

2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention

A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions

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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

Table 1. Applying Classification of Recommendations and Level of Evidence

ESTIMATE OF CERTAINTY (PRECISION) OF TREATMENT EFFECT	CLASS I <i>Benefit >>> Risk</i> Procedure/Treatment SHOULD be performed/ administered	CLASS IIa <i>Benefit >> Risk</i> Additional studies with focused objectives needed IT IS REASONABLE to per- form procedure/administer treatment	CLASS IIb <i>Benefit ≥ Risk</i> Additional studies with broad objectives needed; additional registry data would be helpful Procedure/Treatment MAY BE CONSIDERED	CLASS III <i>No Benefit</i> or CLASS III <i>Harm</i>	
				Procedure/ Test	Treatment
				COR III: No Benefit	No Proven Benefit
				COR III: Harm	Excess Cost w/o Benefit or Harmful
LEVEL A Multiple populations evaluated* Data derived from multiple randomized clinical trials or meta-analyses	<ul style="list-style-type: none"> Recommendation that procedure or treatment is useful/effective Sufficient evidence from multiple randomized trials or meta-analyses 	<ul style="list-style-type: none"> Recommendation in favor of treatment or procedure being useful/effective Some conflicting evidence from multiple randomized trials or meta-analyses 	<ul style="list-style-type: none"> Recommendation's usefulness/efficacy less well established Greater conflicting evidence from multiple randomized trials or meta-analyses 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Recommendation that procedure or treatment is useful/effective Evidence from single randomized trial or nonrandomized studies 	<ul style="list-style-type: none"> Recommendation in favor of treatment or procedure being useful/effective Some conflicting evidence from single randomized trial or nonrandomized studies 	<ul style="list-style-type: none"> Recommendation's usefulness/efficacy less well established Greater conflicting evidence from single randomized trial or nonrandomized studies 	<ul style="list-style-type: none"> 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	<ul style="list-style-type: none"> Recommendation that procedure or treatment is useful/effective Only expert opinion, case studies, or standard of care 	<ul style="list-style-type: none"> Recommendation in favor of treatment or procedure being useful/effective Only diverging expert opinion, case studies, or standard of care 	<ul style="list-style-type: none"> Recommendation's usefulness/efficacy less well established Only diverging expert opinion, case studies, or standard of care 	<ul style="list-style-type: none"> 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.

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 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 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 asked 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/or 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, AHA, and the Society for Cardiovascular Angiography and Interventions (SCAI) 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, several changes to these guidelines will be apparent, including limited narrative text, a focus on summary and evidence tables (with references linked to abstracts in PubMed) and more liberal use of summary recommendation tables (with references that support LOE) to serve as a quick reference.

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 were cited as being compliant with many of the standards that were proposed. 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

The recommendations listed in this document are, whenever possible, evidence based. An extensive evidence review was conducted through November 2010, as well as selected other

references through August 2011. Searches were limited to studies, reviews, and other evidence conducted in human subjects and that were published in English. Key search words included but were not limited to the following: *ad hoc angioplasty, angioplasty, balloon angioplasty, clinical trial, coronary stenting, delayed angioplasty, meta-analysis, percutaneous transluminal coronary angioplasty, randomized controlled trial (RCT), percutaneous coronary intervention (PCI) and angina, angina reduction, antiplatelet therapy, bare-metal stents (BMS), cardiac rehabilitation, chronic stable angina, complication, coronary bifurcation lesion, coronary calcified lesion, coronary chronic total occlusion (CTO), coronary ostial lesions, coronary stent (BMS and drug-eluting stents [DES]; and BMS versus DES), diabetes, distal embolization, distal protection, elderly, ethics, late stent thrombosis, medical therapy, microembolization, mortality, multiple lesions, multi-vessel, myocardial infarction (MI), non-ST-elevation myocardial infarction (NSTEMI), no-reflow, optical coherence tomography, proton pump inhibitor (PPI), return to work, same-day angioplasty and/or stenting, slow flow, stable ischemic heart disease (SIHD), staged angioplasty, STEMI, survival, and unstable angina (UA).* Additional searches cross-referenced these topics with the following subtopics: *anticoagulant therapy, contrast nephropathy, PCI-related vascular complications, unprotected left main PCI, multivessel coronary artery disease (CAD), adjunctive percutaneous interventional devices, percutaneous hemodynamic support devices, and secondary prevention.* 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 and 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 will be provided in the guideline, along with confidence intervals (CIs) and data related to the relative treatment effects such as odds ratio (OR), relative risk, hazard ratio (HR), or incidence rate ratio. The focus of this guideline is the safe, appropriate, and efficacious performance of PCI. The risks of PCI must be balanced against the likelihood of improved survival, symptoms, or functional status. This is especially important in patients with SIHD.

1.2. Organization of the Writing Committee

The committee was composed of physicians with expertise in interventional cardiology, general cardiology, critical care cardiology, cardiothoracic surgery, clinical trials, and health services research. The committee included representatives from the ACCF, AHA, and SCAI.

1.3. Document Review and Approval

This document was reviewed by 2 official reviewers nominated by the ACCF, AHA, and SCAI, as well as 21 individual content reviewers (including members of the ACCF Interventional Scientific Council and ACCF Surgeons' Scientific Council). 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, AHA, and SCAI.

1.4. PCI Guidelines: History and Evolution

In 1982, a 2-page manuscript titled "Guidelines for the Performance of Percutaneous Transluminal Coronary Angioplasty" was published in *Circulation*.⁴ The document, which addressed the specific expertise and experience physicians should have to perform balloon angioplasty, as well as laboratory requirements and the need for surgical support, was written by an ad hoc group whose members included Andreas Grüntzig. In 1980, the ACC and the AHA established the Task Force on Assessment of Diagnostic and Therapeutic Cardiovascular Procedures, which was charged with the development of guidelines related to the role of new therapeutic approaches and of specific noninvasive and invasive procedures in the diagnosis and management of cardiovascular disease. The first ACC/AHA Task Force report on guidelines for coronary balloon angioplasty was published in 1988.⁵ The 18-page document discussed and made recommendations about lesion classification and success rates, indications for and contraindications to balloon angioplasty, institutional review of angioplasty procedures, ad hoc angioplasty after angiography, and on-site surgical backup. Further iterations of the guidelines were published in 1993,⁶ 2001,⁷ and 2005.⁸ In 2007 and 2009, focused updates to the guideline were published to expeditiously address new study results and recent changes in the field of interventional cardiology.^{9,10} The 2009 focused update is notable in that there was direct collaboration between the writing committees for the STEMI guidelines and the PCI guidelines, resulting in a single publication of focused updates on STEMI and PCI.¹⁰

The evolution of the PCI guideline reflects the growth of knowledge in the field and parallels the many advances and innovations in the field of interventional cardiology, including primary PCI, BMS and DES, intravascular ultrasound (IVUS) and physiologic assessments of stenosis, and newer antiplatelet and anticoagulant therapies. The 2011 iteration of the guideline continues this process, addressing ethical aspects of PCI, vascular access considerations, CAD revascularization including hybrid revascularization, revascularization before noncardiac surgery, optical coherence tomography, advanced hemodynamic support devices, no-reflow therapies, and vascular closure devices. Most of this document is organized according to "patient flow," consisting of preprocedural considerations, procedural considerations, and postprocedural considerations. In a major undertaking, the STEMI, PCI, and coronary artery bypass graft (CABG) surgery guidelines were written concurrently, with additional collaboration with the SIHD guideline writing committee, allowing greater collaboration between the different writing committees on topics such as PCI in STEMI and revascularization strategies in patients with CAD (including unprotected left main PCI, multivessel disease revascularization, and hybrid procedures).

In accordance with direction from the Task Force and feedback from readers, in this iteration of the guideline, the text has been shortened, with an emphasis on summary

statements rather than detailed discussion of numerous individual trials. Online supplemental evidence and summary tables have been created to document the studies and data considered for new or changed guideline recommendations.

2. 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 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) improve survival and/or 2) 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 (eg, 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 $\geq 70\%$ diameter narrowing; therefore, for revascularization decisions and recommendations in this section, a “significant” stenosis has been defined as $\geq 70\%$ diameter narrowing ($\geq 50\%$ for left main CAD). Physiological criteria, such as an assessment of fractional flow reserve (FFR), has been used in deciding when revascularization is indicated. Thus, for recommendations about revascularization in this section, coronary stenoses with $\text{FFR} \leq 0.80$ can also be considered to be “significant.”^{11,12}

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 PCI and CABG.^{13,14} 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. Recom-

mendations that refer to SYNTAX scores use them as surrogates for the extent and complexity of CAD.

Revascularization recommendations to improve survival and symptoms are provided in the following text and are 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 1 and 2 for additional data regarding the survival and symptomatic benefits with CABG or PCI for different anatomic subsets.

2.1. 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.^{14–16} (Level of Evidence: C)

Class IIa

1. Calculation of the Society of Thoracic Surgeons (STS) and SYNTAX scores is reasonable in patients with unprotected left main and complex CAD.^{13,14,17–22} (Level of Evidence: B)

One protocol used in RCTs^{14–16,23} 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.^{15,16}

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 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.^{13,14,17–22}

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	14–16
CABG and PCI	IIa—Calculation of STS and SYNTAX scores	B	13,14,17–22
UPLM*			
CABG	I	B	24–30
PCI	IIa—For SIHD when <i>both</i> of the following are present <ul style="list-style-type: none"> Anatomic conditions associated with a low risk of PCI procedural complications and a high likelihood of good long-term outcome (eg, a low SYNTAX score of ≤ 22, ostial or trunk left main CAD) Clinical characteristics that predict a significantly increased risk of adverse surgical outcomes (eg, STS-predicted risk of operative mortality $\geq 5\%$) IIa—For UA/NSTEMI if not a CABG candidate IIa—For STEMI when distal coronary flow is TIMI flow grade < 3 and PCI can be performed more rapidly and safely than CABG IIb—For SIHD when <i>both</i> of the following are present <ul style="list-style-type: none"> Anatomic conditions associated with a low to intermediate risk of PCI procedural complications and an intermediate to high likelihood of good long-term outcome (eg, low-intermediate SYNTAX score of < 33, bifurcation left main CAD) Clinical characteristics that predict an increased risk of adverse surgical outcomes (eg, moderate-severe COPD, disability from prior stroke, or prior cardiac surgery; STS-predicted risk of operative mortality $> 2\%$) III: Harm—For SIHD in patients (versus performing CABG) with unfavorable anatomy for PCI and who are good candidates for CABG	B B B C B B	13,17,19,23,31–48 13,36–39,44,45,47–49 33,50,51 13,17,19,23,31–48,52 13,17,19,24–32
3-vessel disease with or without proximal LAD artery disease*			
CABG	I	B	26,30,53–56
	IIa—It is reasonable to choose CABG over PCI in patients with complex 3-vessel CAD (eg, SYNTAX score > 22) who are good candidates for CABG	B	32,46,56,71,72
PCI	IIb—Of uncertain benefit	B	26,46,53,56,82
2-vessel disease with proximal LAD artery disease*			
CABG	I	B	26,30,53–56
PCI	IIb—Of uncertain benefit	B	26,53,56,82
2-vessel disease without proximal LAD artery disease*			
CABG	IIa—With extensive ischemia	B	60–63
	IIb—Of uncertain benefit without extensive ischemia	C	56
PCI	IIb—Of uncertain benefit	B	26,53,56,82
1-vessel proximal LAD artery disease			
CABG	IIa—With LIMA for long-term benefit	B	30,56,69,70
PCI	IIb—Of uncertain benefit	B	26,53,56,82
1-vessel disease without proximal LAD artery involvement			
CABG	III: Harm	B	30,53,60,61,94–98
PCI	III: Harm	B	30,53,60,61,94–98
LV dysfunction			
CABG	IIa—EF 35% to 50%	B	30,64–68
CABG	IIb—EF $< 35\%$ without significant left main CAD	B	30,64–68,83,84
PCI	Insufficient data		N/A
Survivors of sudden cardiac death with presumed ischemia-mediated VT			
CABG	I	B	57–59
PCI	I	C	57
No anatomic or physiologic criteria for revascularization			
CABG	III: Harm	B	30,53,60,61,94–98
PCI	III: Harm	B	30,53,60,61,94–98

*In patients with multivessel disease who also have diabetes, it is reasonable to choose CABG (with LIMA) over PCI^{62,74–81} (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 ($\geq 50\%$ Left Main or $\geq 70\%$ 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	82,99–108
≥ 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 IIb—CABG	C C	86,89,92 93
Complex 3-vessel CAD (eg, SYNTAX score >22) with or without involvement of the proximal LAD artery and a good candidate for CABG	IIa—CABG preferred over PCI	B	32,46,56,71,72
Viable ischemic myocardium that is perfused by coronary arteries that are not amenable to grafting	IIb—TMR as an adjunct to CABG	B	109–113
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.

2.2. Revascularization to Improve Survival: Recommendations

Left Main CAD Revascularization

Class I

1. CABG to improve survival is recommended for patients with significant ($\geq 50\%$ diameter stenosis) left main coronary artery stenosis.^{24–30} (*Level of Evidence: B*)

Class IIa

1. PCI to improve survival is reasonable as an alternative to CABG in selected stable patients with significant ($\geq 50\%$ 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 (eg, 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 (eg, STS-predicted risk of operative mortality $\geq 5\%$).^{13,17,19,23,31–48} (*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.^{13,36–39,44,45,47–49} (*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 TIMI (Thrombolysis In Myocardial Infarction) grade 3, and PCI can be performed more rapidly and safely than CABG.^{33,50,51} (*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 ($\geq 50\%$ 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 (eg, low-intermediate SYNTAX score of <33 , bifurcation left main CAD); and 2) clinical characteristics that predict an increased risk of adverse surgical outcomes (eg, moderate-severe chronic obstructive pulmonary disease, disability from previous stroke, or previous cardiac surgery; STS-predicted risk of operative mortality $>2\%$).^{13,17,19,23,31–48,52} (*Level of Evidence: B*)

Class III: HARM

1. PCI to improve survival should not be performed in stable patients with significant ($\geq 50\%$ diameter stenosis) unprotected left main CAD who have unfavorable anatomy for PCI and who are good candidates for CABG.^{13,17,19,24–32} (*Level of Evidence: B*)

Non-Left Main CAD Revascularization

Class I

1. CABG to improve survival is beneficial in patients with significant ($\geq 70\%$ diameter) stenoses in 3 major coronary arteries (with or without involvement of the proximal left anterior descending [LAD] artery) or in the proximal LAD plus 1 other major coronary artery.^{26,30,53–56} (*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 ($\geq 70\%$ diameter) stenosis in a major coronary artery. (*CABG Level of Evidence: B^{57–59}; PCI Level of Evidence: C⁵⁷*)

Class IIa

1. CABG to improve survival is reasonable in patients with significant ($\geq 70\%$ diameter) stenoses in 2 major coronary arteries with severe or extensive

myocardial ischemia (eg, 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.^{60–63} (*Level of Evidence: B*)

2. CABG to improve survival is reasonable in patients with mild-moderate left ventricular (LV) systolic dysfunction (ejection fraction [EF] 35% to 50%) and significant ($\geq 70\%$ diameter stenosis) multi-vessel CAD or proximal LAD coronary artery stenosis, when viable myocardium is present in the region of intended revascularization.^{30,64–68} (*Level of Evidence: B*)
3. CABG with a left internal mammary artery (LIMA) graft to improve survival is reasonable in patients with significant ($\geq 70\%$ diameter) stenosis in the proximal LAD artery and evidence of extensive ischemia.^{30,56,69,70} (*Level of Evidence: B*)
4. It is reasonable to choose CABG over PCI to improve survival in patients with complex 3-vessel CAD (eg, SYNTAX score >22), with or without involvement of the proximal LAD artery who are good candidates for CABG.^{32,46,56,71,72} (*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.^{62,74–81} (*Level of Evidence: B*)

Class IIb

1. The usefulness of CABG to improve survival is uncertain in patients with significant ($\geq 70\%$) diameter stenoses in 2 major coronary arteries not involving the proximal LAD artery and without extensive ischemia.⁵⁶ (*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.^{26,53,56,82} (*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.^{30,64–68,83,84} (*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.^{85–93} (*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 (eg, <70% diameter non-left main coronary artery stenosis, FFR >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.^{30,53,60,61,94–98} (*Level of Evidence: B*)

2.3. Revascularization to Improve Symptoms: Recommendations

Class I

1. CABG or PCI to improve symptoms is beneficial in patients with 1 or more significant ($\geq 70\%$ diameter) coronary artery stenoses amenable to revascularization and unacceptable angina despite GDMT.^{82,99–108} (*Level of Evidence: A*)

Class IIa

1. CABG or PCI to improve symptoms is reasonable in patients with 1 or more significant ($\geq 70\%$ 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 ($\geq 70\%$ diameter) coronary artery stenoses associated with ischemia, and unacceptable angina despite GDMT.^{86,89,92} (*Level of Evidence: C*)
3. It is reasonable to choose CABG over PCI to improve symptoms in patients with complex 3-vessel CAD (eg, SYNTAX score >22), with or without involvement of the proximal LAD artery who are good candidates for CABG.^{32,46,56,72,73} (*Level of Evidence: B*)

Class IIb

1. CABG to improve symptoms might be reasonable for patients with previous CABG, 1 or more significant ($\geq 70\%$ diameter) coronary artery stenoses not amenable to PCI, and unacceptable angina despite GDMT.⁹³ (*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.^{109–113} (*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 ($\geq 50\%$ diameter left main or $\geq 70\%$ non-left main stenosis diameter) or physiological (eg, abnormal FFR) criteria for revascularization. (*Level of Evidence: C*)

2.4. 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 Veter-

ans Affairs Cooperative Study,¹¹⁴ European Coronary Surgery Study,⁵⁵ and CASS (Coronary Artery Surgery Study).¹¹⁵ Subsequently, a 1994 meta-analysis of 7 studies that randomized a total of 2649 patients to medical therapy or CABG³⁰ 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 for 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.¹⁰⁴

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) <0.50.¹¹⁶ 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.

