cardiovasc Surg. 2010;139:273–82.
310. Welke KF, Peterson ED, Vaughan-Sarrazin MS, et al. Comparison of cardiac surgery volumes and mortality rates between the Society of Thoracic Surgeons and Medicare databases from 1993 through 2001. Ann Thorac Surg. 2007;84:1538–46.
311. Buszman PE, Kiesz SR, Bochenek A, et al. Acute and late outcomes of unprotected left main stenting in comparison with surgical revascularization. J Am Coll Cardiol. 2008;51:538–45.
312. Caracciolo EA, Davis KB, Sopko G, et al. Comparison of surgical and medical group survival in patients with left main coronary artery disease: long-term CASS experience. Circulation. 1995;91:2325–34.
313. Chaitman BR, Fisher LD, Bourassa MG, et al. Effect of coronary bypass surgery on survival patterns in subsets of patients with left main coronary artery disease: report of the Collaborative Study in Coronary Artery Surgery (CASS). Am J Cardiol. 1981;48:765–77.
314. Dzavik V, Ghali WA, Norris C, et al. Long-term survival in 11,661 patients with multivessel coronary artery disease in the era of stenting: a report from the Alberta Provincial Project for Outcome Assessment in Coronary Heart Disease (APPROACH) Investigators. Am Heart J. 2001;142:119–26.
315. Takaro T, Hultgren HN, Lipton MJ, et al. The VA cooperative randomized study of surgery for coronary arterial occlusive disease II. Subgroup with significant left main lesions. Circulation. 1976;54:III107–17.
316. Takaro T, Peduzzi P, Detre KM, et al. Survival in subgroups of patients with left main coronary artery disease: Veterans Administration Cooperative Study of Surgery for Coronary Arterial Occlusive Disease. Circulation. 1982;66:14–22.
317. Taylor HA, Deumite NJ, Chaitman BR, et al. Asymptomatic left main coronary artery disease in the Coronary Artery Surgery Study (CASS) registry. Circulation. 1989;79:1171–9.
318. Yusuf S, Zucker D, Peduzzi P, et al. Effect of coronary artery bypass graft surgery on survival: overview of 10–year results from randomised trials by the Coronary Artery Bypass Graft Surgery Trialists Collaboration. Lancet. 1994;344:563–70.
319. Capodanno D, Caggegi A, Miano M, et al. Global risk classification and clinical SYNTAX (Synergy between Percutaneous Coronary

Intervention with TAXUS and Cardiac Surgery) score in patients undergoing percutaneous or surgical left main revascularization. J Am Coll Cardiol Intv. 2011;4:287–97.
320. Hannan EL, Wu C, Walford G, et al. Drug-eluting stents vs. coronary-artery bypass grafting in multivessel coronary disease. N Engl J Med. 2008;358:331–41.
321. Ellis SG, Tamai H, Nobuyoshi M, et al. Contemporary percutaneous treatment of unprotected left main coronary stenoses: initial results from a multicenter registry analysis 1994–1996. Circulation. 1997;96:3867–72.
322. Biondi-Zoccai GG, Lotrionte M, Moretti C, et al. A collaborative systematic review and meta-analysis on 1278 patients undergoing percutaneous drug-eluting stenting for unprotected left main coronary artery disease. Am Heart J. 2008;155:274–83.
323. Boudriot E, Thiele H, Walther T, et al. Randomized comparison of percutaneous coronary intervention with sirolimus-eluting stents versus coronary artery bypass grafting in unprotected left main stem stenosis [published correction appears in J Am Coll Cardiol. 2011;57:1792]. J Am Coll Cardiol. 2011;57:538–45.
324. Brener SJ, Galla JM, Bryant RI, et al. Comparison of percutaneous versus surgical revascularization of severe unprotected left main coronary stenosis in matched patients. Am J Cardiol. 2008;101:169–72.
325. Chieffo A, Morici N, Maisano F, et al. Percutaneous treatment with drug-eluting stent implantation versus bypass surgery for unprotected left main stenosis: a single-center experience. Circulation. 2006;113:2542–7.
326. Chieffo A, Magni V, Latib A, et al. 5–year outcomes following percutaneous coronary intervention with drug-eluting stent implantation versus coronary artery bypass graft for unprotected left main coronary artery lesions: the Milan experience. J Am Coll Cardiol Intv. 2010;3:595–601.
327. Lee MS, Kapoor N, Jamal F, et al. Comparison of coronary artery bypass surgery with percutaneous coronary intervention with drug-eluting stents for unprotected left main coronary artery disease. J Am Coll Cardiol. 2006;47:864–70.
328. Makikallio TH, Niemela M, Kervinen K, et al. Coronary angioplasty in drug eluting stent era for the treatment of unprotected left main stenosis compared to coronary artery bypass grafting. Ann Med. 2008;40:437–43.
329. Naik H, White AJ, Chakravarty T, et al. A meta-analysis of 3,773 patients treated with percutaneous coronary intervention or surgery for unprotected left main coronary artery stenosis. J Am Coll Cardiol Intv. 2009;2:739–47.
330. Palmerini T, Marzocchi A, Marrozzini C, et al. Comparison between coronary angioplasty and coronary artery bypass surgery for the treatment of unprotected left main coronary artery stenosis (the Bologna Registry). Am J Cardiol. 2006;98:54–9.
331. Park DW, Seung KB, Kim YH, et al. Long-term safety and efficacy of stenting versus coronary artery bypass grafting for unprotected left main coronary artery disease: 5–year results from the MAIN-COMPARE (Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty Versus Surgical Revascularization) registry. J Am Coll Cardiol. 2010;56:117–24.
332. Rodes-Cabau J, Deblois J, Bertrand OF, et al. Nonrandomized comparison of coronary artery bypass surgery and percutaneous coronary intervention for the treatment of unprotected left main coronary artery disease in octogenarians. Circulation. 2008;118:2374–81.
333. Sanmartin M, Baz JA, Claro R, et al. Comparison of drug-eluting stents versus surgery for unprotected left main coronary artery disease. Am J Cardiol. 2007;100:970–3.
334. Kappetein AP, Mohr FW, Feldman TE, et al. Comparison of coronary bypass surgery with drug-eluting stenting for the treatment of left main and/or three-vessel disease: 3-year follow-up of the SYNTAX trial. Eur Heart J. 2011;17:2125–34.
335. Seung KB, Park DW, Kim YH, et al. Stents versus coronary-artery bypass grafting for left main coronary artery disease. N Engl J Med. 2008;358:1781–92.
336. White AJ, Kedia G, Mirocha JM, et al. Comparison of coronary artery bypass surgery and percutaneous drug-eluting stent implantation for treatment of left main coronary artery stenosis. J Am Coll Cardiol Intv. 2008;1:236–45.
337. Montalescot G, Brieger D, Eagle KA, et al. Unprotected left main revascularization in patients with acute coronary syndromes. Eur Heart J. 2009;30:2308–17.
338. Lee MS, Tseng CH, Barker CM, et al. Outcome after surgery and percutaneous intervention for cardiogenic shock and left main disease. Ann Thorac Surg. 2008;86:29–34.
339. Lee MS, Bokhoor P, Park SJ, et al. Unprotected left main coronary disease and ST-segment elevation myocardial infarction: a contemporary review and argument for percutaneous coronary intervention. J Am Coll Cardiol Intv. 2010;3:791–5.
340. Park SJ, Kim YH, Park DW, et al. Randomized trial of stents versus bypass surgery for left main coronary artery disease. N Engl J Med. 2011;364:1727.
341. Jones RH, Kesler K, Phillips HR, III, et al. Long-term survival benefits of coronary artery bypass grafting and percutaneous transluminal angioplasty in patients with coronary artery disease. J Thorac Cardiovasc Surg. 1996;111:1013–25.
342. Myers WO, Schaff HV, Gersh BJ, et al. Improved survival of surgically treated patients with triple vessel coronary artery disease and severe angina pectoris. A report from the Coronary Artery Surgery Study (CASS) registry. J Thorac Cardiovasc Surg. 1989;97:487–95.
343. Smith PK, Califf RM, Tuttle RH, et al. Selection of surgical or percutaneous coronary intervention provides differential longevity benefit. Ann Thorac Surg. 2006;82:1420–8.
344. Varnauskas E. Twelve-year follow-up of survival in the randomized European Coronary Surgery Study. N Engl J Med. 1988;319:332–7.
345. Borger van der Burg AE, Bax JJ, Boersma E, et al. Impact of percutaneous coronary intervention or coronary artery bypass grafting on outcome after nonfatal cardiac arrest outside the hospital. Am J Cardiol. 2003;91:785–9.
346. Deleted in proof.
347. Kaiser GA, Ghahramani A, Bolooki H, et al. Role of coronary artery surgery in patients surviving unexpected cardiac arrest. Surgery. 1975;78:749–54.
348. Di Carli MF, Maddahi J, Rokhsar S, et al. Long-term survival of patients with coronary artery disease and left ventricular dysfunction: implications for the role of myocardial viability assessment in management decisions. J Thorac Cardiovasc Surg. 1998;116:997–1004.
349. Hachamovitch R, Hayes SW, Friedman JD, et al. Comparison of the short-term survival benefit associated with revascularization compared with medical therapy in patients with no prior coronary artery disease undergoing stress myocardial perfusion single photon emission computed tomography. Circulation. 2003;107:2900–7.
350. Sorajja P, Chareonthaitawee P, Rajagopalan N, et al. Improved survival in asymptomatic diabetic patients with high-risk SPECT imaging treated with coronary artery bypass grafting. Circulation. 2005;112:I311–6.
351. Davies RF, Goldberg AD, Forman S, et al. Asymptomatic Cardiac Ischemia Pilot (ACIP) study two-year follow-up: outcomes of patients randomized to initial strategies of medical therapy versus revascularization. Circulation. 1997;95:2037–43.
352. Alderman EL, Fisher LD, Litwin P, et al. Results of coronary artery surgery in patients with poor left ventricular function (CASS). Circulation. 1983;68:785–95.
353. O'Connor CM, Velazquez EJ, Gardner LH, et al. Comparison of coronary artery bypass grafting versus medical therapy on long-term outcome in patients with ischemic cardiomyopathy (a 25–year experience from the Duke Cardiovascular Disease Databank). Am J Cardiol. 2002;90:101–7.
354. Phillips HR, O'Connor CM, Rogers J. Revascularization for heart failure. Am Heart J. 2007;153:65–73.
355. Tarakji KG, Brunken R, McCarthy PM, et al. Myocardial viability testing and the effect of early intervention in patients with advanced left ventricular systolic dysfunction. Circulation. 2006;113:230–7.
356. Tsuyuki RT, Shrive FM, Galbraith PD, et al. Revascularization in patients with heart failure. CMAJ. 2006;175:361–5.
357. Deleted in proof.
358. Deleted in proof.
359. Brener SJ, Lytle BW, Casserly IP, et al. Propensity analysis of long-term survival after surgical or percutaneous revascularization in patients with multivessel coronary artery disease and high-risk features. Circulation. 2004;109:2290–5.

360. Hannan EL, Racz MJ, Walford G, et al. Long-term outcomes of coronary-artery bypass grafting versus stent implantation. N Engl J Med. 2005;352:2174–83.
361. Deleted in proof.
362. The BARI Investigators. Influence of diabetes on 5–year mortality and morbidity in a randomized trial comparing CABG and PTCA in patients with multivessel disease: the Bypass Angioplasty Revascularization Investigation (BARI). Circulation. 1997;96:1761–9.
363. The BARI Investigators. The final 10–year follow-up results from the BARI randomized trial. J Am Coll Cardiol. 2007;49:1600–6.
364. Banning AP, Westaby S, Morice MC, et al. Diabetic and nondiabetic patients with left main and/or 3–vessel coronary artery disease: comparison of outcomes with cardiac surgery and paclitaxel-eluting stents. J Am Coll Cardiol. 2010;55:1067–75.
365. Hoffman SN, TenBrook JA, Wolf MP, et al. A meta-analysis of randomized controlled trials comparing coronary artery bypass graft with percutaneous transluminal coronary angioplasty: one- to eight-year outcomes. J Am Coll Cardiol. 2003;41:1293–304.
366. Hueb W, Lopes NH, Gersh BJ, et al. Five-year follow-up of the Medicine, Angioplasty, or Surgery Study (MASS II): a randomized controlled clinical trial of 3 therapeutic strategies for multivessel coronary artery disease. Circulation. 2007;115:1082–9.
367. Malenka DJ, Leavitt BJ, Hearne MJ, et al. Comparing long-term survival of patients with multivessel coronary disease after CABG or PCI: analysis of BARI-like patients in northern New England. Circulation. 2005;112:I371–6.
368. Niles NW, McGrath PD, Malenka D, et al., Northern New England Cardiovascular Disease Study Group. Survival of patients with diabetes and multivessel coronary artery disease after surgical or percutaneous coronary revascularization: results of a large regional prospective study. J Am Coll Cardiol. 2001;37:1008–15.
369. Weintraub WS, Stein B, Kosinski A, et al. Outcome of coronary bypass surgery versus coronary angioplasty in diabetic patients with multivessel coronary artery disease. J Am Coll Cardiol. 1998;31:10–9.
370. Boden WE, O'Rourke RA, Teo KK, et al. Optimal medical therapy with or without PCI for stable coronary disease. N Engl J Med. 2007;356:1503–16.
371. Bonow RO, Maurer G, Lee KL, et al. Myocardial Viability and Survival in Ischemic Left Ventricular Dysfunction. N Engl J Med. 2011;364:1625.
372. Velazquez EJ, Lee KL, Deja MA, et al. Coronary-Artery Bypass Surgery in Patients with Left Ventricular Dysfunction. N Engl J Med. 2011;364:1616.
373. Brener SJ, Lytle BW, Casserly IP, et al. Predictors of revascularization method and long-term outcome of percutaneous coronary intervention or repeat coronary bypass surgery in patients with multivessel coronary disease and previous coronary bypass surgery. Eur Heart J. 2006;27:413–8.
374. Gurfinkel EP, Perez dlH, Brito VM, et al. Invasive vs non-invasive treatment in acute coronary syndromes and prior bypass surgery. Int J Cardiol. 2007;119:65–72.
375. Lytle BW, Loop FD, Taylor PC, et al. The effect of coronary reoperation on the survival of patients with stenoses in saphenous vein bypass grafts to coronary arteries. J Thorac Cardiovasc Surg. 1993;105:605–12.
376. Morrison DA, Sethi G, Sacks J, et al. Percutaneous coronary intervention versus coronary artery bypass graft surgery for patients with medically refractory myocardial ischemia and risk factors for adverse outcomes with bypass: a multicenter, randomized trial. Investigators of the Department of Veterans Affairs Cooperative Study #385, the Angina With Extremely Serious Operative Mortality Evaluation (AWESOME). J Am Coll Cardiol. 2001;38:143–9.
377. Pfautsch P, Frantz E, Ellmer A, et al. [Long-term outcome of therapy of recurrent myocardial ischemia after surgical revascularization]. Z Kardiol. 1999;88:489–97.
378. Sergeant P, Blackstone E, Meyns B, et al. First cardiological or cardiosurgical reintervention for ischemic heart disease after primary coronary artery bypass grafting. Eur J Cardiothorac Surg. 1998;14:480–7.
379. Stephan WJ, O'Keefe JH Jr., Piehler JM, et al. Coronary angioplasty versus repeat coronary artery bypass grafting for patients with previous bypass surgery. J Am Coll Cardiol. 1996;28:1140–6.
380. Subramanian S, Sabik JF, III, Houghtaling PL, et al. Decision-making for patients with patent left internal thoracic artery grafts to left anterior descending. Ann Thorac Surg. 2009;87:1392–8.
381. Weintraub WS, Jones EL, Morris DC, et al. Outcome of reoperative coronary bypass surgery versus coronary angioplasty after previous bypass surgery. Circulation. 1997;95:868–77.
382. Shaw LJ, Berman DS, Maron DJ, et al. Optimal medical therapy with or without percutaneous coronary intervention to reduce ischemic burden: results from the Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation (COURAGE) trial nuclear substudy. Circulation. 2008;117:1283–91.
383. Cashin WL, Sanmarco ME, Nessim SA, et al. Accelerated progression of atherosclerosis in coronary vessels with minimal lesions that are bypassed. N Engl J Med. 1984;311:824–8.
384. Pijls NH, De Bruyne B, Peels K, et al. Measurement of fractional flow reserve to assess the functional severity of coronary-artery stenoses. N Engl J Med. 1996;334:1703–8.
385. Tonino PA, De Bruyne B, Pijls NH, et al. Fractional flow reserve versus angiography for guiding percutaneous coronary intervention. N Engl J Med. 2009;360:213–24.
386. Sawada S, Bapat A, Vaz D, et al. Incremental value of myocardial viability for prediction of long-term prognosis in surgically revascularized patients with left ventricular dysfunction. J Am Coll Cardiol. 2003;42:2099–105.
387. TIME Investigators. Trial of invasive versus medical therapy in elderly patients with chronic symptomatic coronary-artery disease (TIME): a randomised trial. Lancet. 2001;358:951–7.
388. Benzer W, Hofer S, Oldridge NB. Health-related quality of life in patients with coronary artery disease after different treatments for angina in routine clinical practice. Herz. 2003;28:421–8.
389. Bonaros N, Schachner T, Ohlinger A, et al. Assessment of health-related quality of life after coronary revascularization. Heart Surg Forum. 2005;8:E380–5.
390. Bucher HC, Hengstler P, Schindler C, et al. Percutaneous transluminal coronary angioplasty versus medical treatment for non-acute coronary heart disease: meta-analysis of randomised controlled trials. BMJ. 2000;321:73–7.
391. Favarato ME, Hueb W, Boden WE, et al. Quality of life in patients with symptomatic multivessel coronary artery disease: a comparative post hoc analyses of medical, angioplasty or surgical strategies-MASS II trial. Int J Cardiol. 2007;116:364–70.
392. Hueb W, Lopes N, Gersh BJ, et al. Ten-year follow-up survival of the Medicine, Angioplasty, or Surgery Study (MASS II): a randomized controlled clinical trial of 3 therapeutic strategies for multivessel coronary artery disease. Circulation. 2010;122:949–57.
393. Pocock SJ, Henderson RA, Seed P, et al. Quality of life, employment status, and anginal symptoms after coronary angioplasty or bypass surgery. 3–year follow-up in the Randomized Intervention Treatment of Angina (RITA) Trial. Circulation. 1996;94:135–42.
394. Pocock SJ, Henderson RA, Clayton T, et al. Quality of life after coronary angioplasty or continued medical treatment for angina: three-year follow-up in the RITA-2 trial. Randomized Intervention Treatment of Angina. J Am Coll Cardiol. 2000;35:907–14.
395. Weintraub WS, Spertus JA, Kolm P, et al. Effect of PCI on quality of life in patients with stable coronary disease. N Engl J Med. 2008;359:677–87.
396. Wijeysundera HC, Nallamothu BK, Krumholz HM, et al. Meta-analysis: effects of percutaneous coronary intervention versus medical therapy on angina relief. Ann Intern Med. 2010;152:370–9.
397. Schofield PM, Sharples LD, Caine N, et al. Transmyocardial laser revascularisation in patients with refractory angina: a randomised controlled trial [published correction appears in Lancet. 1999;353:1714]. Lancet. 1999;353:519–24.
398. Aaberge L, Nordstrand K, Dragsund M, et al. Transmyocardial revascularization with CO2 laser in patients with refractory angina pectoris. Clinical results from the Norwegian randomized trial. J Am Coll Cardiol. 2000;35:1170–7.
399. Burkhoff D, Schmidt S, Schulman SP, et al. Transmyocardial laser revascularisation compared with continued medical therapy for treatment of refractory angina pectoris: a prospective randomised trial. ATLANTIC Investigators. Angina Treatments-Lasers and Normal Therapies in Comparison. Lancet. 1999;354:885–90.
400. Allen KB, Dowling RD, DelRossi AJ, et al. Transmyocardial laser revascularization combined with coronary artery bypass grafting: a

multicenter, blinded, prospective, randomized, controlled trial. J Thorac Cardiovasc Surg. 2000;119:540–9.
401. Stamou SC, Boyce SW, Cooke RH, et al. One-year outcome after combined coronary artery bypass grafting and transmyocardial laser revascularization for refractory angina pectoris. Am J Cardiol. 2002;89:1365–8.
402. The VA Coronary Artery Bypass Surgery Cooperative Study Group. Eighteen-year follow-up in the Veterans Affairs Cooperative Study of Coronary Artery Bypass Surgery for stable angina. Circulation. 1992;86:121–30.
403. Passamani E, Davis KB, Gillespie MJ, et al. A randomized trial of coronary artery bypass surgery. Survival of patients with a low ejection fraction. N Engl J Med. 1985;312:1665–71.
404. Frye RL, August P, Brooks MM, et al. A randomized trial of therapies for type 2 diabetes and coronary artery disease. N Engl J Med. 2009;360:2503–15.
405. Al Suwaidi J, Holmes DR Jr., Salam AM, et al. Impact of coronary artery stents on mortality and nonfatal myocardial infarction: meta-analysis of randomized trials comparing a strategy of routine stenting with that of balloon angioplasty. Am Heart J. 2004;147: 815–22.
406. Brophy JM, Belisle P, Joseph L. Evidence for use of coronary stents. A hierarchical bayesian meta-analysis. Ann Intern Med. 2003;138: 777–86.
407. Trikalinos TA, Alsheikh-Ali AA, Tatsioni A, et al. Percutaneous coronary interventions for non-acute coronary artery disease: a quantitative 20–year synopsis and a network meta-analysis [published correction appears in Lancet. 2009;374:378]. Lancet. 2009; 373:911–8.
408. Kastrati A, Mehilli J, Pache J, et al. Analysis of 14 trials comparing sirolimus-eluting stents with bare-metal stents. N Engl J Med. 2007;356:1030–9.
409. Cecil WT, Kasteridis P, Barnes JW Jr., et al. A meta-analysis update: percutaneous coronary interventions. Am J Manag Care. 2008;14:521–8.
410. Katritsis DG, Ioannidis JP. Percutaneous coronary intervention versus conservative therapy in nonacute coronary artery disease: a meta-analysis. Circulation. 2005;111:2906–12.
411. Schomig A, Mehilli J, de Waha A., et al. A meta-analysis of 17 randomized trials of a percutaneous coronary intervention-based strategy in patients with stable coronary artery disease. J Am Coll Cardiol. 2008;52:894–904.
412. Katritsis DG, Ioannidis JP. PCI for stable coronary disease. N Engl J Med. 2007;357:414–5.
413. Hambrecht R, Walther C, Mobius-Winkler S, et al. Percutaneous coronary angioplasty compared with exercise training in patients with stable coronary artery disease: a randomized trial. Circulation. 2004;109:1371–8.
414. Pitt B, Waters D, Brown WV, et al. Aggressive lipid-lowering therapy compared with angioplasty in stable coronary artery disease. Atorvastatin versus Revascularization Treatment Investigators. N Engl J Med. 1999;341:70–6.
415. Coronary angioplasty versus coronary artery bypass surgery: the Randomized Intervention Treatment of Angina (RITA) trial. Lancet. 1993;341:573–80.
416. CABRI Trial Participants. First-year results of CABRI (Coronary Angioplasty versus Bypass Revascularisation Investigation). Lancet. 1995;346:1179–84.
417. The Bypass Angioplasty Revascularization Investigation (BARI) Investigators. Comparison of coronary bypass surgery with angioplasty in patients with multivessel disease. N Engl J Med. 1996; 335:217–25.
418. Writing Group for the Bypass Angioplasty Revascularization Investigation (BARI) Investigators. Five-year clinical and functional outcome comparing bypass surgery and angioplasty in patients with multivessel coronary disease. A multicenter randomized trial. JAMA. 1997;277:715–21.
419. Carrie D, Elbaz M, Puel J, et al. Five-year outcome after coronary angioplasty versus bypass surgery in multivessel coronary artery disease: results from the French Monocentric Study. Circulation. 1997;96:II6.
420. Goy JJ, Eeckhout E, Burnand B, et al. Coronary angioplasty versus left internal mammary artery grafting for isolated proximal left anterior descending artery stenosis. Lancet. 1994;343:1449–53.
421. Goy JJ, Eeckhout E, Moret C, et al. Five-year outcome in patients with isolated proximal left anterior descending coronary artery stenosis treated by angioplasty or left internal mammary artery grafting. A prospective trial. Circulation. 1999;99:3255–9.
422. Hamm CW, Reimers J, Ischinger T, et al. A randomized study of coronary angioplasty compared with bypass surgery in patients with symptomatic multivessel coronary disease. German Angioplasty Bypass Surgery Investigation (GABI). N Engl J Med. 1994;331: 1037–43.
423. Henderson RA, Pocock SJ, Sharp SJ, et al. Long-term results of RITA-1 trial: clinical and cost comparisons of coronary angioplasty and coronary-artery bypass grafting. Randomised Intervention Treatment of Angina. Lancet. 1998;352:1419–25.
424. Hueb WA, Soares PR, Almeida De OS, et al. Five-year follow-up of the medicine, angioplasty, or surgery study (MASS): a prospective, randomized trial of medical therapy, balloon angioplasty, or bypass surgery for single proximal left anterior descending coronary artery stenosis. Circulation. 1999;100:II107–13.
425. King SB III, Lembo NJ, Weintraub WS, et al. A randomized trial comparing coronary angioplasty with coronary bypass surgery. Emory Angioplasty versus Surgery Trial (EAST). N Engl J Med. 1994;331:1044–50.
426. King SBI, Kosinski AS, Guyton RA, et al. Eight-year mortality in the Emory Angioplasty versus Surgery Trial (EAST). J Am Coll Cardiol. 2000;35:1116–21.
427. Rodriguez A, Boullon F, Perez-Balino N, et al. Argentine randomized trial of percutaneous transluminal coronary angioplasty versus coronary artery bypass surgery in multivessel disease (ERACI): in-hospital results and 1–year follow-up. ERACI Group. J Am Coll Cardiol. 1993;22:1060–7.
428. Rodriguez A, Mele E, Peyregne E, et al. Three-year follow-up of the Argentine Randomized Trial of Percutaneous Transluminal Coronary Angioplasty Versus Coronary Artery Bypass Surgery in Multivessel Disease (ERACI). J Am Coll Cardiol. 1996;27:1178–84.
429. Wahrborg P. Quality of life after coronary angioplasty or bypass surgery. 1–year follow-up in the Coronary Angioplasty versus Bypass Revascularization investigation (CABRI) trial. Eur Heart J. 1999;20:653–8.
430. Coronary artery bypass surgery versus percutaneous coronary intervention with stent implantation in patients with multivessel coronary artery disease (the Stent or Surgery trial): a randomised controlled trial. Lancet. 2002;360:965–70.
431. Cisowski M, Drzewiecki J, Drzewiecka-Gerber A, et al. Primary stenting versus MIDCAB: preliminary report-comparision of two methods of revascularization in single left anterior descending coronary artery stenosis. Ann Thorac Surg. 2002;74:S1334–9.
432. Cisowski M, Drzewiecka-Gerber A, Ulczok R, et al. Primary direct stenting versus endoscopic atraumatic coronary artery bypass surgery in patients with proximal stenosis of the left anterior descending coronary artery—a prospective, randomised study. Kardiol Pol. 2004;61:253–61.
433. Diegeler A, Thiele H, Falk V, et al. Comparison of stenting with minimally invasive bypass surgery for stenosis of the left anterior descending coronary artery. N Engl J Med. 2002;347:561–6.
434. Drenth DJ, Veeger NJ, Winter JB, et al. A prospective randomized trial comparing stenting with off-pump coronary surgery for high-grade stenosis in the proximal left anterior descending coronary artery: three-year follow-up. J Am Coll Cardiol. 2002;40:1955–60.
435. Drenth DJ, Veeger NJ, Middel B, et al. Comparison of late (four years) functional health status between percutaneous transluminal angioplasty intervention and off-pump left internal mammary artery bypass grafting for isolated high-grade narrowing of the proximal left anterior descending coronary artery. Am J Cardiol. 2004;94: 1414–7.
436. Eefting F, Nathoe H, van Dijk D, et al. Randomized comparison between stenting and off-pump bypass surgery in patients referred for angioplasty. Circulation. 2003;108:2870–6.
437. Goy JJ, Kaufmann U, Goy-Eggenberger D, et al. A prospective randomized trial comparing stenting to internal mammary artery grafting for proximal, isolated de novo left anterior coronary artery stenosis: the SIMA trial. Stenting vs Internal Mammary Artery. Mayo Clin Proc. 2000;75:1116–23.
438. Hueb W, Soares PR, Gersh BJ, et al. The medicine, angioplasty, or surgery study (MASS-II): a randomized, controlled clinical trial of