2.5. 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 BMS confers a survival advantage over balloon angioplasty^{117–119} or that the use of DES confers a survival advantage over BMS.^{119,120}

No study to date has demonstrated that PCI in patients with SIHD improves survival rates.^{26,53,56,82,116,119,121–124} Neither COURAGE (Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation)⁸² nor BARI 2D,¹¹⁶ 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 acute coronary syndromes [ACS]) found a 20% reduction in death with PCI compared with medical therapy,¹²³ 2 other large analyses did not.^{119,122} An evaluation of 13 studies reporting

the data from 5442 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.¹²⁴ 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.¹¹⁹

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

- PCI reduces the incidence of angina.^{82,99,104,107,108,125}
- PCI has not been demonstrated to improve survival in stable patients.^{119,121,122}
- PCI may increase the short-term risk of MI.^{82,121,125,126}
- PCI does not lower the long-term risk of MI.^{82,116,119,121,122,126}

2.6. CABG Versus PCI

The results of 26 RCTs comparing CABG and PCI have been published: Of these, 9 compared CABG with balloon angioplasty,^{75,105,128–142} 14 compared CABG with BMS implantation,^{88,143–160} and 3 compared CABG with DES implantation.^{14,161,162}

2.6.1. CABG Versus Balloon Angioplasty or BMS

A systematic review of the 22 RCTs comparing CABG with balloon angioplasty or BMS implantation concluded the following¹⁶³:

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)¹⁶⁴ permitted subgroup analyses of the data from the 7812 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.¹⁶⁴ 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

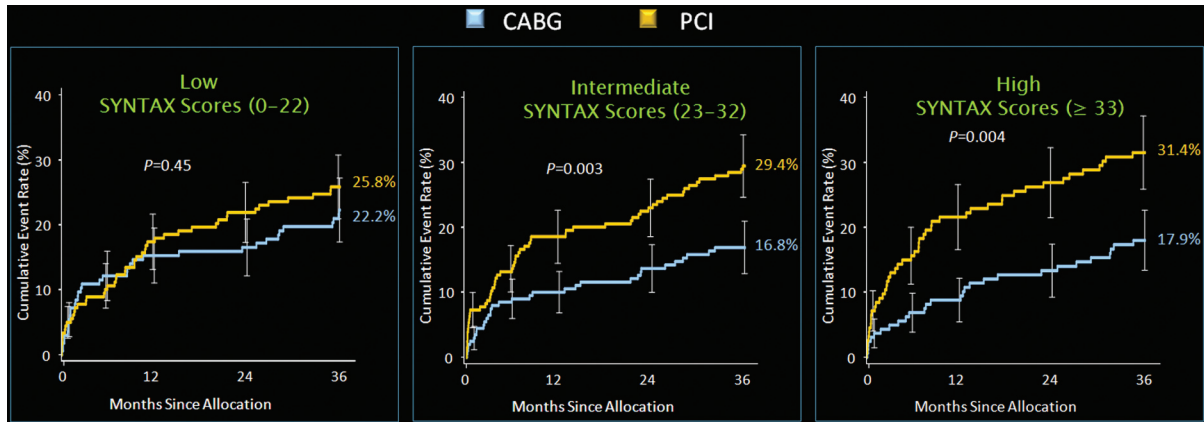


Figure 1. Cumulative incidence of MACE in patients with 3-vessel CAD based on SYNTAX score at 3-year follow-up in the SYNTAX trial treated with either CABG or PCI. CABG indicates coronary artery bypass graft; CAD, coronary artery disease; MACE, major adverse cardiovascular event; PCI, percutaneous coronary intervention; and SYNTAX, Synergy between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery. Adapted with permission from Kappetein.⁴⁶

CABG and PCI were not influenced by other patient characteristics, including the number of diseased coronary arteries.

The aforementioned meta-analysis and systematic review^{163,164} 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 arterial disease, 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.³⁰
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 3 and 4 for additional data comparing CABG with PCI.

2.6.2. CABG Versus DES

Although the results of 9 observational studies comparing CABG and DES implantation have been published,^{32,165–172} 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,¹⁷³ 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 1800 patients (of a total of 4337 who were screened) to receive DES or CABG.^{14,46} 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.⁴⁶

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.¹⁴ 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).⁴⁶

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.⁴⁶

See Online Data Supplements 5 and 6 for additional data comparing CABG with DES.

2.7. Left Main CAD

2.7.1. 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.²⁸ A meta-analysis of these trials demonstrated a 66% reduction in relative risk in mortality with CABG, with the benefit extending to 10 years.³⁰ The CASS Registry²⁴ contained data

from 1484 patients with $\geq 50\%$ diameter stenosis 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.²⁹ Other therapies that subsequently have been shown to be associated with improved long-term outcome, such as the use of aspirin, statins, and internal mammary artery 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.

2.7.2. Studies Comparing PCI Versus CABG for Left Main CAD

Of all subjects undergoing coronary angiography, approximately 4% are found to have left main CAD,¹⁷⁵ >80% of whom have significant ($\geq 70\%$ 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 disease that prevented randomization; 89% of these underwent CABG.^{13,14} In addition, 705 of the 1800 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.¹³ 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 ($P=0.10$).⁴⁶ Because the primary endpoint of SYNTAX was not met (ie, 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,²³ 105 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 internal mammary 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 patients 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%).⁵²

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,⁴¹ 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 7 to 12 for additional data comparing PCI with CABG for left main CAD.

2.7.3. 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.¹⁷⁶ In addition, PCI of bifurcation disease is associated with higher restenosis rates than when disease is confined to the ostium or trunk.^{39,177} 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.⁴⁶ Physicians can estimate operative risk for all CABG candidates 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 2.9.7, 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 guideline⁸ recommended routine angiographic follow-up 2 to 6 months after stenting for unprotected 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.¹⁰

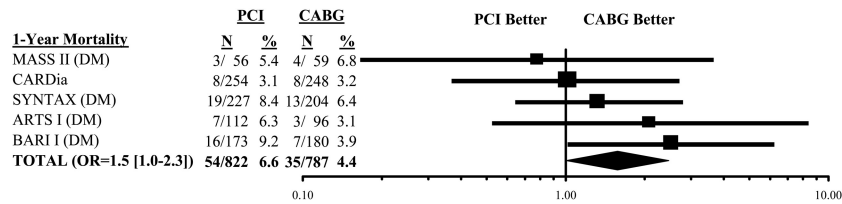


Figure 2. 1-year mortality after revascularization for multivessel disease and diabetes mellitus. An OR of >1 suggests an advantage of CABG over PCI. ARTS I indicates Arterial Revascularization Therapy Study I¹⁸⁵; BARI I, Bypass Angioplasty Revascularization Investigation I⁷⁴; CABG, coronary artery bypass graft; CAD, coronary artery disease; CARDia, Coronary Artery Revascularization in Diabetes¹⁸⁶; CI, confidence interval; MASS II, Medicine, Angioplasty, or Surgery Study II⁷⁸; OR, odds ratio; PCI, percutaneous coronary intervention; SYNTAX, Synergy between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and W, weighted.⁷⁶

Experts have recommended immediate PCI for unprotected left main CAD in the setting of STEMI.⁵¹ The impetus for such a strategy is greatest when left main CAD is the site of the culprit lesion, antegrade coronary flow is diminished (eg, TIMI 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.

2.8. Proximal LAD Artery Disease

A cohort study⁵³ and a meta-analysis³⁰ 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^{30,133,146,148,161,178–181} as well as collaborative- and meta-analyses^{164,182–184} showed that PCI and CABG result in similar survival rates in these patients.

See Online Data Supplement 13 for additional data regarding proximal LAD artery revascularization.

2.9. Clinical Factors That May Influence the Choice of Revascularization

2.9.1. Diabetes Mellitus

An analysis performed in 2009 of data on 7812 patients (1233 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.¹⁶⁴ The BARI 2D trial¹¹⁶ randomly assigned 2368 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 demon-

strated 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.⁷⁶ 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 14 and 15 for additional data regarding diabetes mellitus.

2.9.2. 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.^{187,188}

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,^{189–191} despite the fact that the incidence of periprocedural complications (eg, 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.^{190–196}

2.9.3. Completeness of Revascularization

Most patients undergoing CABG receive complete or nearly complete revascularization, which seems to influence long-term prognosis positively.¹⁹⁷ In contrast, complete revascularization is accomplished less often in subjects receiving PCI (eg, 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 appears 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.^{198–200}

2.9.4. 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.^{30,64–68} 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.^{83,84}

Only very limited data comparing PCI with medical therapy in patients with LV systolic dysfunction are available.⁶⁸ 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,^{71,164,201–203} whereas others showed that those undergoing CABG had better outcomes.³² 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 (eg, 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.

2.9.5. 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.^{85–93} 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.⁹²

Cohort studies comparing PCI and CABG among post-CABG patients report similar rates of mid- and long-term survival after the 2 procedures.^{85,88–91,93,204} 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 internal mammary artery 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.

2.9.6. 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.^{205–207} 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.

2.9.7. 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.**^{208–211} (*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%.²⁰⁸ 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.^{208,212} 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.

2.10. 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,^{213,214} several RCTs of TMR as sole therapy demonstrated a reduction in anginal symptoms compared with intensive medical therapy alone.^{109–111,215–217} A single randomized multicenter comparison of TMR (with a holmium:YAG laser) plus CABG and CABG alone in patients in whom some myocardial segments were perfused by arteries considered not amenable to grafting¹¹² 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.¹¹² 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.^{113,218} 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.

2.11. 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^{219–225} (*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 (ie, excessive vessel tortuosity or CTO).

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,²²⁶ is intended to combine the advantages of CABG (ie, durability of the LIMA graft) and PCI.²²⁷ Patients with multivessel CAD (eg, 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 preferred²²¹ (eg, 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 CTO).

Hybrid coronary revascularization may be performed in a hybrid suite in one operative setting or as a staged procedure (ie, 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 (ie, 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.²²¹

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.^{219–225}

3. PCI Outcomes

3.1. Definitions of PCI Success

The success of a PCI procedure is best defined by 3 interrelated components: angiographic findings, procedural events, and clinical outcomes.

3.1.1. Angiographic Success

A successful PCI produces sufficient enlargement of the lumen at the target site to improve coronary artery blood flow. A successful balloon angioplasty is defined as the reduction of a minimum stenosis diameter to $<50\%$ with a final TIMI flow grade 3 (visually assessed by angiography) without side branch loss, flow-limiting dissection, or angiographic thrombus.⁷ For coronary stents, a minimum stenosis diameter of $<20\%$ (as visually assessed by angiography) has previously been the clinical benchmark of an optimal angiographic result. Given improvements in technology and techniques, as well as recognition of the importance of an adequately deployed stent to decrease the risks of stent restenosis and thrombosis,^{12,228,229} the writing committee concluded that a minimum diameter stenosis of $<10\%$ (with an optimal goal of as close to 0% as possible) should be the new benchmark for lesions treated with coronary stenting. As with balloon angioplasty, there should be final TIMI flow grade 3, without occlusion of a significant side branch, flow-limiting dissection, distal embolization, or angiographic thrombus. Problems with determining angiographic success include disparities between the visual assessment and computer-aided quantitative stenosis measurement and self-reporting of success in clinical reports or databases.

3.1.2. Procedural Success

A successful PCI should achieve angiographic success without associated in-hospital major clinical complications (eg, death, MI, stroke, emergency CABG).^{7,8} Issues regarding the diagnosis and prognostic implications of procedure-related MI are discussed in Sections 3.3 and 5.10.

3.1.3. Clinical Success

In the short term, a clinically successful PCI requires both anatomic and procedural success along with relief of signs and/or symptoms of myocardial ischemia. Long-term clinical success requires that the short-term clinical success remain

durable and that relief of signs and symptoms of myocardial ischemia persist >9 months after the procedure. Restenosis is the principal cause of lack of long-term clinical success after a short-term clinical success has been achieved. Restenosis is not a complication; it is the expected biological response to vascular injury. The frequency of clinically important restenosis may be judged by the frequency with which subsequent revascularization procedures are performed on target arteries after the index procedure.

3.2. Predictors of Clinical Outcome After PCI

Factors associated with increased PCI complication rates include advanced age, diabetes, CKD, ACS, congestive heart failure, and multivessel CAD.^{8,230–232} Several models have been developed and refined over the past 2 decades to predict mortality with PCI.^{230,233–236} At present, perhaps the best accepted system is from the ACC National Cardiovascular Data Registry (NCDR) CathPCI Risk Score system, which uses clinical variables and PCI setting to predict inpatient mortality (Appendix 4A).²³⁶ In general, these models perform very well (C statistic: approximately 0.90), although predictive capability decreases in high-risk patients.

Models have also been developed to predict procedural success. Presently, the modified ACC/AHA score²³⁰ and the SCAI score (Appendix 4B)²³⁷ are both in use, with the latter slightly outperforming the former. Discrimination as measured by the C statistic is generally good to very good (0.70 to 0.82), depending on the outcome variable and patient population.

The angiographic SYNTAX score²³⁸ has been developed to predict long-term risk of MACE after multivessel intervention. The SYNTAX score and its potential utility in helping guide revascularization strategies are discussed in Section 2. Composite models including angiographic and clinical variables have been developed but generally require validation in larger cohorts of patients.

3.3. PCI Complications

In an analysis of the NCDR CathPCI database of patients undergoing PCI between 2004 and 2007, the overall in-hospital mortality rate was 1.27%, ranging from 0.65% in elective PCI to 4.81% in STEMI.²³⁶ Factors associated with an increased risk of PCI-related death include advanced age, comorbidities (eg, diabetes, CKD, congestive heart failure), multivessel CAD, high-risk lesions, and the setting of PCI (eg, STEMI, urgent or emergency procedure, cardiogenic shock).^{56,230–232,236}

Causes of procedural and periprocedural MI include acute artery closure, embolization and no-reflow, side branch occlusion, and acute stent thrombosis. The incidence of procedure-related MI depends to a great degree on the definition of MI used, the patient population studied, and whether or not cardiac biomarkers are routinely assessed after PCI. The definition and clinical significance of PCI-related MI have been controversial. Criteria for defining a PCI-related MI have evolved over time.^{8,239,240} The 2007 universal definition of MI²⁴⁰ states that after PCI, elevations of cardiac biomarkers above the 99th percentile upper reference limit indicate periprocedural myocardial necrosis. Increases of

biomarkers >3 times the 99th percentile upper reference limit were designated as defining PCI-related MI.²⁴⁰ According to this definition, $\geq 15\%$ of patients undergoing PCI would be defined as having periprocedural MI.^{241,242} Issues in procedure-related MI are discussed in Section 5.10.

The need for emergency CABG has dramatically decreased with advances in PCI technology, particularly coronary stents.^{243,244} Recently the NCDR reported the rate of emergency CABG at 0.4%.²⁴⁴ Procedure-related indications for CABG in 1 large series included coronary dissection (27%), acute artery closure (16%), perforation (8%), and failure to cross the lesion (8%).²⁴⁵ The strongest predictors of the need for emergency CABG in several analyses are cardiogenic shock (OR: 11.4), acute MI or emergency PCI (OR: 3.2 to 3.8), multivessel disease (OR: 2.3 to 2.4), and type C lesion (OR: 2.6).^{243,245} In-hospital mortality for emergency CABG ranges from 7.8% to 14%.^{243,245,246}

In a contemporary analysis from the NCDR, the incidence of PCI-related stroke was 0.22%.²⁴⁷ In-hospital mortality in patients with PCI-related stroke is 25% to 30%.^{247,248} Factors associated with an increased risk of stroke include fibrinolytic therapy administered before PCI (OR: 4.7), known cerebrovascular disease (OR: 2.20), STEMI as the indication for PCI (OR: 3.2), use of an intra-aortic balloon pump (IABP) (OR: 2.6), older age (OR: 1.17 per 5-year increase), and female sex.^{247–249} Initial imaging after a stroke in 1 small series revealed hemorrhagic etiology in 18%, ischemic etiology in 58%, and no clear etiology in 24%.²⁴⁸ One potential algorithm for the treatment of catheterization-related stroke has been recently proposed.²⁵⁰ This document includes no specific recommendations for the management of PCI-related stroke but refers the reader to the AHA/American Stroke Association guidelines for the management of adults with stroke.²⁵¹

Vascular complications from PCI are primarily related to vascular access. Important femoral vascular complications include access site hematoma, retroperitoneal hematoma, pseudoaneurysm, arteriovenous fistula, and arterial dissection and/or occlusion.²⁵² The incidence of these vascular complications in various reports generally ranges from 2% to 6% and has decreased with time.^{249,253–257} Factors associated with an increased risk of vascular complication include age ≥ 70 years, body surface area $< 1.6 \text{ m}^2$, emergency procedures, peripheral artery disease, periprocedural use of glycoprotein (GP) IIb/IIIa inhibitors, and female sex (if not corrected for body surface area).^{249,253,254,257,258} Ultrasound guidance has been used for femoral artery access to potentially decrease complications.²⁵⁹ As discussed in Section 5.11, vascular closure devices have not been clearly demonstrated to decrease vascular complication rates. Radial site access decreases the rate of access-related bleeding and complications compared with femoral access.^{255,260} Loss of the radial pulse has been reported in $\leq 5\%$ of radial procedures.²⁶¹ Infrequent to rare complications occurring with the radial artery approach include compartment syndrome, pseudoaneurysm ($< 0.01\%$), and sterile abscess (occurring with previous-generation hydrophilic sheaths).²⁶² Radial artery spasm may occur and treatment at times may be challenging.

Table 4. Summary of Recommendations for Preprocedural Considerations and Interventions in Patients Undergoing PCI

Recommendations	COR	LOE	References
Contrast-induced AKI			
Patients should be assessed for risk of contrast-induced AKI before PCI.	I	C	270,271
Patients undergoing cardiac catheterization with contrast media should receive adequate preparatory hydration.	I	B	272–275
In patients with CKD (creatinine clearance <60 mL/min), the volume of contrast media should be minimized.	I	B	276–278
Administration of N-acetyl-L-cysteine is not useful for the prevention of contrast-induced AKI.	III: No Benefit	A	279–283
Anaphylactoid reactions			
Patients with prior evidence of an anaphylactoid reaction to contrast media should receive appropriate prophylaxis before repeat contrast administration.	I	B	252,284–286
In patients with a prior history of allergic reactions to shellfish or seafood, anaphylactoid prophylaxis for contrast reaction is not beneficial.	III: No Benefit	C	287–289
Statins			
Administration of a high-dose statin is reasonable before PCI to reduce the risk of periprocedural MI.	IIa	A: Statin naïve B: Chronic statin therapy	290–296 297
Bleeding risk			
All patients should be evaluated for risk of bleeding before PCI.	I	C	N/A
CKD			
In patients undergoing PCI, the glomerular filtration rate should be estimated and the dosage of renally cleared medications should be adjusted.	I	B	298–300
Aspirin			
Patients already on daily aspirin therapy should take 81 mg to 325 mg before PCI.	I	B	301–304
Patients not on aspirin therapy should be given nonenteric aspirin 325 mg before PCI.	I	B	301,303,304

AKI indicates acute kidney injury; CKD, chronic kidney disease; COR, class of recommendation; LOE, level of evidence; MI, myocardial infarction; N/A, not applicable; and PCI, percutaneous coronary intervention.

Local hematomas may occur from small-branch vessel hydrophilic wire perforation or inexperience with wristband use.