three therapeutic strategies for multivessel coronary artery disease: one-year results. J Am Coll Cardiol. 2004;43:1743–51.
439. Kim JW, Lim DS, Sun K, et al. Stenting or MIDCAB using ministernotomy for revascularization of proximal left anterior descending artery? Int J Cardiol. 2005;99:437–41.
440. Pohl T, Giehrl W, Reichart B, et al. Retroinfusion-supported stenting in high-risk patients for percutaneous intervention and bypass surgery: results of the prospective randomized myoprotect I study. Catheter Cardiovasc Interv. 2004;62:323–30.
441. Reeves BC, Angelini GD, Bryan AJ, et al. A multi-centre randomised controlled trial of minimally invasive direct coronary bypass grafting versus percutaneous transluminal coronary angioplasty with stenting for proximal stenosis of the left anterior descending coronary artery. Health Technol Assess. 2004;8:1–43.
442. Rodriguez A, Bernardi V, Navia J, et al., ERACI II Investigators. Argentine Randomized Study: Coronary Angioplasty with Stenting versus Coronary Bypass Surgery in patients with Multiple-Vessel Disease (ERACI II): 30–day and one-year follow-up results. J Am Coll Cardiol. 2001;37:51–8.
443. Rodriguez AE, Baldi J, Fernandez PC, et al. Five-year follow-up of the Argentine randomized trial of coronary angioplasty with stenting versus coronary bypass surgery in patients with multiple vessel disease (ERACI II). J Am Coll Cardiol. 2005;46:582–8.
444. Serruys PW, Unger F, Sousa JE, et al. Comparison of coronary-artery bypass surgery and stenting for the treatment of multivessel disease. N Engl J Med. 2001;344:1117–24.
445. Serruys PW, Ong AT, van Herwerden LA, et al. Five-year outcomes after coronary stenting versus bypass surgery for the treatment of multivessel disease: the final analysis of the Arterial Revascularization Therapies Study (ARTS) randomized trial. J Am Coll Cardiol. 2005;46:575–81.
446. Stroupe KT, Morrison DA, Hlatky MA, et al. Cost-effectiveness of coronary artery bypass grafts versus percutaneous coronary intervention for revascularization of high-risk patients. Circulation. 2006; 114:1251–7.
447. Thiele H, Oettel S, Jacobs S, et al. Comparison of bare-metal stenting with minimally invasive bypass surgery for stenosis of the left anterior descending coronary artery: a 5–year follow-up. Circulation. 2005;112:3445–50.
448. Hong SJ, Lim DS, Seo HS, et al. Percutaneous coronary intervention with drug-eluting stent implantation vs. minimally invasive direct coronary artery bypass (MIDCAB) in patients with left anterior descending coronary artery stenosis. Catheter Cardiovasc Interv. 2005;64:75–81.
449. Thiele H, Neumann-Schniedewind P, Jacobs S, et al. Randomized comparison of minimally invasive direct coronary artery bypass surgery versus sirolimus-eluting stenting in isolated proximal left anterior descending coronary artery stenosis. J Am Coll Cardiol. 2009;53:2324–31.
450. Bravata DM, Gienger AL, McDonald KM, et al. Systematic review: the comparative effectiveness of percutaneous coronary interventions and coronary artery bypass graft surgery. Ann Intern Med. 2007; 147:703–16.
451. Hlatky MA, Boothroyd DB, Bravata DM, et al. Coronary artery bypass surgery compared with percutaneous coronary interventions for multivessel disease: a collaborative analysis of individual patient data from ten randomised trials. Lancet. 2009;373:1190–7.
452. Briguori C, Condorelli G, Airoldi F, et al. Comparison of coronary drug-eluting stents versus coronary artery bypass grafting in patients with diabetes mellitus. Am J Cardiol. 2007;99:779–84.
453. Javaid A, Steinberg DH, Buch AN, et al. Outcomes of coronary artery bypass grafting versus percutaneous coronary intervention with drug-eluting stents for patients with multivessel coronary artery disease. Circulation. 2007;116:I200–6.
454. Lee MS, Jamal F, Kedia G, et al. Comparison of bypass surgery with drug-eluting stents for diabetic patients with multivessel disease. Int J Cardiol. 2007;123:34–42.
455. Park DW, Yun SC, Lee SW, et al. Long-term mortality after percutaneous coronary intervention with drug-eluting stent implantation versus coronary artery bypass surgery for the treatment of multivessel coronary artery disease. Circulation. 2008;117:2079–86.
456. Tarantini G, Ramondo A, Napodano M, et al. PCI versus CABG for multivessel coronary disease in diabetics. Catheter Cardiovasc Interv. 2009;73:50–8.
457. Varani E, Balducelli M, Vecchi G, et al. Comparison of multiple drug-eluting stent percutaneous coronary intervention and surgical revascularization in patients with multivessel coronary artery disease: one-year clinical results and total treatment costs. J Invasive Cardiol. 2007;19:469–75.
458. Yang JH, Gwon HC, Cho SJ, et al. Comparison of coronary artery bypass grafting with drug-eluting stent implantation for the treatment of multivessel coronary artery disease. Ann Thorac Surg. 2008;85:65–70.
459. Yang ZK, Shen WF, Zhang RY, et al. Coronary artery bypass surgery versus percutaneous coronary intervention with drug-eluting stent implantation in patients with multivessel coronary disease. J Interv Cardiol. 2007;20:10–6.
460. Benedetto U, Melina G, Angeloni E, et al. Coronary artery bypass grafting versus drug-eluting stents in multivessel coronary disease. A meta-analysis on 24,268 patients. Eur J Cardiothorac Surg. 2009; 36:611–5.
461. Deleted in proof.
462. Deleted in proof.
463. Ragosta M, Dee S, Sarembock IJ, et al. Prevalence of unfavorable angiographic characteristics for percutaneous intervention in patients with unprotected left main coronary artery disease. Catheter Cardiovasc Interv. 2006;68:357–62.
464. Chieffo A, Park SJ, Valgimigli M, et al. Favorable long-term outcome after drug-eluting stent implantation in nonbifurcation lesions that involve unprotected left main coronary artery: a multicenter registry. Circulation. 2007;116:158–62.
465. Tamburino C, Capranzano P, Capodanno D, et al. Plaque distribution patterns in distal left main coronary artery to predict outcomes after stent implantation. J Am Coll Cardiol Intv. 2010; 3:624–31.
466. Smith SC Jr., Feldman TE, Hirshfeld JW Jr., et al. ACC/AHA/SCAI 2005 guideline update for percutaneous coronary intervention. J Am Coll Cardiol. 2006;47:e1–121.
467. Kushner FG, Hand M, Smith SC Jr., et al. 2009 focused updates: ACC/AHA guidelines for the management of patients with ST-elevation myocardial infarction (updating the 2004 guideline and 2007 focused update) and ACC/AHA/SCAI guidelines on percutaneous coronary intervention (updating the 2005 guideline and 2007 focused update). J Am Coll Cardiol. 2009;54:2205–41.
468. Ben-Gal Y, Mohr R, Braunstein R, et al. Revascularization of left anterior descending artery with drug-eluting stents: comparison with minimally invasive direct coronary artery bypass surgery. Ann Thorac Surg. 2006;82:2067–71.
469. Fraund S, Herrmann G, Witzke A, et al. Midterm follow-up after minimally invasive direct coronary artery bypass grafting versus percutaneous coronary intervention techniques. Ann Thorac Surg. 2005;79:1225–31.
470. Goy JJ, Kaufmann U, Hurni M, et al. 10–year follow-up of a prospective randomized trial comparing bare-metal stenting with internal mammary artery grafting for proximal, isolated de novo left anterior coronary artery stenosis the SIMA (Stenting versus Internal Mammary Artery grafting) trial. J Am Coll Cardiol. 2008;52:815–7.
471. Aziz O, Rao C, Panesar SS, et al. Meta-analysis of minimally invasive internal thoracic artery bypass versus percutaneous revascularisation for isolated lesions of the left anterior descending artery. BMJ. 2007;334:617.
472. Jaffery Z, Kowalski M, Weaver WD, et al. A meta-analysis of randomized control trials comparing minimally invasive direct coronary bypass grafting versus percutaneous coronary intervention for stenosis of the proximal left anterior descending artery. Eur J Cardiothorac Surg. 2007;31:691–7.
473. Kapoor JR, Gienger AL, Ardehali R, et al. Isolated disease of the proximal left anterior descending artery comparing the effectiveness of percutaneous coronary interventions and coronary artery bypass surgery. J Am Coll Cardiol Intv. 2008;1:483–91.
474. Abizaid A, Costa MA, Centemero M, et al. Clinical and economic impact of diabetes mellitus on percutaneous and surgical treatment of multivessel coronary disease patients: insights from the Arterial Revascularization Therapy Study (ARTS) trial. Circulation. 2001; 104:533–8.
475. Kapur A, Hall RJ, Malik IS, et al. Randomized comparison of percutaneous coronary intervention with coronary artery bypass grafting in diabetic patients. 1–year results of the CARDia (Coro-

nary Artery Revascularization in Diabetes) trial. J Am Coll Cardiol. 2010;55:432–40.
476. Sarnak MJ, Levey AS, Schoolwerth AC, et al. Kidney disease as a risk factor for development of cardiovascular disease: a statement from the American Heart Association Councils on Kidney in Cardiovascular Disease, High Blood Pressure Research, Clinical Cardiology, and Epidemiology and Prevention. Circulation. 2003; 108:2154–69.
477. Roger VL, Go AS, Lloyd-Jones DM, et al., on behalf of the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Heart disease and stroke statistics—2011 update: a report from the American Heart Association. Circulation. 2011;123:e18–209.
478. Sedlis SP, Jurkovitz CT, Hartigan PM, et al. Optimal medical therapy with or without percutaneous coronary intervention for patients with stable coronary artery disease and chronic kidney disease. Am J Cardiol. 2009;104:1647–53.
479. Hemmelgarn BR, Southern D, Culleton BF, et al. Survival after coronary revascularization among patients with kidney disease. Circulation. 2004;110:1890–5.
480. Reddan DN, Szczech LA, Tuttle RH, et al. Chronic kidney disease, mortality, and treatment strategies among patients with clinically significant coronary artery disease. J Am Soc Nephrol. 2003;14: 2373–80.
481. Bae KS, Park HC, Kang BS, et al. Percutaneous coronary intervention versus coronary artery bypass grafting in patients with coronary artery disease and diabetic nephropathy: a single center experience. Korean J Intern Med. 2007;22:139–46.
482. Herzog CA, Ma JZ, Collins AJ. Comparative survival of dialysis patients in the United States after coronary angioplasty, coronary artery stenting, and coronary artery bypass surgery and impact of diabetes. Circulation. 2002;106:2207–11.
483. Ix JH, Mercado N, Shlipak MG, et al. Association of chronic kidney disease with clinical outcomes after coronary revascularization: the Arterial Revascularization Therapies Study (ARTS). Am Heart J. 2005;149:512–9.
484. Koyanagi T, Nishida H, Kitamura M, et al. Comparison of clinical outcomes of coronary artery bypass grafting and percutaneous transluminal coronary angioplasty in renal dialysis patients. Ann Thorac Surg. 1996;61:1793–6.
485. Szczech LA, Reddan DN, Owen WF, et al. Differential survival after coronary revascularization procedures among patients with renal insufficiency. Kidney Int. 2001;60:292–9.
486. Jones EL, Craver JM, Guyton RA, et al. Importance of complete revascularization in performance of the coronary bypass operation. Am J Cardiol. 1983;51:7–12.
487. Bell MR, Bailey KR, Reeder GS, et al. Percutaneous transluminal angioplasty in patients with multivessel coronary disease: how important is complete revascularization for cardiac event-free survival? J Am Coll Cardiol. 1990;16:553–62.
488. Bourassa MG, Yeh W, Holubkov R, et al. Long-term outcome of patients with incomplete vs complete revascularization after multivessel PTCA. A report from the NHLBI PTCA Registry. Eur Heart J. 1998;19:103–11.
489. Faxon DP, Ghalilli K, Jacobs AK, et al. The degree of revascularization and outcome after multivessel coronary angioplasty. Am Heart J. 1992;123:854–9.
490. Berger PB, Velianou JL, Aslanidou VH, et al. Survival following coronary angioplasty versus coronary artery bypass surgery in anatomic subsets in which coronary artery bypass surgery improves survival compared with medical therapy. Results from the Bypass Angioplasty Revascularization Investigation (BARI). J Am Coll Cardiol. 2001;38:1440–9.
491. Gioia G, Matthai W, Gillin K, et al. Revascularization in severe left ventricular dysfunction: outcome comparison of drug-eluting stent implantation versus coronary artery by-pass grafting. Catheter Cardiovasc Interv. 2007;70:26–33.
492. O'Keefe JH Jr., Allan JJ, McCallister BD, et al. Angioplasty versus bypass surgery for multivessel coronary artery disease with left ventricular ejection fraction < or = 40%. Am J Cardiol. 1993;71: 897–901.
493. Cole JH, Jones EL, Craver JM, et al. Outcomes of repeat revascularization in diabetic patients with prior coronary surgery. J Am Coll Cardiol. 2002;40:1968–75.
494. Choudhry NK, Singh JM, Barolet A, et al. How should patients with unstable angina and non-ST-segment elevation myocardial infarction be managed? A meta-analysis of randomized trials. Am J Med. 2005;118:465–74.
495. Fox KA, Poole-Wilson PA, Henderson RA, et al. Interventional versus conservative treatment for patients with unstable angina or non-ST-elevation myocardial infarction: the British Heart Foundation RITA 3 randomised trial. Randomized Intervention Trial of unstable Angina. Lancet. 2002;360:743–51.
496. Fox KA, Clayton TC, Damman P, et al. Long-term outcome of a routine versus selective invasive strategy in patients with non-ST-segment elevation acute coronary syndrome a meta-analysis of individual patient data. J Am Coll Cardiol. 2010;55:2435–45.
497. Grines CL, Bonow RO, Casey DE Jr., et al. Prevention of premature discontinuation of dual antiplatelet therapy in patients with coronary artery stents: a science advisory from the American Heart Association, American College of Cardiology, Society for Cardiovascular Angiography and Interventions, American College of Surgeons, and American Dental Association, with representation from the American College of Physicians. J Am Coll Cardiol. 2007;6:734–9.
498. Leon MB, Baim DS, Popma JJ, et al. A clinical trial comparing three antithrombotic-drug regimens after coronary-artery stenting. Stent Anticoagulation Restenosis Study Investigators. N Engl J Med. 1998;339:1665–71.
499. Mauri L, Hsieh WH, Massaro JM, et al. Stent thrombosis in randomized clinical trials of drug-eluting stents. N Engl J Med. 2007;356:1020–9.
500. McFadden EP, Stabile E, Regar E, et al. Late thrombosis in drug-eluting coronary stents after discontinuation of antiplatelet therapy. Lancet. 2004;364:1519–21.
501. Eisenstein EL, Anstrom KJ, Kong DF, et al. Clopidogrel use and long-term clinical outcomes after drug-eluting stent implantation. JAMA. 2007;297:159–68.
502. Bridges CR, Horvath KA, Nugent WC, et al. The Society of Thoracic Surgeons practice guideline series: transmyocardial laser revascularization. Ann Thorac Surg. 2004;77:1494–502.
503. Vineberg AM. Development of an anastomosis between the coronary vessels and a transplanted internal mammary artery. Can Med Assoc J. 1946;55:117–9.
504. Aaberge L, Rootwelt K, Blomhoff S, et al. Continued symptomatic improvement three to five years after transmyocardial revascularization with CO(2) laser: a late clinical follow-up of the Norwegian Randomized trial with transmyocardial revascularization. J Am Coll Cardiol. 2002;39:1588–93.
505. Allen KB, Dowling RD, Fudge TL, et al. Comparison of transmyocardial revascularization with medical therapy in patients with refractory angina. N Engl J Med. 1999;341:1029–36.
506. Frazier OH, March RJ, Horvath KA. Transmyocardial revascularization with a carbon dioxide laser in patients with end-stage coronary artery disease. N Engl J Med. 1999;341:1021–8.
507. Peterson ED, Kaul P, Kaczmarek RG, et al. From controlled trials to clinical practice: monitoring transmyocardial revascularization use and outcomes. J Am Coll Cardiol. 2003;42:1611–6.
508. Bonatti J, Schachner T, Bonaros N, et al. Simultaneous hybrid coronary revascularization using totally endoscopic left internal mammary artery bypass grafting and placement of rapamycin eluting stents in the same interventional session. The COMBINATION pilot study. Cardiology. 2008;110:92–5.
509. Gilard M, Bezon E, Cornily JC, et al. Same-day combined percutaneous coronary intervention and coronary artery surgery. Cardiology. 2007;108:363–7.
510. Holzhey DM, Jacobs S, Mochalski M, et al. Minimally invasive hybrid coronary artery revascularization. Ann Thorac Surg. 2008; 86:1856–60.
511. Kon ZN, Brown EN, Tran R, et al. Simultaneous hybrid coronary revascularization reduces postoperative morbidity compared with results from conventional off-pump coronary artery bypass. J Thorac Cardiovasc Surg. 2008;135:367–75.
512. Reicher B, Poston RS, Mehra MR, et al. Simultaneous "hybrid" percutaneous coronary intervention and minimally invasive surgical bypass grafting: feasibility, safety, and clinical outcomes. Am Heart J. 2008;155:661–7.

513. Vassiliades TA Jr., Douglas JS, Morris DC, et al. Integrated coronary revascularization with drug-eluting stents: immediate and seven-month outcome. J Thorac Cardiovasc Surg. 2006;131:956–62.
514. Zhao DX, Leacche M, Balaguer JM, et al. Routine intraoperative completion angiography after coronary artery bypass grafting and 1–stop hybrid revascularization results from a fully integrated hybrid catheterization laboratory/operating room. J Am Coll Cardiol. 2009;53:232–41.
515. Angelini GD, Wilde P, Salerno TA, et al. Integrated left small thoracotomy and angioplasty for multivessel coronary artery revascularisation. Lancet. 1996;347:757–8.
516. Simoons ML. Myocardial revascularization—bypass surgery or angioplasty? N Engl J Med. 1996;335:275–7.
517. Bybee KA, Powell BD, Valeti U, et al. Preoperative aspirin therapy is associated with improved postoperative outcomes in patients undergoing coronary artery bypass grafting. Circulation. 2005;112: I286–92.
518. Dacey LJ, Munoz JJ, Johnson ER, et al. Effect of preoperative aspirin use on mortality in coronary artery bypass grafting patients. Ann Thorac Surg. 2000;70:1986–90.
519. Mangano DT, Multicenter Study of Perioperative Ischemia Research Group. Aspirin and mortality from coronary bypass surgery. N Engl J Med. 2002;347:1309–17.
520. Berger JS, Frye CB, Harshaw Q, et al. Impact of clopidogrel in patients with acute coronary syndromes requiring coronary artery bypass surgery: a multicenter analysis. J Am Coll Cardiol. 2008;52: 1693–701.
521. Held C, Asenblad N, Bassand JP, et al. Ticagrelor versus clopidogrel in patients with acute coronary syndromes undergoing coronary artery bypass surgery. Results from the PLATO (Platelet Inhibition and Patient Outcomes) trial. J Am Coll Cardiol. 2010; 57:672–84.
522. Hongo RH, Ley J, Dick SE, et al. The effect of clopidogrel in combination with aspirin when given before coronary artery bypass grafting. J Am Coll Cardiol. 2002;40:231–7.
523. Firanescu CE, Martens EJ, Schonberger JP, et al. Postoperative blood loss in patients undergoing coronary artery bypass surgery after preoperative treatment with clopidogrel. A prospective randomised controlled study. Eur J Cardiothorac Surg. 2009;36:856–62.
524. Herman CR, Buth KJ, Kent BA, et al. Clopidogrel increases blood transfusion and hemorrhagic complications in patients undergoing cardiac surgery. Ann Thorac Surg. 2010;89:397–402.
525. Mehta RH, Sheng S, O'Brien SM, et al. Reoperation for bleeding in patients undergoing coronary artery bypass surgery: incidence, risk factors, time trends, and outcomes. Circ Cardiovasc Qual Outcomes. 2009;2:583–90.
526. Bizzarri F, Scolletta S, Tucci E, et al. Perioperative use of tirofiban hydrochloride (Aggrastat) does not increase surgical bleeding after emergency or urgent coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2001;122:1181–5.
527. Dyke CM, Bhatia D, Lorenz TJ, et al. Immediate coronary artery bypass surgery after platelet inhibition with eptifibatide: results from PURSUIT. Platelet Glycoprotein IIb/IIIa in Unstable Angina: Receptor Suppression Using Integrelin Therapy. Ann Thorac Surg. 2000;70:866–71.
528. Lincoff AM, LeNarz LA, Despotis GJ, et al. Abciximab and bleeding during coronary surgery: results from the EPILOG and EPISTENT trials. Improve Long-term Outcome with abciximab GP IIb/IIIa blockade. Evaluation of Platelet IIb/IIIa Inhibition in STENTing. Ann Thorac Surg. 2000;70:516–26.
529. Ebrahimi R, Dyke C, Mehran R, et al. Outcomes following pre-operative clopidogrel administration in patients with acute coronary syndromes undergoing coronary artery bypass surgery: the ACUITY (Acute Catheterization and Urgent Intervention Triage strategY) trial. J Am Coll Cardiol. 2009;53:1965–72.
530. Fox KA, Mehta SR, Peters R, et al. Benefits and risks of the combination of clopidogrel and aspirin in patients undergoing surgical revascularization for non-ST-elevation acute coronary syndrome: the Clopidogrel in Unstable angina to prevent Recurrent ischemic Events (CURE) Trial. Circulation. 2004;110:1202–8.
531. Kim JH, Newby LK, Clare RM, et al. Clopidogrel use and bleeding after coronary artery bypass graft surgery. Am Heart J. 2008;156: 886–92.
532. Mehta RH, Roe MT, Mulgund J, et al. Acute clopidogrel use and outcomes in patients with non-ST-segment elevation acute coronary syndromes undergoing coronary artery bypass surgery. J Am Coll Cardiol. 2006;48:281–6.
533. Wiviott SD, Braunwald E, McCabe CH, et al. for the TRITON-TIMI 38 Investigators. Prasugrel versus clopidogrel in patients with acute coronary syndromes. N Engl J Med. 2007;357:2001–15.
534. Gurbel PA, Bliden KP, Butler K, et al. Randomized double-blind assessment of the ONSET and OFFSET of the antiplatelet effects of ticagrelor versus clopidogrel in patients with stable coronary artery disease: the ONSET/OFFSET study. Circulation. 2009;120: 2577–85.
535. Sethi GK, Copeland JG, Goldman S, et al. Implications of preoperative administration of aspirin in patients undergoing coronary artery bypass grafting. Department of Veterans Affairs Cooperative Study on Antiplatelet Therapy. J Am Coll Cardiol. 1990; 15:15–20.
536. Collaborative meta-analysis of randomised trials of antiplatelet therapy for prevention of death, myocardial infarction, and stroke in high risk patients [published correction appears in BMJ. 2002;324: 141]. BMJ. 2002;324:71–86.
537. Lorenz RL, Schacky CV, Weber M, et al. Improved aortocoronary bypass patency by low-dose aspirin (100 mg daily). Effects on platelet aggregation and thromboxane formation. Lancet. 1984;1: 1261–4.
538. Sharma GV, Khuri SF, Josa M, et al. The effect of antiplatelet therapy on saphenous vein coronary artery bypass graft patency. Circulation. 1983;68:II218–21.
539. Stein PD, Schunemann HJ, Dalen JE, et al. Antithrombotic therapy in patients with saphenous vein and internal mammary artery bypass grafts: the Seventh ACCP Conference on Antithrombotic and Thrombolytic Therapy. Chest. 2004;126:600S–8S.
540. Goldman S, Copeland J, Moritz T, et al. Internal mammary artery and saphenous vein graft patency. Effects of aspirin. Circulation. 1990;82:IV237–42.
541. Lim E, Ali Z, Ali A, et al. Indirect comparison meta-analysis of aspirin therapy after coronary surgery [published correction appears in BMJ. 2004;328:147]. BMJ. 2003;327:1309.
542. Maree AO, Curtin RJ, Dooley M, et al. Platelet response to low-dose enteric-coated aspirin in patients with stable cardiovascular disease. J Am Coll Cardiol. 2005;46:1258–63.
543. Limet R, David JL, Magotteaux P, et al. Prevention of aorta-coronary bypass graft occlusion. Beneficial effect of ticlopidine on early and late patency rates of venous coronary bypass grafts: a double-blind study. J Thorac Cardiovasc Surg. 1987;94:773–83.
544. Veeger NJ, Zijlstra F, Hillege HL, et al. Fourteen-year follow-up from CABADAS: vitamin K antagonists or dipyridamole not superior to aspirin. Ann Thorac Surg. 2010;90:1515–21.
545. The Post Coronary Artery Bypass Graft Trial Investigators. The effect of aggressive lowering of low-density lipoprotein cholesterol levels and low-dose anticoagulation on obstructive changes in saphenous-vein coronary-artery bypass grafts. N Engl J Med. 1997;336:153–62.
546. Yli-Mayry S, Huikuri HV, Korhonen UR, et al. Efficacy and safety of anticoagulant therapy started pre-operatively in preventing coronary vein graft occlusion. Eur Heart J. 1992;13:1259–64.
547. Harker LA, Boissel JP, Pilgrim AJ, et al., CAPRIE Steering Committee and Investigators. Comparative safety and tolerability of clopidogrel and aspirin: results from CAPRIE. Clopidogrel versus aspirin in patients at risk of ischaemic events. Drug Saf. 1999;21: 325–35.
548. Third Report of the National Cholesterol Education Program (NCEP) Expert Panel on Detection, Evaluation, and Treatment of High Blood Cholesterol in Adults (Adult Treatment Panel III) final report. Circulation. 2002;106:3143–421.
549. Baigent C, Blackwell L, Emberson J, et al. Efficacy and safety of more intensive lowering of LDL cholesterol: a meta-analysis of data from 170,000 participants in 26 randomised trials. Lancet. 2010; 376:1670–81.
550. Pedersen TR, Faergeman O, Kastelein JJ, et al. High-dose atorvastatin vs usual-dose simvastatin for secondary prevention after myocardial infarction: the IDEAL study: a randomized controlled trial [published correction appears in JAMA. 2005;294:3092]. JAMA. 2005;294:2437–45.

551. LaRosa JC, Grundy SM, Waters DD, et al. Intensive lipid lowering with atorvastatin in patients with stable coronary disease. N Engl J Med. 2005;352:1425–35.
552. MRC/BHF Heart Protection Study of cholesterol lowering with simvastatin in 20,536 high-risk individuals: a randomised placebo-controlled trial. Lancet. 2002;360:7–22.
553. Dotani MI, Elnicki DM, Jain AC, et al. Effect of preoperative statin therapy and cardiac outcomes after coronary artery bypass grafting. Am J Cardiol. 2000;86:1128–30, A6.
554. Mannacio VA, Iorio D, De Amicis V, et al. Effect of rosuvastatin pretreatment on myocardial damage after coronary surgery: a randomized trial. J Thorac Cardiovasc Surg. 2008;136:1541–8.
555. Liakopoulos OJ, Choi YH, Haldenwang PL, et al. Impact of preoperative statin therapy on adverse postoperative outcomes in patients undergoing cardiac surgery: a meta-analysis of over 30,000 patients. Eur Heart J. 2008;29:1548–59.
556. Knatterud GL, Rosenberg Y, Campeau L, et al., Post CABG Investigators. Long-term effects on clinical outcomes of aggressive lowering of low-density lipoprotein cholesterol levels and low-dose anticoagulation in the post coronary artery bypass graft trial. Circulation. 2000;102:157–65.
557. Christenson JT. Preoperative lipid-control with simvastatin reduces the risk of postoperative thrombocytosis and thrombotic complications following CABG. Eur J Cardiothorac Surg. 1999;15:394–9.
558. Pascual DA, Arribas JM, Tornel PL, et al. Preoperative statin therapy and troponin T predict early complications of coronary artery surgery. Ann Thorac Surg. 2006;81:78–83.
559. Pan W, Pintar T, Anton J, et al. Statins are associated with a reduced incidence of perioperative mortality after coronary artery bypass graft surgery. Circulation. 2004;110:II45–9.
560. Deleted in proof.
561. Cannon CP, Braunwald E, McCabe CH, et al. Intensive versus moderate lipid lowering with statins after acute coronary syndromes [published correction appears in N Engl J Med. 2006;354:778]. N Engl J Med. 2004;350:1495–504.
562. Cannon CP, Steinberg BA, Murphy SA, et al. Meta-analysis of cardiovascular outcomes trials comparing intensive versus moderate statin therapy. J Am Coll Cardiol. 2006;48:438–45.
563. Grundy SM, Cleeman JI, Merz CN, et al. Implications of recent clinical trials for the National Cholesterol Education Program Adult Treatment Panel III guidelines. Circulation. 2004;110:227–39.
564. FDA Safety Alert. Zocor (simvastatin): increased risk of muscle injury with high doses. U.S. Department of Health and Human Services. 2011. Available at: http://www.fda.gov/Safety/MedWatch/SafetyInformation/SafetyAlertsforHumanMedicalProducts/ucm205404.htm. Accessed June 30, 2011.
565. Collard CD, Body SC, Shernan SK, et al. Preoperative statin therapy is associated with reduced cardiac mortality after coronary artery bypass graft surgery. J Thorac Cardiovasc Surg. 2006;132:392–400.
566. Kulik A, Brookhart MA, Levin R, et al. Impact of statin use on outcomes after coronary artery bypass graft surgery. Circulation. 2008;118:1785–92.
567. Thielmann M, Neuhauser M, Marr A, et al. Lipid-lowering effect of preoperative statin therapy on postoperative major adverse cardiac events after coronary artery bypass surgery. J Thorac Cardiovasc Surg. 2007;134:1143–9.
568. Deleted in proof.
569. Deleted in proof.
570. Deleted in proof.
571. Marin F, Pascual DA, Roldan V, et al. Statins and postoperative risk of atrial fibrillation following coronary artery bypass grafting. Am J Cardiol. 2006;97:55–60.
572. Patti G, Chello M, Candura D, et al. Randomized trial of atorvastatin for reduction of postoperative atrial fibrillation in patients undergoing cardiac surgery: results of the ARMYDA-3 (Atorvastatin for Reduction of MYocardial Dysrhythmia After cardiac surgery) study. Circulation. 2006;114:1455–61.
573. Aboyans V, Labrousse L, Lacroix P, et al. Predictive factors of stroke in patients undergoing coronary bypass grafting: statins are protective. Eur J Cardiothorac Surg. 2006;30:300–4.
574. Katznelson R, Djaiani GN, Borger MA, et al. Preoperative use of statins is associated with reduced early delirium rates after cardiac surgery. Anesthesiology. 2009;110:67–73.
575. Tabata M, Khalpey Z, Pirundini PA, et al. Renoprotective effect of preoperative statins in coronary artery bypass grafting. Am J Cardiol. 2007;100:442–4.
576. Coleman CI, Lucek DM, Hammond J, et al. Preoperative statins and infectious complications following cardiac surgery. Curr Med Res Opin. 2007;23:1783–90.
577. Kulik A, Ruel M. Statins and coronary artery bypass graft surgery: preoperative and postoperative efficacy and safety. Expert Opin Drug Saf. 2009;8:559–71.
578. Pasternak RC, Smith SC Jr., Bairey-Merz CN, et al. ACC/AHA/NHLBI clinical advisory on the use and safety of statins. J Am Coll Cardiol. 2002;40:567–72.
579. Baigent C, Keech A, Kearney PM, et al. Efficacy and safety of cholesterol-lowering treatment: prospective meta-analysis of data from 90,056 participants in 14 randomised trials of statins [published corrections appear in Lancet. 2005;366:1358; 2008;371:2084]. Lancet. 2005;366:1267–78.
580. Armitage J. The safety of statins in clinical practice. Lancet. 2007;370:1781–90.
581. Furnary AP, Gao G, Grunkemeier GL, et al. Continuous insulin infusion reduces mortality in patients with diabetes undergoing coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2003;125:1007–21.
582. Ingels C, Debaveye Y, Milants I, et al. Strict blood glucose control with insulin during intensive care after cardiac surgery: impact on 4–years survival, dependency on medical care, and quality-of-life. Eur Heart J. 2006;27:2716–24.
583. van den Berghe G, Wouters P, Weekers F, et al. Intensive insulin therapy in the critically ill patients. N Engl J Med. 2001;345:1359–67.
584. Butterworth J, Wagenknecht LE, Legault C, et al. Attempted control of hyperglycemia during cardiopulmonary bypass fails to improve neurologic or neurobehavioral outcomes in patients without diabetes mellitus undergoing coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2005;130:1319.
585. Duncan AE, Abd-Elsayed A, Maheshwari A, et al. Role of intraoperative and postoperative blood glucose concentrations in predicting outcomes after cardiac surgery. Anesthesiology. 2010;112:860–71.
586. Gandhi GY, Nuttall GA, Abel MD, et al. Intensive intraoperative insulin therapy versus conventional glucose management during cardiac surgery: a randomized trial. Ann Intern Med. 2007;146:233–43.
587. Hulley S, Grady D, Bush T, et al., Heart and Estrogen/progestin Replacement Study (HERS) Research Group. Randomized trial of estrogen plus progestin for secondary prevention of coronary heart disease in postmenopausal women. JAMA. 1998;280:605–13.
588. Rossouw JE, Anderson GL, Prentice RL, et al. Risks and benefits of estrogen plus progestin in healthy postmenopausal women: principal results From the Women's Health Initiative randomized controlled trial. JAMA. 2002;288:321–33.
589. Ouyang P, Tardif JC, Herrington DM, et al. Randomized trial of hormone therapy in women after coronary bypass surgery. Evidence of differential effect of hormone therapy on angiographic progression of disease in saphenous vein grafts and native coronary arteries. Atherosclerosis. 2006;189:375–86.
590. Ouattara A, Lecomte P, Le Manach Y, et al. Poor intraoperative blood glucose control is associated with a worsened hospital outcome after cardiac surgery in diabetic patients. Anesthesiology. 2005;103:687–94.
591. Doenst T, Wijeysundera D, Karkouti K, et al. Hyperglycemia during cardiopulmonary bypass is an independent risk factor for mortality in patients undergoing cardiac surgery. J Thorac Cardiovasc Surg. 2005;130:1144.
592. Gandhi GY, Nuttall GA, Abel MD, et al. Intraoperative hyperglycemia and perioperative outcomes in cardiac surgery patients. Mayo Clin Proc. 2005;80:862–6.
593. Furnary AP, Zerr KJ, Grunkemeier GL, et al. Continuous intravenous insulin infusion reduces the incidence of deep sternal wound infection in diabetic patients after cardiac surgical procedures. Ann Thorac Surg. 1999;67:352–60.
594. Hruska LA, Smith JM, Hendy MP, et al. Continuous insulin infusion reduces infectious complications in diabetics following coronary surgery. J Card Surg. 2005;20:403–7.

595. Anderson RE, Klerdal K, Ivert T, et al. Are even impaired fasting blood glucose levels preoperatively associated with increased mortality after CABG surgery? Eur Heart J. 2005;26:1513–8.
596. Lazar HL, McDonnell M, Chipkin SR, et al. The Society of Thoracic Surgeons practice guideline series: Blood glucose management during adult cardiac surgery. Ann Thorac Surg. 2009;87:663–9.
597. Rodondi N, den Elzen WP, Bauer DC, et al. Subclinical hypothyroidism and the risk of coronary heart disease and mortality. JAMA. 2010;304:1365–74.
598. Ladenson PW, Levin AA, Ridgway EC, et al. Complications of surgery in hypothyroid patients. Am J Med. 1984;77:261–6.
599. Park YJ, Yoon JW, Kim KI, et al. Subclinical hypothyroidism might increase the risk of transient atrial fibrillation after coronary artery bypass grafting. Ann Thorac Surg. 2009;87:1846–52.
600. Klemperer JD, Klein IL, Ojamaa K, et al. Triiodothyronine therapy lowers the incidence of atrial fibrillation after cardiac operations. Ann Thorac Surg. 1996;61:1323–7.
601. Bennett-Guerrero E, Jimenez JL, White WD, et al., Duke T3 Study Group. Cardiovascular effects of intravenous triiodothyronine in patients undergoing coronary artery bypass graft surgery. A randomized, double-blind, placebo- controlled trial. JAMA. 1996;275:687–92.
602. Klemperer JD, Klein I, Gomez M, et al. Thyroid hormone treatment after coronary-artery bypass surgery. N Engl J Med. 1995;333:1522–7.
603. Sarma AK, Krishna M, Karunakaran J, et al. Severe hypothyroidism after coronary artery bypass grafting. Ann Thorac Surg. 2005;80:714–6.
604. Crystal E, Garfinkle MS, Connolly SS, et al. Interventions for preventing post-operative atrial fibrillation in patients undergoing heart surgery. Cochrane Database Syst Rev. 2004;CD003611.
605. Connolly SJ, Cybulsky I, Lamy A, et al. Double-blind, placebo-controlled, randomized trial of prophylactic metoprolol for reduction of hospital length of stay after heart surgery: the beta-Blocker Length Of Stay (BLOS) study. Am Heart J. 2003;145:226–32.
606. Andrews TC, Reimold SC, Berlin JA, et al. Prevention of supraventricular arrhythmias after coronary artery bypass surgery. A meta-analysis of randomized control trials. Circulation. 1991;84:III236–44.
607. Mariscalco G, Klersy C, Zanobini M, et al. Atrial fibrillation after isolated coronary surgery affects late survival. Circulation. 2008;118:1612–8.
608. Fuster V, Ryden LE, Cannom DS, et al. 2011 ACCF/AHA/HRS focused updates incorporated into the ACC/AHA/ESC 2006 guidelines for the management of patients with atrial fibrillation: a report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines. J Am Coll Cardiol. 2011;57:e101–98.
608a. Al-Khatib SM, Hafley G, Harrington RA, et al. Patterns of management of atrial fibrillation complicating coronary artery bypass grafting: results from the PRoject of Ex-vivo Vein graft ENgineering via Transfection IV (PREVENT-IV) Trial. Am Heart J. 2009;158:792–8.
608b. Silverman NA, Wright R, Levitsky S. Efficacy of low-dose propranolol in preventing postoperative supraventricular tachyarrhythmias: a prospective, randomized study. Ann Surg. 1982;196:194–7.
608c. Ali IM, Sanalla AA, Clark V. Beta-blocker effects on postoperative atrial fibrillation. Eur J Cardiothorac Surg. 1997;11:1154–7.
609. Ferguson TB Jr., Coombs LP, Peterson ED. Preoperative beta-blocker use and mortality and morbidity following CABG surgery in North America. JAMA. 2002;287:2221–7.
610. ten Broecke P, De Hert S, Mertens E. Effect of preoperative beta-blockade on perioperative mortality in coronary surgery. Br J Anaesth. 2003;90:27–31.
611. Weightman WM, Gibbs NM, Sheminant MR, et al. Drug therapy before coronary artery surgery: nitrates are independent predictors of mortality and beta-adrenergic blockers predict survival. Anesth Analg. 1999;88:286–91.
612. Chung F, Houston PL, Cheng DC, et al. Calcium channel blockade does not offer adequate protection from perioperative myocardial ischemia. Anesthesiology. 1988;69:343–7.
613. Podesser BK, Schwarzacher S, Zwoelfer W, et al. Comparison of perioperative myocardial protection with nifedipine versus nifedipine and metoprolol in patients undergoing elective coronary artery bypass grafting. J Thorac Cardiovasc Surg. 1995;110:1461–9.
614. Slogoff S, Keats AS. Does chronic treatment with calcium entry blocking drugs reduce perioperative myocardial ischemia? Anesthesiology. 1988;68:676–80.
615. Wiesbauer F, Schlager O, Domanovits H, et al. Perioperative beta-blockers for preventing surgery-related mortality and morbidity: a systematic review and meta-analysis. Anesth Analg. 2007;104:27–41.
616. Halonen J, Hakala T, Auvinen T, et al. Intravenous administration of metoprolol is more effective than oral administration in the prevention of atrial fibrillation after cardiac surgery. Circulation. 2006;114:I1–4.
617. Lin T, Hasaniya NW, Krider S, et al. Mortality reduction with beta-blockers in ischemic cardiomyopathy patients undergoing coronary artery bypass grafting. Congest Heart Fail. 2010;16:170–4.
618. Guru V, Anderson GM, Fremes SE, et al. The identification and development of Canadian coronary artery bypass graft surgery quality indicators. J Thorac Cardiovasc Surg. 2005;130:1257.
619. Shahian DM, Edwards FH, Ferraris VA, et al. Quality measurement in adult cardiac surgery: part 1–-Conceptual framework and measure selection. Ann Thorac Surg. 2007;83:S3–12.
620. Deleted in proof.
621. The MACB Study Group. Effect of metoprolol on death and cardiac events during a 2–year period after coronary artery bypass grafting. Eur Heart J. 1995;16:1825–32.
622. Goyal A, Alexander JH, Hafley GE, et al. Outcomes associated with the use of secondary prevention medications after coronary artery bypass graft surgery. Ann Thorac Surg. 2007;83:993–1001.
623. Sjoland H, Caidahl K, Lurje L, et al. Metoprolol treatment for two years after coronary bypass grafting: effects on exercise capacity and signs of myocardial ischaemia. Br Heart J. 1995;74:235–41.
624. Chen J, Radford MJ, Wang Y, et al. Are beta-blockers effective in elderly patients who undergo coronary revascularization after acute myocardial infarction? Arch Intern Med. 2000;160:947–52.
625. Chan AY, McAlister FA, Norris CM, et al. Effect of beta-blocker use on outcomes after discharge in patients who underwent cardiac surgery. J Thorac Cardiovasc Surg. 2010;140:182–7.
626. Smith SC Jr., Allen J, Blair SN, et al. AHA/ACC guidelines for secondary prevention for patients with coronary and other atherosclerotic vascular disease: 2006 update. J Am Coll Cardiol. 2006;47:2130–9.
627. Oosterga M, Voors AA, Pinto YM, et al. Effects of quinapril on clinical outcome after coronary artery bypass grafting (The QUO VADIS Study). QUinapril on Vascular Ace and Determinants of Ischemia. Am J Cardiol. 2001;87:542–6.
627a. Collaborative Group on ACE Inhibitor Trials. Overview of randomized trials of angiotensin-converting enzyme inhibitors on mortality and morbidity in patients with heart failure. JAMA. 1995;273:1450–6.
627b. The Heart Outcomes Prevention Evaluation Study Investigators. Effects of an angiotensin-converting enzyme inhibitor, ramipril, on cardiovascular events in high-risk patients. [published corrections appear in N Engl J Med. 2000;342:1376; 2000;342:748]. N Engl J Med. 2000;342:145–53.
628. Fox KM, Bertrand ME, Remme WJ, et al. Efficacy of perindopril in reducing risk of cardiac events in patients with revascularized coronary artery disease. Am Heart J. 2007;153:629–35.
629. Kjoller-Hansen L, Steffensen R, Grande P. The Angiotensin-converting Enzyme Inhibition Post Revascularization Study (APRES). J Am Coll Cardiol. 2000;35:881–8.
630. Rouleau JL, Warnica WJ, Baillot R, et al. Effects of angiotensin-converting enzyme inhibition in low-risk patients early after coronary artery bypass surgery. Circulation. 2008;117:24–31.
631. Arora P, Rajagopalam S, Ranjan R, et al. Preoperative use of angiotensin-converting enzyme inhibitors/angiotensin receptor blockers is associated with increased risk for acute kidney injury after cardiovascular surgery. Clin J Am Soc Nephrol. 2008;3:1266–73.
632. Benedetto U, Sciarretta S, Roscitano A, et al. Preoperative angiotensin-converting enzyme inhibitors and acute kidney injury after coronary artery bypass grafting. Ann Thorac Surg. 2008;86:1160–5.

633. Levin MA, Lin HM, Castillo JG, et al. Early on-cardiopulmonary bypass hypotension and other factors associated with vasoplegic syndrome. Circulation. 2009;120:1664–71.
634. Miceli A, Capoun R, Fino C, et al. Effects of angiotensin-converting enzyme inhibitor therapy on clinical outcome in patients undergoing coronary artery bypass grafting. J Am Coll Cardiol. 2009;54:1778–84.
635. Rader F, Van Wagoner DR, Gillinov AM, et al. Preoperative angiotensin-blocking drug therapy is not associated with atrial fibrillation after cardiac surgery. Am Heart J. 2010;160:329–36, e1.
636. White CM, Kluger J, Lertsburapa K, et al. Effect of preoperative angiotensin converting enzyme inhibitor or angiotensin receptor blocker use on the frequency of atrial fibrillation after cardiac surgery: a cohort study from the atrial fibrillation suppression trials II and III. Eur J Cardiothorac Surg. 2007;31:817–20.
637. Deleted in proof.
638. Raja SG, Fida N. Should angiotensin converting enzyme inhibitors/angiotensin II receptor antagonists be omitted before cardiac surgery to avoid postoperative vasodilation? Interact Cardiovasc Thorac Surg. 2008;7:470–5.
639. Levin R, Leacche M, Petracek MR, et al. Extending the use of the pacing pulmonary artery catheter for safe minimally invasive cardiac surgery. J Cardiothorac Vasc Anesth. 2010;24:568–73.
640. Eagle KA, Guyton RA, Davidoff R, et al. ACC/AHA 2004 guideline update for coronary artery bypass graft surgery: summary article. A report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (Committee to Update the 1999 Guidelines for Coronary Artery Bypass Graft Surgery). J Am Coll Cardiol. 2004;44:e213–310.
641. Anthonisen NR, Skeans MA, Wise RA, et al. The effects of a smoking cessation intervention on 14.5-year mortality: a randomized clinical trial. Ann Intern Med. 2005;142:233–9.
642. Hilleman DE, Mohiuddin SM, Packard KA. Comparison of conservative and aggressive smoking cessation treatment strategies following coronary artery bypass graft surgery. Chest. 2004;125:435–8.
643. Rigotti NA, Munafo MR, Stead LF. Smoking cessation interventions for hospitalized smokers: a systematic review. Arch Intern Med. 2008;168:1950–60.
644. Smith PM, Burgess E. Smoking cessation initiated during hospital stay for patients with coronary artery disease: a randomized controlled trial. CMAJ. 2009;180:1297–303.
645. Cavender JB, Rogers WJ, Fisher LD, et al., CASS Investigators. Effects of smoking on survival and morbidity in patients randomized to medical or surgical therapy in the Coronary Artery Surgery Study (CASS): 10–year follow-up. J Am Coll Cardiol. 1992;20:287–94.
646. Vlietstra RE, Kronmal RA, Oberman A, et al. Effect of cigarette smoking on survival of patients with angiographically documented coronary artery disease. Report from the CASS registry. JAMA. 1986;255:1023–7.
647. Ockene JK, Kuller LH, Svendsen KH, et al. The relationship of smoking cessation to coronary heart disease and lung cancer in the Multiple Risk Factor Intervention Trial (MRFIT). Am J Public Health. 1990;80:954–8.
648. van Domburg RT, Meeter K, van Berkel DF, et al. Smoking cessation reduces mortality after coronary artery bypass surgery: a 20–year follow-up study. J Am Coll Cardiol. 2000;36:878–83.
649. van Domburg RT, op Reimer WS, Hoeks SE, et al. Three life-years gained from smoking cessation after coronary artery bypass surgery: a 30–year follow-up study. Am Heart J. 2008;156:473–6.
650. Voors AA, van Brussel BL, Plokker HW, et al. Smoking and cardiac events after venous coronary bypass surgery. A 15–year follow-up study. Circulation. 1996;93:42–7.
651. Amoroso G, Mariani MA, Tio RA, et al. Continued cigarette smoking after coronary artery bypass surgery reduces endothelium-dependent vasodilation in internal thoracic artery grafts. Ital Heart J. 2001;2:139–41.
652. FitzGibbon GM, Leach AJ, Kafka HP. Atherosclerosis of coronary artery bypass grafts and smoking. CMAJ. 1987;136:45–7.
653. Goldenberg I, Jonas M, Tenenbaum A, et al. Current smoking, smoking cessation, and the risk of sudden cardiac death in patients with coronary artery disease. Arch Intern Med. 2003;163:2301–5.
654. Al-Sarraf N, Thalib L, Hughes A, et al. Effect of smoking on short-term outcome of patients undergoing coronary artery bypass surgery. Ann Thorac Surg. 2008;86:517–23.
655. Arabaci U, Akdur H, Yigit Z. Effects of smoking on pulmonary functions and arterial blood gases following coronary artery surgery in Turkish patients. Jpn Heart J. 2003;44:61–72.
656. Olsen MA, Lock-Buckley P, Hopkins D, et al. The risk factors for deep and superficial chest surgical-site infections after coronary artery bypass graft surgery are different. J Thorac Cardiovasc Surg. 2002;124:136–45.
657. Quist-Paulsen P, Bakke PS, Gallefoss F. Predictors of smoking cessation in patients admitted for acute coronary heart disease. Eur J Cardiovasc Prev Rehabil. 2005;12:472–7.
658. Rigotti NA, McKool KM, Shiffman S. Predictors of smoking cessation after coronary artery bypass graft surgery. Results of a randomized trial with 5–year follow-up. Ann Intern Med. 1994;120:287–93.
659. Harrington KF, Bailey WC. Smoking cessation through the utilization of pharmacotherapy. Expert Rev Respir Med. 2009;3:475–85.
660. Hurt RD, Sachs DP, Glover ED, et al. A comparison of sustained-release bupropion and placebo for smoking cessation. N Engl J Med. 1997;337:1195–202.
661. Jorenby DE, Hays JT, Rigotti NA, et al. Efficacy of varenicline, an alpha4beta2 nicotinic acetylcholine receptor partial agonist, vs placebo or sustained-release bupropion for smoking cessation: a randomized controlled trial [published correction appears in JAMA. 2006;296:1355]. JAMA. 2006;296:56–63.
662. Hubbard R, Lewis S, Smith C, et al. Use of nicotine replacement therapy and the risk of acute myocardial infarction, stroke, and death. Tob Control. 2005;14:416–21.
663. Lee AH, Afessa B. The association of nicotine replacement therapy with mortality in a medical intensive care unit. Crit Care Med. 2007;35:1517–21.
664. Paciullo CA, Short MR, Steinke DT, et al. Impact of nicotine replacement therapy on postoperative mortality following coronary artery bypass graft surgery. Ann Pharmacother. 2009;43:1197–202.
665. Blumenthal JA, Lett HS, Babyak MA, et al. Depression as a risk factor for mortality after coronary artery bypass surgery. Lancet. 2003;362:604–9.
666. Connerney I, Shapiro PA, McLaughlin JS, et al. Relation between depression after coronary artery bypass surgery and 12–month outcome: a prospective study. Lancet. 2001;358:1766–71.
667. Freedland KE, Skala JA, Carney RM, et al. Treatment of depression after coronary artery bypass surgery: a randomized controlled trial. Arch Gen Psychiatry. 2009;66:387–96.
668. Rollman BL, Belnap BH, LeMenager MS, et al. Telephone-delivered collaborative care for treating post-CABG depression: a randomized controlled trial. JAMA. 2009;302:2095–103.
669. Rollman BL, Belnap BH, LeMenager MS, et al. The Bypassing the Blues treatment protocol: stepped collaborative care for treating post-CABG depression. Psychosom Med. 2009;71:217–30.
670. Oxman TE, Freeman DH Jr., Manheimer ED. Lack of social participation or religious strength and comfort as risk factors for death after cardiac surgery in the elderly. Psychosom Med. 1995;57:5–15.
671. Ruberman W, Weinblatt E, Goldberg JD, et al. Psychosocial influences on mortality after myocardial infarction. N Engl J Med. 1984;311:552–9.
672. Frasure-Smith N, Prince R. The ischemic heart disease life stress monitoring program: impact on mortality. Psychosom Med. 1985;47:431–45.
673. Borowicz L Jr., Royall R, Grega M, et al. Depression and cardiac morbidity 5 years after coronary artery bypass surgery. Psychosomatics. 2002;43:464–71.
674. Gallagher R, McKinley S. Anxiety, depression and perceived control in patients having coronary artery bypass grafts. J Adv Nurs. 2009;65:2386–96.
675. Hedges C, Redeker NS. Comparison of sleep and mood in patients after on-pump and off-pump coronary artery bypass surgery. Am J Crit Care. 2008;17:133–40.
676. Martin F. Recognizing depression after a coronary artery bypass graft. Br J Nurs. 2006;15:703–6.