The risk of coronary perforation is approximately 0.2%, most commonly by wire perforation during PCI for CTO or by ablative or oversized devices during PCI of heavily diseased or tortuous coronary arteries.²⁶³ The risk of tamponade and management of the perforation varies with the type of perforation.²⁶⁴

Periprocedural bleeding is now recognized to be associated with subsequent mortality,^{265,266} and the avoidance of bleeding complications has become an important consideration in performing PCI. The risk of bleeding is associated with patient factors (eg, advanced age, low body mass index, CKD, baseline anemia), as well as the degree of platelet and thrombin inhibition, vascular access site, and sheath size.^{267–269} Issues of periprocedural bleeding are discussed in Section 4.7.

The incidence of contrast-induced acute kidney injury (AKI) or “contrast nephropathy” in published reports depends on the definition of contrast nephropathy used and the frequency of risk factors for contrast-induced AKI in the patient population studied. Important risk factors for contrast-induced AKI include advanced age, CKD, congestive heart failure, diabetes, and the volume of contrast administered. Contrast-induced AKI and strategies to prevent it are discussed in Section 4.4.

4. Preprocedural Considerations

Table 4 contains recommendations for preprocedural considerations and interventions in patients undergoing PCI.

4.1. Cardiac Catheterization Laboratory Requirements

4.1.1. Equipment

Defibrillators are considered by The Joint Commission to be life-support equipment requiring routine assessment and completion of appropriate logs. Many hospitals require periodic inspection of consoles for ancillary devices used in coronary intervention (eg, Doppler wires, pressure-tipped sensor wires, and IVUS catheters). Point-of-care testing devices (eg, activated clotting time and arterial blood gas machines) require routine calibration. Duration of storage of digital cine images is often mandated by law. Operating parameters for x-ray imaging equipment are adjusted at installation and periodically assessed by a qualified physicist in cooperation with the equipment manufacturer. Familiarity with radiation dose-reducing features of catheterization laboratory equipment and assistance from a qualified physicist are important for radiation dose minimization and image optimization.

4.1.2. Staffing

An interventional cardiologist must be present in the laboratory for the duration of each procedure and is responsible for

procedure outcome. Nursing and technical personnel are also required to be present in the catheterization laboratory, with specific staffing dependent on state requirements and laboratory caseload and mix. Catheterization laboratory technical staff may include nurse practitioners, registered nurses, licensed vocational or practical nurses, physician assistants, nursing assistants, radiology technicians, or catheterization laboratory technicians. All catheterization laboratory staff are usually certified in basic life support, advanced cardiovascular life support, and, where appropriate, pediatric advanced life support. Catheterization laboratory personnel have a nursing degree/certification or invasive cardiovascular credentials such as registered cardiovascular invasive specialist or American Society of Radiation technologists.³⁰⁵

4.1.3. 'Time-Out' Procedures

In 2003, The Joint Commission mandated a universal protocol requiring proper preoperative identification of the patient by the members of the catheterization laboratory team, marking of the operative site, and a final time-out just before the procedure.³⁰⁶ Although initially intended to prevent wrong-site surgery, this has been expanded to include all invasive procedures despite limited scientific evidence of its effectiveness.³⁰⁷ The intent of the time-out is for all members of the team to improve patient care by collectively discussing the case. The content of a time-out includes confirmation of the correct patient, correct side and site, agreement on the procedure to be performed, correct patient position, and availability of needed equipment, supplies, and implants. The timeout may be checklist driven or conversational, depending on laboratory preferences.³⁰⁸ The writing committee strongly endorses the practice of conducting a time-out before all PCI procedures.

4.2. Ethical Aspects

The 3 principles of medical ethics are beneficence, autonomy, and justice. Beneficence involves the physician's duty to act in the best interests of the patient and avoid maleficence, or harm (*primum non nocere*). Autonomy describes the physician's duty to help the patient maintain control over his or her medical treatments. Justice describes the physician's duty to treat the individual patient responsibly with due consideration of other patients and stakeholders in the healthcare system. Ethical considerations specific to PCI have been previously discussed³⁰⁹ and are highlighted below:

- Place the patient's best interest first and foremost when making clinical decisions (beneficence).
- Ensure that patients actively participate in decisions affecting their care (autonomy).
- Consider how decisions regarding one patient may also affect other patients and providers (justice).
- Plan and perform procedures and provide care with the intention of improving the patient's quality of life and/or decreasing the risk of mortality, independent of reimbursement considerations and without inappropriate bias or influence from industry, administrators, referring physicians, or other sources.
- Before performing procedures, obtain informed consent after giving an explanation regarding the details of the

procedure and the risks and benefits of both the procedure and alternatives to the procedure.

- Plan and perform procedures according to standards of care and recommended guidelines, and deviate from them when appropriate or necessary in the care of individual patients.
- Seek advice, assistance, or consultation from colleagues when such consultation would benefit the patient.

4.2.1. Informed Consent

Obtaining informed consent for procedures is a legal and ethical necessity. Ideally, informed consent is obtained long enough before the procedure that the patient can fully consider informed consent issues and discuss them with family or other providers, avoiding any sense of coercion. Ad hoc PCI, or PCI immediately following diagnostic procedures, presents special problems. When informed consent for PCI is obtained before diagnostic catheterization is performed, it is impossible to predict the levels of risk and benefit from an ad hoc PCI.^{310,311} If diagnostic catheterization reveals anatomy that poses a particularly high risk or for which the superiority of PCI compared with other strategies is unclear, the precatheterization informed consent discussion may be inadequate. In such cases, deferral of PCI until additional informed consent discussions and/or consultations occur may be appropriate, even though it inconveniences the patient and the healthcare system. It is the responsibility of the interventionalist to act in the patient's best interest in these circumstances.

Informed consent before emergency procedures is particularly difficult.^{312–314} The patient presenting with STEMI is usually in distress and often sedated, making true informed consent impossible. Rapid triage, transport, and treatment of STEMI patients create a pressured atmosphere that by necessity limits a prolonged and detailed informed consent process. Nevertheless, the interventionalist must attempt to provide information about the risks and benefits of different strategies to the patient and family and balance the benefit of thorough discussion with the benefits of rapid intervention.

4.2.2. Potential Conflicts of Interest

Decisions about the performance and timing of PCI may pose additional ethical dilemmas. When considering whether to perform multivessel PCI in 1 stage versus 2 stages, safety and convenience for the patient must guide the decision, regardless of payment policies that maximize reimbursement when PCI is staged.³¹¹ A separate issue is self-referral, through which diagnostic catheterization often leads seamlessly to PCI by the same operator.³¹⁵ The interventionalist has an ethical obligation to the patient to consider all treatment options, consult with additional specialists (eg, cardiac surgeons) when their input would be helpful to the patient, avoid unnecessary interventional procedures, and allow the patient to consult family members and other physicians.³¹¹

4.3. Radiation Safety: Recommendation

Class I

1. Cardiac catheterization laboratories should routinely record relevant available patient procedural

radiation dose data (eg, total air kerma at the international reference point [$K_{a,r}$], air kerma air product [P_{KA}], fluoroscopy time, number of cine images), and should define thresholds with corresponding follow-up protocols for patients who receive a high procedural radiation dose. (*Level of Evidence: C*)

The issue of radiation exposure during imaging procedures has received increased attention, and the writing committee believes that radiation safety should be addressed in this guideline. Current standards for cardiac catheterization laboratories include the following:

- Specific procedures and policies are in place to minimize patient (and operator) risk.
- A radiation safety officer coordinates all radiation safety issues and works conjointly with the medical or health physicist.
- Patient radiation exposure is reduced to as low a level as reasonably can be achieved.
- Patients at increased risk for high procedural radiation exposure are identified.
- Informed consent includes radiation safety information, particularly for the high-risk patient.

A basic primer on the physics of x-ray imaging, essential to the safe practice of radiation dose management, has been published in an ACCF/AHA/Heart Rhythm Society/SCAI clinical competence statement.³¹⁶ Appendix 4C summarizes strategies to minimize patient and operator radiation exposure. Adverse radiation effects are now well recognized as infrequent but potentially serious complications of prolonged interventional procedures.³¹⁷ Fluoroscopic time does not include cine acquisition imaging and is therefore not an accurate measure of patient radiation dose. Total air kerma at the interventional reference point ($K_{a,r}$, in Gy) and air kerma area product (P_{KA} , in Gy \cdot cm²) are required to be reported on interventional x-ray systems since 2006. These are useful in the assessment of potential tissue adverse effects or long-term radiation sequelae, respectively, and it is reasonable to include them in the catheterization record at the conclusion of each procedure. Appendix 4D summarizes considerations for patient follow-up based on radiation dose during the procedure.³¹⁷

4.4. Contrast-Induced AKI: Recommendations

Class I

1. Patients should be assessed for risk of contrast-induced AKI before PCI.^{270,271} (*Level of Evidence: C*)
2. Patients undergoing cardiac catheterization with contrast media should receive adequate preparatory hydration.^{272–275} (*Level of Evidence: B*)
3. In patients with CKD (creatinine clearance <60 mL/min), the volume of contrast media should be minimized.^{276–278} (*Level of Evidence: B*)

Class III: NO BENEFIT

1. Administration of N-acetyl-L-cysteine is not useful for the prevention of contrast-induced AKI.^{279–283} (*Level of Evidence: A*)

See Online Data Supplements 16 to 18 for additional data regarding contrast-induced AKI.

Contrast-induced AKI or “contrast nephropathy” is one of the leading causes of hospital-acquired AKI. Major risk factors for contrast-induced AKI include advanced age, CKD, congestive heart failure, diabetes, and the volume of contrast administered. A risk-scoring system is available to predict the risk of contrast nephropathy using these risk factors and additional variables.²⁷⁰ Thus far, the only strategies clearly shown to reduce the risk of contrast-induced AKI are hydration and minimizing the amount of contrast media. Other than saline hydration, measures that were believed to reduce the risk of contrast-induced AKI have been found to be neutral, to have deleterious effects, or to be characterized by heterogeneous and conflicting data.

Studies of hydration to reduce the risk of contrast-induced AKI suggest that isotonic saline is preferable to half isotonic saline, intravenous (IV) hydration is preferable to oral hydration, hydration for hours before and after exposure to contrast media is preferable to a bolus administration of saline immediately before or during contrast media exposure, and administration of isotonic saline alone is preferable to administration of isotonic saline plus mannitol or furosemide.^{272–275,320} On the basis of these studies, a reasonable hydration regimen would be isotonic crystalloid (1.0 to 1.5 mL/kg per hour) for 3 to 12 hours before the procedure and continuing for 6 to 24 hours after the procedure.^{272–275,284,320,321}

Prior studies of N-acetyl-L-cysteine and sodium bicarbonate have produced conflicting results. Some, often small, earlier studies suggested benefit, but many other more contemporary studies and meta-analyses found no clear evidence of benefit, and there are potential issues of publication bias and poor methodology issues in several analyses.^{279–282,322–332} The recently completed largest randomized study on N-acetyl-L-cysteine and contrast nephropathy in patients undergoing angiographic procedures, ACT (Acetylcysteine for Contrast-Induced Nephropathy Trial), demonstrated no benefit in primary or secondary endpoints. An updated meta-analysis using only high-quality trials similarly demonstrated no benefit.²⁸³ Taken as a whole, these studies do not support any recommendation for the use of N-acetyl-L-cysteine, they do, however, provide sufficient data to conclude that N-acetyl-L-cysteine does not prevent contrast-induced AKI in patients undergoing angiographic procedures.

The correlation between the volume of contrast media and the risk of contrast-induced AKI has been documented in several studies.^{276,277} Thus, minimization of contrast media volume is important to prevent contrast-induced AKI in patients undergoing angiography. The volume of contrast already administered during diagnostic catheterization is an important factor when considering possible “ad hoc” PCI.

Comparative studies of different contrast media (eg, low-osmolar versus iso-osmolar, one agent versus another agent) have produced variable and sometimes contradictory re-

sults.^{334–339} Thus, current data are insufficient to justify specific recommendations about low- and isoosmolar contrast media. This issue is discussed in detail in the 2011 UA/NSTEMI focused update.³⁴⁰ For a further discussion of contrast media and PCI, the reader is referred to a position statement by the SCAI.²⁸⁴

4.5. Anaphylactoid Reactions: Recommendations

Class I

1. **Patients with prior evidence of an anaphylactoid reaction to contrast media should receive appropriate steroid and antihistamine prophylaxis before repeat contrast administration.**^{252,284–286} (*Level of Evidence: B*)

Class III: NO BENEFIT

1. **In patients with a prior history of allergic reactions to shellfish or seafood, anaphylactoid prophylaxis for contrast reaction is not beneficial.**^{287–289} (*Level of Evidence: C*)

The incidence of anaphylactoid reactions to contrast media is $\leq 1\%$, and the incidence of severe reactions may be as low as 0.04%.²⁸⁴ Limited data suggest that in patients with a history of prior anaphylactoid reaction, the recurrence rate without prophylaxis is in the range of 16% to 44%.³⁴¹ Adequate pretreatment of patients with prior anaphylactoid reactions reduces the recurrence rate to close to zero.^{284–286} A regimen of 50 mg of prednisone administered 13 hours, 7 hours, and 1 hour before the procedure (as well as 50 mg of diphenhydramine 1 hour before the procedure) has been shown to reduce the risk of recurrent anaphylactoid reaction.²⁸⁶ In practice, a regimen of 60 mg of prednisone the night before and morning of the procedure (as well as 50 mg of diphenhydramine 1 hour before the procedure) is often used.²⁵² There are minimal data on the “pretreatment” of patients undergoing emergency PCI.³⁴² One group has suggested IV steroids (eg, 80 mg to 125 mg of methylprednisolone, 100 mg of hydrocortisone sodium succinate), as well as oral or IV diphenhydramine and possible IV cimetidine.²⁸⁴ For a more detailed discussion of issues related to contrast-induced anaphylactoid reactions, the reader is referred to several dedicated discussions on contrast agents.^{284,341}

There are no data to suggest that those patients with seafood or shellfish allergies are at risk for an anaphylactoid reaction from exposure to contrast media. Iodine does not mediate seafood, shellfish, or contrast media reactions. The common misconception that seafood allergies and contrast reactions are cross-reactions to iodine probably arose from a survey published in 1975 in which 15% of patients with a history of contrast reaction reported a personal history of shellfish allergy, but nearly identical proportions of patients reported allergies to other foods, such as milk and egg, in the same survey.²⁸⁷ Pretreatment of patients with steroids based only on a history of seafood or shellfish allergy has a small but non-zero risk of adverse effect (eg, hyperglycemia in a patient with diabetes) without any demonstrated benefit.^{288,289}

4.6. Statin Treatment: Recommendation

Class IIa

1. **Administration of a high-dose statin is reasonable before PCI to reduce the risk of periprocedural MI.** (*Level of Evidence: A for statin-naïve patients*^{290–296}; (*Level of Evidence: B for those on chronic statin therapy*²⁹⁷)

See Online Data Supplement 19 for additional data regarding preprocedural statin treatment.

Statins have long-term benefits in patients with CAD^{343,344} and ACS.^{345,346} The benefits of statins in ACS begin early, before substantial lipid lowering has occurred,^{345,347} suggesting pleiotropic effects of statins. These might include anti-inflammatory effects, improvement of endothelial function, decrease of oxidative stress, or inhibition of thrombogenic responses.³⁴⁸ Statins were beneficial when pretreatment was started from 7 days to just before PCI.^{290–297}

4.7. Bleeding Risk: Recommendation

Class I

1. **All patients should be evaluated for risk of bleeding before PCI.** (*Level of Evidence: C*)

Periprocedural bleeding is now recognized as a major risk factor for subsequent mortality.^{265,266} Bleeding may lead to mortality directly (because of the bleeding event) or through ischemic complications that occur when antiplatelet or anticoagulant agents are withdrawn in response to the bleeding. Bleeding may also be a marker of comorbidities associated with worse prognosis (eg, occult cancer). The risk of bleeding is associated with a number of patient factors (eg, advanced age, low body mass index, CKD, baseline anemia), as well as the degree of platelet and thrombin inhibition, vascular access site, and sheath size.^{267–269} The overall approach to PCI should be individualized to minimize both ischemic and bleeding risks.

Measures to minimize the risks of bleeding complications are discussed in several sections of this guideline. These include use of anticoagulation regimens associated with a lower risk of bleeding, weight-based dosing of heparin and other agents, use of activated clotting times to guide unfractionated heparin (UFH) dosing, avoidance of excess anticoagulation,³⁴⁹ dosing adjustments in patients with CKD (eg, eptifibatide, tirofiban, bivalirudin),³⁵⁰ use of radial artery access site,²⁵⁵ and avoidance of femoral vein cannulation when possible. Vascular closure devices have not been clearly demonstrated to decrease bleeding complications and are discussed in detail in Section 5.11.

4.8. PCI in Hospitals Without On-Site Surgical Backup: Recommendations

Class IIa

1. **Primary PCI is reasonable in hospitals without on-site cardiac surgery, provided that appropriate planning for program development has been accomplished.**^{351,352} (*Level of Evidence: B*)

Class IIb

1. Elective PCI might be considered in hospitals without on-site cardiac surgery, provided that appropriate planning for program development has been accomplished and rigorous clinical and angiographic criteria are used for proper patient selection.^{352–354} (Level of Evidence: B)

Class III: HARM

1. Primary or elective PCI should not be performed in hospitals without on-site cardiac surgery capabilities without a proven plan for rapid transport to a cardiac surgery operating room in a nearby hospital or without appropriate hemodynamic support capability for transfer. (Level of Evidence: C)

See Online Data Supplement 20 for additional data regarding hospitals without on-site surgical backup.

Primary and elective PCI can be performed at hospitals without on-site cardiac surgical backup with a high success rate, low in-hospital mortality rate, and low rate for emergency CABG.^{351,353,354} The best outcomes for patients with STEMI are achieved at hospitals with 24/7 access to primary PCI.³⁵⁵ Criteria for the performance of PCI without on-site surgical backup have been proposed in an SCAI expert consensus document.³⁵² Consideration of elective PCI without on-site cardiac surgical backup is thought to be appropriate only when performed by experienced operators with complication rates and outcomes equivalent or superior to national benchmarks. Accurate assessment of complication rates and patient outcomes via a regional or national data registry, so that outcomes can be compared with established benchmarks, is an important quality control component of any PCI program. Desires for personal or institutional financial gain, prestige, market share, or other similar motives are not appropriate considerations for initiation of PCI programs without on-site cardiac surgery. It is only appropriate to consider initiation of a PCI program without on-site cardiac surgical backup if this program will clearly fill a void in the healthcare needs of the community. Competition with another PCI program in the same geographic area, particularly an established program with surgical backup, may not be in the best interests of the community.