677. Goyal TM, Idler EL, Krause TJ, et al. Quality of life following cardiac surgery: impact of the severity and course of depressive symptoms. Psychosom Med. 2005;67:759–65.
678. Tully PJ, Baker RA, Knight JL. Anxiety and depression as risk factors for mortality after coronary artery bypass surgery. J Psychosom Res. 2008;64:285–90.
679. Engblom E, Korpilahti K, Hamalainen H, et al. Quality of life and return to work 5 years after coronary artery bypass surgery. Long-term results of cardiac rehabilitation. J Cardiopulm Rehabil. 1997; 17:29–36.
680. Hansen D, Dendale P, Leenders M, et al. Reduction of cardiovascular event rate: different effects of cardiac rehabilitation in CABG and PCI patients. Acta Cardiol. 2009;64:639–44.
681. Milani RV, Lavie CJ. The effects of body composition changes to observed improvements in cardiopulmonary parameters after exercise training with cardiac rehabilitation. Chest. 1998;113:599–601.
681a. Taylor RS, Brown A, Ebrahim S, et al. Exercise-based rehabilitation for patients with coronary heart disease: systematic review and meta-analysis of randomized controlled trials. Am J Med. 2004;116: 682–92.
681b. Clark AM, Hartling L, Vandermeer B, McAlister FA. Meta-analysis: secondary prevention programs for patients with coronary artery disease. Ann Intern Med 2005;143:659–72.
681c. Thomas RJ, King M, Lui K, et al. AACVPR/ACC/AHA 2007 performance measures on cardiac rehabilitation for referral to and delivery of cardiac rehabilitation/secondary prevention services. J Am Coll Cardiol. 2007;50:1400–33.
681d. Walther C, Mobius-Winkler S, Linke A, et al. Regular exercise training compared with percutaneous intervention leads to a reduction of inflammatory markers and cardiovascular events in patients with coronary artery disease. Eur J Cardiovasc Prev Rehabil. 2008;15:107–12.
682. Wenger NK, Hellerstein HK. Rehabilitation of the coronary patient 2nd ed. 1998.
683. O'Connor GT, Buring JE, Yusuf S, et al. An overview of randomized trials of rehabilitation with exercise after myocardial infarction. Circulation. 1989;80:234–44.
684. Oldridge NB, Guyatt GH, Fischer ME, et al. Cardiac rehabilitation after myocardial infarction. Combined experience of randomized clinical trials. JAMA. 1988;260:945–50.
685. Moholdt TT, Amundsen BH, Rustad LA, et al. Aerobic interval training versus continuous moderate exercise after coronary artery bypass surgery: a randomized study of cardiovascular effects and quality of life. Am Heart J. 2009;158:1031–7.
686. Shiran A, Kornfeld S, Zur S, et al. Determinants of improvement in exercise capacity in patients undergoing cardiac rehabilitation. Cardiology. 1997;88:207–13.
687. Friedman DB, Williams AN, Levine BD. Compliance and efficacy of cardiac rehabilitation and risk factor modification in the medically indigent. Am J Cardiol. 1997;79:281–5.
688. Ades PA, Huang D, Weaver SO. Cardiac rehabilitation participation predicts lower rehospitalization costs. Am Heart J. 1992;123: 916–21.
689. Smith SC Jr., Benjamin EJ, Bonow RO, et al. AHA/ACCF secondary prevention and risk reduction therapy for patients with coronary and other atherosclerotic vascular disease: 2011 update: a guideline from the American Heart Association and American College of Cardiology Foundation. Circulation. 2011: published online before print November 3, 2011, doi:10.1161/CIR.0b013e318235eb4d. Accessed November 3, 2011.
690. Drew BJ, Califf RM, Funk M, et al. Practice standards for electrocardiographic monitoring in hospital settings: an American Heart Association scientific statement from the Councils on Cardiovascular Nursing, Clinical Cardiology, and Cardiovascular Disease in the Young [published correction appears in Circulation. 2005;111:378]. Circulation. 2004;110:2721–46.
691. Echahidi N, Pibarot P, O'Hara G, et al. Mechanisms, prevention, and treatment of atrial fibrillation after cardiac surgery. J Am Coll Cardiol. 2008;51:793–801.
692. Gordon MA, Urban MK, O'Connor T, et al. Is the pressure rate quotient a predictor or indicator of myocardial ischemia as measured by ST-segment changes in patients undergoing coronary artery bypass surgery? Anesthesiology. 1991;74:848–53.
693. Jain U, Laflamme CJ, Aggarwal A, et al., Multicenter Study of Perioperative Ischemia (McSPI) Research Group. Electrocardiographic and hemodynamic changes and their association with myocardial infarction during coronary artery bypass surgery. A multicenter study. Anesthesiology. 1997;86:576–91.
694. Knight AA, Hollenberg M, London MJ, et al. Perioperative myocardial ischemia: importance of the preoperative ischemic pattern. Anesthesiology. 1988;68:681–8.
695. Mangano DT, Siliciano D, Hollenberg M, et al., the Study of Perioperative Ischemia (SPI) Research Group. Postoperative myocardial ischemia. Therapeutic trials using intensive analgesia following surgery. Anesthesiology. 1992;76:342–53.
696. Zvara DA, Groban L, Rogers AT, et al. Prophylactic nitroglycerin did not reduce myocardial ischemia during accelerated recovery management of coronary artery bypass graft surgery patients. J Cardiothorac Vasc Anesth. 2000;14:571–5.
697. Berry PD, Thomas SD, Mahon SP, et al. Myocardial ischaemia after coronary artery bypass grafting: early vs late extubation [published corrections appear in Br J Anaesth. 1998;80:572; 1998;81: 111]. Br J Anaesth. 1998;80:20–5.
698. Cheng DC, Karski J, Peniston C, et al. Morbidity outcome in early versus conventional tracheal extubation after coronary artery bypass grafting: a prospective randomized controlled trial. J Thorac Cardiovasc Surg. 1996;112:755–64.
699. Practice guidelines for pulmonary artery catheterization: an updated report by the American Society of Anesthesiologists Task Force on Pulmonary Artery Catheterization. Anesthesiology. 2003;99:988–1014.
700. Pearson KS, Gomez MN, Moyers JR, et al. A cost/benefit analysis of randomized invasive monitoring for patients undergoing cardiac surgery. Anesth Analg. 1989;69:336–41.
701. Resano FG, Kapetanakis EI, Hill PC, et al. Clinical outcomes of low-risk patients undergoing beating-heart surgery with or without pulmonary artery catheterization. J Cardiothorac Vasc Anesth. 2006;20:300–6.
702. Schwann TA, Zacharias A, Riordan CJ, et al. Safe, highly selective use of pulmonary artery catheters in coronary artery bypass grafting: an objective patient selection method. Ann Thorac Surg. 2002;73: 1394–401.
703. Stewart RD, Psyhojos T, Lahey SJ, et al. Central venous catheter use in low-risk coronary artery bypass grafting. Ann Thorac Surg. 1998;66:1306–11.
704. Tuman KJ, McCarthy RJ, Spiess BD, et al. Effect of pulmonary artery catheterization on outcome in patients undergoing coronary artery surgery. Anesthesiology. 1989;70:199–206.
705. Avidan MS, Zhang L, Burnside BA, et al. Anesthesia awareness and the bispectral index. N Engl J Med. 2008;358:1097–108.
706. Hemmerling TM, Olivier JF, Basile F, et al. Bispectral index as an indicator of cerebral hypoperfusion during off-pump coronary artery bypass grafting. Anesth Analg. 2005;100:354–6.
707. Myles PS, Leslie K, McNeil J, et al. Bispectral index monitoring to prevent awareness during anaesthesia: the B-Aware randomised controlled trial. Lancet. 2004;363:1757–63.
708. Brady K, Joshi B, Zweifel C, et al. Real-time continuous monitoring of cerebral blood flow autoregulation using near-infrared spectroscopy in patients undergoing cardiopulmonary bypass. Stroke. 2010; 41:1951–6.
709. Murkin JM, Adams SJ, Novick RJ, et al. Monitoring brain oxygen saturation during coronary bypass surgery: a randomized, prospective study. Anesth Analg. 2007;104:51–8.
710. Slater JP, Guarino T, Stack J, et al. Cerebral oxygen desaturation predicts cognitive decline and longer hospital stay after cardiac surgery. Ann Thorac Surg. 2009;87:36–44.
711. American Society of Anesthesiologists. Standards for Basic Anesthetic Monitoring. Committee of Origin: Standards and Practice Parameters. http://asahq.org/For-Healthcare-Professionals/~/media/For Members/documents/Standards Guidelines Stmts/Basic Anesthetic Monitoring 2011.ashx. Last amended October 20, 2010. Accessed July 1, 2011.
712. Chatterjee K. The Swan-Ganz catheters: past, present, and future. A viewpoint. Circulation. 2009;119:147–52.
713. London MJ, Moritz TE, Henderson WG, et al. Standard versus fiberoptic pulmonary artery catheterization for cardiac surgery in the

Department of Veterans Affairs: a prospective, observational, multicenter analysis. Anesthesiology. 2002;96:860–70.
714. Vincent JL, Pinsky MR, Sprung CL, et al. The pulmonary artery catheter: in medio virtus. Crit Care Med. 2008;36:3093–6.
715. Bernard GR, Sopko G, Cerra F, et al. Pulmonary artery catheterization and clinical outcomes: National Heart, Lung, and Blood Institute and Food and Drug Administration Workshop Report. Consensus Statement. JAMA. 2000;283:2568–72.
716. Fleisher LA, Beckman JA, Brown KA, et al. 2009 ACCF/AHA focused update on perioperative beta blockade incorporated into the ACC/AHA 2007 guidelines on perioperative cardiovascular evaluation and care for noncardiac surgery. J Am Coll Cardiol. 2009;54:e13–118.
717. Isley MR, Edmonds HL Jr., Stecker M. Guidelines for intraoperative neuromonitoring using raw (analog or digital waveforms) and quantitative electroencephalography: a position statement by the American Society of Neurophysiological Monitoring. J Clin Monit Comput. 2009;23:369–90.
718. Edmonds HL Jr., Isley MR, Sloan TB, et al. American Society of Neurophysiologic Monitoring and American Society of Neuroimaging Joint Guidelines for Transcranial Doppler Ultrasonic Monitoring. J Neuroimaging. 2011;21:177–83.
719. Practice Advisory for Intraoperative Awareness and Brain Function Monitoring: A Report by the American Society of Anesthesiologists Task Force on Intraoperative Awareness. Anesthesiology. 2006;104:864.
720. Edmonds HL Jr. 2010 standard of care for central nervous system monitoring during cardiac surgery. J Cardiothorac Vasc Anesth. 2010;24:541–3.
721. Kertai MD, Pal N, Palanca BJ, et al. Association of perioperative risk factors and cumulative duration of low bispectral index with intermediate-term mortality after cardiac surgery in the B-Unaware Trial. Anesthesiology. 2010;112:1116–27.
722. Monk TG, Saini V, Weldon BC, et al. Anesthetic management and one-year mortality after noncardiac surgery. Anesth Analg. 2005;100:4–10.
723. Murkin J, Arango M. Near-infrared spectroscopy as an index of brain and tissue oxygenation. Br J Anaesth. 2009;103:i3–13.
724. Heringlake M, Garbers C, Kabler J, et al. Preoperative Cerebral Oxygen Saturation and Clinical Outcomes in Cardiac Surgery. Anesthesiology. 2010;114:12–3.
725. Clark RE. The development of The Society of Thoracic Surgeons voluntary national database system: genesis, issues, growth, and status. Best Pract Benchmarking Healthc. 1996;1:62–9.
726. Deleted in proof.
727. Kouchoukos NT, Ebert PA, Grover FL, et al. Report of the Ad Hoc Committee on Risk Factors for Coronary Artery Bypass Surgery. Ann Thorac Surg. 1988;45:348–9.
728. Geraci JM, Johnson ML, Gordon HS, et al. Mortality after cardiac bypass surgery: prediction from administrative versus clinical data. Med Care. 2005;43:149–58.
729. Hannan EL, Kilburn H Jr., Lindsey ML, et al. Clinical versus administrative data bases for CABG surgery. Does it matter? Med Care. 1992;30:892–907.
730. Hannan EL, Racz MJ, Jollis JG, et al. Using Medicare claims data to assess provider quality for CABG surgery: does it work well enough? Health Serv Res. 1997;31:659–78.
731. Hartz AJ, Kuhn EM. Comparing hospitals that perform coronary artery bypass surgery: the effect of outcome measures and data sources. Am J Public Health. 1994;84:1609–14.
732. Jones RH, Hannan EL, Hammermeister KE, et al., the Working Group Panel on the Cooperative CABG Database Project. Identification of preoperative variables needed for risk adjustment of short-term mortality after coronary artery bypass graft surgery. J Am Coll Cardiol. 1996;28:1478–87.
733. Mack MJ, Herbert M, Prince S, et al. Does reporting of coronary artery bypass grafting from administrative databases accurately reflect actual clinical outcomes? J Thorac Cardiovasc Surg. 2005;129:1309–17.
734. Shahian DM, Silverstein T, Lovett AF, et al. Comparison of clinical and administrative data sources for hospital coronary artery bypass graft surgery report cards. Circulation. 2007;115:1518–27.
735. Tu JV, Sykora K, Naylor CD, Steering Committee of the Cardiac Care Network of Ontario. Assessing the outcomes of coronary artery bypass graft surgery: how many risk factors are enough? J Am Coll Cardiol. 1997;30:1317–23.
736. Grover FL, Johnson RR, Marshall G, et al. Factors predictive of operative mortality among coronary artery bypass subsets. Ann Thorac Surg. 1993;56:1296–306.
737. Grover FL, Johnson RR, Shroyer AL, et al. The Veterans Affairs Continuous Improvement in Cardiac Surgery Study. Ann Thorac Surg. 1994;58:1845–51.
738. Grover FL, Shroyer AL, Hammermeister KE. Calculating risk and outcome: the Veterans Affairs database. Ann Thorac Surg. 1996;62 5 Suppl:S6–11.
739. O'Connor GT, Plume SK, Olmstead EM, et al., the Northern New England Cardiovascular Disease Study Group. A regional prospective study of in-hospital mortality associated with coronary artery bypass grafting. JAMA. 1991;266:803–9.
740. O'Connor GT, Plume SK, Olmstead EM, et al. Multivariate prediction of in-hospital mortality associated with coronary artery bypass graft surgery. Northern New England Cardiovascular Disease Study Group. Circulation. 1992;85:2110–8.
741. Hannan EL, Kilburn H Jr., O'Donnell JF, et al. Adult open heart surgery in New York State. An analysis of risk factors and hospital mortality rates. JAMA. 1990;264:2768–74.
742. Hannan EL, Kumar D, Racz M, et al. New York State's Cardiac Surgery Reporting System: four years later. Ann Thorac Surg. 1994;58:1852–7.
743. Shahian DM, Normand SL, Torchiana DF, et al. Cardiac surgery report cards: comprehensive review and statistical critique. Ann Thorac Surg. 2001;72:2155–68.
744. Shahian DM, Torchiana DF, Normand SL. Implementation of a cardiac surgery report card: lessons from the Massachusetts experience. Ann Thorac Surg. 2005;80:1146–50.
745. Hammermeister KE, Daley J, Grover FL. Using outcomes data to improve clinical practice: what we have learned. Ann Thorac Surg. 1994;58:1809–11.
746. Hammermeister KE, Johnson R, Marshall G, et al. Continuous assessment and improvement in quality of care. A model from the Department of Veterans Affairs Cardiac Surgery. Ann Surg. 1994;219:281–90.
747. Ferguson TB Jr., Dziuban SW Jr., Edwards FH, et al. The STS National Database: current changes and challenges for the new millennium. Committee to Establish a National Database in Cardiothoracic Surgery, The Society of Thoracic Surgeons. Ann Thorac Surg. 2000;69:680–91.
748. Ferguson TB Jr., Peterson ED, Coombs LP, et al. Use of continuous quality improvement to increase use of process measures in patients undergoing coronary artery bypass graft surgery: a randomized controlled trial. JAMA. 2003;290:49–56.
749. O'Connor GT, Plume SK, Olmstead EM, et al., the Northern New England Cardiovascular Disease Study Group. A regional intervention to improve the hospital mortality associated with coronary artery bypass graft surgery. JAMA. 1996;275:841–6.
750. Hannan EL, Kilburn H Jr., Racz M, et al. Improving the outcomes of coronary artery bypass surgery in New York State. JAMA. 1994;271:761–6.
751. Hannan EL, Siu AL, Kumar D, et al. The decline in coronary artery bypass graft surgery mortality in New York State. The role of surgeon volume. JAMA. 1995;273:209–13.
752. Peterson ED, DeLong ER, Jollis JG, et al. The effects of New York's bypass surgery provider profiling on access to care and patient outcomes in the elderly. J Am Coll Cardiol. 1998;32:993–9.
753. Ghali WA, Ash AS, Hall RE, et al. Statewide quality improvement initiatives and mortality after cardiac surgery. JAMA. 1997;277:379–82.
754. Guru V, Fremes SE, Naylor CD, et al. Public versus private institutional performance reporting: what is mandatory for quality improvement? Am Heart J. 2006;152:573–8.
755. Hannan EL, Sarrazin MS, Doran DR, et al. Provider profiling and quality improvement efforts in coronary artery bypass graft surgery: the effect on short-term mortality among Medicare beneficiaries. Med Care. 2003;41:1164–72.
756. Chassin MR. Achieving and sustaining improved quality: lessons from New York State and cardiac surgery. Health Aff (Millwood). 2002;21:40–51.

757. Erickson LC, Torchiana DF, Schneider EC, et al. The relationship between managed care insurance and use of lower-mortality hospitals for CABG surgery. JAMA. 2000;283:1976–82.
758. Hannan EL, Stone CC, Biddle TL, et al. Public release of cardiac surgery outcomes data in New York: what do New York state cardiologists think of it [corrected and republished in: Am Heart J. 1997;134:1120–8]? Am Heart J. 1997;134:55–61.
759. Jha AK, Epstein AM. The predictive accuracy of the New York State coronary artery bypass surgery report-card system. Health Aff (Millwood). 2006;25:844–55.
760. Mukamel DB, Mushlin AI. Quality of care information makes a difference: an analysis of market share and price changes after publication of the New York State Cardiac Surgery Mortality Reports. Med Care. 1998;36:945–54.
761. Mukamel DB, Mushlin AI. The impact of quality report cards on choice of physicians, hospitals, and HMOs: a midcourse evaluation. Jt Comm J Qual Improv. 2001;27:20–7.
762. Mukamel DB, Weimer DL, Mushlin AI. Interpreting market share changes as evidence for effectiveness of quality report cards. Med Care. 2007;45:1227–32.
763. Schauffler HH, Mordavsky JK. Consumer reports in health care: do they make a difference? Annu Rev Public Health. 2001;22:69–89.
764. Shahian DM, Yip W, Westcott G, et al. Selection of a cardiac surgery provider in the managed care era. J Thorac Cardiovasc Surg. 2000;120:978–87.
765. Werner RM, Asch DA. The unintended consequences of publicly reporting quality information. JAMA. 2005;293:1239–44.
766. Romano PS, Zhou H. Do well-publicized risk-adjusted outcomes reports affect hospital volume? Med Care. 2004;42:367–77.
767. Hibbard JH, Sofaer S, Jewett JJ. Condition-specific performance information: assessing salience, comprehension, and approaches for communicating quality. Health Care Financ Rev. 1996;18:95–109.
768. Hibbard JH, Jewett JJ. Will quality report cards help consumers? Health Aff (Millwood). 1997;16:218–28.
769. Hibbard JH, Slovic P, Jewett JJ. Informing consumer decisions in health care: implications from decision-making research. Milbank Q. 1997;75:395–414.
770. Hibbard JH, Peters E, Slovic P, et al. Making health care quality reports easier to use. Jt Comm J Qual Improv. 2001;27:591–604.
771. Hibbard JH, Peters E. Supporting informed consumer health care decisions: data presentation approaches that facilitate the use of information in choice. Annu Rev Public Health. 2003;24:413–33.
772. Green J, Wintfeld N. Report cards on cardiac surgeons. Assessing New York State's approach. N Engl J Med. 1995;332:1229–32.
773. Dranove D, Kessler D, McClellan M, et al. Is more information better? The effects of "report cards" on health care providers. J Polit Econ. 2003;111:555–88.
774. Jones RH. In search of the optimal surgical mortality. Circulation. 1989;79:I132–6.
775. Omoigui NA, Miller DP, Brown KJ, et al. Outmigration for coronary bypass surgery in an era of public dissemination of clinical outcomes. Circulation. 1996;93:27–33.
776. Schneider EC, Epstein AM. Influence of cardiac-surgery performance reports on referral practices and access to care. A survey of cardiovascular specialists. N Engl J Med. 1996;335:251–6.
777. Iezzoni LI. Risk Adjustment for Measuring Health Care Outcomes. Chicago, Ill: Health Administration Press; 2003.
778. Kassirer JP. The use and abuse of practice profiles. N Engl J Med. 1994;330:634–6.
779. Krumholz HM, Brindis RG, Brush JE, et al. Standards for statistical models used for public reporting of health outcomes: an American Heart Association Scientific Statement from the Quality of Care and Outcomes Research Interdisciplinary Writing Group. Circulation. 2006;113:456–62.
780. Selker HP. Systems for comparing actual and predicted mortality rates: characteristics to promote cooperation in improving hospital care. Ann Intern Med. 1993;118:820–2.
781. Austin PC, Alter DA, Tu JV. The use of fixed- and random-effects models for classifying hospitals as mortality outliers: a Monte Carlo assessment. Med Decis Making. 2003;23:526–39.
782. Christiansen CL, Morris CN. Improving the statistical approach to health care provider profiling. Ann Intern Med. 1997;127:764–8.
783. Goldstein H, Spiegelhalter D. League tables and their limitations: statistical issues in comparisons of institutional performance. J R Statist Soc A. 1996;159:385–443.
784. Localio AR, Hamory BH, Fisher AC, et al. The public release of hospital and physician mortality data in Pennsylvania. A case study. Med Care. 1997;35:272–86.
785. Normand S-L, Glickman M, Gatsonis C. Statistical methods for profiling providers of medical care: issues and applications. J Am Stat Assoc. 1997;92:803–814.
786. Normand S-L, Shahian D. Statistical and clinical aspects of hospital outcomes profiling. Statistical Science. 2007;22:206–226.
787. Shahian DM, Blackstone EH, Edwards FH, et al. Cardiac surgery risk models: a position article. Ann Thorac Surg. 2004;78:1868–77.
788. Shahian DM, Normand SL. Comparison of "risk-adjusted" hospital outcomes. Circulation. 2008;117:1955–63.
789. Institute of Medicine. Performance Measure: Accelerating Improvement. Washington, DC: The National Academies Press, 2006.
790. O'Brien SM, Shahian DM, DeLong ER, et al. Quality measurement in adult cardiac surgery: part 2–-Statistical considerations in composite measure scoring and provider rating. Ann Thorac Surg. 2007;83 4 Suppl:S13–26.
791. Clark RE, the Ad Hoc Committee on Cardiac Surgery Credentialing of The Society of Thoracic Surgeons. Outcome as a function of annual coronary artery bypass graft volume. Ann Thorac Surg. 1996;61:21–6.
792. Grumbach K, Anderson GM, Luft HS, et al. Regionalization of cardiac surgery in the United States and Canada. Geographic access, choice, and outcomes. JAMA. 1995;274:1282–8.
793. Hannan EL, Kilburn H Jr., Bernard H, et al. Coronary artery bypass surgery: the relationship between inhospital mortality rate and surgical volume after controlling for clinical risk factors. Med Care. 1991;29:1094–107.
794. Hannan EL, Wu C, Ryan TJ, et al. Do hospitals and surgeons with higher coronary artery bypass graft surgery volumes still have lower risk-adjusted mortality rates? Circulation. 2003;108:795–801.
795. Kalant N, Shrier I. Volume and outcome of coronary artery bypass graft surgery: are more and less the same? Can J Cardiol. 2004;20:81–6.
796. Nallamothu BK, Saint S, Ramsey SD, et al. The role of hospital volume in coronary artery bypass grafting: is more always better? J Am Coll Cardiol. 2001;38:1923–30.
797. Peterson ED, Coombs LP, DeLong ER, et al. Procedural volume as a marker of quality for CABG surgery. JAMA. 2004;291:195–201.
798. Rathore SS, Epstein AJ, Volpp KG, et al. Hospital coronary artery bypass graft surgery volume and patient mortality, 1998–2000. Ann Surg. 2004;239:110–7.
799. Deleted in proof.
800. Showstack JA, Rosenfeld KE, Garnick DW, et al. Association of volume with outcome of coronary artery bypass graft surgery. Scheduled vs nonscheduled operations. JAMA. 1987;257:785–9.
801. Shroyer AL, Marshall G, Warner BA, et al. No continuous relationship between Veterans Affairs hospital coronary artery bypass grafting surgical volume and operative mortality. Ann Thorac Surg. 1996;61:17–20.
802. Sowden AJ, Deeks JJ, Sheldon TA. Volume and outcome in coronary artery bypass graft surgery: true association or artefact? BMJ. 1995;311:151–5.
803. Welke KF, Barnett MJ, Sarrazin MS, et al. Limitations of hospital volume as a measure of quality of care for coronary artery bypass graft surgery. Ann Thorac Surg. 2005;80:2114–9.
804. Wu C, Hannan EL, Ryan TJ, et al. Is the impact of hospital and surgeon volumes on the in-hospital mortality rate for coronary artery bypass graft surgery limited to patients at high risk? Circulation. 2004;110:784–9.
805. Flood AB, Scott WR, Ewy W. Does practice make perfect? Part I: The relation between hospital volume and outcomes for selected diagnostic categories. Med Care. 1984;22:98–114.
806. Hannan EL, Kilburn H Jr., O'Donnell JF, et al. A longitudinal analysis of the relationship between in-hospital mortality in New York State and the volume of abdominal aortic aneurysm surgeries performed. Health Serv Res. 1992;27:517–42.

807. Luft HS, Bunker JP, Enthoven AC. Should operations be regionalized? The empirical relation between surgical volume and mortality. N Engl J Med. 1979;301:1364–9.
808. Halm EA, Lee C, Chassin MR. Is volume related to outcome in health care? A systematic review and methodologic critique of the literature. Ann Intern Med. 2002;137:511–20.
809. Hughes CM. Influence of hospital volume on mortality following major cancer surgery. JAMA. 1999;281:1375.
810. Hughes RG, Hunt SS, Luft HS. Effects of surgeon volume and hospital volume on quality of care in hospitals. Med Care. 1987;25:489–503.
811. Dudley RA, Johansen KL, Brand R, et al. Selective referral to high-volume hospitals: estimating potentially avoidable deaths. JAMA. 2000;283:1159–66.
812. Birkmeyer JD, Sun Y, Goldfaden A, et al. Volume and process of care in high-risk cancer surgery. Cancer. 2006;106:2476–81.
813. Birkmeyer JD, Finlayson SR, Tosteson AN, et al. Effect of hospital volume on in-hospital mortality with pancreaticoduodenectomy. Surgery. 1999;125:250–6.
814. Birkmeyer JD, Warshaw AL, Finlayson SR, et al. Relationship between hospital volume and late survival after pancreaticoduodenectomy. Surgery. 1999;126:178–83.
815. Birkmeyer JD. High-risk surgery—follow the crowd. JAMA. 2000;283:1191–3.
816. Birkmeyer JD, Lucas FL, Wennberg DE. Potential benefits of regionalizing major surgery in Medicare patients. Eff Clin Pract. 1999;2:277–83.
817. Birkmeyer JD. Should we regionalize major surgery? Potential benefits and policy considerations. J Am Coll Surg. 2000;190:341–9.
818. Birkmeyer JD, Siewers AE, Finlayson EV, et al. Hospital volume and surgical mortality in the United States. N Engl J Med. 2002;346:1128–37.
819. Birkmeyer JD, Stukel TA, Siewers AE, et al. Surgeon volume and operative mortality in the United States. N Engl J Med. 2003;349:2117–27.
820. Chang AC, Birkmeyer JD. The volume-performance relationship in esophagectomy. Thorac Surg Clin. 2006;16:87–94.
821. Hollenbeck BK, Wei Y, Birkmeyer JD. Volume, process of care, and operative mortality for cystectomy for bladder cancer. Urology. 2007;69:871–5.
822. Hannan EL. The relation between volume and outcome in health care. N Engl J Med. 1999;340:1677–9.
823. Hannan EL, Radzyner M, Rubin D, et al. The influence of hospital and surgeon volume on in-hospital mortality for colectomy, gastrectomy, and lung lobectomy in patients with cancer. Surgery. 2002;131:6–15.
824. Hannan EL, Wu C, Walford G, et al. Volume-outcome relationships for percutaneous coronary interventions in the stent era. Circulation. 2005;112:1171–9.
825. Hannan EL, Racz M, Ryan TJ, et al. Coronary angioplasty volume-outcome relationships for hospitals and cardiologists. JAMA. 1997;277:892–8.
826. Hannan EL, Popp AJ, Tranmer B, et al. Relationship between provider volume and mortality for carotid endarterectomies in New York state. Stroke. 1998;29:2292–7.
827. Shahian DM, Normand SL. The volume-outcome relationship: from Luft to Leapfrog. Ann Thorac Surg. 2003;75:1048–58.
828. Birkmeyer JD, Finlayson EV, Birkmeyer CM. Volume standards for high-risk surgical procedures: potential benefits of the Leapfrog initiative. Surgery. 2001;130:415–22.
829. Halm E, Lee C, Chassin M. How is volume related to quality in health care? A systematic review of the research literature. In: Hewitt M, editor. Interpreting the volume-outcome relationship in the context of health care quality: workshop summary. Washington, DC: National Academy Press; 2000.
830. Luft H, Garnick D, Mark D. Hospital volume, physician volume, and patient outcomes: assessing the evidence. Ann Harbor, MI: Health Administration Press; 1990.
831. Hewitt M. Interpreting the volume-outcome relationship in the context of health care quality: workshop summary. Washington, DC: National Academy Press; 2000.
832. Urbach DR, Austin PC. Conventional models overestimate the statistical significance of volume-outcome associations, compared with multilevel models. J Clin Epidemiol. 2005;58:391–400.
833. Shahian DM. Improving cardiac surgery quality—volume, outcome, process? JAMA. 2004;291:246–8.
834. Shahian DM, Normand SL. Low-volume coronary artery bypass surgery: measuring and optimizing performance. J Thorac Cardiovasc Surg. 2008;135:1202–9.
835. Spiegelhalter DJ. Funnel plots for comparing institutional performance. Stat Med. 2005;24:1185–202.
836. de Leval MR, Francois K, Bull C, et al. Analysis of a cluster of surgical failures. Application to a series of neonatal arterial switch operations. J Thorac Cardiovasc Surg. 1994;107:914–23.
837. Grigg OA, Farewell VT, Spiegelhalter DJ. Use of risk-adjusted CUSUM and RSPRT charts for monitoring in medical contexts. Stat Methods Med Res. 2003;12:147–70.
838. Spiegelhalter D, Grigg O, Kinsman R, et al. Risk-adjusted sequential probability ratio tests: applications to Bristol, Shipman and adult cardiac surgery. Int J Qual Health Care. 2003;15:7–13.
839. Luft HS. Better for whom? Policy implications of acting on the relation between volume and outcome in coronary artery bypass grafting. J Am Coll Cardiol. 2001;38:1931–3.
840. Selim M. Perioperative stroke. N Engl J Med. 2007;356:706–13.
841. McKhann GM, Goldsborough MA, Borowicz LM Jr., et al. Predictors of stroke risk in coronary artery bypass patients. Ann Thorac Surg. 1997;63:516–21.
842. Filsoufi F, Rahmanian PB, Castillo JG, et al. Incidence, topography, predictors and long-term survival after stroke in patients undergoing coronary artery bypass grafting. Ann Thorac Surg. 2008;85:862–70.
843. Tarakji KG, Sabik JF, III, Bhudia SK, et al. Temporal onset, risk factors, and outcomes associated with stroke after coronary artery bypass grafting. JAMA. 2011;305:381–90.
844. Gottesman RF, Sherman PM, Grega MA, et al. Watershed strokes after cardiac surgery: diagnosis, etiology, and outcome. Stroke. 2006;37:2306–11.
845. Caplan LR, Hennerici M. Impaired clearance of emboli (washout) is an important link between hypoperfusion, embolism, and ischemic stroke. Arch Neurol. 1998;55:1475–82.
846. Roach GW, Kanchuger M, Mangano CM, et al., Multicenter Study of Perioperative Ischemia Research Group and the Ischemia Research and Education Foundation Investigators. Adverse cerebral outcomes after coronary bypass surgery. N Engl J Med. 1996;335:1857–63.
846a. Legare JF, Buth KJ, King S, et al. Coronary bypass surgery performed off pump does not result in lower in-hospital morbidity than coronary artery bypass grafting performed on pump. Circulation. 2004;109:887–92.
846b. Muneretto C, Bisleri G, Negri A, et al. Off-pump coronary artery bypass surgery technique for total arterial myocardial revascularization: a prospective randomized study. Ann Thorac Surg. 2003;76:778–82.
847. Nakamura M, Okamoto F, Nakanishi K, et al. Does intensive management of cerebral hemodynamics and atheromatous aorta reduce stroke after coronary artery surgery? Ann Thorac Surg. 2008;85:513–9.
848. Rosenberger P, Shernan SK, Loffler M, et al. The influence of epiaortic ultrasonography on intraoperative surgical management in 6051 cardiac surgical patients. Ann Thorac Surg. 2008;85:548–53.
849. Yamaguchi A, Adachi H, Tanaka M, et al. Efficacy of intraoperative epiaortic ultrasound scanning for preventing stroke after coronary artery bypass surgery. Ann Thorac Cardiovasc Surg. 2009;15:98–104.
850. van der Linden J, Hadjinikolaou L, Bergman P, et al. Postoperative stroke in cardiac surgery is related to the location and extent of atherosclerotic disease in the ascending aorta. J Am Coll Cardiol. 2001;38:131–5.
851. Suvarna S, Smith A, Stygall J, et al. An intraoperative assessment of the ascending aorta: a comparison of digital palpation, transesophageal echocardiography, and epiaortic ultrasonography. J Cardiothorac Vasc Anesth. 2007;21:805–9.
852. Sylivris S, Calafiore P, Matalanis G, et al. The intraoperative assessment of ascending aortic atheroma: epiaortic imaging is superior to both transesophageal echocardiography and direct palpation. J Cardiothorac Vasc Anesth. 1997;11:704–7.

853. Goto T, Baba T, Matsuyama K, et al. Aortic atherosclerosis and postoperative neurological dysfunction in elderly coronary surgical patients. Ann Thorac Surg. 2003;75:1912–8.
854. Hangler HB, Nagele G, Danzmayr M, et al. Modification of surgical technique for ascending aortic atherosclerosis: impact on stroke reduction in coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2003;126:391–400.
855. Schachner T, Nagele G, Kacani A, et al. Factors associated with presence of ascending aortic atherosclerosis in CABG patients. Ann Thorac Surg. 2004;78:2028–32.
856. Gold JP, Torres KE, Maldarelli W, et al. Improving outcomes in coronary surgery: the impact of echo-directed aortic cannulation and perioperative hemodynamic management in 500 patients. Ann Thorac Surg. 2004;78:1579–85.
857. Zingone B, Rauber E, Gatti G, et al. The impact of epiaortic ultrasonographic scanning on the risk of perioperative stroke. Eur J Cardiothorac Surg. 2006;29:720–8.
858. Durand DJ, Perler BA, Roseborough GS, et al. Mandatory versus selective preoperative carotid screening: a retrospective analysis. Ann Thorac Surg. 2004;78:159–66.
859. Sheiman RG, Janne d'Othee B. Screening carotid sonography before elective coronary artery bypass graft surgery: who needs it [published correction appears in Am J Roentgenol. 2007;189:512]. Am J Roentgenol. 2007;188:W475–79.
860. Naylor AR, Mehta Z, Rothwell PM, et al. Carotid artery disease and stroke during coronary artery bypass: a critical review of the literature. Eur J Vasc Endovasc Surg. 2002;23:283–94.
861. Executive Committee for the Asymptomatic Carotid Atherosclerosis Study. Endarterectomy for asymptomatic carotid artery stenosis. JAMA. 1995;273:1421–8.
862. Evans BA, Wijdicks EF. High-grade carotid stenosis detected before general surgery: is endarterectomy indicated? Neurology. 2001;57:1328–30.
863. Mortaz H, Mostafazadeh D, Sahraian M. Carotid endarterectomy for carotid stenosis in patients selected for coronary artery bypass graft surgery (Review). Cochrane Database Syst Rev. 2009; CD006074.
864. Wijns W, Kolh P, Danchin N, et al. Guidelines on myocardial revascularization: The Task Force on Myocardial Revascularization of the European Society of Cardiology (ESC) and the European Association for Cardio-Thoracic Surgery (EACTS). Eur Heart J. 2010;31:2501–55.
865. Cywinski JB, Koch CG, Krajewski LP, et al. Increased risk associated with combined carotid endarterectomy and coronary artery bypass graft surgery: a propensity-matched comparison with isolated coronary artery bypass graft surgery. J Cardiothorac Vasc Anesth. 2006;20:796–802.
866. Bucerius J, Gummert JF, Borger MA, et al. Predictors of delirium after cardiac surgery delirium: effect of beating-heart (off-pump) surgery. J Thorac Cardiovasc Surg. 2004;127:57–64.
867. Gottesman RF, Grega MA, Bailey MM, et al. Delirium after coronary artery bypass graft surgery and late mortality. Ann Neurol. 2010;67:338–44.
868. Rudolph JL, Jones RN, Rasmussen LS, et al. Independent vascular and cognitive risk factors for postoperative delirium. Am J Med. 2007;120:807–13.
869. Veliz-Reissmuller G, Aguero TH, van der Linden J, et al. Preoperative mild cognitive dysfunction predicts risk for post-operative delirium after elective cardiac surgery. Aging Clin Exp Res. 2007; 19:172–7.
870. Rudolph JL, Babikian VL, Treanor P, et al. Microemboli are not associated with delirium after coronary artery bypass graft surgery. Perfusion. 2009;24:409–15.
871. Hudetz JA, Iqbal Z, Gandhi SD, et al. Postoperative delirium and short-term cognitive dysfunction occur more frequently in patients undergoing valve surgery with or without coronary artery bypass graft surgery compared with coronary artery bypass graft surgery alone: results of a pilot study. J Cardiothorac Vasc Anesth. 2011; 25:811–6.
872. Rudolph JL, Inouye SK, Jones RN, et al. Delirium: an independent predictor of functional decline after cardiac surgery. J Am Geriatr Soc. 2010;58:643–9.
873. Andrew MJ, Baker RA, Bennetts J, et al. A comparison of neuropsychologic deficits after extracardiac and intracaradiac surgery. J Cardiothorac Vasc Anesth. 2001;15:9–14.
874. Fearn SJ, Pole R, Wesnes K, et al. Cerebral injury during cardiopulmonary bypass: emboli impair memory. J Thorac Cardiovasc Surg. 2001;121:1150–60.
875. Raymond PD, Hinton-Bayre AD, Radel M, et al. Assessment of statistical change criteria used to define significant change in neuropsychological test performance following cardiac surgery. Eur J Cardiothorac Surg. 2006;29:82–8.
876. Selnes OA, Goldsborough MA, Borowicz LM Jr., et al. Determinants of cognitive change after coronary artery bypass surgery: a multifactorial problem. Ann Thorac Surg. 1999;67:1669–76.
877. Selnes OA, Pham L, Zeger S, et al. Defining cognitive change after CABG: decline versus normal variability. Ann Thorac Surg. 2006; 82:388–90.
878. Johnson T, Monk T, Rasmussen LS, et al. Postoperative cognitive dysfunction in middle-aged patients. Anesthesiology. 2002;96: 1351–7.
879. Monk TG, Weldon BC, Garvan CW, et al. Predictors of cognitive dysfunction after major noncardiac surgery. Anesthesiology. 2008; 108:18–30.
880. Rasmussen LS, Moller JT. Central nervous system dysfunction after anesthesia in the geriatric patient. Anesthesiol Clin North America. 2000;18:59–70.
881. Ho PM, Arciniegas DB, Grigsby J, et al. Predictors of cognitive decline following coronary artery bypass graft surgery. Ann Thorac Surg. 2004;77:597–603.
882. Goto T, Baba T, Honma K, et al. Magnetic resonance imaging findings and postoperative neurologic dysfunction in elderly patients undergoing coronary artery bypass grafting. Ann Thorac Surg. 2001;72:137–42.
883. Takagi H, Tanabashi T, Kawai N, et al. A meta-analysis of minimally invasive coronary artery bypass versus percutaneous coronary intervention with stenting for isolated left anterior descending artery disease is indispensable. J Thorac Cardiovasc Surg. 2007;134: 548–9.
884. Marasco SF, Sharwood LN, Abramson MJ. No improvement in neurocognitive outcomes after off-pump versus on-pump coronary revascularisation: a meta-analysis. Eur J Cardiothorac Surg. 2008; 33:961–70.
885. Rosengart TK, Sweet JJ, Finnin E, et al. Stable cognition after coronary artery bypass grafting: comparisons with percutaneous intervention and normal controls. Ann Thorac Surg. 2006;82:597–607.
886. Sweet JJ, Finnin E, Wolfe PL, et al. Absence of cognitive decline one year after coronary bypass surgery: comparison to nonsurgical and healthy controls. Ann Thorac Surg. 2008;85:1571–8.
887. Selnes OA, Grega MA, Borowicz LM Jr., et al. Cognitive changes with coronary artery disease: a prospective study of coronary artery bypass graft patients and nonsurgical controls. Ann Thorac Surg. 2003;75:1377–84.
888. Newman MF, Kirchner JL, Phillips-Bute B, et al. Longitudinal assessment of neurocognitive function after coronary-artery bypass surgery. N Engl J Med. 2001;344:395–402.
889. Stygall J, Newman SP, Fitzgerald G, et al. Cognitive change 5 years after coronary artery bypass surgery. Health Psychol. 2003;22:579–86.
890. Selnes OA, Grega MA, Bailey MM, et al. Cognition 6 years after surgical or medical therapy for coronary artery disease. Ann Neurol. 2008;63:581–90.
891. van DD, Spoor M, Hijman R, et al. Cognitive and cardiac outcomes 5 years after off-pump vs on-pump coronary artery bypass graft surgery. JAMA. 2007;297:701–8.
892. Kreter B, Woods M. Antibiotic prophylaxis for cardiothoracic operations. Meta-analysis of thirty years of clinical trials. J Thorac Cardiovasc Surg. 1992;104:590–9.
893. Goodman JS, Schaffner W, Collins HA, et al. Infection after cardiovascular surgery. Clinical study including examination of antimicrobial prophylaxis. N Engl J Med. 1968;278:117–23.
894. Fong IW, Baker CB, McKee DC. The value of prophylactic antibiotics in aorat-coronary bypass operations: a double-blind randomized trial. J Thorac Cardiovasc Surg. 1979;78:908–13.
895. Fekety FR Jr., Cluff LE, Sabiston DC Jr., et al. A study of antibiotic prophylaxis in cardiac surgery. J Thorac Cardiovasc Surg. 1969;57: 757–63.

896. Austin TW, Coles JC, Burnett R, et al. Aortocoronary bypass procedures and sternotomy infections: a study of antistaphylococcal prophylaxis. Can J Surg. 1980;23:483–5.
897. Kaiser AB, Petracek MR, Lea JW, et al. Efficacy of cefazolin, cefamandole, and gentamicin as prophylactic agents in cardiac surgery. Results of a prospective, randomized, double-blind trial in 1030 patients. Ann Surg. 1987;206:791–7.
898. Bolon MK, Morlote M, Weber SG, et al. Glycopeptides are no more effective than beta-lactam agents for prevention of surgical site infection after cardiac surgery: a meta-analysis. Clin Infect Dis. 2004;38:1357–63.
899. Finkelstein R, Rabino G, Mashiah T, et al. Vancomycin versus cefazolin prophylaxis for cardiac surgery in the setting of a high prevalence of methicillin-resistant staphylococcal infections. J Thorac Cardiovasc Surg. 2002;123:326–32.
900. Maki DG, Bohn MJ, Stolz SM, et al. Comparative study of cefazolin, cefamandole, and vancomycin for surgical prophylaxis in cardiac and vascular operations. A double-blind randomized trial. J Thorac Cardiovasc Surg. 1992;104:1423–34.
901. Saginur R, Croteau D, Bergeron MG, the ESPRIT Group. Comparative efficacy of teicoplanin and cefazolin for cardiac operation prophylaxis in 3027 patients. J Thorac Cardiovasc Surg. 2000;120:1120–30.
902. Salminen US, Viljanen TU, Valtonen VV, et al. Ceftriaxone versus vancomycin prophylaxis in cardiovascular surgery. J Antimicrob Chemother. 1999;44:287–90.
903. Townsend TR, Reitz BA, Bilker WB, et al. Clinical trial of cefamandole, cefazolin, and cefuroxime for antibiotic prophylaxis in cardiac operations. J Thorac Cardiovasc Surg. 1993;106:664–70.
904. Vuorisalo S, Pokela R, Syrjala H. Comparison of vancomycin and cefuroxime for infection prophylaxis in coronary artery bypass surgery. Infect Control Hosp Epidemiol. 1998;19:234–9.
905. Wilson AP, Treasure T, Gruneberg RN, et al. Antibiotic prophylaxis in cardiac surgery: a prospective comparison of two dosage regimens of teicoplanin with a combination of flucloxacillin and tobramycin. J Antimicrob Chemother. 1988;21:213–23.
906. Centers for Diseases Control and Prevention. Recommendations for preventing the spread of vancomycin resistance. Recommendations of the Hospital Infection Control Practices Advisory Committee. MMWR Morb Mortal Wkly Rep. 2010;44:1–13.
907. Spelman D, Harrington G, Russo P, et al. Clinical, microbiological, and economic benefit of a change in antibiotic prophylaxis for cardiac surgery. Infect Control Hosp Epidemiol. 2002;23:402–4.
908. Walsh EE, Greene L, Kirshner R. Sustained Reduction in Methicillin-Resistant Staphylococcus aureus Wound Infections After Cardiothoracic Surgery. Arch Intern Med. 2010;171:68–73.
909. Jurkiewicz MJ, Bostwick J, III, Hester TR, et al. Infected median sternotomy wound. Successful treatment by muscle flaps. Ann Surg. 1980;191:738–44.
910. Rand RP, Cochran RP, Aziz S, et al. Prospective trial of catheter irrigation and muscle flaps for sternal wound infection. Ann Thorac Surg. 1998;65:1046–9.
911. Wong CH, Senewiratne S, Garlick B, et al. Two-stage management of sternal wound infection using bilateral pectoralis major advancement flap. Eur J Cardiothorac Surg. 2006;30:148–52.
912. Argenta LC, Morykwas MJ. Vacuum-assisted closure: a new method for wound control and treatment: clinical experience. Ann Plast Surg. 1997;38:563–76.
913. Baillot R, Cloutier D, Montalin L, et al. Impact of deep sternal wound infection management with vacuum-assisted closure therapy followed by sternal osteosynthesis: a 15–year review of 23,499 sternotomies. Eur J Cardiothorac Surg. 2010;37:880–7.
914. Cowan KN, Teague L, Sue SC, et al. Vacuum-assisted wound closure of deep sternal infections in high-risk patients after cardiac surgery. Ann Thorac Surg. 2005;80:2205–12.
915. Doss M, Martens S, Wood JP, et al. Vacuum-assisted suction drainage versus conventional treatment in the management of poststernotomy osteomyelitis. Eur J Cardiothorac Surg. 2002;22:934–8.
916. Ennker IC, Malkoc A, Pietrowski D, et al. The concept of negative pressure wound therapy (NPWT) after poststernotomy mediastinitis—a single center experience with 54 patients. J Cardiothorac Surg. 2009;4:5.
917. Fleck T, Moidl R, Giovanoli P, et al. A conclusion from the first 125 patients treated with the vacuum assisted closure system for postoperative sternal wound infection. Interact Cardiovasc Thorac Surg. 2006;5:145–8.
918. Fleck TM, Fleck M, Moidl R, et al. The vacuum-assisted closure system for the treatment of deep sternal wound infections after cardiac surgery. Ann Thorac Surg. 2002;74:1596–600.
919. Luckraz H, Murphy F, Bryant S, et al. Vacuum-assisted closure as a treatment modality for infections after cardiac surgery. J Thorac Cardiovasc Surg. 2003;125:301–5.
920. Sjogren J, Gustafsson R, Nilsson J, et al. Clinical outcome after poststernotomy mediastinitis: vacuum-assisted closure versus conventional treatment. Ann Thorac Surg. 2005;79:2049–55.
921. Sjogren J, Nilsson J, Gustafsson R, et al. The impact of vacuum-assisted closure on long-term survival after post-sternotomy mediastinitis. Ann Thorac Surg. 2005;80:1270–5.
922. Furnary AP, Wu Y. Eliminating the diabetic disadvantage: the Portland Diabetic Project. Semin Thorac Cardiovasc Surg. 2006;18:302–8.
923. Kirdemir P, Yildirim V, Kiris I, et al. Does continuous insulin therapy reduce postoperative supraventricular tachycardia incidence after coronary artery bypass operations in diabetic patients? J Cardiothorac Vasc Anesth. 2008;22:383–7.
924. Bilgin YM, van de Watering LM, Eijsman L, et al. Double-blind, randomized controlled trial on the effect of leukocyte-depleted erythrocyte transfusions in cardiac valve surgery. Circulation. 2004;109:2755–60.
925. Blumberg N, Heal JM, Cowles JW, et al. Leukocyte-reduced transfusions in cardiac surgery results of an implementation trial. Am J Clin Pathol. 2002;118:376–81.
926. Romano G, Mastroianni C, Bancone C, et al. Leukoreduction program for red blood cell transfusions in coronary surgery: association with reduced acute kidney injury and in-hospital mortality. J Thorac Cardiovasc Surg. 2010;140:188–95.
927. van de Watering LM, Hermans J, Houbiers JG, et al. Beneficial effects of leukocyte depletion of transfused blood on postoperative complications in patients undergoing cardiac surgery: a randomized clinical trial. Circulation. 1998;97:562–8.
928. Konvalinka A, Errett L, Fong IW. Impact of treating Staphylococcus aureus nasal carriers on wound infections in cardiac surgery. J Hosp Infect. 2006;64:162–8.
929. van Rijen M, Bonten M, Wenzel R, et al. Mupirocin ointment for preventing Staphylococcus aureus infections in nasal carriers. Cochrane Database Syst Rev. 2008;CD006216.
930. Fletcher N, Sofianos D, Berkes MB, et al. Prevention of perioperative infection. J Bone Joint Surg Am. 2007;89:1605–18.
931. Geelhoed GW, Sharpe K, Simon GL. A comparative study of surgical skin preparation methods. Surg Gynecol Obstet. 1983;157:265–8.
932. Kaiser AB, Kernodle DS, Barg NL, et al. Influence of preoperative showers on staphylococcal skin colonization: a comparative trial of antiseptic skin cleansers. Ann Thorac Surg. 1988;45:35–8.
933. Risk factors for deep sternal wound infection after sternotomy: a prospective, multicenter study. J Thorac Cardiovasc Surg. 1996;111:1200–7.
934. Bratzler DW, Hunt DR. The surgical infection prevention and surgical care improvement projects: national initiatives to improve outcomes for patients having surgery. Clin Infect Dis. 2006;43:322–30.
935. Ko W, Lazenby WD, Zelano JA, et al. Effects of shaving methods and intraoperative irrigation on suppurative mediastinitis after bypass operations. Ann Thorac Surg. 1992;53:301–5.
936. Nishida H, Grooters RK, Soltanzadeh H, et al. Discriminate use of electrocautery on the median sternotomy incision. A 0.16% wound infection rate. J Thorac Cardiovasc Surg. 1991;101:488–94.
937. Tanner J, Woodings D, Moncaster K. Preoperative hair removal to reduce surgical site infection. Cochrane Database Syst Rev. 2006;CD004122.
938. Nelson DR, Buxton TB, Luu QN, et al. The promotional effect of bone wax on experimental Staphylococcus aureus osteomyelitis. J Thorac Cardiovasc Surg. 1990;99:977–80.
939. Bennett B, Duff P. The effect of double gloving on frequency of glove perforations. Obstet Gynecol. 1991;78:1019–22.
940. Berridge DC, Starky G, Jones NA, et al. A randomized controlled trial of double-versus single-gloving in vascular surgery. J R Coll Surg Edinb. 1998;43:9–10.