Tables 5 and 6 list the SCAI expert consensus document requirements for PCI programs without on-site surgical backup. Table 7 gives the requirements for primary PCI and emergency CABG at hospitals without on-site cardiac surgery, and Table 8 lists the requirements for patient and lesion selection and backup strategy for nonemergency PCI.³⁵²

5. Procedural Considerations

5.1. Vascular Access: Recommendation

Class IIa

1. The use of radial artery access can be useful to decrease access site complications.^{255,260,356–362} (Level of Evidence: A)

See Online Data Supplement 21 for additional data regarding radial access.

Table 5. SCAI Expert Consensus Document Personnel and Facility Requirements for PCI Programs Without On-Site Surgical Backup

Experienced nursing and technical laboratory staff with training in interventional laboratories. Personnel must be comfortable treating acutely ill patients with hemodynamic and electrical instability.

On-call schedule with operation of laboratory 24 h/d, 365 d/y.*

Experienced coronary care unit nursing staff comfortable with invasive hemodynamic monitoring, operation of temporary pacemaker, and management of IABP. Personnel capable of endotracheal intubation and ventilator management both on-site and during transfer if necessary.

Full support from hospital administration in fulfilling the necessary institutional requirements, including appropriate support services (eg, respiratory care, blood bank).

Written agreements for emergency transfer of patients to a facility with cardiac surgery. Transport protocols should be developed and tested a minimum of 2 times per year.

Well-equipped and maintained cardiac catheterization laboratory with high-resolution digital imaging capability and IABP equipment compatible with transport vehicles. The capability for real-time transfer of images and hemodynamic data (via T-1 transmission line) as well as audio and video images to review terminals for consultation at the facility providing surgical backup support is ideal.

Appropriate inventory of interventional equipment, including guide catheters, balloons, and stents in multiple sizes; thrombectomy and distal protection devices; covered stents; temporary pacemakers; and pericardiocentesis trays. Pressure wire device and IVUS equipment are optimal but not mandatory. Rotational or other atherectomy devices should be used cautiously in these facilities because of the greater risk of perforation.

Meticulous clinical and angiographic selection criteria for PCI (Tables 6 and 7).

Performance of primary PCI as the treatment of first choice for STEMI to ensure streamlined care paths and increased case volumes. Door-to-balloon times should be tracked, and <90 min outlier cases should be carefully reviewed for process improvement opportunities.

On-site rigorous data collection, outcomes analysis, benchmarking, quality improvement, and formalized periodic case review.

Participation in a national data registry where available, such as the ACC NCDR in the United States.

*Required for US facilities but may not be possible for all facilities worldwide.

ACC indicates American College of Cardiology; IABP, intra-aortic balloon pump; IVUS, intravascular ultrasound; NCDR, National Cardiovascular Data Registry; PCI, percutaneous coronary intervention; SCAI, Society for Cardiovascular Angiography and Interventions; and STEMI, ST-elevation myocardial infarction.

Adapted with permission from Dehmer et al.³⁵²

Femoral artery access remains the most commonly used approach in patients undergoing PCI in the United States. Choosing a femoral artery puncture site is facilitated by fluoroscopic landmark identification or ultrasound guidance. Low punctures have a high incidence of peripheral artery complications, whereas high punctures have an increased risk of retroperitoneal hemorrhage. In patients with a synthetic graft, arterial access is possible after the graft is a few months old and complication rates are not increased.²⁵⁴

Radial site access is used frequently in Europe and Canada but not in the United States.²⁶⁰ A learning curve exists for the radial approach that will affect procedure time and radiation dose, with a trend toward lower procedural success rates for radial versus femoral access.²⁵⁵ However, compared with femoral access, radial access decreases the rate of access-

Table 6. SCAI Expert Consensus Document Requirements for Off-Site Surgical Backup

- Interventional cardiologists establish a working relationship with cardiac surgeons at the receiving facility.
- Cardiac surgeon must have privileges at the referring facility to allow review of treatment options as time allows.
- Cardiac surgeon and receiving hospital agree to provide cardiac surgical backup for urgent cases at all hours and for elective cases at mutually agreed hours.
- Surgeon and receiving facility ensure that patients will be accepted based on medical condition, capacity of surgeon to provide services at the time of request, and availability of resources. If this cannot be ensured before the start of an elective procedure, the case should not be done at this time.
- Interventional cardiologists must review with surgeons the immediate needs and status of any patient transferred for urgent surgery.
- Hospital administrations from both facilities endorse transfer agreement.
- Transferring and receiving facilities establish a rigorous protocol for rapid transfer of patients, including the proper personnel with appropriate experience.
- A transport provider is available to begin transport within 20 min of the request and provide vehicle/helicopter with necessary life-sustaining equipment, including IABP and monitoring capability.
- Transferring physician obtains consent for surgery from patient or appropriate surrogate.
- Initial informed consent for PCI discloses that the procedure is being done without on-site surgical backup and acknowledges the possibility of risks related to transfer. The consent process should include the risk of urgent surgery (approximately 0.3%) and state that a written plan for transfer exists.
- As part of the local continuous quality improvement program, a regular review of all patients transferred for emergency surgery with the outcome of surgery and identification of any improvement opportunities.

IABP indicates intra-aortic balloon pump; PCI, percutaneous coronary intervention; and SCAI, Society for Cardiovascular Angiography and Interventions.

Adapted with permission from Dehmer et al.³⁵²

related bleeding and complications.^{255,260,363} In a recent large RCT comparing radial and femoral access in patients with ACS undergoing PCI, there was no difference in the primary composite endpoint (death, MI, stroke, major bleeding), although there was a lower rate of vascular complications with the use of radial access.³⁶² Radial artery access is particularly appealing in patients with coagulopathy, elevated international normalized ratio due to warfarin, or morbid obesity.

5.2. PCI in Specific Clinical Situations

5.2.1. UA/NSTEMI: Recommendations

Class I

- An early invasive strategy (ie, diagnostic angiography with intent to perform revascularization) is indicated in UA/NSTEMI patients who have refractory angina or hemodynamic or electrical instability (without serious comorbidities or contraindications to such procedures).^{207,364,365} (*Level of Evidence: B*)
- An early invasive strategy (ie, diagnostic angiography with intent to perform revascularization) is indicated in initially stabilized UA/NSTEMI patients (without

Table 7. SCAI Expert Consensus Document Requirements for Primary PCI and Emergency Aortocoronary Bypass Surgery at Hospitals Without On-Site Cardiac Surgery

Avoid intervention in patients with

- >50% diameter stenosis of left main artery proximal to infarct-related lesion, especially if the area in jeopardy is relatively small and overall LV function is not severely impaired
- Long, calcified, or severely angulated target lesions at high risk for PCI failure with TIMI flow grade 3 present during initial diagnostic angiography
- Lesions in other than the infarct artery (unless they appeared to be flow limiting in patients with hemodynamic instability or ongoing symptoms)
- Lesions with TIMI flow grade 3 that are not amenable to stenting in patients with left main or 3-vessel disease that will require coronary bypass surgery
- Culprit lesions in more distal branches jeopardizing only a modest amount of myocardium when there is more proximal disease that could be worsened by attempted intervention

Transfer emergently for coronary bypass surgery patients with

- High-grade left main or 3-vessel coronary disease with clinical or hemodynamic instability after successful or unsuccessful PCI of an occluded vessel and preferably with IABP support
- Failed or unstable PCI result and ongoing ischemia, with IABP support during transfer

IABP indicates intra-aortic balloon pump; LV, left ventricular; PCI, percutaneous coronary intervention; SCAI, Society for Cardiovascular Angiography and Interventions; and TIMI, Thrombolysis in Myocardial Infarction.

Adapted with permission from Dehmer et al.³⁵²

serious comorbidities or contraindications to such procedures) who have an elevated risk for clinical events.^{207,365–367} (*Level of Evidence: A*)

- The selection of PCI or CABG as the means of revascularization in the patient with ACS should generally be based on the same considerations as those without ACS.^{53,156,207,368} (*Level of Evidence: B*)

Class III: NO BENEFIT

- An early invasive strategy (ie, diagnostic angiography with intent to perform revascularization) is not recommended in patients with extensive comorbidities (eg, liver or pulmonary failure, cancer) in whom (*Level of Evidence: C*)
 - The risks of revascularization and comorbid conditions are likely to outweigh the benefits of revascularization,
 - There is a low likelihood of ACS despite acute chest pain, or
 - Consent to revascularization will not be granted regardless of the findings.

The goals of coronary angiography and revascularization in UA/NSTEMI patients are to reduce the risk of death and MI and provide symptom relief. To improve prognosis, early risk stratification is essential for selection of medical and/or invasive treatment strategies. Indications for revascularization depend on the patient's clinical risk characteristics and coronary anatomy and are in general stronger in the presence of high-risk clinical presentation (eg, dynamic electrocardio-

Table 8. SCAI Expert Consensus Document Requirements for Patient and Lesion Selection and Backup Strategy for Nonemergency PCI by Experienced Operators at Hospitals Without On-Site Cardiac Surgery

Patient risk: expected clinical risk in case of occlusion caused by procedure

High patient risk: Patients with any of the following

- Decompensated congestive heart failure (Killip Class 3) without evidence for active ischemia, recent CVA, advanced malignancy, known clotting disorders
- LVEF <25%
- Left main stenosis ($\geq 50\%$ diameter) or 3-vessel disease unprotected by prior bypass surgery ($>70\%$ stenoses in the proximal segment of all major epicardial coronary arteries)
- Single-target lesion that jeopardizes $>50\%$ of remaining viable myocardium

Lesion risk: probability that procedure will cause acute vessel occlusion

Increased lesion risk: lesions in open vessels with any of the following characteristics

- Diffuse disease (>2 cm in length) and excessive tortuosity of proximal segments
- More than moderate calcification of a stenosis or proximal segment
- Location in an extremely angulated segment ($>90^\circ$)
- Inability to protect major side branches
- Degenerated older vein grafts with friable lesions
- Substantial thrombus in the vessel or at the lesion site
- Any other feature that may, in the operator's judgment, impede successful stent deployment

Aggressive measures to open CTOs are also discouraged because of an increased risk of perforation

Strategy for surgical backup based on lesion and patient risk

- High-risk patients with high-risk lesions should not undergo nonemergency PCI at a facility without on-site surgery.
- High-risk patients with non-high-risk lesions: Nonemergency patients with this profile may undergo PCI, but confirmation that a cardiac surgeon and operating room are immediately available is necessary.
- Non-high-risk patients with high-risk lesions require no additional precautions.
- Non-high-risk patients with non-high-risk lesions require no additional precautions. Best scenario for PCI without on-site surgery.

CTO indicates chronic total occlusion; CVA, cerebrovascular accident; LVEF, left ventricular ejection fraction; PCI, percutaneous coronary intervention; and SCAI, Society for Cardiovascular Angiography and Interventions.

Adapted with permission from Dehmer et al.³⁵²

gram [ECG] changes, elevated troponin, high Global Registry of Acute Coronary Events score), recurrent symptoms, threatened viable myocardium, CKD, and larger ischemic burden (Appendix 4E). For choice of revascularization technique, the anatomical considerations are generally those used for stable CAD, although PCI may initially be performed in the index lesion to stabilize the patient (Section 2).

Contemporary studies variably comparing strategies of very early (within hours of admission), early (within 24 hours of admission), and delayed (1 to 7 days after admission) cardiac catheterization and revascularization support a strategy of *early* angiography and revascularization to reduce the risk of recurrent ischemia and MI, particularly among those at high risk (eg, Global Registry of Acute Coronary Events score >140),^{367,369,370} whereas a delayed approach is reasonable in low-intermediate risk patients (based on clinical

course). There is no evidence that incremental benefit is derived by angiography and PCI performed within the first few hours of hospital admission.^{207,367,371–378}

5.2.2. ST-Elevation Myocardial Infarction

5.2.2.1. Coronary Angiography Strategies in STEMI: Recommendations

Class I

1. A strategy of immediate coronary angiography with intent to perform PCI (or emergency CABG) in patients with STEMI is recommended for
 - a. Patients who are candidates for primary PCI.^{351,379–382} (*Level of Evidence: A*)
 - b. Patients with severe heart failure or cardiogenic shock who are suitable candidates for revascularization.^{383,384} (*Level of Evidence: B*)

Class IIa

1. A strategy of immediate coronary angiography (or transfer for immediate coronary angiography) with intent to perform PCI is reasonable for patients with STEMI, a moderate to large area of myocardium at risk, and evidence of failed fibrinolysis.^{385,386} (*Level of Evidence: B*)
2. A strategy of coronary angiography (or transfer for coronary angiography) 3 to 24 hours after initiating fibrinolytic therapy with intent to perform PCI is reasonable for hemodynamically stable patients with STEMI and evidence for successful fibrinolysis when angiography and revascularization can be performed as soon as logistically feasible in this time frame.^{387–391} (*Level of Evidence: A*)

Class IIb

1. A strategy of coronary angiography performed before hospital discharge might be reasonable in stable patients with STEMI who did not undergo cardiac catheterization within 24 hours of STEMI onset. (*Level of Evidence: C*)

Class III: NO BENEFIT

1. A strategy of coronary angiography with intent to perform PCI is not recommended in patients with STEMI in whom the risks of revascularization are likely to outweigh the benefits or when the patient or designee does not want invasive care. (*Level of Evidence: C*)

The historical reperfusion strategies of “primary PCI,” “immediate PCI,” “rescue PCI,” “deferred PCI,” “facilitated PCI,” and the “pharmacoinvasive strategy” have evolved in parallel with advances in antithrombotic therapy and STEMI prehospital and hospital systems of care. The clinical challenge in primary PCI is achieving rapid time to treatment and increasing patient access to this preferred reperfusion strategy. The clinical challenge in patients treated with fibrinolytic therapy is deciding for whom and when to perform coronary angiography.

In unstable patients (eg, severe heart failure or cardiogenic shock, hemodynamically compromising ventricular arrhyth-

Table 9. Indications for Coronary Angiography in STEMI

Indications	COR	LOE	References
Immediate coronary angiography			
Candidate for primary PCI	I	A	351,379–382
Severe heart failure or cardiogenic shock (if suitable revascularization candidate)	I	B	383,384
Moderate to large area of myocardium at risk and evidence of failed fibrinolysis	IIa	B	385,386
Coronary angiography 3 to 24 h after fibrinolysis			
Hemodynamically stable patients with evidence for successful fibrinolysis	IIa	A	387–391
Coronary angiography before hospital discharge			
Stable patients	IIb	C	N/A
Coronary angiography at any time			
Patients in whom the risks of revascularization are likely to outweigh the benefits or the patient or designee does not want invasive care	III: No Benefit	C	N/A

COR indicates class of recommendation; LOE, level of evidence; N/A, not applicable; PCI, percutaneous coronary intervention; and STEMI, ST-elevation myocardial infarction.

mias) not treated initially with primary PCI, a strategy of immediate coronary angiography with intent to perform PCI is implemented unless invasive management is considered futile or unsuitable given the clinical circumstances.^{383,384}

In stable patients treated with fibrinolytic therapy and clinical suspicion of reperfusion failure, a strategy of immediate coronary angiography followed by PCI improves outcome in those at high risk.^{385,386} Such a strategy is also implemented in patients with evidence for infarct artery reocclusion (Table 9). The clinical diagnosis of failed fibrinolysis is difficult but is best made when there is <50% ST-segment resolution 90 minutes after initiation of therapy in the lead showing the greatest degree of ST-segment elevation at presentation. Given the association between bleeding events and adverse cardiac events, a reasonable approach is to select moderate- and high-risk patients for PCI and treat low-risk patients with medical therapy. ECG and clinical findings of anterior MI or inferior MI with right ventricular involvement or precordial ST-segment depression, as well as ongoing pain, usually predicts increased risk and the greatest potential benefit.³⁹² Conversely, patients with symptom resolution, improving ST-segment elevation, or inferior MI localized to 3 ECG leads probably gain little benefit.

In stable patients treated with fibrinolytic therapy and clinical evidence for successful reperfusion, an early invasive strategy with cardiac catheterization performed within 24 hours decreases reinfarction and recurrent ischemic events.^{388,390,391} Because of the associated increased bleeding risk, very early (<2 to 3 hours) catheterization after administration of fibrinolytic therapy with intent to perform revascularization should be reserved for patients with evidence of failed fibrinolysis and significant myocardial jeopardy for whom immediate angiography and revascularization would be appropriate.³⁹³

5.2.2.2. Primary PCI of the Infarct Artery: Recommendations

Class I

1. Primary PCI should be performed in patients within 12 hours of onset of STEMI.^{379–382} (Level of Evidence: A)

2. Primary PCI should be performed in patients with STEMI presenting to a hospital with PCI capability within 90 minutes of first medical contact as a systems goal.^{394,395} (Level of Evidence: B)
3. Primary PCI should be performed in patients with STEMI presenting to a hospital without PCI capability within 120 minutes of first medical contact as a systems goal.^{396–398} (Level of Evidence: B)
4. Primary PCI should be performed in patients with STEMI who develop severe heart failure or cardiogenic shock and are suitable candidates for revascularization as soon as possible, irrespective of time delay.^{383,384} (Level of Evidence: B)
5. Primary PCI should be performed as soon as possible in patients with STEMI and contraindications to fibrinolytic therapy with ischemic symptoms for less than 12 hours.^{399,400} (Level of Evidence: B)

Class IIa

1. Primary PCI is reasonable in patients with STEMI if there is clinical and/or electrocardiographic evidence of ongoing ischemia between 12 and 24 hours after symptom onset.^{401–403} (Level of Evidence: B)

Class IIb

1. Primary PCI might be considered in asymptomatic patients with STEMI and higher risk presenting between 12 and 24 hours after symptom onset. (Level of Evidence: C)

Class III: HARM

1. PCI should not be performed in a noninfarct artery at the time of primary PCI in patients with STEMI without hemodynamic compromise.^{404–408} (Level of Evidence: B)

Primary PCI is preferred to fibrinolytic therapy when time-to-treatment delays are short and the patient presents to a high-volume, well-equipped center staffed with expert interventional cardiologists and skilled support staff. Compared with fibrinolytic therapy in RCTs, primary PCI produces higher rates for infarct artery patency, TIMI flow grade 3, and

Table 10. Indications for PCI in STEMI

Indications	COR	LOE	References
Primary PCI*			
STEMI symptoms within 12 h	I	A	379–382
Severe heart failure or cardiogenic shock	I	B	383,384
Contraindications to fibrinolytic therapy with ischemic symptoms <12 h	I	B	399,400
Clinical and/or electrocardiographic evidence of ongoing ischemia between 12 and 24 h after symptom onset	IIa	B	401–403
Asymptomatic patients presenting between 12 and 24 h after symptom onset and higher risk	IIb	C	N/A
Noninfarct artery PCI at the time of primary PCI in patients without hemodynamic compromise	III: Harm	B	404–408
Delayed or elective PCI in patients with STEMI			
Clinical evidence for fibrinolytic failure or infarct artery reocclusion	IIa	B	385,386
Patent infarct artery 3 to 24 h after fibrinolytic therapy	IIa	B	390,391
Ischemia on noninvasive testing	IIa	B	410,411
Hemodynamically significant stenosis in a patent infarct artery >24 h after STEMI	IIb	B	413–417
Totally occluded infarct artery >24 h after STEMI in a hemodynamically stable asymptomatic patient without evidence of severe ischemia	III: No Benefit	B	418–420

*Systems goal of performing primary PCI within 90 min of first medical contact when the patient presents to a hospital with PCI capability^{394,395} (Class I; LOE: B) and within 120 min when the patient presents to a hospital without PCI capability^{396–398} (Class I; LOE: B).