941. Gani JS, Anseline PF, Bissett RL. Efficacy of double versus single gloving in protecting the operating team. Aust N Z J Surg. 1990;60:171–5.
942. Webb JM, Pentlow BD. Double gloving and surgical technique. Ann R Coll Surg Engl. 1993;75:291–2.
943. Wong PS, Young VK, Youhana A, et al. Surgical glove punctures during cardiac operations. Ann Thorac Surg. 1993;56:108–10.
944. Crabtree TD, Codd JE, Fraser VJ, et al. Multivariate analysis of risk factors for deep and superficial sternal infection after coronary artery bypass grafting at a tertiary care medical center. Semin Thorac Cardiovasc Surg. 2004;16:53–61.
945. Edwards FH, Engelman RM, Houck P, et al. The Society of Thoracic Surgeons Practice Guideline Series: Antibiotic Prophylaxis in Cardiac Surgery, Part I: Duration. Ann Thorac Surg. 2006;81:397–404.
946. Ridderstolpe L, Gill H, Granfeldt H, et al. Superficial and deep sternal wound complications: incidence, risk factors and mortality. Eur J Cardiothorac Surg. 2001;20:1168–75.
947. Milano CA, Kesler K, Archibald N, et al. Mediastinitis after coronary artery bypass graft surgery. Risk factors and long-term survival. Circulation. 1995;92:2245–51.
948. Abboud CS, Wey SB, Baltar VT. Risk factors for mediastinitis after cardiac surgery. Ann Thorac Surg. 2004;77:676–83.
949. Loop FD, Lytle BW, Cosgrove DM, et al. J. Maxwell Chamberlain memorial paper. Sternal wound complications after isolated coronary artery bypass grafting: early and late mortality, morbidity, and cost of care. Ann Thorac Surg. 1990;49:179–86.
950. Braxton JH, Marrin CA, McGrath PD, et al. 10–year follow-up of patients with and without mediastinitis. Semin Thorac Cardiovasc Surg. 2004;16:70–6.
951. Borger MA, Rao V, Weisel RD, et al. Deep sternal wound infection: risk factors and outcomes. Ann Thorac Surg. 1998;65:1050–6.
952. Stahle E, Tammelin A, Bergstrom R, et al. Sternal wound complications—incidence, microbiology and risk factors. Eur J Cardiothorac Surg. 1997;11:1146–53.
953. Toumpoulis IK, Anagnostopoulos CE, Derose JJ Jr., et al. The impact of deep sternal wound infection on long-term survival after coronary artery bypass grafting. Chest. 2005;127:464–71.
954. Filsoufi F, Castillo JG, Rahmanian PB, et al. Epidemiology of deep sternal wound infection in cardiac surgery. J Cardiothorac Vasc Anesth. 2009;23:488–94.
955. Losanoff JE, Richman BW, Jones JW. Disruption and infection of median sternotomy: a comprehensive review. Eur J Cardiothorac Surg. 2002;21:831–9.
956. De Paulis R, de Notaris S, Scaffa R, et al. The effect of bilateral internal thoracic artery harvesting on superficial and deep sternal infection: The role of skeletonization. J Thorac Cardiovasc Surg. 2005;129:536–43.
957. Savage EB, Grab JD, O'Brien SM, et al. Use of both internal thoracic arteries in diabetic patients increases deep sternal wound infection. Ann Thorac Surg. 2007;83:1002–6.
958. Saso S, James D, Vecht JA, et al. Effect of skeletonization of the internal thoracic artery for coronary revascularization on the incidence of sternal wound infection. Ann Thorac Surg. 2010;89:661–70.
959. Murphy GJ, Reeves BC, Rogers CA, et al. Increased mortality, postoperative morbidity, and cost after red blood cell transfusion in patients having cardiac surgery. Circulation. 2007;116:2544–52.
960. Chelemer SB, Prato BS, Cox PM Jr., et al. Association of bacterial infection and red blood cell transfusion after coronary artery bypass surgery. Ann Thorac Surg. 2002;73:138–42.
961. Banbury MK, Brizzio ME, Rajeswaran J, et al. Transfusion increases the risk of postoperative infection after cardiovascular surgery. J Am Coll Surg. 2006;202:131–8.
962. Leal-Noval SR, Rincon-Ferrari MD, Garcia-Curiel A, et al. Transfusion of blood components and postoperative infection in patients undergoing cardiac surgery. Chest. 2001;119:1461–8.
963. Blanchard A, Hurni M, Ruchat P, et al. Incidence of deep and superficial sternal infection after open heart surgery. A ten years retrospective study from 1981 to 1991. Eur J Cardiothorac Surg. 1995;9:153–7.
964. Risnes I, Abdelnoor M, Almdahl SM, et al. Mediastinitis after coronary artery bypass grafting risk factors and long-term survival. Ann Thorac Surg. 2010;89:1502–9.
965. Bilgin YM, van de Watering LM, Versteegh MI, et al. Effects of allogeneic leukocytes in blood transfusions during cardiac surgery on inflammatory mediators and postoperative complications. Crit Care Med. 2010;38:546–52.
966. Dodds Ashley ES, Carroll DN, Engemann JJ, et al. Risk factors for postoperative mediastinitis due to methicillin-resistant Staphylococcus aureus. Clin Infect Dis. 2004;38:1555–60.
967. Olsson C, Tammelin A, Thelin S. Staphylococcus aureus bloodstream infection after cardiac surgery: risk factors and outcome. Infect Control Hosp Epidemiol. 2006;27:83–5.
968. Martorell C, Engelman R, Corl A, et al. Surgical site infections in cardiac surgery: an 11–year perspective. Am J Infect Control. 2004;32:63–8.
969. Kachroo S, Dao T, Zabaneh F, et al. Tolerance of vancomycin for surgical prophylaxis in patients undergoing cardiac surgery and incidence of vancomycin-resistant enterococcus colonization. Ann Pharmacother. 2006;40:381–5.
970. Ariano RE, Zhanel GG. Antimicrobial prophylaxis in coronary bypass surgery: a critical appraisal. DICP. 1991;25:478–84.
971. Matros E, Aranki SF, Bayer LR, et al. Reduction in incidence of deep sternal wound infections: random or real? J Thorac Cardiovasc Surg. 2010;139:680–5.
972. Jones G, Jurkiewicz MJ, Bostwick J, et al. Management of the infected median sternotomy wound with muscle flaps. The Emory 20–year experience. Ann Surg. 1997;225:766–76.
973. Sjogren J, Malmsjo M, Gustafsson R, et al. Poststernotomy mediastinitis: a review of conventional surgical treatments, vacuum-assisted closure therapy and presentation of the Lund University Hospital mediastinitis algorithm. Eur J Cardiothorac Surg. 2006;30:898–905.
974. Ascione R, Nason G, Al-Ruzzeh S, et al. Coronary revascularization with or without cardiopulmonary bypass in patients with preoperative nondialysis-dependent renal insufficiency. Ann Thorac Surg. 2001;72:2020–5.
975. Chukwuemeka A, Weisel A, Maganti M, et al. Renal dysfunction in high-risk patients after on-pump and off-pump coronary artery bypass surgery: a propensity score analysis. Ann Thorac Surg. 2005;80:2148–53.
976. Di Mauro M, Gagliardi M, Iaco AL, et al. Does off-pump coronary surgery reduce postoperative acute renal failure? The importance of preoperative renal function. Ann Thorac Surg. 2007;84:1496–502.
977. Nigwekar SU, Kandula P, Hix JK, et al. Off-pump coronary artery bypass surgery and acute kidney injury: a meta-analysis of randomized and observational studies. Am J Kidney Dis. 2009;54:413–23.
978. Sajja LR, Mannam G, Chakravarthi RM, et al. Coronary artery bypass grafting with or without cardiopulmonary bypass in patients with preoperative non-dialysis dependent renal insufficiency: a randomized study. J Thorac Cardiovasc Surg. 2007;133:378–88.
979. Del Duca D, Iqbal S, Rahme E, et al. Renal failure after cardiac surgery: timing of cardiac catheterization and other perioperative risk factors. Ann Thorac Surg. 2007;84:1264–71.
980. Medalion B, Cohen H, Assali A, et al. The effect of cardiac angiography timing, contrast media dose, and preoperative renal function on acute renal failure after coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2010;139:1539–44.
981. Ranucci M, Ballotta A, Kunkl A, et al. Influence of the timing of cardiac catheterization and the amount of contrast media on acute renal failure after cardiac surgery. Am J Cardiol. 2008;101:1112–8.
982. Adabag AS, Ishani A, Bloomfield HE, et al. Efficacy of N-acetylcysteine in preventing renal injury after heart surgery: a systematic review of randomized trials. Eur Heart J. 2009;30:1910–7.
983. Amar D, Fleisher M. Diltiazem treatment does not alter renal function after thoracic surgery. Chest. 2001;119:1476–9.
984. Caimmi PP, Pagani L, Micalizzi E, et al. Fenoldopam for renal protection in patients undergoing cardiopulmonary bypass. J Cardiothorac Vasc Anesth. 2003;17:491–4.
985. Cogliati AA, Vellutini R, Nardini A, et al. Fenoldopam infusion for renal protection in high-risk cardiac surgery patients: a randomized clinical study. J Cardiothorac Vasc Anesth. 2007;21:847–50.
986. Davis RF, Giesecke NM. Hemodilution and priming solutions. In: Gravlee GP, Davis RF, Kurusz M, Utley JR, editors. Cardiopulmonary Bypass: Principles and Practice. 2nd ed. Philadelphia, Pa: Lippincott Williams & Wilkins; 2000:186–196.

987. El-Hamamsy I, Stevens LM, Carrier M, et al. Effect of intravenous N-acetylcysteine on outcomes after coronary artery bypass surgery: a randomized, double-blind, placebo-controlled clinical trial. J Thorac Cardiovasc Surg. 2007;133:7–12.
988. Fansa I, Gol M, Nisanoglu V, et al. Does diltiazem inhibit the inflammatory response in cardiopulmonary bypass? Med Sci Monit. 2003;9:PI30–6.
989. Fischer UM, Tossios P, Mehlhorn U. Renal protection by radical scavenging in cardiac surgery patients. Curr Med Res Opin. 2005;21:1161–4.
990. Friedrich JO, Adhikari N, Herridge MS, et al. Meta-analysis: low-dose dopamine increases urine output but does not prevent renal dysfunction or death. Ann Intern Med. 2005;142:510–24.
991. Haase M, Haase-Fielitz A, Bagshaw SM, et al. Phase II, randomized, controlled trial of high-dose N-acetylcysteine in high-risk cardiac surgery patients. Crit Care Med. 2007;35:1324–31.
992. Ip-Yam PC, Murphy S, Baines M, et al. Renal function and proteinuria after cardiopulmonary bypass: the effects of temperature and mannitol. Anesth Analg. 1994;78:842–7.
993. Landoni G, Biondi-Zoccai GG, Tumlin JA, et al. Beneficial impact of fenoldopam in critically ill patients with or at risk for acute renal failure: a meta-analysis of randomized clinical trials. Am J Kidney Dis. 2007;49:56–68.
994. Landoni G, Biondi-Zoccai GG, Marino G, et al. Fenoldopam reduces the need for renal replacement therapy and in-hospital death in cardiovascular surgery: a meta-analysis. J Cardiothorac Vasc Anesth. 2008;22:27–33.
995. Murphy MB, Murray C, Shorten GD. Fenoldopam: a selective peripheral dopamine-receptor agonist for the treatment of severe hypertension. N Engl J Med. 2001;345:1548–57.
996. Nigwekar SU, Hix JK. The role of natriuretic peptide administration in cardiovascular surgery-associated renal dysfunction: a systematic review and meta-analysis of randomized controlled trials. J Cardiothorac Vasc Anesth. 2009;23:151–60.
997. Piper SN, Kumle B, Maleck WH, et al. Diltiazem may preserve renal tubular integrity after cardiac surgery. Can J Anaesth. 2003; 50:285–92.
998. Ranucci M, Soro G, Barzaghi N, et al. Fenoldopam prophylaxis of postoperative acute renal failure in high-risk cardiac surgery patients. Ann Thorac Surg. 2004;78:1332–7.
999. Ranucci M, De Benedetti D, Bianchini C, et al. Effects of fenoldopam infusion in complex cardiac surgical operations: a prospective, randomized, double-blind, placebo-controlled study. Minerva Anestesiol. 2010;76:249–59.
1000. Sirivella S, Gielchinsky I, Parsonnet V. Mannitol, furosemide, and dopamine infusion in postoperative renal failure complicating cardiac surgery. Ann Thorac Surg. 2000;69:501–6.
1001. Tumlin JA, Finkel KW, Murray PT, et al. Fenoldopam mesylate in early acute tubular necrosis: a randomized, double-blind, placebo-controlled clinical trial. Am J Kidney Dis. 2005;46:26–34.
1002. Vesely DL. Natriuretic peptides and acute renal failure. Am J Physiol Renal Physiol. 2003;285:F167–77.
1003. Wang G, Bainbridge D, Martin J, et al. N-acetylcysteine in cardiac surgery: do the benefits outweigh the risks? A meta-analytic reappraisal. J Cardiothorac Vasc Anesth. 2010;2:268–75.
1004. Young EW, Diab A, Kirsh MM. Intravenous diltiazem and acute renal failure after cardiac operations. Ann Thorac Surg. 1998;65:1316–9.
1005. Abraham VS, Swain JA. Cardiopulmonary bypass and kidney. In: Gravlee GP, Davis R, editors. Cardiopulmonary Bypass: Principles and Practice. Philadelphia, PA: Lippincott, Williams & Wilkins; 2000:382–91.
1006. Mangano CM, Diamondstone LS, Ramsay JG, et al., the Multicenter Study of Perioperative Ischemia Research Group. Renal dysfunction after myocardial revascularization: risk factors, adverse outcomes, and hospital resource utilization. Ann Intern Med. 1998;128:194–203.
1007. Andersson LG, Ekroth R, Bratteby LE, et al. Acute renal failure after coronary surgery—a study of incidence and risk factors in 2009 consecutive patients. Thorac Cardiovasc Surg. 1993;41:237–41.
1008. Zanardo G, Michielon P, Paccagnella A, et al. Acute renal failure in the patient undergoing cardiac operation. Prevalence, mortality rate, and main risk factors. J Thorac Cardiovasc Surg. 1994;107: 1489–95.
1009. Mehta RH, Grab JD, O'Brien SM, et al. Bedside tool for predicting the risk of postoperative dialysis in patients undergoing cardiac surgery. Circulation. 2006;114:2208–16.
1010. Ostermann ME, Taube D, Morgan CJ, et al. Acute renal failure following cardiopulmonary bypass: a changing picture. Intensive Care Med. 2000;26:565–71.
1011. Chertow GM, Lazarus JM, Christiansen CL, et al. Preoperative renal risk stratification. Circulation. 1997;95:878–84.
1012. Fortescue EB, Bates DW, Chertow GM. Predicting acute renal failure after coronary bypass surgery: cross-validation of two risk-stratification algorithms. Kidney Int. 2000;57:2594–602.
1013. Thakar CV, Arrigain S, Worley S, et al. A clinical score to predict acute renal failure after cardiac surgery. J Am Soc Nephrol. 2005;16:162–8.
1014. Regragui IA, Izzat MB, Birdi I, et al. Cardiopulmonary bypass perfusion temperature does not influence perioperative renal function. Ann Thorac Surg. 1995;60:160–4.
1015. Boodhwani M, Rubens FD, Wozny D, et al. Effects of mild hypothermia and rewarming on renal function after coronary artery bypass grafting. Ann Thorac Surg. 2009;87:489–95.
1016. Kourliouros A, Valencia O, Phillips SD, et al. Low cardiopulmonary bypass perfusion temperatures are associated with acute kidney injury following coronary artery bypass surgery. Eur J Cardiothorac Surg. 2010;37:704–9.
1017. Hix JK, Thakar CV, Katz EM, et al. Effect of off-pump coronary artery bypass graft surgery on postoperative acute kidney injury and mortality. Crit Care Med. 2006;34:2979–83.
1018. Swaminathan M, Phillips-Bute BG, Conlon PJ, et al. The association of lowest hematocrit during cardiopulmonary bypass with acute renal injury after coronary artery bypass surgery. Ann Thorac Surg. 2003;76:784–91.
1019. DeFoe GR, Ross CS, Olmstead EM, et al., Northern New England Cardiovascular Disease Study Group. Lowest hematocrit on bypass and adverse outcomes associated with coronary artery bypass grafting. Ann Thorac Surg. 2001;71:769–76.
1020. Deleted in proof.
1021. Christenson JT, Cohen M, Ferguson JJI, et al. Trends in intraaortic balloon counterpulsation complications and outcomes in cardiac surgery. Ann Thorac Surg. 2002;74:1086–90.
1022. Christenson JT, Simonet F, Badel P, et al. Optimal timing of preoperative intraaortic balloon pump support in high-risk coronary patients. Ann Thorac Surg. 1999;68:934–9.
1023. Christenson JT, Licker M, Kalangos A. The role of intra-aortic counterpulsation in high-risk OPCAB surgery: a prospective randomized study. J Card Surg. 2003;18:286–94.
1024. Christenson JT, Schmuziger M, Simonet F. Effective surgical management of high-risk coronary patients using preoperative intra-aortic balloon counterpulsation therapy. Cardiovasc Surg. 2001;9:383–90.
1025. Urban PM, Freedman RJ, Ohman EM, et al. In-hospital mortality associated with the use of intra-aortic balloon counterpulsation. Am J Cardiol. 2004;94:181–5.
1026. Santa-Cruz RA, Cohen MG, Ohman EM. Aortic counterpulsation: a review of the hemodynamic effects and indications for use. Catheter Cardiovasc Interv. 2006;67:68–77.
1027. Theologou T, Bashir M, Rengarajan A, et al. Preoperative intra aortic balloon pumps in patients undergoing coronary artery bypass grafting. Cochrane Database Syst Rev. 2011;CD004472.
1028. Alexander JH, Hafley G, Harrington RA, et al., for the PREVENT IV Investigators. Efficacy and safety of edifoligide, an E2F transcription factor decoy, for prevention of vein graft failure following coronary artery bypass graft surgery: PREVENT IV: a randomized controlled trial. JAMA. 2005;294:2446–54.
1029. Koch CG, Li L, Duncan AI, et al. Transfusion in coronary artery bypass grafting is associated with reduced long-term survival. Ann Thorac Surg. 2006;81:1650–7.
1030. Surgenor SD, DeFoe GR, Fillinger MP, et al. Intraoperative red blood cell transfusion during coronary artery bypass graft surgery increases the risk of postoperative low-output heart failure. Circulation. 2006;114:I43–8.
1031. van Straten AH, Bekker MW, Soliman Hamad MA, et al. Transfusion of red blood cells: the impact on short-term and long-term survival after coronary artery bypass grafting, a ten-year follow-up. Interact Cardiovasc Thorac Surg. 2010;10:37–42.

1032. van Straten AH, Kats S, Bekker MW, et al. Risk factors for red blood cell transfusion after coronary artery bypass graft surgery. J Cardiothorac Vasc Anesth. 2010;24:413–7.
1033. Deleted in proof.
1034. Deleted in proof.
1035. Deleted in proof.
1036. Daoud EG, Strickberger SA, Man KC, et al. Preoperative amiodarone as prophylaxis against atrial fibrillation after heart surgery. N Engl J Med. 1997;337:1785–91.
1037. Williams DB, Misbach GA, Kruse AP, et al. Oral verapamil for prophylaxis of supraventricular tachycardia after myocardial revascularization. A randomized trial. J Thorac Cardiovasc Surg. 1985; 90:592–6.
1038. Davison R, Hartz R, Kaplan K, et al. Prophylaxis of supraventricular tachyarrhythmia after coronary bypass surgery with oral verapamil: a randomized, double-blind trial. Ann Thorac Surg. 1985;39:336–9.
1039. Tyras DH, Stothert JC, Jr., Kaiser GC, et al. Supraventricular tachyarrhythmias after myocardial revascularization: a randomized trial of prophylactic digitalization. J Thorac Cardiovasc Surg. 1979;77:310–4.
1040. Weiner B, Rheinlander HF, Decker EL, et al. Digoxin prophylaxis following coronary artery bypass surgery. Clin Pharm. 1986;5:55–8.
1041. Johnson LW, Dickstein RA, Fruehan CT, et al. Prophylactic digitalization for coronary artery bypass surgery. Circulation. 1976; 53:819–22.
1042. Rahimi K, Emberson J, McGale P, et al. Effect of statins on atrial fibrillation: collaborative meta-analysis of published and unpublished evidence from randomised controlled trials. BMJ. 2011;342: d1250.
1043. Deleted in proof.
1044. Fergusson DA, Hebert PC, Mazer CD, et al. A comparison of aprotinin and lysine analogues in high-risk cardiac surgery [published correction appears in N Engl J Med. 2010;363:1290]. N Engl J Med. 2008;358:2319–31.
1045. Greilich PE, Jessen ME, Satyanarayana N, et al. The effect of epsilon-aminocaproic acid and aprotinin on fibrinolysis and blood loss in patients undergoing primary, isolated coronary artery bypass surgery: a randomized, double-blind, placebo-controlled, noninferiority trial. Anesth Analg. 2009;109:15–24.
1046. Kikura M, Levy JH, Tanaka KA, et al. A double-blind, placebo-controlled trial of epsilon-aminocaproic acid for reducing blood loss in coronary artery bypass grafting surgery. J Am Coll Surg. 2006; 202:216–22.
1047. Mehr-Aein A, Sadeghi M, Madani-civi M. Does tranexamic acid reduce blood loss in off-pump coronary artery bypass? Asian Cardiovasc Thorac Ann. 2007;15:285–9.
1048. Mehr-Aein A, Davoodi S, Madani-civi M. Effects of tranexamic acid and autotransfusion in coronary artery bypass. Asian Cardiovasc Thorac Ann. 2007;15:49–53.
1049. Murphy GJ, Mango E, Lucchetti V, et al. A randomized trial of tranexamic acid in combination with cell salvage plus a meta-analysis of randomized trials evaluating tranexamic acid in off-pump coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2006; 132:475–80, e1–8.
1050. Santos AT, Kalil RA, Bauemann C, et al. A randomized, double-blind, and placebo-controlled study with tranexamic acid of bleeding and fibrinolytic activity after primary coronary artery bypass grafting. Braz J Med Biol Res. 2006;39:63–9.
1051. Taghaddomi RJ, Mirzaee A, Attar AS, et al. Tranexamic acid reduces blood loss in off-pump coronary artery bypass surgery. J Cardiothorac Vasc Anesth. 2009;23:312–5.
1052. Paone G, Spencer T, Silverman NA. Blood conservation in coronary artery surgery. Surgery. 1994;116:672–7.
1053. Nuttall GA, Oliver WC, Santrach PJ, et al. Efficacy of a simple intraoperative transfusion algorithm for nonerythrocyte component utilization after cardiopulmonary bypass. Anesthesiology. 2001;94: 773–81.
1054. Royston D, von Kier S. Reduced haemostatic factor transfusion using heparinase-modified thrombelastography during cardiopulmonary bypass. Br J Anaesth. 2001;86:575–8.
1055. Avidan MS, Alcock EL, Da Fonseca J, et al. Comparison of structured use of routine laboratory tests or near-patient assessment with clinical judgement in the management of bleeding after cardiac surgery. Br J Anaesth. 2004;92:178–86.
1056. Despotis GJ, Grishaber JE, Goodnough LT. The effect of an intraoperative treatment algorithm on physicians' transfusion practice in cardiac surgery. Transfusion. 1994;34:290–6.
1057. Shore-Lesserson L, Manspeizer HE, DePerio M, et al. Thromboelastography-guided transfusion algorithm reduces transfusions in complex cardiac surgery. Anesth Analg. 1999;88:312–9.
1058. Chu MW, Wilson SR, Novick RJ, et al. Does clopidogrel increase blood loss following coronary artery bypass surgery? Ann Thorac Surg. 2004;78:1536–41.
1059. Englberger L, Faeh B, Berdat PA, et al. Impact of clopidogrel in coronary artery bypass grafting. Eur J Cardiothorac Surg. 2004;26: 96–101.
1060. Kapetanakis EI, Medlam DA, Petro KR, et al. Effect of clopidogrel premedication in off-pump cardiac surgery: are we forfeiting the benefits of reduced hemorrhagic sequelae? Circulation. 2006;113: 1667–74.
1061. Maltais S, Perrault LP, Do QB. Effect of clopidogrel on bleeding and transfusions after off-pump coronary artery bypass graft surgery: impact of discontinuation prior to surgery. Eur J Cardiothorac Surg. 2008;34:127–31.
1062. Vaccarino GN, Thierer J, Albertal M, et al. Impact of preoperative clopidogrel in off pump coronary artery bypass surgery: a propensity score analysis. J Thorac Cardiovasc Surg. 2009;137:309–13.
1063. Yusuf S, Zhao F, Mehta SR, et al. Effects of clopidogrel in addition to aspirin in patients with acute coronary syndromes without ST-segment elevation [published corrections appear in N Engl J Med. 2011;345:1506; 2011;345:1716]. N Engl J Med. 2001;345: 494–502.
1064. Renda G, Di Pillo R, D'Alleva A, et al. Surgical bleeding after pre-operative unfractionated heparin and low molecular weight heparin for coronary bypass surgery. Haematologica. 2007;92:366–73.
1065. McDonald SB, Renna M, Spitznagel EL, et al. Preoperative use of enoxaparin increases the risk of postoperative bleeding and re-exploration in cardiac surgery patients. J Cardiothorac Vasc Anesth. 2005;19:4–10.
1066. Jones HU, Muhlestein JB, Jones KW, et al. Preoperative use of enoxaparin compared with unfractionated heparin increases the incidence of re-exploration for postoperative bleeding after open-heart surgery in patients who present with an acute coronary syndrome: clinical investigation and reports. Circulation. 2002;106: I19–22.
1067. Kincaid EH, Monroe ML, Saliba DL, et al. Effects of preoperative enoxaparin versus unfractionated heparin on bleeding indices in patients undergoing coronary artery bypass grafting. Ann Thorac Surg. 2003;76:124–8.
1068. Medalion B, Frenkel G, Patachenko P, et al. Preoperative use of enoxaparin is not a risk factor for postoperative bleeding after coronary artery bypass surgery. J Thorac Cardiovasc Surg. 2003;126: 1875–9.
1069. Angelini GD, Taylor FC, Reeves BC, et al. Early and midterm outcome after off-pump and on-pump surgery in Beating Heart Against Cardioplegic Arrest Studies (BHACAS 1 and 2): a pooled analysis of two randomised controlled trials. Lancet. 2002;359: 1194–9.
1070. Cheng DC, Bainbridge D, Martin JE, et al. Does off-pump coronary artery bypass reduce mortality, morbidity, and resource utilization when compared with conventional coronary artery bypass? A meta-analysis of randomized trials. Anesthesiology. 2005; 102:188–203.
1071. Czerny M, Baumer H, Kilo J, et al. Complete revascularization in coronary artery bypass grafting with and without cardiopulmonary bypass. Ann Thorac Surg. 2001;71:165–9.
1072. Puskas JD, Williams WH, Duke PG, et al. Off-pump coronary artery bypass grafting provides complete revascularization with reduced myocardial injury, transfusion requirements, and length of stay: a prospective randomized comparison of two hundred unselected patients undergoing off-pump versus conventional coronary artery bypass grafting. J Thorac Cardiovasc Surg. 2003;125: 797–808.
1073. Raja SG, Dreyfus GD. Impact of off-pump coronary artery bypass surgery on postoperative bleeding: current best available evidence. J Card Surg. 2006;21:35–41.

1074. van Dijk D, Nierich AP, Jansen EW, et al. Early outcome after off-pump versus on-pump coronary bypass surgery: results from a randomized study. Circulation. 2001;104:1761–6.
1075. Graves EJ. National hospital discharge survey: annual summary, 1991. Vital Health Stat 13. 1993;1–62.
1076. Koch CG, Khandwala F, Li L, et al. Persistent effect of red cell transfusion on health-related quality of life after cardiac surgery. Ann Thorac Surg. 2006;82:13–20.
1077. Deleted in proof.
1078. Ferraris VA, Ferraris SP. Limiting excessive postoperative blood transfusion after cardiac procedures. A review. Tex Heart Inst J. 1995;22:216–30.
1079. Ferraris VA, Gildengorin V. Predictors of excessive blood use after coronary artery bypass grafting. A multivariate analysis. J Thorac Cardiovasc Surg. 1989;98:492–7.
1080. Karkouti K, Cohen MM, McCluskey SA, et al. A multivariable model for predicting the need for blood transfusion in patients undergoing first-time elective coronary bypass graft surgery. Transfusion. 2001;41:1193–203.
1081. Magovern JA, Sakert T, Benckart DH, et al. A model for predicting transfusion after coronary artery bypass grafting. Ann Thorac Surg. 1996;61:27–32.
1082. Welsby I, Crow J, Bandarenko N, et al. A clinical prediction tool to estimate the number of units of red blood cells needed in primary elective coronary artery bypass surgery. Transfusion. 2010;50:2343.
1083. Dial S, Delabays E, Albert M, et al. Hemodilution and surgical hemostasis contribute significantly to transfusion requirements in patients undergoing coronary artery bypass. J Thorac Cardiovasc Surg. 2005;130:654–61.
1084. Khanna MP, Hebert PC, Fergusson DA. Review of the clinical practice literature on patient characteristics associated with perioperative allogeneic red blood cell transfusion. Transfus Med Rev. 2003;17:110–9.
1085. Parr KG, Patel MA, Dekker R, et al. Multivariate predictors of blood product use in cardiac surgery. J Cardiothorac Vasc Anesth. 2003;17:176–81.
1086. DeBois W, Liu J, Lee L, et al. Cardiopulmonary bypass in patients with pre-existing coagulopathy. J Extra Corpor Technol. 2005;37:15–22.
1087. Lee LY, DeBois W, Krieger KH, et al. The effects of platelet inhibitors on blood use in cardiac surgery. Perfusion. 2002;17:33–7.
1088. Berkowitz SD, Stinnett S, Cohen M, et al. Prospective comparison of hemorrhagic complications after treatment with enoxaparin versus unfractionated heparin for unstable angina pectoris or non-ST-segment elevation acute myocardial infarction. Am J Cardiol. 2001;88:1230–4.
1089. Ferraris VA, Ferraris SP, Joseph O, et al. Aspirin and postoperative bleeding after coronary artery bypass grafting. Ann Surg. 2002;235:820–7.
1090. Johnson WC, Williford WO. Benefits, morbidity, and mortality associated with long-term administration of oral anticoagulant therapy to patients with peripheral arterial bypass procedures: a prospective randomized study. J Vasc Surg. 2002;35:413–21.
1091. Fuller J, Copeland J. Does short-term preoperative aspirin in coronary bypass patients increase post-operative bleeding? Vasc Surg. 1985;19:174–8.
1092. Karwande SV, Weksler BB, Gay WA, Jr., et al. Effect of preoperative antiplatelet drugs on vascular prostacyclin synthesis. Ann Thorac Surg. 1987;43:318–22.
1093. Ferraris VA, Ferraris SP, Lough FC, et al. Preoperative aspirin ingestion increases operative blood loss after coronary artery bypass grafting. Ann Thorac Surg. 1988;45:71–4.
1094. Goldman S, Copeland J, Moritz T, et al. Starting aspirin therapy after operation. Effects on early graft patency. Department of Veterans Affairs Cooperative Study Group. Circulation. 1991;84:520–6.
1095. Hockings BE, Ireland MA, Gotch-Martin KF, et al. Placebo-controlled trial of enteric coated aspirin in coronary bypass graft patients. Effect on graft patency. Med J Aust. 1993;159:376–8.
1096. Kallis P, Tooze JA, Talbot S, et al. Pre-operative aspirin decreases platelet aggregation and increases post-operative blood loss—a prospective, randomised, placebo controlled, double-blind clinical trial in 100 patients with chronic stable angina. Eur J Cardiothorac Surg. 1994;8:404–9.
1097. Matsuzaki K, Okabe H, Kajihara N, et al. [A prospective study on the timing of discontinuation of aspirin before coronary artery bypass grafting]. Nippon Kyobu Geka Gakkai Zasshi. 1997;45:1710–4.
1098. Morawski W, Sanak M, Cisowski M, et al. Prediction of the excessive perioperative bleeding in patients undergoing coronary artery bypass grafting: role of aspirin and platelet glycoprotein IIIa polymorphism. J Thorac Cardiovasc Surg. 2005;130:791–6.
1099. Srinivasan AK, Grayson AD, Pullan DM, et al. Effect of preoperative aspirin use in off-pump coronary artery bypass operations. Ann Thorac Surg. 2003;76:41–5.
1100. Sun JC, Whitlock R, Cheng J, et al. The effect of pre-operative aspirin on bleeding, transfusion, myocardial infarction, and mortality in coronary artery bypass surgery: a systematic review of randomized and observational studies. Eur Heart J. 2008;29:1057–71.
1101. Yende S, Wunderink RG. Effect of clopidogrel on bleeding after coronary artery bypass surgery. Crit Care Med. 2001;29:2271–5.
1102. Gansera B, Schmidtler F, Spiliopoulos K, et al. Urgent or emergent coronary revascularization using bilateral internal thoracic artery after previous clopidogrel antiplatelet therapy. Thorac Cardiovasc Surg. 2003;51:185–9.
1103. Ray JG, Deniz S, Olivieri A, et al. Increased blood product use among coronary artery bypass patients prescribed preoperative aspirin and clopidogrel. BMC Cardiovasc Disord. 2003;3:3.
1104. Badreldin A, Kroener A, Kamiya H, et al. Effect of clopidogrel on perioperative blood loss and transfusion in coronary artery bypass graft surgery. Interact Cardiovasc Thorac Surg. 2010;10:48–52.
1105. Filsoufi F, Rahmanian PB, Castillo JG, et al. Clopidogrel treatment before coronary artery bypass graft surgery increases postoperative morbidity and blood product requirements. J Cardiothorac Vasc Anesth. 2008;22:60–6.
1106. Shim JK, Choi YS, Oh YJ, et al. Effects of preoperative aspirin and clopidogrel therapy on perioperative blood loss and blood transfusion requirements in patients undergoing off-pump coronary artery bypass graft surgery. J Thorac Cardiovasc Surg. 2007;134:59–64.
1107. Dempsey CM, Lim MS, Stacey SG. A prospective audit of blood loss and blood transfusion in patients undergoing coronary artery bypass grafting after clopidogrel and aspirin therapy. Crit Care Resusc. 2004;6:248–52.
1108. Braunwald E, Antman EM, Beasley JW, et al. ACC/AHA 2002 guideline update for the management of patients with unstable angina and non–ST-segment elevation myocardial infarction—summary article: a report of the American College of Cardiology/American Heart Association task force on practice guidelines (Committee on the Management of Patients With Unstable Angina). J Am Coll Cardiol. 2002;40:1366–74.
1109. Ferraris VA, Ferraris SP, Saha SP, et al. Perioperative blood transfusion and blood conservation in cardiac surgery: the Society of Thoracic Surgeons and The Society of Cardiovascular Anesthesiologists clinical practice guideline. Ann Thorac Surg. 2007;83 5 Suppl:S27–S86.
1110. Ferraris VA, Ferraris SP, Moliterno DJ, et al. The Society of Thoracic Surgeons practice guideline series: aspirin and other antiplatelet agents during operative coronary revascularization (executive summary). Ann Thorac Surg. 2005;79:1454–61.
1111. Henry D, Carless P, Fergusson D, et al. The safety of aprotinin and lysine-derived antifibrinolytic drugs in cardiac surgery: a meta-analysis. CMAJ. 2009;180:183–93.
1112. Sowade O, Warnke H, Scigalla P, et al. Avoidance of allogeneic blood transfusions by treatment with epoetin beta (recombinant human erythropoietin) in patients undergoing open-heart surgery. Blood. 1997;89:411–8.
1113. D'Ambra MN, Gray RJ, Hillman R, et al. Effect of recombinant human erythropoietin on transfusion risk in coronary bypass patients. Ann Thorac Surg. 1997;64:1686–93.
1114. Podesta A, Carmagnini E, Parodi E, et al. Elective coronary and valve surgery without blood transfusion in patients treated with recombinant human erythropoietin (epoetin-alpha). Minerva Cardioangiol. 2000;48:341–7.
1115. Schmoeckel M, Nollert G, Mempel M, et al. Effects of recombinant human erythropoietin on autologous blood donation before open heart surgery. Thorac Cardiovasc Surg. 1993;41:364–8.

1116. Kulier AH, Gombotz H, Fuchs G, et al. Subcutaneous recombinant human erythropoietin and autologous blood donation before coronary artery bypass surgery. Anesth Analg. 1993;76:102–6.
1117. Hayashi J, Kumon K, Takanashi S, et al. Subcutaneous administration of recombinant human erythropoietin before cardiac surgery: a double-blind, multicenter trial in Japan. Transfusion. 1994;34:142–6.
1118. Walpoth B, Galliker B, Spirig P, et al. Use of epoetin alfa in autologous blood donation programs for patients scheduled for elective cardiac surgery. Semin Hematol. 1996;33:75–6.
1119. Watanabe Y, Fuse K, Naruse Y, et al. Subcutaneous use of erythropoietin in heart surgery. Ann Thorac Surg. 1992;54:479–83.
1120. Kiyama H, Ohshima N, Imazeki T, et al. Autologous blood donation with recombinant human erythropoietin in anemic patients. Ann Thorac Surg. 1999;68:1652–6.
1121. Gombotz H. Subcutaneous epoetin alfa as an adjunct to autologous blood donation before elective coronary artery bypass graft surgery. Semin Hematol. 1996;33:69–70.
1122. Weltert L, D'Alessandro S, Nardella S, et al. Preoperative very short-term, high-dose erythropoietin administration diminishes blood transfusion rate in off-pump coronary artery bypass: a randomized blind controlled study. J Thorac Cardiovasc Surg. 2010;139:621–6.
1123. Alghamdi AA, Albanna MJ, Guru V, et al. Does the use of erythropoietin reduce the risk of exposure to allogeneic blood transfusion in cardiac surgery? A systematic review and meta-analysis. J Card Surg. 2006;21:320–6.
1124. Rosengart TK, Helm RE, Klemperer J, et al. Combined aprotinin and erythropoietin use for blood conservation: results with Jehovah's Witnesses. Ann Thorac Surg. 1994;58:1397–403.
1125. Gaudiani VA, Mason HD. Preoperative erythropoietin in Jehovah's Witnesses who require cardiac procedures. Ann Thorac Surg. 1991;51:823–4.
1126. Bardakci H, Cheema FH, Topkara VK, et al. Discharge to home rates are significantly lower for octogenarians undergoing coronary artery bypass graft surgery. Ann Thorac Surg. 2007;83:483–9.
1127. Alexander KP, Anstrom KJ, Muhlbaier LH, et al. Outcomes of cardiac surgery in patients > or = 80 years: results from the National Cardiovascular Network. J Am Coll Cardiol. 2000;35:731–8.
1128. Engoren M, Arslanian-Engoren C, Steckel D, et al. Cost, outcome, and functional status in octogenarians and septuagenarians after cardiac surgery. Chest. 2002;122:1309–15.
1129. Filsoufi F, Rahmanian PB, Castillo JG, et al. Results and predictors of early and late outcomes of coronary artery bypass graft surgery in octogenarians. J Cardiothorac Vasc Anesth. 2007;21:784–92.
1130. Scott BH, Seifert FC, Grimson R, et al. Octogenarians undergoing coronary artery bypass graft surgery: resource utilization, postoperative mortality, and morbidity. J Cardiothorac Vasc Anesth. 2005;19:583–8.
1131. Conaway DG, House J, Bandt K, et al. The elderly: health status benefits and recovery of function one year after coronary artery bypass surgery. J Am Coll Cardiol. 2003;42:1421–6.
1132. Huber CH, Goeber V, Berdat P, et al. Benefits of cardiac surgery in octogenarians—a postoperative quality of life assessment. Eur J Cardiothorac Surg. 2007;31:1099–105.
1133. Jacobs AK, Kelsey SF, Brooks MM, et al. Better outcome for women compared with men undergoing coronary revascularization: a report from the bypass angioplasty revascularization investigation (BARI). Circulation. 1998;98:1279–85.
1134. Brandrup-Wognsen G, Berggren H, Hartford M, et al. Female sex is associated with increased mortality and morbidity early, but not late, after coronary artery bypass grafting. Eur Heart J. 1996;17:1426–31.
1135. Davis KB, Chaitman B, Ryan T, et al. Comparison of 15–year survival for men and women after initial medical or surgical treatment for coronary artery disease: a CASS registry study. Coronary Artery Surgery Study. J Am Coll Cardiol. 1995;25:1000–9.
1136. Hammar N, Sandberg E, Larsen FF, et al. Comparison of early and late mortality in men and women after isolated coronary artery bypass graft surgery in Stockholm, Sweden, 1980 to 1989. J Am Coll Cardiol. 1997;29:659–64.
1137. Risum O, Abdelnoor M, Nitter-Hauge S, et al. Coronary artery bypass surgery in women and in men; early and long-term results. A study of the Norwegian population adjusted by age and sex. Eur J Cardiothorac Surg. 1997;11:539–46.
1138. Abramov D, Tamariz MG, Sever JY, et al. The influence of gender on the outcome of coronary artery bypass surgery. Ann Thorac Surg. 2000;70:800–5.
1139. Kim C, Redberg RF, Pavlic T, et al. A systematic review of gender differences in mortality after coronary artery bypass graft surgery and percutaneous coronary interventions. Clin Cardiol. 2007;30:491–5.
1140. Blankstein R, Ward RP, Arnsdorf M, et al. Female gender is an independent predictor of operative mortality after coronary artery bypass graft surgery: contemporary analysis of 31 Midwestern hospitals. Circulation. 2005;112:I323–7.
1141. Bukkapatnam RN, Yeo KK, Li Z, et al. Operative mortality in women and men undergoing coronary artery bypass grafting (from the California Coronary Artery Bypass Grafting Outcomes Reporting Program). Am J Cardiol. 2010;105:339–42.
1142. Christakis GT, Weisel RD, Buth KJ, et al. Is body size the cause for poor outcomes of coronary artery bypass operations in women? J Thorac Cardiovasc Surg. 1995;110:1344–56.
1143. Guru V, Fremes SE, Austin PC, et al. Gender differences in outcomes after hospital discharge from coronary artery bypass grafting. Circulation. 2006;113:507–16.
1144. Hochman JS, McCabe CH, Stone PH, et al. Outcome and profile of women and men presenting with acute coronary syndromes: a report from TIMI IIIB. TIMI Investigators. Thrombolysis in Myocardial Infarction. J Am Coll Cardiol. 1997;30:141–8.
1145. Humphries KH, Gao M, Pu A, et al. Significant improvement in short-term mortality in women undergoing coronary artery bypass surgery (1991 to 2004). J Am Coll Cardiol. 2007;49:1552–8.
1146. O'Connor GT, Morton JR, Diehl MJ, et al., the Northern New England Cardiovascular Disease Study Group. Differences between men and women in hospital mortality associated with coronary artery bypass graft surgery. Circulation. 1993;88:2104–10.
1147. Ramstrom J, Lund O, Cadavid E, et al. Multiarterial coronary artery bypass grafting with special reference to small vessel disease and results in women. Eur Heart J. 1993;14:634–9.
1148. Rexius H, Brandrup-Wognsen G, Oden A, et al. Gender and mortality risk on the waiting list for coronary artery bypass grafting. Eur J Cardiothorac Surg. 2004;26:521–7.
1149. King KB, Clark PC, Hicks GL, Jr. Patterns of referral and recovery in women and men undergoing coronary artery bypass grafting. Am J Cardiol. 1992;69:179–82.
1150. King KB, Clark PC, Norsen LH, et al. Coronary artery bypass graft surgery in older women and men. Am J Crit Care. 1992;1:28–35.
1151. Nguyen JT, Berger AK, Duval S, et al. Gender disparity in cardiac procedures and medication use for acute myocardial infarction. Am Heart J. 2008;155:862–8.
1152. Anand SS, Xie CC, Mehta S, et al. Differences in the management and prognosis of women and men who suffer from acute coronary syndromes. J Am Coll Cardiol. 2005;46:1845–51.
1153. Fox AA, Nussmeier NA. Does gender influence the likelihood or types of complications following cardiac surgery? Semin Cardiothorac Vasc Anesth. 2004;8:283–95.
1154. Koch CG, Higgins TL, Capdeville M, et al. The risk of coronary artery surgery in women: a matched comparison using preoperative severity of illness scoring. J Cardiothorac Vasc Anesth. 1996;10:839–43.
1155. Koch CG, Weng YS, Zhou SX, et al. Prevalence of risk factors, and not gender per se, determines short- and long-term survival after coronary artery bypass surgery. J Cardiothorac Vasc Anesth. 2003;17:585–93.
1156. Sharoni E, Kogan A, Medalion B, et al. Is gender an independent risk factor for coronary bypass grafting? Thorac Cardiovasc Surg. 2009;57:204–8.
1157. Becker ER, Rahimi A. Disparities in race/ethnicity and gender in in-hospital mortality rates for coronary artery bypass surgery patients. J Natl Med Assoc. 2006;98:1729–39.
1158. Simchen E, Israeli A, Merin G, et al. Israeli women were at a higher risk than men for mortality following coronary bypass surgery. Eur J Epidemiol. 1997;13:503–9.

1159. Czech B, Kucewicz-Czech E, Pacholewicz J, et al. Early results of coronary artery bypass graft surgery in women. Kardiol Pol. 2007; 65:627–33.
1160. Ranucci M, Pazzaglia A, Bianchini C, et al. Body size, gender, and transfusions as determinants of outcome after coronary operations. Ann Thorac Surg. 2008;85:481–6.
1161. Utley JR, Wilde EF, Leyland SA, et al. Intraoperative blood transfusion is a major risk factor for coronary artery bypass grafting in women. Ann Thorac Surg. 1995;60:570–4.
1162. Abbaszadeh M, Arabnia MK, Rabbani A, et al. The risk factors affecting the complications of saphenous vein graft harvesting in aortocoronary bypass surgery. Rev Bras Cir Cardiovasc. 2008;23: 317–22.
1163. Bundy JK, Gonzalez VR, Barnard BM, et al. Gender risk differences for surgical site infections among a primary coronary artery bypass graft surgery cohort: 1995–1998. Am J Infect Control. 2006;34: 114–21.
1164. Patel S, Smith JM, Engel AM. Gender differences in outcomes after off-pump coronary artery bypass graft surgery. Am Surg. 2006;72: 310–3.
1165. Salehi OA, Karimi A, Ahmadi SH, et al. Superficial and deep sternal wound infection after more than 9000 coronary artery bypass graft (CABG): incidence, risk factors and mortality. BMC Infect Dis. 2007;7:112.
1166. Cartier R, Bouchot O, El-Hamamsy I. Influence of sex and age on long-term survival in systematic off-pump coronary artery bypass surgery. Eur J Cardiothorac Surg. 2008;34:826–32.
1167. Ennker IC, Albert A, Pietrowski D, et al. Impact of gender on outcome after coronary artery bypass surgery. Asian Cardiovasc Thorac Ann. 2009;17:253–8.
1168. Gansera B, Gillrath G, Lieber M, et al. Are men treated better than women? Outcome of male versus female patients after CABG using bilateral internal thoracic arteries. Thorac Cardiovasc Surg. 2004; 52:261–7.
1169. Kurlansky PA, Dorman MJ, Galbut DL, et al. Bilateral internal mammary artery grafting in women: a 21–year experience. Ann Thorac Surg. 1996;62:63–9.
1170. Myers WO, Blackstone EH, Davis K, et al. CASS Registry long term surgical survival. Coronary Artery Surgery Study. J Am Coll Cardiol. 1999;33:488–98.
1171. Alserius T, Hammar N, Nordqvist T, et al. Improved survival after coronary artery bypass grafting has not influenced the mortality disadvantage in patients with diabetes mellitus. J Thorac Cardiovasc Surg. 2009;138:1115–22.
1172. Kubal C, Srinivasan AK, Grayson AD, et al. Effect of risk-adjusted diabetes on mortality and morbidity after coronary artery bypass surgery. Ann Thorac Surg. 2005;79:1570–6.
1173. Singh SK, Desai ND, Petroff SD, et al. The impact of diabetic status on coronary artery bypass graft patency: insights from the radial artery patency study. Circulation. 2008;118:S222–5.
1174. Bair TL, Muhlestein JB, May HT, et al. Surgical revascularization is associated with improved long-term outcomes compared with percutaneous stenting in most subgroups of patients with multivessel coronary artery disease: results from the Intermountain Heart Registry. Circulation. 2007;116:I226–31.
1175. Farkouh ME, Dangas G, Leon MB, et al. Design of the Future REvascularization Evaluation in patients with Diabetes mellitus: Optimal management of Multivessel disease (FREEDOM) trial. Am Heart J. 2008;155:215–23.
1176. Chaitman BR, Hardison RM, Adler D, et al. The Bypass Angioplasty Revascularization Investigation 2 Diabetes randomized trial of different treatment strategies in type 2 diabetes mellitus with stable ischemic heart disease: impact of treatment strategy on cardiac mortality and myocardial infarction. Circulation. 2009;120:2529–40.
1177. Halkos ME, Puskas JD, Lattouf OM, et al. Elevated preoperative hemoglobin A1c level is predictive of adverse events after coronary artery bypass surgery. J Thorac Cardiovasc Surg. 2008;136:631–40.
1178. Jones KW, Cain AS, Mitchell JH, et al. Hyperglycemia predicts mortality after CABG: postoperative hyperglycemia predicts dramatic increases in mortality after coronary artery bypass graft surgery. J Diabetes Complications. 2008;22:365–70.
1179. Basso C, Maron BJ, Corrado D, et al. Clinical profile of congenital coronary artery anomalies with origin from the wrong aortic sinus leading to sudden death in young competitive athletes. J Am Coll Cardiol. 2000;35:1493–501.
1180. Thomas D, Salloum J, Montalescot G, et al. Anomalous coronary arteries coursing between the aorta and pulmonary trunk: clinical indications for coronary artery bypass. Eur Heart J. 1991;12:832–4.
1181. Krasuski RA, Magyar D, Hart S, et al. Long-term outcome and impact of surgery on adults with coronary arteries originating from the opposite coronary cusp. Circulation. 2011;123:154–62.
1182. Frommelt PC, Sheridan DC, Berger S, et al. Ten-year experience with surgical unroofing of anomalous aortic origin of a coronary artery from the opposite sinus with an interarterial course. J Thorac Cardiovasc Surg. 2011: published online before print March 23, 2011.
1183. Davis JA, Cecchin F, Jones TK, et al. Major coronary artery anomalies in a pediatric population: incidence and clinical importance. J Am Coll Cardiol. 2001;37:593–7.
1184. Maron BJ, Epstein SE, Roberts WC. Causes of sudden death in competitive athletes. J Am Coll Cardiol. 1986;7:204–14.
1185. Corrado D, Thiene G, Nava A, et al. Sudden death in young competitive athletes: clinicopathologic correlations in 22 cases. Am J Med. 1990;89:588–96.
1186. Thiene G, Nava A, Corrado D, et al. Right ventricular cardiomyopathy and sudden death in young people. N Engl J Med. 1988;318:129–33.
1187. Maron BJ, Shirani J, Poliac LC, et al. Sudden death in young competitive athletes. Clinical, demographic, and pathological profiles. JAMA. 1996;276:199–204.
1188. Cheitlin MD, De Castro CM, McAllister HA. Sudden death as a complication of anomalous left coronary origin from the anterior sinus of Valsalva, a not-so-minor congenital anomaly. Circulation. 1974;50:780–7.
1189. Roberts WC. Major anomalies of coronary arterial origin seen in adulthood. Am Heart J. 1986;111:941–63.
1190. Taylor AJ, Rogan KM, Virmani R. Sudden cardiac death associated with isolated congenital coronary artery anomalies. J Am Coll Cardiol. 1992;20:640–7.
1191. Charrot F, Tarmiz A, Glock Y, et al. Diagnosis and surgical treatment of an aneurysm on a cervical aortic arch associated with an anomalous origin of the left main coronary artery. Interact Cardiovasc Thorac Surg. 2010;10:346–7.
1192. Mustafa I, Gula G, Radley-Smith R, et al. Anomalous origin of the left coronary artery from the anterior aortic sinus: a potential cause of sudden death. Anatomic characterization and surgical treatment. J Thorac Cardiovasc Surg. 1981;82:297–300.
1193. Roberts WC, Siegel RJ, Zipes DP. Origin of the right coronary artery from the left sinus of valsalva and its functional consequences: analysis of 10 necropsy patients. Am J Cardiol. 1982;49:863–8.
1194. Taylor AJ, Byers JP, Cheitlin MD, et al. Anomalous right or left coronary artery from the contralateral coronary sinus: "high-risk" abnormalities in the initial coronary artery course and heterogeneous clinical outcomes. Am Heart J. 1997;133:428–35.
1195. Rigatelli G, Cardaioli P. Endovascular therapy for congenital coronary artery anomalies in adults. J Cardiovasc Med (Hagerstown). 2008;9:113–21.
1196. Fedoruk LM, Kern JA, Peeler BB, et al. Anomalous origin of the right coronary artery: right internal thoracic artery to right coronary artery bypass is not the answer. J Thorac Cardiovasc Surg. 2007; 133:456–60.
1197. Davies JE, Burkhart HM, Dearani JA, et al. Surgical management of anomalous aortic origin of a coronary artery. Ann Thorac Surg. 2009;88:844–7.
1198. Mainwaring RD, Reddy VM, Reinhartz O, et al. Anomalous aortic origin of a coronary artery: medium-term results after surgical repair in 50 patients. Ann Thorac Surg. 2011;92:691–7.
1199. Hulzebos EH, Helders PJ, Favie NJ, et al. Preoperative intensive inspiratory muscle training to prevent postoperative pulmonary complications in high-risk patients undergoing CABG surgery: a randomized clinical trial. JAMA. 2006;296:1851–7.
1200. Haeffener MP, Ferreira GM, Barreto SS, et al. Incentive spirometry with expiratory positive airway pressure reduces pulmonary complications, improves pulmonary function and 6–minute walk distance in patients undergoing coronary artery bypass graft surgery. Am Heart J. 2008;156:900e1–8.