COR indicates class of recommendation; LOE, level of evidence; N/A, not applicable; PCI, percutaneous coronary intervention; and STEMI, ST-elevation myocardial infarction.

lower rates for recurrent ischemia, reinfarction, emergency repeat revascularization procedures, intracranial hemorrhage, and death.³⁷⁹ Early, successful PCI also greatly decreases the complications of STEMI that result from longer ischemic times or unsuccessful fibrinolytic therapy, allowing earlier hospital discharge and resumption of daily activities. The greatest mortality benefit of primary PCI is in high-risk patients. PCI outcomes may not be as successful with prolonged time-to-treatment or low-volume hospitals and operators (Table 10).

Several reports have shown excellent outcomes for patients with STEMI undergoing interhospital transfer where first medical contact-to-door balloon time modestly exceeded the systematic goal of <90 minutes.^{396–398,409} In these reports, the referring hospital and the receiving hospital established a transfer protocol that minimized transfer delays, and outcomes were similar to those of direct-admission patients. On the basis of these results, the PCI and STEMI guideline writing committees have modified the first medical contact-to-device time goal from 90 minutes to 120 minutes for interhospital transfer patients,³⁹⁷ while emphasizing that systems should continue to strive for times ≤90 minutes. Hospitals that cannot meet these criteria should use fibrinolytic therapy as their primary reperfusion strategy.

PCI of a noninfarct artery at the time of primary PCI in stable patients is associated with worse clinical outcomes unless the patient is in cardiogenic shock where PCI of a severe stenosis in a coronary artery supplying a large territory of myocardium might improve hemodynamic stability.^{404,406,408} Delayed PCI can be performed in noninfarct arteries at a later time if clinically indicated.^{410–412}

5.2.2.3. Delayed or Elective PCI in Patients With STEMI: Recommendations

Class IIa

1. PCI is reasonable in patients with STEMI and clinical evidence for fibrinolytic failure or infarct artery reocclusion.^{385,386} (Level of Evidence: B)
2. PCI is reasonable in patients with STEMI and a patent infarct artery 3 to 24 hours after fibrinolytic therapy.^{390,391} (Level of Evidence: B)
3. PCI is reasonable in patients with STEMI who demonstrate ischemia on noninvasive testing.^{410,411} (Level of Evidence: B)

Class IIb

1. PCI of a hemodynamically significant stenosis in a patent infarct artery greater than 24 hours after STEMI may be considered as part of an invasive strategy.^{413–417} (Level of Evidence: B)

Class III: NO BENEFIT

1. PCI of a totally occluded infarct artery greater than 24 hours after STEMI should not be performed in asymptomatic patients with 1- or 2-vessel disease if patients are hemodynamically and electrically stable and do not have evidence of severe ischemia.^{418–420} (Level of Evidence: B)

Studies and meta-analyses suggest potential benefit for PCI in fibrinolytic failure.^{385,386} In stable patients treated with fibrinolytic therapy and clinical evidence for successful reperfusion, an early invasive strategy with cardiac catheterization performed within 24 hours decreases reinfarction and recurrent ischemic events.^{388,390,391}

PCI for a hemodynamically significant stenosis in a patent infarct artery >24 hours after STEMI as part of a revascularization strategy improves outcome.^{410,411,413–417} PCI of an occluded infarct artery 1 to 28 days after MI in asymptomatic patients without evidence of myocardial ischemia has no incremental benefit beyond optimal medical therapy with aspirin, beta blockers, angiotensin-converting enzyme inhibitors, and statins in preserving LV function and preventing subsequent cardiovascular events.^{418–420} It is important to note that elective PCI of an occluded infarct artery has not been studied in patients with New York Heart Association functional class III or IV heart failure, rest angina, serum creatinine >2.5 mg/dL, left main or 3-vessel CAD, clinical instability, or severe inducible ischemia on stress testing in an infarct zone that is not akinetic or dyskinetic.

5.2.3. Cardiogenic Shock: Recommendations

Class I

1. **PCI is recommended for patients with acute MI who develop cardiogenic shock and are suitable candidates.**^{384,421–423} (*Level of Evidence: B*)
2. **A hemodynamic support device is recommended for patients with cardiogenic shock after STEMI who do not quickly stabilize with pharmacological therapy.**^{384,424–427} (*Level of Evidence: B*)

See Online Data Supplement 22 for additional data regarding cardiogenic shock.

Cardiogenic shock is the leading cause of in-hospital mortality complicating STEMI. Revascularization is the only treatment proven to decrease mortality rates.^{384,421–423} Although revascularization is almost always accomplished through PCI, selected patients with severe 3-vessel or left main disease can benefit from emergency CABG. Revascularization attempts may be futile and not indicated in cases of severe multiorgan failure.⁴²⁷ Patient selection for revascularization is more important in the elderly, but several observational reports demonstrate acceptable outcomes in patients with few comorbidities and a reasonable potential for survival.^{428–431} Patients who present to hospitals without PCI capability are usually emergently transported to a PCI center, because mortality without transfer is markedly elevated.⁴³²

5.2.3.1. Procedural Considerations for Cardiogenic Shock

Patients with cardiogenic shock should receive standard pharmacological therapies, including aspirin, a P2Y₁₂ receptor antagonist, and anticoagulation.^{427,433} Inotropic and vasopressor therapy improves perfusion pressure. Historically, negative inotropes and vasodilators are avoided. IV GP IIb/IIIa inhibitors have been shown to provide benefit in observational studies but not in 1 small RCT.⁴³³

Endotracheal intubation and mechanical ventilation with positive end-expiratory pressure is usually necessary in patients with respiratory failure. Placement of a temporary pacemaker is indicated for patients with bradycardia or high-degree atrioventricular heart block. A pulmonary artery catheter can provide information to dose and titrate inotropes and pressors. Further hemodynamic support is available with

IABP counterpulsation or percutaneous LV assist devices, although no data support a reduction in mortality rates.⁴³⁴

Contrast medium injections should be minimized. Orthogonal angiograms of the left coronary artery and a left anterior oblique angiogram of the right coronary artery are usually sufficient to identify the infarct artery.⁴³⁵ Although most patients undergoing revascularization will receive a stent as part of the procedure, there are conflicting data on the impact of stenting over balloon angioplasty. Some studies reveal lower mortality rates,^{436–438} whereas others reveal no benefit⁴³⁹ or higher mortality rates.⁴⁴⁰ There are no data comparing the choice of BMS versus DES in cardiogenic shock; however, BMS are often used because compliance with long-term DAPT is often unclear in the emergency setting.

In patients with multivessel disease, revascularization of the noninfarct artery may be necessary to maximize myocardial perfusion. Alternatively, in patients with multivessel disease and particularly left main disease, emergency CABG as a primary reperfusion strategy may be preferred.^{50,441} Refractory cardiogenic shock unresponsive to revascularization may necessitate institution of more intensive cardiac support with a ventricular assist device or other hemodynamic support devices to allow for myocardial recovery or subsequent cardiac transplantation in suitable patients.

5.2.4. Revascularization Before Noncardiac Surgery: Recommendations

Class IIa

1. **For patients who require PCI and are scheduled for elective noncardiac surgery in the subsequent 12 months, a strategy of balloon angioplasty, or BMS implantation followed by 4 to 6 weeks of DAPT, is reasonable.**^{442–448} (*Level of Evidence: B*)
2. **For patients with DES who must undergo urgent surgical procedures that mandate the discontinuation of DAPT, it is reasonable to continue aspirin if possible and restart the P2Y₁₂ inhibitor as soon as possible in the immediate postoperative period.**⁴⁴⁴ (*Level of Evidence: C*)

Class III: HARM

1. **Routine prophylactic coronary revascularization should not be performed in patients with stable CAD before noncardiac surgery.**^{449,450} (*Level of Evidence: B*)
2. **Elective noncardiac surgery should not be performed in the 4 to 6 weeks after balloon angioplasty or BMS implantation or the 12 months after DES implantation in patients in whom the P2Y₁₂ inhibitor will need to be discontinued perioperatively.**^{208,447, 451,452} (*Level of Evidence: B*)

The 2007 and 2009 ACC/AHA Guidelines on Perioperative Cardiovascular Evaluation and Care for Noncardiac Surgery gave detailed recommendations for the evaluation of patients undergoing noncardiac surgery.⁴⁴⁴ Patients with evidence of ACS should receive standard therapy, including early revascularization, to minimize the risk of adverse events. Patients with known significant left main or 3-vessel CAD who would otherwise benefit from revascularization in terms of survival

or symptomatic relief also generally undergo revascularization before elective noncardiac surgery.

Two RCTs^{449,450} found no benefit with routine preoperative revascularization before noncardiac surgery. Noncardiac surgery early after coronary stenting, particularly in the first 4 weeks, is associated with a high risk of stent thrombosis and death.^{444,446,448} When emergency surgery is necessary, the patient should proceed to surgery without prior PCI. When surgery is required within 30 days and coronary revascularization is required before surgery, many clinicians perform balloon angioplasty alone to avoid the need for DAPT. In situations where preoperative revascularization is required and surgery can be deferred for at least 30 days, many clinicians use BMS and discontinue DAPT after 30 days. If surgery is elective and can be deferred for 1 year, most clinicians would consider DES to reduce the long-term risk of restenosis. A dilemma occurs when a patient has undergone PCI and then unexpectedly requires noncardiac surgery. Many patients can undergo surgery on DAPT, where the risk-benefit ratio will favor continued dual antiplatelet inhibition. If it is necessary to hold P2Y₁₂ inhibitor therapy, most clinicians will still continue aspirin uninterrupted during the perioperative period if the bleeding risk is not prohibitive. When the risk of delaying surgery or performing surgery while the patient is on DAPT exceeds the risk of stent thrombosis from stopping DAPT, the P2Y₁₂ inhibitor is stopped before surgery and resumed as soon as possible afterward. No P2Y₁₂ inhibitor “bridging” strategy (eg, GP IIb/IIIa inhibitor, antithrombin therapy) has been validated.

5.3. Coronary Stents: Recommendations

Class I

1. Before implantation of DES, the interventional cardiologist should discuss with the patient the need for and duration of DAPT and the ability of the patient to comply with and tolerate DAPT.²¹² (*Level of Evidence: C*)
2. DES are useful as an alternative to BMS to reduce the risk of restenosis in cases in which the risk of restenosis is increased and the patient is likely to be able to tolerate and comply with prolonged DAPT (*Level of Evidence: A for elective PCI*^{453,453a,454–456}; *Level of Evidence: C for UA/NSTEMI*⁴⁵³; *Level of Evidence: A for STEMI*^{453,456–459}).
3. Balloon angioplasty or BMS should be used in patients with high bleeding risk, inability to comply with 12 months of DAPT, or anticipated invasive or surgical procedures within the next 12 months, during which time DAPT may be interrupted.^{208,460–462} (*Level of Evidence: B*)

Class III: HARM

1. PCI with coronary stenting should not be performed if the patient is not likely to be able to tolerate and comply with DAPT.^{208–211} (*Level of Evidence: B*)
2. DES should not be implanted if the patient is not likely to be able to tolerate and comply with prolonged DAPT or this cannot be determined before stent implantation.^{208,460–462} (*Level of Evidence: B*)

Coronary stent implantation is commonly performed during PCI to prevent recoil, abrupt closure, and late restenosis.^{463,464} BMS are composed of either stainless steel or cobalt chromium alloys. Because the risk of stent thrombosis is greatest within the first 30 days after implantation, the use of DAPT is required for 30 days after implantation of BMS.²⁰⁸

In the United States, 4 types of DES are currently approved: sirolimus-eluting stents, paclitaxel-eluting stents, zotarolimus-eluting stents, and everolimus-eluting stents. DES vary according to stent scaffold material and design, drug content, and the polymer used for drug elution; however, several common clinical features are present. First, sirolimus-eluting stents, paclitaxel-eluting stents, and zotarolimus-eluting stents have been demonstrated in RCTs to be associated with a reduced need for repeat revascularization and no increase in death or MI compared with BMS at 4 years' follow-up.⁴⁶⁵ Everolimus-eluting stents have been demonstrated in RCTs to be associated with a lower need for repeat revascularization than paclitaxel-eluting stents, and, by inference, a lower risk for repeat revascularization than BMS,^{466,467} with no increase in death or MI at 2-year follow-up.⁴⁶⁸ Second, each of these stents is presumed to be associated with delayed healing based on pathologic studies and longer periods of risk for thrombosis compared with BMS and require longer duration of DAPT.⁴⁶⁹ In the RCTs that led to the US Food and Drug Administration (FDA) approval of these stents, the recommended minimum duration of DAPT therapy was 3 to 6 months. Recently, the consensus of clinical practice has been 12 months of DAPT following DES implantation to avoid late (after 30 days) thrombosis,²⁰⁸ based on observational studies of paclitaxel-eluting stents and sirolimus-eluting stents that indicate lower risk of late stent thrombosis with >6 months of therapy.²¹² Extending DAPT beyond 1 year is considered reasonable by some practitioners based on observational data analysis,²¹² but RCTs to determine whether longer DAPT is associated with reduction in stent thrombosis risk have not been completed. Finally, DES therapy is more expensive than BMS. Cost-effectiveness analysis has shown a reduction in total cost associated with DES because of avoidance of repeat procedures, yet it may be reasonable to consider use of BMS in patient subsets in which the risk of restenosis is low.⁴⁷⁰

This risk-benefit profile is most favorable for DES over BMS when the risk of restenosis with BMS is high (Table 11). Pooled and meta-analyses have demonstrated that in patients with diabetes, use of DES decreases the risk of restenosis compared with BMS.^{471,472} DES may be more appealing for unprotected left main PCI, given the rate and clinical consequences of restenosis in this location.^{473–475} The risk of stent thrombosis is higher in populations or lesion types excluded from RCTs of DES (eg, STEMI, smaller arteries [<2.5 mm diameter], longer lesions, bifurcations).^{210,465} Importantly, these features also predict both stent thrombosis⁴⁷⁶ and restenosis in BMS.⁴⁷⁷ The greatest risk of stent thrombosis is within the first year, ranging from 0.7% to 2.0%, depending on patient and lesion complexity. Late stent thrombosis risk after 1 year with DES is observed at a rate of 0.2% to 0.4% per year.^{210,478}

Table 11. Clinical Situations Associated With DES or BMS Selection Preference

DES Generally Preferred Over BMS (Efficacy Considerations)	BMS Preferred Over DES (Safety Considerations)
<ul style="list-style-type: none"> • Left main disease • Small vessels • In-stent restenosis • Bifurcations • Diabetes • Long lesions • Multiple lesions • Saphenous vein grafts 	<ul style="list-style-type: none"> • Unable to tolerate or comply with DAPT • Anticipated surgery requiring discontinuation of DAPT within 12 mo • High risk of bleeding

BMS indicates bare-metal stent(s); DAPT, dual antiplatelet therapy; and DES, drug-eluting stent(s).

Compared with balloon angioplasty, routine BMS implantation during primary PCI decreases risk for target-vessel revascularization and possibly reduces MI rates but does not reduce mortality rates.⁴⁷⁹ More recent primary PCI studies and meta-analyses have demonstrated lower restenosis rates without increased risk of adverse stent outcome with DES compared with BMS. Although stent thrombosis rates in trials of STEMI are higher than in trials of elective PCI, the rates of stent thrombosis are not higher with DES compared with BMS in STEMI.^{453,456–459}

The greatest risk for DES thrombosis is early discontinuation of DAPT.^{208,460–462} It is therefore important to determine that the patient will likely be able to tolerate and comply with DAPT before implantation of DES. Therefore, DES should not be used in the presence of financial barriers to continuing prolonged DAPT, social barriers that may limit patient compliance, or medical issues involving bleeding risks or the need for invasive or surgical procedures in the following year that would interrupt antiplatelet therapy. The need for use of long-term warfarin and the associated increased risk of bleeding with long-term “triple therapy” is also a consideration in deciding on DES versus BMS.⁴⁸⁰

Patients implanted with most contemporary coronary stents can undergo magnetic resonance imaging (MRI) examination any time after implantation.^{481,482} The effect of the MRI examination on heating of the drug or polymer coating used in DES is unknown. There is no indication for antibiotic prophylaxis before dental or invasive procedures in patients with coronary stents.⁴⁸³

5.4. Adjunctive Diagnostic Devices

5.4.1. FFR: Recommendation

Class IIa

1. FFR is reasonable to assess angiographic intermediate coronary lesions (50% to 70% diameter stenosis) and can be useful for guiding revascularization decisions in patients with SIHD.^{12,97,484–486} (Level of Evidence: A)

See Online Data Supplement 23 for additional data regarding FFR.