1201. Zarbock A, Mueller E, Netzer S, et al. Prophylactic nasal continuous positive airway pressure following cardiac surgery protects from postoperative pulmonary complications: a prospective, randomized, controlled trial in 500 patients. Chest. 2009;135:1252–9.
1202. Kofidis T, Baraki H, Singh H, et al. The minimized extracorporeal circulation system causes less inflammation and organ damage. Perfusion. 2008;23:147–51.
1203. Angouras DC, Anagnostopoulos CE, Chamogeorgakis TP, et al. Postoperative and long-term outcome of patients with chronic obstructive pulmonary disease undergoing coronary artery bypass grafting. Ann Thorac Surg. 2010;89:1112–8.
1204. Fuster RG, Argudo JA, Albarova OG, et al. Prognostic value of chronic obstructive pulmonary disease in coronary artery bypass grafting. Eur J Cardiothorac Surg. 2006;29:202–9.
1205. Canver CC, Nichols RD, Kroncke GM. Influence of age-specific lung function on survival after coronary bypass. Ann Thorac Surg. 1998;66:144–7.
1206. Bapoje SR, Whitaker JF, Schulz T, et al. Preoperative evaluation of the patient with pulmonary disease. Chest. 2007;132:1637–45.
1207. Bingol H, Cingoz F, Balkan A, et al. The effect of oral prednisolone with chronic obstructive pulmonary disease undergoing coronary artery bypass surgery. J Card Surg. 2005;20:252–6.
1208. Starobin D, Kramer MR, Garty M, et al. Morbidity associated with systemic corticosteroid preparation for coronary artery bypass grafting in patients with chronic obstructive pulmonary disease: a case control study. J Cardiothorac Surg. 2007;2:25.
1209. Staton GW, Williams WH, Mahoney EM, et al. Pulmonary outcomes of off-pump vs on-pump coronary artery bypass surgery in a randomized trial. Chest. 2005;127:892–901.
1210. Liu JY, Birkmeyer NJ, Sanders JH, et al., Northern New England Cardiovascular Disease Study Group. Risks of morbidity and mortality in dialysis patients undergoing coronary artery bypass surgery. Circulation. 2000;102:2973–7.
1211. Lloyd-Jones D. Heart Disease and Stroke Statistics. Circulation. 2010;121–78.
1212. United States Renal Data System: National Institute of Health, National Institute of Diabetes and Digestive and Kidney Diseases. USRDS 2009 Annual Data Report: Atlas of Chronic Kidney Disease and End-Stage Renal Disease. Bethesda, Md: 2009. NIH Publication No. 09-3176.
1213. Anderson RJ, O'Brien M, MaWhinney S, et al. Renal failure predisposes patients to adverse outcome after coronary artery bypass surgery. VA Cooperative Study #5. Kidney Int. 1999;55:1057–62.
1214. Cooper WA, O'Brien SM, Thourani VH, et al. Impact of renal dysfunction on outcomes of coronary artery bypass surgery: results from the Society of Thoracic Surgeons National Adult Cardiac Database. Circulation. 2006;113:1063–70.
1215. Leavitt BJ, Sheppard L, Maloney C, et al. Effect of diabetes and associated conditions on long-term survival after coronary artery bypass graft surgery. Circulation. 2004;110:II41–4.
1216. Szczech LA, Best PJ, Crowley E, et al. Outcomes of patients with chronic renal insufficiency in the bypass angioplasty revascularization investigation. Circulation. 2002;105:2253–8.
1217. Filsoufi F, Aklog L, Adams DH, et al. Management of mild to moderate aortic stenosis at the time of coronary artery bypass grafting. J Heart Valve Dis. 2002;11 Suppl 1:S45–9.
1218. Smith WT IV, Ferguson TB Jr., Ryan T, et al. Should coronary artery bypass graft surgery patients with mild or moderate aortic stenosis undergo concomitant aortic valve replacement? A decision analysis approach to the surgical dilemma. J Am Coll Cardiol. 2004;44:1241–7.
1219. Pereira JJ, Balaban K, Lauer MS, et al. Aortic valve replacement in patients with mild or moderate aortic stenosis and coronary bypass surgery. Am J Med. 2005;118:735–42.
1220. Gillinov AM, Garcia MJ. When is concomitant aortic valve replacement indicated in patients with mild to moderate stenosis undergoing coronary revascularization? Curr Cardiol Rep. 2005;7:101–4.
1221. Gillinov AM, Wierup PN, Blackstone EH, et al. Is repair preferable to replacement for ischemic mitral regurgitation? J Thorac Cardiovasc Surg. 2001;122:1125–41.
1222. Aklog L, Filsoufi F, Flores KQ, et al. Does coronary artery bypass grafting alone correct moderate ischemic mitral regurgitation? Circulation. 2001;104:I68–75.
1223. Trichon BH, Glower DD, Shaw LK, et al. Survival after coronary revascularization, with and without mitral valve surgery, in patients with ischemic mitral regurgitation. Circulation. 2003;108 Suppl 1:II103–10.
1224. Fattouch K, Guccione F, Sampognaro R, et al. POINT: Efficacy of adding mitral valve restrictive annuloplasty to coronary artery bypass grafting in patients with moderate ischemic mitral valve regurgitation: a randomized trial. J Thorac Cardiovasc Surg. 2009;138:278–85.
1225. Fattouch K, Sampognaro R, Speziale G, et al. Impact of moderate ischemic mitral regurgitation after isolated coronary artery bypass grafting. Ann Thorac Surg. 2010;90:1187–94.
1226. Zoghbi W, Sarano M. Recommendations for the Evaluation of the Severity of NativeValvular Regurgitation with Two-dimensional and Doppler Echocardiography. J Am Soc of Echocardiography. 2003;16:777–802.
1227. Sergeant P, Blackstone E, Meyns B. Is return of angina after coronary artery bypass grafting immutable, can it be delayed, and is it important? J Thorac Cardiovasc Surg. 1998;116:440–53.
1228. Lytle BW, Loop FD, Taylor PC, et al. Vein graft disease: the clinical impact of stenoses in saphenous vein bypass grafts to coronary arteries. J Thorac Cardiovasc Surg. 1992;103:831–40.
1229. Christenson JT, Simonet F, Schmuziger M. The impact of a short interval (< or = 1 year) between primary and reoperative coronary artery bypass grafting procedures. Cardiovasc Surg. 1996;4:801–7.
1230. Fuster V, Vorchheimer DA. Prevention of atherosclerosis in coronary-artery bypass grafts. N Engl J Med. 1997;336:212–3.
1231. He GW, Acuff TE, Ryan WH, et al. Determinants of operative mortality in reoperative coronary artery bypass grafting. J Thorac Cardiovasc Surg. 1995;110:971–8.
1232. Noyez L, van Eck FM. Long-term cardiac survival after reoperative coronary artery bypass grafting. Eur J Cardiothorac Surg. 2004;25:59–64.
1233. Sabik JFI, Blackstone EH, Houghtaling PL, et al. Is reoperation still a risk factor in coronary artery bypass surgery? Ann Thorac Surg. 2005;80:1719–27.
1234. van Eck FM, Noyez L, Verheugt FW, et al. Changing profile of patients undergoing redo-coronary artery surgery. Eur J Cardiothorac Surg. 2002;21:205–11.
1235. Yap CH, Sposato L, Akowuah E, et al. Contemporary results show repeat coronary artery bypass grafting remains a risk factor for operative mortality. Ann Thorac Surg. 2009;87:1386–91.
1236. Di Mauro M, Iacò AL, Contini M, et al. Reoperative coronary artery bypass grafting: analysis of early and late outcomes. Ann Thorac Surg. 2005;79:81–7.
1237. Brooks N, Honey M, Cattell M, et al. Reoperation for recurrent angina. Br Heart J. 1979;42:333–8.
1238. Oglietti J, Cooley DA. Myocardial revascularization. Early and late results after reoperation. J Thorac Cardiovasc Surg. 1976;71:736–40.
1239. Safley DM, House JA, Borkon AM, et al. Comparison of quality of life after repeat versus initial coronary artery bypass grafting. Am J Cardiol. 2004;94:494–7.
1240. Bucerius J, Gummert JF, Borger MA, et al. Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. Ann Thorac Surg. 2003;75:472–8.
1241. Birkmeyer JD, O'Connor GT, Quinton HB, et al. The effect of peripheral vascular disease on in-hospital mortality rates with coronary artery bypass surgery. Northern New England Cardiovascular Disease Study Group. J Vasc Surg. 1995;21:445–52.
1242. Hlatky MA, Rogers WJ, Johnstone I, et al. Medical care costs and quality of life after randomization to coronary angioplasty or coronary bypass surgery. Bypass Angioplasty Revascularization Investigation (BARI) Investigators. N Engl J Med. 1997;336:92–9.
1243. Song HK, Diggs BS, Slater MS, et al. Improved quality and cost-effectiveness of coronary artery bypass grafting in the United States from 1988 to 2005. J Thorac Cardiovasc Surg. 2009;137:65–9.
1244. Toor I, Bakhai A, Keogh B, et al. Age >or=75 years is associated with greater resource utilization following coronary artery bypass grafting. Interact Cardiovasc Thorac Surg. 2009;9:827–31.
1245. Agarwal S, Banerjee S, Tuzcu EM, et al. Influence of age on revascularization related costs of hospitalization among patients of stable coronary artery disease. Am J Cardiol. 2010;105:1549–54.
1246. Brown PP, Kugelmass AD, Cohen DJ, et al. The frequency and cost of complications associated with coronary artery bypass grafting

surgery: results from the United States Medicare program. Ann Thorac Surg. 2008;85:1980–6.
1247. Saleh SS, Racz M, Hannan E. The effect of preoperative and hospital characteristics on costs for coronary artery bypass graft. Ann Surg. 2009;249:335–41.
1248. Puskas JD, Williams WH, Mahoney EM, et al. Off-pump vs conventional coronary artery bypass grafting: early and 1–year graft patency, cost, and quality-of-life outcomes: a randomized trial. JAMA. 2004;291:1841–9.
1249. Hu S, Zheng Z, Yuan X, et al. Increasing long-term major vascular events and resource consumption in patients receiving off-pump coronary artery bypass: a single-center prospective observational study. Circulation. 2010;121:1800–8.
1250. Hlatky MA, Boothroyd DB, Melsop KA, et al. Medical costs and quality of life 10 to 12 years after randomization to angioplasty or bypass surgery for multivessel coronary artery disease. Circulation. 2004;110:1960–6.
1251. Eisenstein EL, Sun JL, Anstrom KJ, et al. Assessing the economic attractiveness of coronary artery revascularization in chronic kidney disease patients. J Med Syst. 2009;33:287–97.
1252. Shimizu T, Ohno T, Ando J, et al. Mid-term results and costs of coronary artery bypass vs drug-eluting stents for unprotected left main coronary artery disease. Circ J. 2010;74:449–55.
1253. Vassiliades T, Jr. Enabling technology for minimally invasive coronary artery bypass grafting. Semin Thorac Cardiovasc Surg. 2009;21:237–44.
1254. Biancari F, Lahtinen J, Ojala R, et al. Spyder aortic connector system in off-pump coronary artery bypass surgery. Ann Thorac Surg. 2007;84:254–7.
1255. Kempfert J, Opfermann UT, Richter M, et al. Twelve-month patency with the PAS-Port proximal connector device: a single center prospective randomized trial. Ann Thorac Surg 2008;85:1579–84.
1256. Gummert JF, Demertzis S, Matschke K. Six-month angiographic follow-up of the PAS-Port II clinical trial. Ann Thorac Surg 2006;81:90–6.
1257. Cai TH, Acuff TE, Bolton JWR, Dizney LR, Poon M. Prospective evaluation of patency and early experience utilizing an automated distal anastomosis device (C-Port). Innovations: Technology & Techniques in Cardiothoracic & Vascular Surgery. 2007;2:245–50.
1258. Matschke KE, Gummert JF, Demertzis S, et al. The Cardica C-Port System: clinical and angiographic evaluation of a new device for automated, compliant distal anastomoses in coronary artery bypass grafting surgery—a multicenter prospective clinical trial. J Thorac Cardiovasc Surg. 2005;130:1645–52.
1259. Leacche M, Balaguer JM, Byrne JG. Intraoperative grafts assessment. Semin Thorac Cardiovasc Surg. 2009;21:207–12.
1260. Alexander JH, Hafley G, Harrington RA, et al. Efficacy and safety of edifoligide, an E2F transcription factor decoy, for prevention of vein graft failure following coronary artery bypass graft surgery: PREVENT IV: a randomized controlled trial. JAMA. 2005;294:2446–54.
1261. Balacumaraswami L, Taggart DP. Intraoperative imaging techniques to assess coronary artery bypass graft patency. Ann Thorac Surg. 2007;83:2251–7.
1262. Simons M, Laham RJ, Post M, et al. Therapeutic angiogenesis: potential role of basic fibroblast growth factor in patients with severe ischaemic heart disease. BioDrugs. 2000;14:13–20.
1263. Laham RJ, Sellke FW, Edelman ER, et al. Local perivascular delivery of basic fibroblast growth factor in patients undergoing coronary bypass surgery: results of a phase I randomized, double-blind, placebo-controlled trial. Circulation. 1999;100:1865–71.
1264. Ramphal PS, Coore DN, Craven MP, et al. A high fidelity tissue-based cardiac surgical simulator. Eur J Cardiothorac Surg. 2005;27:910–6.

Key Words: ACCF/AHA Practice Guidelines ■ acute coronary syndromes ■ anticoagulants ■ antiplatelet agents ■ arrhythmias, cardiac ■ coronary angiography ■ coronary artery revascularization interventions: stents ■ drug therapy ■ heart diseases ■ myocardial revasularization ■ platelet aggregation inhibitor ■ ultrasound.

APPENDIX 1. AUTHOR RELATIONSHIPS WITH INDUSTRY AND OTHER ENTITIES (RELEVANT)—2011 ACCF/AHA GUIDELINE FOR CORONARY ARTERY BYPASS GRAFT SURGERY

Committee Member	Employer/Title	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section Numbers*
L. David Hillis *(Chair)*	University of Texas Health Science Center at San Antonio—Professor and Chair of the Department of Medicine	None	None	None	None	None	None	None
Peter K. Smith *(Vice Chair)*	Duke University Medical Center: Private Diagnostic Clinic—Professor of Surgery; Chief of Thoracic Surgery	• Eli Lilly • Baxter BioSurgery	None	None	None	None	None	2.2.3 4.1 4.2 5.2.6
Jeffrey L. Anderson	Intermountain Medical Center—Associate Chief of Cardiology	• BMS/sanofi-aventis	None	None	• AstraZeneca • Gilead Pharma • Toshiba†	None	None	2.1.6 2.2.3 4.1 4.2 4.3 5.2.6

Committee Member	Employer/Title	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section Numbers*
John A. Bittl	Ocala Heart Institute Munroe Regional Medical Center—Interventional Cardiologist	None	None	None	None	None	None	None
Charles R. Bridges	University of Pennsylvania Medical Center—Chief of Cardiothoracic Surgery	• Baxter BioSurgery† • Zymogenetics	• Bayer Pharmaceuticals	None	None	None	• Plaintiff, alleged mitral valve dysfunction, 2009 • Defendant, retinal artery occlusion (stroke) after CABG, 2009 • Defendant, timely insertion of IABP after CABG, 2009 • Defendant, timely transport after acute aortic dissection, 2009 • Plaintiff, unexpected intra-abdominal hemorrhage and death after AVR, 2009	2.2.3 4.1 4.2 5.2.6
John G. Byrne	Vanderbilt University Medical Center: Division of Cardiac Surgery—Chairman of Cardiac Surgery	None	None	None	None	None	None	None
Joaquin E. Cigarroa	Oregon Health and Science University—Associate Professor of Medicine	None	None	None	None	None	None	None
Verdi J. DiSesa	John Hopkins Hospital, Division of Cardiac Surgery—Clinical Associate	None	None	None	None	None	None	None
Loren F. Hiratzka	Cardiac, Vascular and Thoracic Surgeons, Inc.—Medical Director of Cardiac Surgery	None	None	None	None	None	None	None
Adolph M. Hutter	Massachusetts General Hospital—Professor of Medicine	None	None	None	None	None	None	None
Michael E. Jessen	UT Southwestern Medical Center—Professor of Cardiothoracic Surgery	• Quest Medical†	None	None	None	None	None	2.1.8

JACC Vol. 58, No. 24, 2011
December 6, 2011:e123–210

Committee Member	Employer/Title	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section Numbers*
Ellen C. Keeley	University of Virginia—Associate Professor of Internal Medicine	None	None	None	None	None	None	None
Stephen J. Lahey	University of Connecticut—Professor and Chief of Cardiothoracic Surgery	None	None	None	None	None	• Defendant, mitral valve replacement, 2009	None
Richard A. Lange	University of Texas Health Science Center at San Antonio—Professor of Medicine	None	None	None	None	None	None	None
Martin J. London	University of California San Francisco, Veterans Affairs Medical Center—Professor of Clinical Anesthesia	None	None	None	None	None	None	None
Michael J. Mack	The Heart Hospital Baylor Plano—Cardiovascular Surgery, Medical Director	• Cordis • Marquett • Medtronic • Edwards Lifesciences†	None	None	None	None	None	2.1.3 2.2.1 5.2.1.1 5.2.1.2
Manesh R. Patel	Duke University Medical Center—Associate Professor of Medicine	None	None	None	None	None	None	None
John D. Puskas	Emory University/ Emory Healthcare—Chief of Cardiac Surgery	• Marquett • Medtronic	None	None	• Marquett‡ • Medtronic‡	None	None	2.1.3 2.2.1 2.2.2
Joseph F. Sabik	Cleveland Clinic Foundation—Professor of Surgery	• Edwards Lifesciences • Medtronic	None	None	None	None	None	2.2.2 5.2.1.1 5.2.1.2
Ola Selnes	John Hopkins Hospital, Department of Neurology—Professor of Neurology	None	None	None	None	None	None	None
David M. Shahian	Massachusetts General Hospital—Professor of Surgery	None	None	None	None	None	None	None
Jeffrey C. Trost	John Hopkins School of Medicine—Assistant Professor of Medicine	None	None	None	• Toshiba‡	None	None	2.1.7 4.10 4.10.1 4.10.2 4.10.3 5.2.1.1.1 5.2.1.1.2

Committee Member	Employer/Title	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness	Voting Recusals by Section Numbers*
Michael D. Winniford	University of Mississippi Medical Center—Professor of Medicine	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 ACCF/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. †No financial benefit. ‡Significant relationship.

AVR indicates aortic valve replacement; CABG, coronary artery bypass graft surgery; and IABP, intraaortic balloon pump.

APPENDIX 2. REVIEWER RELATIONSHIPS WITH INDUSTRY AND OTHER ENTITIES (RELEVANT)—2011 ACCF/AHA GUIDELINE FOR CORONARY ARTERY BYPASS GRAFT SURGERY

Peer Reviewer	Representation	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Robert Guyton	Official Reviewer—ACCF/AHA Task Force on Practice Guidelines	None	None	None	• Edwards Lifesciences	None	None
Jeffrey Jacobs	Official Reviewer—ACCF/AHA Task Force on Data Standards	None	None	None	None	None	None
L. Kristin Newby	Official Reviewer—AHA	• AstraZeneca	None	None	• Eli Lilly* • GlaxoSmithKline†	None	None
Eric D. Peterson	Official Reviewer—ACCF/AHA Task Force on Performance Measures	• AstraZeneca	None	None	• BMS/sanofi-aventis† • Eli Lilly†	None	None
Richard J. Shemin	Official Reviewer—AHA	• Edwards Lifesciences	None	None	None	None	None
Hector Ventura	Official Reviewer—ACCF Board of Governors	None	• Actelion • Gilead	None	None	None	None
Thad F. Waites	Official Reviewer—ACCF Board of Trustees	None	None	None	None	None	None
T. Bruce Ferguson, Jr.	Organizational Reviewer—STS	None	None	None	None	None	None
Stephen E. Fremes	Organizational Reviewer—AATS	None	None	None	None	Merck	• Defendant, leaking thoracic aortic aneurysm, 2009 • Defendant, aortic dissection, 2009
Colleen G. Koch	Organizational Reviewer—SCA	None	None	None	None	None	None
Harold L. Lazar	Organizational Reviewer—AATS	None	None	None	None	None	None
Walter H. Merrill	Organizational Reviewer—STS	None	None	None	None	None	None

JACC Vol. 58, No. 24, 2011
December 6, 2011:e123–210

Peer Reviewer	Representation	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Stanton K. Shernan	Organizational Reviewer—SCA	None	• Philips Healthcare	None	None	None	• Plaintiff, communication of echocardiography results, 2010
Joseph S. Alpert	Content Reviewer	• Bayer • Sanofi-aventis	None	None	None	None	None
Robert M. Califf	Content Reviewer	• AstraZeneca • Daiichi-Sankyo • GlaxoSmithKline • Medtronic • Sanofi-aventis	None	None	• Eli Lilly† • Bayer	None	None
Robbin G. Cohen	Content Reviewer	None	None	None	None	None	• Defendant, death after minimally invasive heart surgery, 2011 • Defendant, diagnosis of aortic dissection, 2010 • Plaintiff, renal failure and Aprotinin, 2010
Mark A. Creager	Content Reviewer—ACCF/AHA Task Force on Practice Guidelines	• AstraZeneca • Genzyme • Merck • Roche • Vascutek	None	None	• Merck	None	• Plaintiff, Fasudil Development: *Asahi Pharma v Actelion,* 2010
Steven M. Ettinger	Content Review—ACCF/AHA Task Force on Practice Guidelines	None	None	None	• Medtronic	None	None
David P. Faxon	Content Reviewer	• Sanofi-aventis	None	None	None	None	• Defendant, cath vascular access site complication, 2009
Kirsten E. Fleischmann	Content Reviewer	None	None	None	None	None	None
Lee Fleisher	Content Reviewer	None	None	None	• Pfizer	• AstraZeneca†	• Defendant, perioperative stroke, 2009
Anthony P. Furnary	Content Reviewer—ACCF Surgeons' Scientific Council	None	None	None	None	None	• Defendant, Bayer Corp. Trasylol litigation, 2009 to 2011
Valentin Fuster	Content Reviewer	None	None	None	None	None	None
John W. Hirshfeld, Jr.	Content Reviewer	• GlaxoSmithKline	None	None	None	None	None
Judith S. Hochman	Content Reviewer—ACCF/AHA Task Force on Practice Guidelines	• Eli Lilly • GlaxoSmithKline	None	None	None	None	None
James L. Januzzi, Jr.	Content Reviewer	• Roche	None	None	• Roche	None	None
Frederick G. Kushner	Content Reviewer—Vice Chair, 2012 STEMI Guideline Writing Committee	None	None	None	None	None	None
Glenn Levine	Content Review—Chair, 2011 PCI Guideline Writing Committee	None	None	None	None	None	None

Peer Reviewer	Representation	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Donald Likosky	Content Reviewer	None	None	None	• Maquet† • Medtronic†	None	None
James J. Livesay	Content Reviewer—Southern Thoracic Surgical Association	None	None	None	None	None	• Defendant, acute aortic dissection, 2011 • Defendant, cardiac mortality review, 2010 • Defendant, heparin induced thrombocytopenia, 2010
Bruce W. Lytle	Content Reviewer—2004 CABG Guideline Writing Committee	None	None	None	None	None	None
Robert A. Marlow	Content Reviewer—2004 CABG Guideline Writing Committee	None	None	None	None	None	None
Rick A. Nishimura	Content Reviewer—ACCF Board of Trustees	None	None	None	None	None	None
Patrick O'Gara	Content Reviewer—Chair, 2012 STEMI Guideline Writing Committee	None	None	None	None	None	None
E. Magnus Ohman	Content Reviewer—ACCF/AHA Task Force on Practice Guidelines	• AstraZeneca • Bristol-Myers Squibb • Boehringer Ingelheim • Gilead Sciences • Merck • Pozen • Sanofi-aventis	• Boehringer Ingelheim • Gilead Sciences	None	• Daiichi-Sankyo • Datascope • Eli Lilly	None	None
John D. Rutherford	Content Reviewer	None	None	None	None	None	None
George A. Stouffer	Content Reviewer	None	None	None	None	None	• Defendant, review of malpractice claim, 2010
Mathew Williams	Content—ACCF Interventional Scientific Council	• Edwards Lifesciences • Medtronic	None	None	None	None	None

This table represents the relationships of reviewers with industry and other entities that were disclosed at the time of peer review and determined to be relevant. It 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. A relationship is considered to be modest if it is less than significant under the preceding definition. Relationships that exist with no financial benefit are also included for the purpose of transparency. Relationships in this table are modest unless otherwise noted. Names are listed in alphabetical order within each category of review.

According to the ACCF/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*.

*No financial benefit. †Significant relationship.

AATS indicates American Association for Thoracic Surgery; ACCF, American College of Cardiology Foundation; AHA, American Heart Association; CABG, coronary artery bypass graft surgery; PCI, percutaneous coronary intervention; SCA, Society of Cardiovascular Anesthesiologists; STEMI, ST-elevation myocardial infarction; and STS, Society of Thoracic Surgeons.

APPENDIX 3. ABBREVIATION LIST

ACE = angiotensin-converting enzyme
ACS = acute coronary syndrome
AF = atrial fibrillation
AKI = acute kidney injury
ARB = angiotensin-receptor blockers
BMS = bare-metal stent
CABG = coronary artery bypass graft surgery
CAD = coronary artery disease
CKD = chronic kidney disease
CPB = cardiopulmonary bypass
DAPT = dual antiplatelet therapy
DES = drug-eluting stent
EF = ejection fraction
GDMT = guideline–directed medical therapy
ICU = intensive care unit
IMA = internal mammary artery
LAD = left anterior descending
LDL = low-density lipoprotein
LIMA = left internal mammary artery
LV = left ventricular
LVEF = left ventricular ejection fraction
MACE = major adverse coronary events
MI = myocardial infarction
NSTEMI = non–ST-elevation myocardial infarction
PAC = pulmonary artery catheter
PAD = peripheral artery disease
PCI = percutaneous coronary intervention
RCT = randomized controlled trial
SIHD = stable ischemic heart disease
SIRS = systemic inflammatory response system
STEMI = ST-elevation myocardial infarction
SVG = saphenous vein graft
TEE = transesophageal echocardiography
TIA = transient ischemic attack
TMR = transmyocardial laser revascularization
UA = unstable angina

2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery: A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines Developed in Collaboration With the American Association for Thoracic Surgery, Society of Cardiovascular Anesthesiologists, and Society of Thoracic Surgeons

L. David Hillis, Peter K. Smith, Jeffrey L. Anderson, John A. Bittl, Charles R. Bridges, John G. Byrne, Joaquin E. Cigarroa, Verdi J. DiSesa, Loren F. Hiratzka, Adolph M. Hutter, Jr, Michael E. Jessen, Ellen C. Keeley, Stephen J. Lahey, Richard A. Lange, Martin J. London, Michael J. Mack, Manesh R. Patel, John D. Puskas, Joseph F. Sabik, Ola Selnes, David M. Shahian, Jeffrey C. Trost, and Michael D. Winniford

J. Am. Coll. Cardiol. 2011;58;e123-e210; originally published online Nov 7, 2011; doi:10.1016/j.jacc.2011.08.009