The limitations of coronary angiography for determination of lesion severity have been well described. Angiography

may under- or overestimate lesion stenosis. Various physiologic measurements can be made in the catheterization laboratory, including coronary flow reserve and FFR. The correlation of ischemia on stress testing with FFR values of <0.75 has been established in numerous comparative studies with high sensitivity (88%), specificity (100%), positive predictive value (100%), and overall accuracy (93%).⁴⁸⁷ The 5-year outcomes for patients with medical therapy based on an FFR >0.75 were superior compared with PCI in the DEFER (Deferral Versus Performance of Balloon Angioplasty in Patients Without Documented Ischemia) study.⁴⁸⁵ The FAME (Fractional Flow Reserve Versus Angiography for Multivessel Evaluation) study identified the benefit for deferring PCI in patients with multivessel disease and lesion FFR >0.80, with reduced rates of cardiac events at both 1 and 2 years.^{97,486} Whereas both FFR and IVUS have been used for assessment of intermediate angiographic stenosis with favorable outcomes, FFR may reduce the need for revascularization when compared with IVUS.⁴⁸⁸ Although IVUS is often considered in the assessment of equivocal left main stenosis, FFR may be similarly effective.⁴⁸⁴

5.4.2. IVUS: Recommendations

Class IIa

1. IVUS is reasonable for the assessment of angiographically indeterminant left main CAD.^{489–491} (Level of Evidence: B)
2. IVUS and coronary angiography are reasonable 4 to 6 weeks and 1 year after cardiac transplantation to exclude donor CAD, detect rapidly progressive cardiac allograft vasculopathy, and provide prognostic information.^{492–494} (Level of Evidence: B)
3. IVUS is reasonable to determine the mechanism of stent restenosis.⁴⁹⁵ (Level of Evidence: C)

Class IIb

1. IVUS may be reasonable for the assessment of non-left main coronary arteries with angiographically intermediate coronary stenoses (50% to 70% diameter stenosis).^{489,496,497} (Level of Evidence: B)
2. IVUS may be considered for guidance of coronary stent implantation, particularly in cases of left main coronary artery stenting.^{490,495,498} (Level of Evidence: B)
3. IVUS may be reasonable to determine the mechanism of stent thrombosis.⁴⁹⁵ (Level of Evidence: C)

Class III: NO BENEFIT

1. IVUS for routine lesion assessment is not recommended when revascularization with PCI or CABG is not being contemplated. (Level of Evidence: C)

IVUS provides a unique coronary artery assessment of lesion characteristics, minimal and maximal lumen diameters, cross-sectional area, and plaque area. Diagnostic uses for IVUS include the assessment of angiographic indeterminant coronary artery stenoses, determination of the mechanism of stent restenosis or thrombosis, and postcardiac transplantation surveillance of CAD.^{488,490–492,499} For left main coronary artery stenoses, a minimal lumen diameter of <2.8 mm or a

minimal lumen area of $<6 \text{ mm}^2$ suggests a physiologically significant lesion for which patients may benefit from revascularization. A minimal lumen area $>7.5 \text{ mm}^2$ suggests that revascularization may be safely deferred.⁴⁹⁰ A minimal lumen area between 6 and 7.5 mm^2 requires further physiological assessment, such as measurement of FFR.^{487,500} For non-left main stenoses, minimal lumen diameter $>2.0 \text{ mm}$ and minimal lumen area $>4.0 \text{ mm}^2$ correlate with low event rates.⁴⁸⁹ However, in smaller-diameter arteries (minimal lumen area $<3.0 \text{ mm}^2$), measurement of FFR may more accurately reflect a significant stenosis.⁴⁸⁸ Studies correlating IVUS measures with ischemia have not specified the size of coronary arteries for which such correlations are valid.^{488,489,497}

IVUS assessment after stent thrombosis may serve to identify stent underexpansion or malapposition.⁴⁹⁹ IVUS is superior to angiography in the early detection of the diffuse, immune-mediated, cardiac allograft vasculopathy; recommendations about the use of IVUS for this purpose were published in 2010 by the International Society of Heart and Lung Transplantation.⁴⁹² Whereas IVUS has been an important research tool in interventional cardiology, most clinical studies of IVUS have not been able to demonstrate that its routine use results in a reduction of MACE or restenosis rates.^{498,501,502} IVUS has been inappropriately used in clinical practice to justify implanting stents in mildly diseased segments that may require no intervention.⁵⁰³

5.4.3. Optical Coherence Tomography

Compared with IVUS, optical coherence tomography has greater resolution (10 to 20 micronmeter axially) but more limited depth of imaging (1 to 1.5 mm).^{504,505} Unlike IVUS, optical coherence tomography requires that the artery be perfused with saline solution or crystalloid during image acquisition and therefore does not permit imaging of ostial lesions. Clinical studies have shown low optical coherence tomography complication rates,^{506,507} similar to those of IVUS.⁵⁰⁸ The excellent resolution of optical coherence tomography permits detailed in vivo 2-dimensional imaging of plaque morphological characteristics (eg, calcification, lipid, thrombus, fibrous cap thickness, and plaque ulceration or rupture)^{508–510} and evaluation of the arterial response to stent implantation (eg, stent strut neointimal thickness and apposition)^{511–513} and may be of value in clinical research. The appropriate role for optical coherence tomography in routine clinical decision making has not been established.

5.5. Adjunctive Therapeutic Devices

5.5.1. Coronary Atherectomy: Recommendations

Class IIa

1. Rotational atherectomy is reasonable for fibrotic or heavily calcified lesions that might not be crossed by a balloon catheter or adequately dilated before stent implantation.^{514,515} (Level of Evidence: C)

Class III: NO BENEFIT

1. Rotational atherectomy should not be performed routinely for de novo lesions or in-stent restenosis.^{516–519} (Level of Evidence: A)

Rotational atherectomy in RCTs was associated with higher rates of MACE at 30 days and no reduction in restenosis. It has a limited role in facilitating the dilation or stenting of lesions that cannot be crossed or expanded with PCI.^{520,521} Devices for directional coronary atherectomy are no longer marketed in the United States.

5.5.2. Thrombectomy: Recommendation

Class IIa

1. Aspiration thrombectomy is reasonable for patients undergoing primary PCI.^{522–524} (Level of Evidence: B)

The benefit of thrombectomy in patients with STEMI appears to be dependent on the type of thrombectomy technique used.^{522–526} No clinical benefit for routine rheolytic thrombectomy (AngioJet device, MEDRAD Interventional, Minneapolis, MN and Pittsburgh, PA) has been demonstrated in primary PCI.^{524–526} Two RCTs^{522,523} and a meta-analysis⁵²⁴ support the use of manual aspiration thrombectomy during primary PCI to improve microvascular reperfusion and decrease MACE. It is not known whether a strategy of selective thrombus aspiration in patients with a large thrombus burden might be equivalent to routine thrombus aspiration.

5.5.3. Laser Angioplasty: Recommendations

Class IIb

1. Laser angioplasty might be considered for fibrotic or moderately calcified lesions that cannot be crossed or dilated with conventional balloon angioplasty.⁵²⁷ (Level of Evidence: C)

Class III: NO BENEFIT

1. Laser angioplasty should not be used routinely during PCI.^{516,518,528} (Level of Evidence: A)

RCTs of laser angioplasty have not demonstrated improved clinical or angiographic PCI outcomes, although some practitioners think that laser angioplasty may be of use in the treatment of lesions that are difficult to dilate with balloon angioplasty.⁵²⁷

5.5.4. Cutting Balloon Angioplasty: Recommendations

Class IIb

1. Cutting balloon angioplasty might be considered to avoid slippage-induced coronary artery trauma during PCI for in-stent restenosis or ostial lesions in side branches.⁵²⁹ (Level of Evidence: C)

Class III: NO BENEFIT

1. Cutting balloon angioplasty should not be performed routinely during PCI.^{516,529,530} (Level of Evidence: A)

Although some small, single-center trials have suggested that cutting balloon angioplasty was more efficacious than bal-

loon angioplasty, it was not found to be safer or more effective in several large trials.^{516,529,531} When balloon dilation is required for in-stent restenosis, however, cutting balloons are less likely to slip and may offer a technical advantage over conventional balloons.⁵²⁹ Scoring balloons have been used by some cardiologists as an alternative to cutting balloons, but no RCTs have been reported.⁵³¹

5.5.5. Embolic Protection Devices: Recommendation

Class I

- 1. Embolic protection devices (EPDs) should be used during saphenous vein graft (SVG) PCI when technically feasible.^{532–535} (Level of Evidence: B)**

The incidence of MACE doubles in SVG PCI compared with native-artery PCI.⁵³⁶ A distal balloon occlusion EPD decreased the 30-day composite outcome of death, MI, emergency CABG, or target-lesion revascularization (9.6% versus 16.5%) in the only RCT.⁵³² Subsequent noninferiority comparisons have demonstrated similar benefit with proximal occlusion and distal filter EPDs, with benefit limited to reduction in periprocedural MI^{534,535} (Section 5.10). Distal EPDs do not improve survival or reinfarction rates in patients undergoing native-artery PCI.^{524,537}

5.6. Percutaneous Hemodynamic Support Devices: Recommendation

Class IIb

- 1. Elective insertion of an appropriate hemodynamic support device as an adjunct to PCI may be reasonable in carefully selected high-risk patients. (Level of Evidence: C)**

IABP counterpulsation is frequently used as an adjunct to PCI in hemodynamically unstable patients.^{538,539} In single-center series, the routine prophylactic use of IABP during PCI in high-risk patients was associated with lower mortality and fewer major complications compared with rescue use of IABP.^{540,541} In the only RCT in high-risk PCI patients (BCIS-1 [Balloon Pump-Assisted Coronary Intervention Study]),⁵⁴² there was no difference in the primary composite outcome between routine and provisional use of IABP. There were also no differences in major secondary endpoints except major procedural complications (eg, prolonged hypotension, ventricular tachycardia/fibrillation, cardiopulmonary arrest), which were lower in the routine IABP group. Bleeding and access site complication rates tended to be higher in the routine IABP group. The “bailout” rate of IABP insertion in the provisional IABP group was 12%, mostly for procedural hypotension.⁵⁴² A meta-analysis of IABP therapy in patients with STEMI did not show improved outcomes with the use of IABP.⁴³⁴

The Impella Recover LP 2.5 System (Abiomed, Aachen, Germany/Danvers, Massachusetts) is a 12.5 Fr catheter that is inserted percutaneously through a 13 Fr femoral artery sheath and placed across the aortic valve into the left ventricle, through which a transaxial blood pump provides flows of up to 2.5 L/min. This has been used in patients with cardiogenic shock^{543,544} as well as elective PCI.⁵⁴⁵ The hemodynamic

effects of the Impella 2.5 have been studied in high-risk PCI patients, demonstrating beneficial LV unloading effect (decreased end-diastolic pressure and wall stress) with no change in global or systolic LV function.⁵⁴⁶ The PROTECT I (A Prospective Feasibility Trial Investigating the Use of the IMPELLA Recover LP 2.5 System in Patients Undergoing High-Risk PCI) trial in 20 patients undergoing high-risk PCI with the Impella 2.5 system concluded that this device was safe, easy to implant, and hemodynamically effective.⁵⁴⁷ The Europella Registry included 144 patients undergoing high-risk PCI and reported the safety, feasibility, and potential usefulness of the device and that RCTs were warranted.⁵⁴⁸ The randomized PROTECT II (A Prospective, Multicenter, Randomized Controlled Trial of the IMPELLA Recover LP 2.5 System Versus Intra Aortic Balloon Pump in Patients Undergoing Non Emergent High Risk PCI) trial, which was designed to demonstrate superiority of Impella over IABP in terms of 1-month adverse events, was halted for futility after interim analysis of study results.⁵⁴⁹

The TandemHeart (CardiacAssist, Inc, Pittsburgh, PA) is a left atrial to aorta catheter-based system that includes a centrifugal blood pump providing flows of up to 4 L/min. This device uses a 21 Fr cannula percutaneously inserted into the femoral vein for transseptal access of the left atrium with a 15 Fr catheter placed in the contralateral femoral artery and positioned above the aortic bifurcation. An extracorporeal pump then returns oxygenated blood from the left atrium to the arterial system, thereby unloading the left ventricle.^{550,551} The hemodynamic effects have been studied in patients undergoing high-risk PCI.⁵⁵² Several small studies have addressed the clinical efficacy of the TandemHeart in high-risk patients undergoing PCI.^{551,553–556} In a single-center report of 68 patients undergoing high-risk PCI using either TandemHeart or Impella Recover 2.5, success rates (>90%) and vascular complications (7%) were similar.⁵⁵³

High-risk patients may include those undergoing unprotected left main or last-remaining-conduit PCI, those with severely depressed EF undergoing PCI of a vessel supplying a large territory, and/or those with cardiogenic shock. Patient risk, hemodynamic support, ease of application/removal, and operator and laboratory expertise are all factors involved in consideration of use of these devices. With devices that require large cannula insertion, the risk of vascular injury and related complications are important considerations regarding necessity and choice of device.

5.7. Interventional Pharmacotherapy

5.7.1. Procedural Sedation

The term *conscious sedation* is falling out of favor with the recognition that there is a spectrum of procedural sedation levels. Most patients undergoing PCI fall under the definition of either minimal sedation (anxiolysis) or moderate sedation (depressed consciousness with the ability to respond purposefully to verbal commands).⁵⁵⁷ Nonetheless, an underlying principle of procedural sedation is that the physician should be prepared to manage one level of sedation deeper than the level intended. Thus, cardiologists should be cognizant of the principles of managing deep sedation (depressed conscious-

ness without easy arousal that may require assistance in maintaining airway patency or spontaneous ventilation).

A full review of procedural sedation is beyond the scope of this document, but practice guidelines for sedation and analgesia by nonanesthesiologists, along with The Joint Commission standards, provides a reasonable framework. These guidelines outline several general principles.^{558,559} Before the procedure the patient should be assessed for predictors of difficult intubation or a history of prior difficult intubation. The patient should be monitored by someone dedicated to observing the level and effects of sedation. Level of consciousness, respiratory rate, blood pressure, cardiac rhythm, and oxygen saturation by pulse oximetry should be monitored. Available equipment should include a high-flow oxygen source, suction, airway management equipment, a defibrillator, resuscitation drugs, and reversal agents appropriate for the drugs being used. A free-flowing IV line should be established. Supplemental oxygen is usually administered, even in the absence of preexisting hypoxia, to provide a margin of safety.

Agents used for sedation are best given in incremental doses, allowing adequate time for the development and assessment of peak effect. The most commonly used agents are listed in Appendix 4F.

5.7.2. Oral Antiplatelet Therapy: Recommendations

Class I

1. Patients already taking daily aspirin therapy should take 81 mg to 325 mg before PCI.^{301–304} (*Level of Evidence: B*)
2. Patients not on aspirin therapy should be given nonenteric aspirin 325 mg before PCI.^{301,303,304} (*Level of Evidence: B*)
3. After PCI, use of aspirin should be continued indefinitely.^{560–563} (*Level of Evidence: A*)
4. A loading dose of a P2Y₁₂ receptor inhibitor should be given to patients undergoing PCI with stenting^{564–568} (*Level of Evidence: A*). Options include
 - a. Clopidogrel 600 mg (ACS and non-ACS patients)^{564–566} (*Level of Evidence: B*)
 - b. Prasugrel 60 mg (ACS patients)⁵⁶⁷ (*Level of Evidence: B*)
 - c. Ticagrelor 180 mg (ACS patients)⁵⁶⁸ (*Level of Evidence: B*)
5. The loading dose of clopidogrel for patients undergoing PCI after fibrinolytic therapy should be 300 mg within 24 hours and 600 mg more than 24 hours after receiving fibrinolytic therapy.^{565,569} (*Level of Evidence: C*)
6. Patients should be counseled on the need for and risks of DAPT before placement of intracoronary stents, especially DES, and alternative therapies should be pursued if patients are unwilling or unable to comply with the recommended duration of DAPT.²⁰⁸ (*Level of Evidence: C*)
7. The duration of P2Y₁₂ inhibitor therapy after stent implantation should generally be as follows:

- a. In patients receiving a stent (BMS or DES) during PCI for ACS, P2Y₁₂ inhibitor therapy should be given for at least 12 months. Options include clopidogrel 75 mg daily,⁵⁷⁰ prasugrel 10 mg daily,⁵⁶⁷ and ticagrelor 90 mg twice daily.⁵⁶⁸ (*Level of Evidence: B*)
- b. In patients receiving DES for a non-ACS indication, clopidogrel 75 mg daily should be given for at least 12 months if patients are not at high risk of bleeding.^{208,212,571} (*Level of Evidence: B*)
- c. In patients receiving BMS for a non-ACS indication, clopidogrel should be given for a minimum of 1 month and ideally up to 12 months (unless the patient is at increased risk of bleeding; then it should be given for a minimum of 2 weeks).^{208,572} (*Level of Evidence: B*)

Class IIa

1. After PCI, it is reasonable to use aspirin 81 mg per day in preference to higher maintenance doses.^{302,573–576} (*Level of Evidence: B*)
2. If the risk of morbidity from bleeding outweighs the anticipated benefit afforded by a recommended duration of P2Y₁₂ inhibitor therapy after stent implantation, earlier discontinuation (eg, <12 months) of P2Y₁₂ inhibitor therapy is reasonable. (*Level of Evidence: C*)

Class IIb

1. Continuation of DAPT beyond 12 months may be considered in patients undergoing DES implantation.^{567,568} (*Level of Evidence: C*)

Class III: HARM

1. Prasugrel should not be administered to patients with a prior history of stroke or transient ischemic attack.⁵⁶⁷ (*Level of Evidence: B*)

Aspirin reduces the frequency of ischemic complications after PCI. Although the minimum effective aspirin dosage in the setting of PCI has not been established, aspirin 325 mg given at least 2 hours, and preferably 24 hours, before PCI is recommended.^{302,303} after which aspirin 81 mg daily should be continued indefinitely.

Several investigations have explored various loading doses of clopidogrel before or during PCI. Compared with a 300-mg loading dose, doses of either 600 mg or 900 mg achieve greater degrees of platelet inhibition with fewer low responders.⁵⁷⁷ A meta-analysis of 7 studies that included 25,383 patients undergoing PCI demonstrated that intensified loading of clopidogrel with 600 mg reduces the rate of MACE without an increase in major bleeding compared with 300 mg.⁵⁷⁸ Another study suggested that a 600-mg loading dose of clopidogrel is associated with improvements in procedural angiographic endpoints and 1-year clinical outcomes in patients with STEMI who undergo primary PCI compared with a 300-mg dose.⁵⁷⁹ There is no benefit with increasing the loading dose to 900 mg compared with 600 mg.⁵⁷⁷ Clopidogrel 75 mg daily should be given for a minimum of 4 weeks after balloon angioplasty or BMS

implantation (a minimum of 2 weeks if increased bleeding risk is present)⁵⁸⁰ and for at least 12 months after DES implantation (unless the risk of bleeding outweighs the anticipated benefit). Patients should be counseled on the need for and risks of DAPT before stent implantation, especially DES implantation, and alternative therapies pursued (BMS or balloon angioplasty) if they are unwilling or unable to comply with the recommended duration of DAPT.

The efficacy of clopidogrel pretreatment remains controversial. Although some studies have suggested that pretreatment with clopidogrel is associated with decreased platelet aggregation and a significantly lower incidence of periprocedural MI after elective PCI, others have suggested no benefit to pretreatment compared with administration of the drug in the catheterization laboratory.^{572,581,582}

When prasugrel was compared with clopidogrel in patients with ACS in TRITON-TIMI 38 (Trial to Assess Improvement in Therapeutic Outcomes by Optimizing Platelet Inhibition with Prasugrel-Thrombolysis In Myocardial Infarction), prasugrel was associated with a significant 2.2% reduction in absolute risk and a 19% reduction in relative risk in the composite endpoint of cardiovascular death, nonfatal MI, or nonfatal stroke, and a significant increase in the rate of TIMI major hemorrhage (1.8% versus 2.4%).⁵⁶⁷ Prasugrel is contraindicated in patients with a history of transient ischemic attack or stroke. Patients weighing <60 kg have an increased risk of bleeding on the 10 mg daily maintenance dose. The package insert suggests that consideration should be given to lowering the maintenance dose to 5 mg daily, although the effectiveness and safety of the 5-mg dose has not been studied. Prasugrel is not recommended for patients >75 years of age because of the increased risk of fatal and intracranial bleeding and lack of benefit, except in patients with diabetes or a history of prior MI. Prasugrel should not be started in patients likely to undergo urgent CABG. Prasugrel has not been studied in elective PCI, and thus no recommendation can be made regarding its use in this clinical setting.

Ticagrelor reversibly binds the P2Y₁₂ receptor. Unlike clopidogrel or prasugrel, ticagrelor is not a thienopyridine. It also does not require metabolic conversion to an active metabolite. Compared with clopidogrel in patients with ACS in the PLATO (Platelet Inhibition and Patient Outcomes) trial, ticagrelor was associated with a significant 1.9% reduction in absolute risk and a 16% reduction in relative risk in the primary composite endpoint of vascular death, nonfatal MI, or nonfatal stroke.⁵⁶⁸ Importantly, a significant reduction in vascular mortality and all-cause mortality was observed. Although CABG-related bleeding was not significantly increased with ticagrelor compared with clopidogrel, a significantly greater incidence of major bleeding was observed in patients not undergoing CABG. Ticagrelor was associated with higher rates of transient dyspnea and bradycardia compared with clopidogrel, although only a very small percentage of patients discontinued the study drug because of dyspnea. Based on post hoc analysis of the PLATO study, specifically the results in the US patient cohort, a black box warning states that maintenance doses of aspirin above 100 mg reduce the effectiveness of ticagrelor and should be avoided. After any initial dose, ticagrelor should be used with aspirin 75 mg

to 100 mg per day.⁵⁸³ Given the twice-daily dosing and reversible nature of the drug, patient compliance may be a particularly important issue to consider and emphasize. Ticagrelor has not been studied in elective PCI or in patients who received fibrinolytic therapy; thus, no recommendations about its use in these clinical settings can be made.

5.7.3. IV Antiplatelet Therapy: Recommendations

STEMI

Class IIa

1. In patients undergoing primary PCI treated with UFH, it is reasonable to administer a GP IIb/IIIa inhibitor (abciximab, double-bolus eptifibatide, or high-bolus dose tirofiban), whether or not patients were pretreated with clopidogrel.^{584–590} (For GP IIb/IIIa inhibitor administration in patients not pretreated with clopidogrel, Level of Evidence: A; for GP IIb/IIIa inhibitor administration in patients pretreated with clopidogrel, Level of Evidence: C)

Class IIb

1. In patients undergoing primary PCI with abciximab, it may be reasonable to administer intracoronary abciximab.^{589,591–604} (Level of Evidence: B)

Class III: NO BENEFIT

1. Routine precatheterization laboratory (eg, ambulance or emergency department) administration of GP IIb/IIIa inhibitors as part of an upstream strategy for patients with STEMI undergoing PCI is not beneficial.^{605–612} (Level of Evidence: B)

UA/NSTEMI

Class I

1. In UA/NSTEMI patients with high-risk features (eg, elevated troponin level) not treated with bivalirudin and not adequately pre-treated with clopidogrel, it is useful at the time of PCI to administer a GP IIb/IIIa inhibitor (abciximab, double-bolus eptifibatide, or high-bolus dose tirofiban) in patients treated with UFH.^{613–618} (Level of Evidence: A)

Class IIa

1. In UA/NSTEMI patients with high-risk features (eg, elevated troponin level) treated with UFH and adequately pretreated with clopidogrel, it is reasonable at the time of PCI to administer a GP IIb/IIIa inhibitor (abciximab, double-bolus eptifibatide, or high-bolus dose tirofiban).^{616,619} (Level of Evidence: B)

SIHD

Class IIa

1. In patients undergoing elective PCI treated with UFH and not pretreated with clopidogrel, it is reasonable to administer a GP IIb/IIIa inhibitor (abciximab, double-bolus eptifibatide, or high-bolus dose tirofiban).^{619–621} (Level of Evidence: B)

Class IIb

- 1. In patients undergoing elective PCI with stent implantation treated with UFH and adequately pretreated with clopidogrel, it might be reasonable to administer a GP IIb/IIIa inhibitor (abciximab, double-bolus eptifibatide, or high-bolus dose tirofiban).^{619,622–624} (Level of Evidence: B)**

See Online Data Supplement 24 for additional data regarding IV antiplatelet therapy.

In the era before DAPT, trials of adequately dosed GP IIb/IIIa inhibitors in patients undergoing balloon angioplasty and coronary stent implantation demonstrated a reduction in the incidence of composite ischemic events with GP IIb/IIIa treatment, primarily through a reduction of enzymatically defined MI.^{613,615,618,620,621} Earlier RCTs of GP IIb/IIIa inhibitors were generally conducted in patients treated with UFH. In some trials, use of GP IIb/IIIa inhibitors are associated with some increased bleeding risk, and trials of these agents have generally excluded patients at high risk of bleeding (eg, coagulopathy).^{584,587–589,613–618,620–626} Thus, recommendations about use of GP IIb/IIIa inhibitors are best construed as applying to those patients not at high risk of bleeding complications. Abciximab, double-bolus eptifibatide (180 mcg/kg bolus followed 10 minutes later by a second 180 mcg/kg bolus), and high-bolus dose tirofiban (25 mcg/kg) all result in a high degree of platelet inhibition,^{627–629} have been demonstrated to reduce ischemic complications in patients undergoing PCI,^{608,609,613,615,618–621} and appear to lead to comparable angiographic and clinical outcomes.^{630,631}

Trials of GP IIb/IIIa inhibitors in the setting of STEMI and primary PCI were conducted in the era before routine stenting and DAPT. The results of these and more recent trials, as well as several meta-analyses, have yielded mixed results.^{584–590} Therefore, it is reasonable to administer GP IIb/IIIa inhibitors in patients with STEMI undergoing PCI, although these agents cannot be definitively recommended as routine therapy. These agents might provide more benefit in selective use, such as in patients with large anterior MI and/or large thrombus burden. Trials of precatheterization laboratory (eg, ambulance or emergency room) administered GP IIb/IIIa inhibitors in patients with STEMI undergoing PCI, with or without fibrinolytic therapy, have generally shown no clinical benefit, and GP IIb/IIIa inhibitor use in this setting may be associated with an increased risk of bleeding.^{605–610,612} Studies of intracoronary GP IIb/IIIa inhibitor administration (predominantly using abciximab) consist of several small RCTs, retrospective analyses, retrospective and prospective registries, cohort analyses, and case reports. Although most of these published studies have reported some benefit of intracoronary administration in terms of acute angiographic parameters, infarct size, left ventricle myocardial salvage, and composite clinical endpoints, several other studies have not detected any benefit with intracoronary administration.^{589,591–604}

Trials of GP IIb/IIIa inhibitors in patients with UA/NSTEMI undergoing PCI demonstrated reduced ischemic outcomes, particularly in those with high-risk features such as positive biomarkers. Most trials were conducted in a

prior PCI era and without P2Y₁₂ inhibitor pretreatment,^{613,615,618,632,633} although several trials have also demonstrated benefit in patients with high-risk features pretreated with clopidogrel.^{616,619} In most older studies of stable patients undergoing balloon angioplasty or coronary stenting, treatment with GP IIb/IIIa inhibitors resulted in a reduction of composite ischemic events, primarily enzymatically defined MI.^{613–618,620,621,634,635} More contemporary trials of patients pretreated with a thienopyridine have not demonstrated any benefit with GP IIb/IIIa inhibitor therapy in patients with stable symptoms undergoing elective PCI.^{619,622–624}

5.7.4. Anticoagulant Therapy

5.7.4.1. Use of Parenteral Anticoagulants During PCI: Recommendation

Class I

- 1. An anticoagulant should be administered to patients undergoing PCI. (Level of Evidence: C)**

Anticoagulant therapy prevents thrombus formation at the site of arterial injury, on the coronary guidewire, and in the catheters used for PCI.⁸ With rare exceptions,⁶³⁶ all PCI studies have used some form of anticoagulant. It is the consensus of the writing committee that PCI be performed with the use of some form of anticoagulant therapy. Suggested dosing regimens of parenteral agents used in PCI are given in Table 12. Recommendations for antiplatelet and antithrombin pharmacotherapy in PCI are given in Table 13.

5.7.4.2. UFH: Recommendation

Class I

- 1. Administration of IV UFH is useful in patients undergoing PCI. (Level of Evidence: C)**

As the only anticoagulant available for PCI for many years, UFH became the standard of care by default.⁸ The dose of UFH for PCI has been based on empiricism and experience from RCTs. Suggested UFH dosing regimens are given in Table 12. When UFH is used during PCI, most cardiologists assess the degree of anticoagulation by measuring the activated clotting time. Although measurements are useful to show that an anti-IIa anticoagulant has been given, the value of the activated clotting time in current practice has been questioned. Although studies in the balloon angioplasty era did demonstrate a relationship between activated clotting time levels and ischemic complications,^{653–655} more recent analyses from the coronary stent era have not found a clear relationship between activated clotting time and outcomes.^{349,656,657} There may, however, be a modest relation between bleeding and activated clotting time levels.^{349,657} In addition, not only are there differences between activated clotting time levels measured by Hemochron and HemoTec devices, but both devices have less than optimal precision.⁶⁵⁸ Thus, although traditional target activated clotting time levels are included in this document, the utility of measured activated clotting time levels in current practice should be considered uncertain.

Table 12. Dosing of Parenteral Anticoagulants During PCI

Drug	Patient Has Received Prior Anticoagulant Therapy	Patient Has Not Received Prior Anticoagulant Therapy
UFH	<ul style="list-style-type: none"> • IV GPI planned: additional UFH as needed (eg, 2000 to 5000 U) to achieve an ACT of 200 to 250 s • No IV GPI planned: additional UFH as needed (eg, 2000 to 5000 U) to achieve an ACT of 250 to 300 s for HemoTec, 300 to 350 s for Hemochron 	<ul style="list-style-type: none"> • IV GPI planned: 50 to 70 U/kg bolus to achieve an ACT of 200 to 250 s • No IV GPI planned: 70 to 100 U/kg bolus to achieve target ACT of 250 to 300 s for HemoTec, 300 to 350 s for Hemochron
Enoxaparin	<ul style="list-style-type: none"> • For prior treatment with enoxaparin, if the last SC dose was administered 8 to 12 h earlier or if only 1 SC dose of enoxaparin has been administered, an IV dose of 0.3 mg/kg of enoxaparin should be given. • If the last SC dose was administered within the prior 8 h, no additional enoxaparin should be given. 	0.5 to 0.75 mg/kg IV bolus
Bivalirudin	For patients who have received UFH, wait 30 min, then give 0.75 mg/kg IV bolus, then 1.75 mg/kg per h IV infusion.	0.75 mg/kg bolus, 1.75 mg/kg per h IV infusion
Fondaparinux	For prior treatment with fondaparinux, administer additional IV treatment with an anticoagulant possessing anti-IIa activity, taking into account whether GPI receptor antagonists have been administered.	N/A
Argatroban	200 mcg/kg IV bolus, then 15 mcg/kg per min IV infusion	350 mcg/kg bolus, then 25 mcg/kg per min IV infusion

ACT indicates activated clotting time; IV, intravenous; GPI, glycoprotein inhibitor; N/A, not applicable; PCI, percutaneous coronary intervention; SC, subcutaneous; and UFH, unfractionated heparin.

Most cardiologists remove femoral sheaths when the activated clotting time falls to <150 to 180 seconds or when the activated partial thromboplastin time falls to <50 seconds. Full-dose anticoagulation is no longer used after successful PCI procedures. Almost all large clinical trials have enrolled patients who underwent transfemoral PCI, but recent small studies assessing the transradial approach have used similar doses of UFH⁶⁵⁹ and similar activated clotting time target levels.⁶⁶⁰

5.7.4.3. Enoxaparin: Recommendations

Class I

1. An additional dose of 0.3 mg/kg IV enoxaparin should be administered at the time of PCI to patients who have received fewer than 2 therapeutic subcutaneous doses (eg, 1 mg/kg) or received the last subcutaneous enoxaparin dose 8 to 12 hours before PCI.^{649,661–664} (Level of Evidence: B)

Class IIb

1. Performance of PCI with enoxaparin may be reasonable in patients either treated with “upstream” subcutaneous enoxaparin for UA/NSTEMI or who have not received prior antithrombin therapy and are administered IV enoxaparin at the time of PCI.^{646–650} (Level of Evidence: B)

Class III: HARM

1. UFH should not be given to patients already receiving therapeutic subcutaneous enoxaparin.^{649,665} (Level of Evidence: B)

Trials of enoxaparin relevant to PCI include both studies in which patients with UA/NSTEMI were started on upstream subcutaneous enoxaparin therapy that was continued up to the time of PCI and trials in which patients who had

received no prior antithrombin therapy were treated with IV enoxaparin at the time of PCI.^{646–650,661–663,666} In the SYNERGY (Superior Yield of the New strategy of Enoxaparin, Revascularization and Glycoprotein IIb/IIIa Inhibitors) trial, there was an increased incidence of bleeding in those treated with upstream enoxaparin, later attributed at least in part to the fact that some patients being treated with enoxaparin were also administered UFH at the time of PCI (so-called “stacking”).^{649,665} Almost all patients undergoing elective PCI who are administered enoxaparin (0.5 mg/kg IV) will have a peak anti-Xa level >0.5 IU/mL.⁶⁴⁷ Most clinical studies have used a regimen of 0.5 to 0.75 mg IV.⁶⁶⁷ Several studies have used this regimen in elective patients and those with STEMI.⁶⁴⁶ Patients who have received multiple doses of subcutaneously administered enoxaparin who undergo PCI within 8 hours of the last subcutaneous dose generally have adequate degrees of anticoagulation to undergo PCI, but the degree of anticoagulation may diminish in the 8- to 12-hour period after the last subcutaneous dose. In such patients, as well as in patients who have received only 1 subcutaneous dose of enoxaparin, the addition of enoxaparin (0.3 mg/kg IV) at the time of PCI provides an additional degree of anticoagulation and has become standard practice.^{648,661–664} Patients who undergo PCI >12 hours after the last subcutaneous dose are usually treated with full-dose de novo anticoagulation using an established regimen (eg, full-dose UFH or bivalirudin).

5.7.4.4. Bivalirudin and Argatroban: Recommendations

Class I

1. For patients undergoing PCI, bivalirudin is useful as an anticoagulant with or without prior treatment with UFH.^{625,637–645} (Level of Evidence: B)

Table 13. Recommendations for Antiplatelet and Antithrombin Pharmacotherapy at the Time of PCI

	COR	LOE	References	Relevant Caveats/Comments
Oral antiplatelet agents				
Aspirin	I	B	301–304,560–563	N/A
P2Y ₁₂ inhibitors	I	A	564–568	<ul style="list-style-type: none"> A loading dose of a P2Y₁₂ inhibitor should be given to patients undergoing PCI with stenting.
• Clopidogrel	I	B	564–566	<ul style="list-style-type: none"> 600-mg loading dose now recommended.
• Prasugrel	I	B	567	<ul style="list-style-type: none"> Contraindicated in patients with prior TIA/CVA: Class III: Harm; LOE: B. Generally not recommended in patients >75 y of age (Section 5.7.2). Consideration of using a lower maintenance dose in patients weighing <60 kg suggested by FDA (Section 5.7.2).
• Ticagrelor	I	B	568	<ul style="list-style-type: none"> Issues of patient compliance may be especially important.
GP IIb/IIIa inhibitors (abciximab, double-bolus eptifibatide, high-bolus dose tirofiban)				
• No clopidogrel pretreatment	STEMI: IIa	A	584–590	<ul style="list-style-type: none"> UA/NSTEMI recommendation applies to those with high-risk features.
	UA/NSTEMI: I	A	613–618	<ul style="list-style-type: none"> GPI use in STEMI may be most appropriate in those with large anterior MI and/or large thrombus burden.
	SIHD: IIa	B	619–621	<ul style="list-style-type: none"> IC abciximab administration in STEMI: Class IIb; LOE: B.
• Clopidogrel pretreatment	STEMI: IIa	C	584–590	<ul style="list-style-type: none"> Precatheterization laboratory GPI administration in STEMI: Class III: No Benefit; LOE: B.
	UA/NSTEMI: IIa	B	616,619	<ul style="list-style-type: none"> Recommendations apply to those not at high risk for bleeding complications.
	SIHD: IIb	B	619,622–624	
Antithrombin agents				
UFH	I	C	N/A	<ul style="list-style-type: none"> Dosing based on whether or not GPI was administered.
Bivalirudin	I	B	625,637–645	<ul style="list-style-type: none"> Lower bleeding rates associated with bivalirudin are mitigated when used concomitantly with a GPI.
Enoxaparin	IIb	B	646–650	<ul style="list-style-type: none"> Recommendations apply to administration of IV enoxaparin at the time of PCI for those who have not received prior antithrombin therapy or who have received “upstream” SC enoxaparin therapy for UA/NSTEMI. An additional dose of 0.3 mg/kg IV enoxaparin should be administered at the time of PCI to patients who have received <2 therapeutic SC doses (eg, 1 mg/kg) or received the last SC enoxaparin dose 8 to 12 h before PCI: Class I; LOE: B. Patients treated with SC enoxaparin within 12 h of PCI should not receive additional treatment with UFH during PCI (“stacking”): Class III: Harm; LOE: B.
Anti-Xa inhibitors				
Fondaparinux	III: Harm	C	651,652	<ul style="list-style-type: none"> PCI should not be performed with fondaparinux as the sole antithrombin agent in patients treated with upstream fondaparinux. An additional anticoagulant with anti-IIa activity should be administered.

ACT indicates activated clotting time; COR, class of recommendation; CVA, cerebrovascular accident; FDA, US Food and Drug Administration; GP, glycoprotein; GPI, glycoprotein IIb/IIIa inhibitor; IC, intracoronary; IV, intravenous; LOE, level of evidence; MI, myocardial infarction; N/A, not applicable; PCI, percutaneous coronary intervention; SC, subcutaneous; SIHD, stable ischemic heart disease; STEMI, ST-elevation myocardial infarction; TIA, transient ischemic attack; UA/NSTEMI, unstable angina/non-ST-elevation myocardial infarction; and UFH, unfractionated heparin.

2. For patients with heparin-induced thrombocytopenia, it is recommended that bivalirudin or argatroban be used to replace UFH.^{668,669} (Level of Evidence: B)

Bivalirudin is being increasingly used in clinical practice⁶⁷⁰ as evidence emerges from clinical trials across the spectrum of CAD.^{638–644} In individual trials and meta-analyses, the use of bivalirudin has been associated with reduced bleeding compared with UFH plus a GP IIb/IIIa inhibitor, although concerns about ischemic events have emerged in individual studies.^{625,637–645} Longer-term follow-up of the major bivalirudin trials, however, suggests that small or nominal increases in ischemic events have not translated into long-term consequences and that treatment at or before the time of PCI with clopidogrel may mitigate any increased early ischemic risk.^{637–645} Thus, a treatment strategy of bivalirudin compared with heparin (or enoxaparin) plus GP IIb/IIIa inhibitor ap-

pears to lower the risk of bleeding complications. The lower bleeding rates associated with bivalirudin (compared with UFH plus a GP IIb/IIIa inhibitor) are mitigated when used concomitantly with a GP IIb/IIIa inhibitor.⁶³⁹ A strategy of use of provisional GP IIb/IIIa inhibitor in patients treated with bivalirudin is widely accepted.^{639,643,644}

In patients with heparin-induced thrombocytopenia,^{671,672} a direct-thrombin inhibitor (argatroban) has been approved as an alternative parenteral anticoagulant to be used during PCI.⁶⁶⁸ The use of bivalirudin for heparin-induced thrombocytopenia has been reported as well.⁶⁶⁹

5.7.4.5. Fondaparinux: Recommendation

Class III: HARM

1. Fondaparinux should not be used as the sole anticoagulant to support PCI. An additional anticoagulant

with anti-IIa activity should be administered because of the risk of catheter thrombosis.^{651,652} (Level of Evidence: C)

Fondaparinux, a pentasaccharide, is an indirect factor Xa inhibitor but has no effect on thrombin. On the basis of reports of catheter thrombosis when fondaparinux is used alone during primary PCI,^{651,652} the writing committee recommends that an anticoagulant with anti-IIa activity be used in patients undergoing PCI.^{651,652} One study suggested that clinical outcomes were better when fondaparinux was replaced during PCI by a standard dose of UFH (85 U/kg, 60 U/kg with GP IIb/IIIa inhibitors) rather than by a low dose (50 U/kg).⁶⁷³

5.7.5. No-Reflow Pharmacological Therapies: Recommendation

Class IIa

- 1. Administration of an intracoronary vasodilator (adenosine, calcium channel blocker, or nitroprusside) is reasonable to treat PCI-related no-reflow that occurs during primary or elective PCI.^{674–689} (Level of Evidence: B)**

See Online Data Supplement 25 for additional data regarding no-reflow therapies.

No-reflow is a broad term used to describe 2 distinct entities. The first is “interventional no-reflow” attributed to vasospasm and downstream embolization of debris dislodged during PCI, usually in the setting of atherectomy, thrombus, or degenerated SVGs. The second entity is suboptimal reperfusion of an infarct artery, attributed to endothelial injury in addition to embolization and vasospasm. Angiographic no-reflow is the most obvious sequela of the same pathophysiology that produces abnormal TIMI frame counts and TIMI blush scores, so these measures are often used interchangeably. The principal clinical sequela of no-reflow is myonecrosis. Efforts to prevent no-reflow overlap with strategies to reduce MI size and prevent periprocedural MI.

In the setting of MI, several drugs have been shown to reduce the incidence of no-reflow. Evidence for a beneficial effect on no-reflow exists for abciximab, adenosine, nicorandil, and nitroprusside.^{674,675,680,682,683,685,687,688,690} However, their adoption into clinical practice has depended on their effect on hard clinical endpoints such as infarct size and mortality. These benefits, and consequentially the use of these agents, have been limited.

For interventional no-reflow, several therapies have proven effective after no-reflow has started. These include adenosine, calcium channel blockers, and nitroprusside.^{676,678,679,681,684,686,689,691} There are fewer data to support the use of epinephrine.⁶⁹² No-reflow after rotational atherectomy was less common with nicorandil compared with verapamil infusions in 3 studies,^{693–695} and an infusion of nicorandil/adenosine during rotational atherectomy prevented no-reflow in 98% of patients.⁶⁷⁷ Trials of pre-PCI intracoronary verapamil, nicardipine, and adenosine have reported them to be safe but have not demonstrated reductions in post-PCI no-reflow.^{696–698} Mechanical devices to prevent

interventional and myocardial infarct reperfusion no-reflow are also covered in Section 5.5.5.

5.8. PCI in Specific Anatomic Situations

5.8.1. CTOs: Recommendation

Class IIa

- 1. PCI of a CTO in patients with appropriate clinical indications and suitable anatomy is reasonable when performed by operators with appropriate expertise.^{699–703} (Level of Evidence: B)**

See Online Data Supplements 26 to 28 for additional data regarding CTOs.

Approximately one third of patients with suspected CAD who undergo coronary angiography have ≥ 1 CTO (defined as occlusion of a duration >3 months).⁷⁰⁴ Although stress-induced ischemia can be elicited in the majority of patients with CTO despite the presence of collaterals,^{706,707} only 8% to 15% of these patients undergo PCI.^{708,709} The disparity between the frequency of CTOs and percutaneous treatment underscores not only the technical and procedural complexities of this lesion subtype but also the clinical uncertainties regarding which patients benefit from CTO revascularization. Studies suggest that patients who undergo successful, rather than failed, recanalization of CTOs fare better in terms of symptom status and need for CABG,⁶⁹⁹ as well as LV function.⁷¹⁰ However, the impact of successful CTO recanalization on long-term survival remains unsettled.^{701,711,712} The decision to try PCI for a CTO (versus continued medical therapy or surgical revascularization) requires an individualized risk-benefit analysis encompassing clinical, angiographic, and technical considerations. Consultation with a cardiothoracic surgeon and use of the Heart Team approach in cases of CTO in which a large territory is subtended and/or multivessel CAD is present are frequently done.

From a technical perspective, successful recanalization of CTOs has steadily increased over the years because of adoption of dedicated wires, novel techniques, and increased operator experience.⁷⁰² In patients who undergo successful CTO recanalization, use of DES significantly reduces the need for repeated target-vessel revascularization, compared with BMS and balloon angioplasty, without compromising safety.^{703,713–719}

5.8.2. SVGs: Recommendations

Class I

- 1. EPDs should be used during SVG PCI when technically feasible.^{532–535} (Level of Evidence: B)**

Class III: NO BENEFIT

- 1. Platelet GP IIb/IIIa inhibitors are not beneficial as adjunctive therapy during SVG PCI.^{212,571,720,721} (Level of Evidence: B)**

Class III: HARM

- 1. PCI is not recommended for chronic SVG occlusions.^{722–724} (Level of Evidence: C)**

See Online Data Supplement 29 for additional data regarding SVG.

Adverse cardiac event rates are doubled after SVG PCI compared with native-artery PCI.⁵³⁶ A distal balloon occlusion EPD decreased the 30-day composite outcome of death, MI, emergency CABG, or target-lesion revascularization (9.6% versus 16.5%) in the only RCT comparing embolic protection with no embolic protection.⁵³² Subsequent noninferiority comparisons have demonstrated similar benefit with proximal occlusion and distal filter EPDs, with benefit limited to reduction in periprocedural MI.^{534,535} PCI in chronic SVG occlusion is associated with low success rates, high complication rates, and poor long-term patency rates.^{722,723} Restenosis and target-vessel revascularization rates are lower with DES compared with BMS, although mortality and stent thrombosis rates are similar.⁷²⁵ The use of covered stents is limited to the treatment of the uncommon complication of SVG perforation. Balloon angioplasty for distal SVG anastomotic stenoses has low restenosis rates,⁷²⁴ so stenting is commonly reserved at this location for suboptimal balloon angioplasty results or restenosis. Routine GP IIb/IIIa inhibitor therapy has not proven beneficial in SVG PCI.⁷²⁰ Fibrinolytic therapy is no longer used for thrombus-containing lesions, but rheolytic or manual aspiration thrombectomy is sometimes employed.

5.8.3. Bifurcation Lesions: Recommendations

Class I

1. **Provisional side-branch stenting should be the initial approach in patients with bifurcation lesions when the side branch is not large and has only mild or moderate focal disease at the ostium.**^{726–729} (Level of Evidence: A)

Class IIa

1. **It is reasonable to use elective double stenting in patients with complex bifurcation morphology involving a large side branch where the risk of side-branch occlusion is high and the likelihood of successful side-branch reaccess is low.**^{730–733} (Level of Evidence: B)

Side-branch occlusion or severe stenosis after stenting the main artery in coronary bifurcation PCI occurs in 8% to 80% of unselected patients.^{732,734} The frequency of side-branch occlusion is related to complex bifurcation morphology (severe and/or long side-branch ostial stenosis, large plaque burden in the side-branch ostium, and/or unfavorable side-branch angulation).^{732,735,736} Side-branch occlusion after PCI is associated with Q-wave and non-Q-wave MI.^{734,735} Therefore, preservation of physiologic flow in the side branch after PCI is important.⁷³⁶ There are 2 bifurcation PCI strategies: provisional stenting (stenting the main vessel with additional balloon angioplasty or stenting of the side branch only in the case of an unsatisfactory result) and elective double stenting of the main vessel and the side branch. When there is an unsatisfactory result in the side branch from the provisional stent in the main branch, sometimes balloon angioplasty alone in the side branch will improve the result and stenting the side branch is not necessary. Some experts have suggested that using the side-

branch balloon alone will distort the main branch stent and thus this always needs to be a kissing balloon inflation.

In patients with low-risk bifurcation lesions (minimal or moderate ostial side-branch disease [$<50\%$ diameter stenosis] of focal length [5 to 6 mm]), provisional stenting yields similar clinical outcome to elective double stenting, with lower incidence of periprocedural biomarker elevation.^{726–729} Conversely, in patients with high-risk bifurcations, elective double stenting is associated with a trend toward higher angiographic success rates, lower in-hospital MACE, and better long-term patency of the side branch compared with provisional stenting.¹⁹³ Culotte, Crush, and T-stent techniques have been studied in RCTs.^{726–729,737} Use of DES yields better outcomes than BMS,⁷³⁸ and sirolimus-eluting stents yield better outcomes than paclitaxel-eluting stents.^{739–742} Clinical evidence supports the use of final kissing balloon inflation after elective double stenting.⁷⁴³

5.8.4. Aorto-Ostial Stenoses: Recommendations

Class IIa

1. **IVUS is reasonable for the assessment of angiographically indeterminant left main CAD.**^{744,745} (Level of Evidence: B)
2. **Use of DES is reasonable when PCI is indicated in patients with an aorto-ostial stenosis.**^{746,747} (Level of Evidence: B)

Aorto-ostial stenoses of native coronary arteries (left main coronary artery and right coronary artery) are most commonly caused by atherosclerosis, but they can also occur in patients with congenital malformations, radiation exposure, vasculitides, and aortic valve replacement. The angiographic diagnosis of aorto-ostial disease is not always straightforward, especially in the ostial left main coronary artery, where eccentricity and angulation can be mistaken for stenosis.^{490,748} Aorto-ostial disease can be evaluated with IVUS^{744,745}; FFR (with IV adenosine) has also been used.^{484,749} The treatment of aorto-ostial stenoses with balloon angioplasty has been associated with lower procedural success rates, more frequent in-hospital complications, and a greater likelihood of late restenosis.⁷⁵⁰ Although atherectomy devices (directional atherectomy, rotational atherectomy, and excimer laser angioplasty) have improved acute angiographic results over balloon angioplasty, restenosis has remained a limitation.⁷⁵¹ In patients with aorto-ostial stenoses undergoing PCI, use of DES has been shown to reduce restenosis compared with BMS.^{176,746,752}

5.8.5. Calcified Lesions: Recommendation

Class IIa

1. **Rotational atherectomy is reasonable for fibrotic or heavily calcified lesions that might not be crossed by a balloon catheter or adequately dilated before stent implantation.**^{514,515,520} (Level of Evidence: C)

The presence of coronary calcification is a marker for significant CAD and increased long-term mortality.⁷⁵³ Calcified coronary lesions are not a homogenous entity, and their response to PCI varies according to severity of calcification.

Severely calcified lesions respond poorly to balloon angioplasty,^{230,754} and when stents are implanted in such lesions, an incomplete and asymmetrical stent expansion occurs in the majority of cases.⁷⁵⁵ Attempts to remedy the underexpanded stents with aggressive high-pressure balloon dilatation may result in coronary artery rupture.⁷⁵⁶ All the published prospective RCTs that evaluated the various catheter-based coronary interventional devices excluded patients with severely calcified lesions. Therefore, the evidence base for best PCI practices in patients with severely calcified lesions comes from nonrandomized single-arm studies. Among the various adjunct devices that are used to facilitate PCI in severely calcified lesions, only rotational atherectomy has been shown to have potential utility.^{514,757} Although rotational atherectomy increases the chances of angiographic success in severely calcified lesions, its use as a stand-alone device has not led to a reduction in restenosis.^{520,521,758} Several retrospective studies have shown that in patients with severely calcified lesions, the use of rotational atherectomy before implantation of BMS⁵¹⁴ or DES⁵¹⁵ is safe. Intermediate-term patency is more favorable with DES than BMS.⁷⁵⁹

5.9. PCI in Specific Patient Populations

Several specific patient subsets with higher risks for PCI, and at times higher absolute clinical benefit, have traditionally been underrepresented in RCTs and are described below.

5.9.1. Elderly

The elderly constitute a growing proportion of patients considered for PCI.⁷⁶⁰ In 1 series examining trends over a 25-year period, the proportion of patients undergoing PCI who were 75 to 84 years of age doubled, and those >85 years of age increased 5-fold.⁷⁶¹ Age is one of the strongest predictors of mortality after PCI,⁷⁶² and elderly patients present with a substantially higher clinical risk profile.⁷⁶⁰ Nonetheless, the angiographic success rates and clinical benefits of PCI in elderly patients are similar to younger patients.⁷⁶³ In fact, the absolute benefit is typically greater because of higher absolute risk of adverse outcomes in these patients.⁷⁶⁴ However, increased risks of complications such as major bleeding and stroke mandate careful consideration of the benefits and risks of PCI in elderly patients.³⁷³

5.9.2. Diabetes

Patients with diabetes represent approximately one third of patients undergoing PCI in the United States. Restenosis, which had been a major limitation of PCI, is significantly reduced in patients with diabetes treated with DES compared with BMS.⁴⁷¹ However, there are no definitive data from RCTs supporting different clinical outcomes for different types of DES,⁷⁶⁵ with a recent meta-analysis of 35 RCTs involving 3852 patients with diabetes unable to find major differences between patients receiving sirolimus-eluting stents or paclitaxel-eluting stents.⁴⁷² Numerous analyses and clinical studies have evaluated how the presence of diabetes may impact the clinical outcome of patients undergoing PCI and decisions about PCI or CABG.^{14,116,163,164,186} These studies and the approach to revascularization decisions in diabetes are addressed in Section 4.

Diabetes is an important risk factor for the development of contrast-induced AKI. Strategies to reduce the risk of contrast-induced AKI in patients with diabetes are discussed in Section 4.4.

5.9.3. Women

Cardiovascular disease is the leading cause of death in women in the United States and Europe,⁷⁶⁶ and an estimated 35% of PCIs in the United States are performed in women.^{767,768} Women undergoing PCI usually have more risk factors (including hypertension, advanced age, elevated cholesterol, and more significant and diffuse CAD) compared with men.⁷⁶⁹ Women with STEMI are also less likely to receive early medical treatments and experience longer delays to reperfusion therapy.^{770,771} In subgroup analyses of clinical trials, use of DES appears to be similarly efficacious in women and men.⁷⁷²

5.9.4. CKD: Recommendation

Class I

1. In patients undergoing PCI, the glomerular filtration rate should be estimated and the dosage of renally cleared medications should be adjusted.^{298–300} (*Level of Evidence: B*)

CKD is an independent risk factor for the development and progression of CAD,^{773,774} and is also associated with worse prognosis after MI or PCI.^{369,775} A glomerular filtration rate of <60 mL/min per 1.73 m² of body surface area should be considered abnormal. Patients with CKD undergoing PCI have a higher risk of complications, including bleeding,⁷⁷⁶ AKI, and death,^{236,777} but CKD is not a strong predictor of restenosis after BMS or DES.⁷⁷⁸ Strategies to reduce the risk of contrast-induced AKI in patients with CKD are discussed in Section 4.4. Platelet dysfunction and overdosing of antiplatelet and antithrombin drugs³⁵⁰ in patients with CKD contribute to the increased risk of bleeding. The Cockcroft-Gault formula is commonly used as a surrogate marker for estimating creatinine clearance, which in turn estimates glomerular filtration rate.^{298,299,779,780} Medications that require dosage adjustments in patients with CKD include eptifibatide, tirofiban, bivalirudin, enoxaparin, and fondaparinux.⁷⁸¹

5.9.5. Cardiac Allografts

Cardiac allograft vasculopathy is a major cause of death in cardiac transplant recipients after their first year of survival.⁷⁸² In general, revascularization for cardiac allograft vasculopathy with PCI is only palliative, with no evidence supporting benefit in regard to long-term survival or avoidance of retransplantation. The restenosis rate after PCI in patients with cardiac allograft vasculopathy is high, although stent implantation reduces early and midterm restenosis compared with balloon angioplasty. DES have been shown to have a tendency to lower restenosis rates compared with BMS.^{783,784} Thus, many clinicians perform stenting with DES or BMS in cardiac transplant patients with discrete lesions who have an abnormal stress test or symptoms suggestive of myocardial ischemia.

5.10. Periprocedural MI

Assessment: Recommendations

Class I

1. In patients who have signs or symptoms suggestive of MI during or after PCI or in asymptomatic patients with significant *persistent* angiographic complications (eg, large side-branch occlusion, flow-limiting dissection, no-reflow phenomenon, or coronary thrombosis), creatine kinase-MB and/or troponin I or T should be measured. (*Level of Evidence: C*)

Class IIb

1. Routine measurement of cardiac biomarkers (creatinine kinase-MB and/or troponin I or T) in all patients after PCI may be reasonable. (*Level of Evidence: C*)

Major events leading to ischemia or MI after PCI include acute closure, embolization and no-reflow, side-branch occlusion, and acute stent thrombosis. Issues surrounding the routine assessment of cardiac biomarkers after PCI are complex, especially given that the definition of PCI-related MI has evolved over the years and most events are asymptomatic. The most recent consensus definition of MI considers troponin elevations of 3 times the upper limit of normal as a PCI-related MI in patients with normal baseline levels; this is further classified as a type 4a MI.²⁴⁰ This definition is supported by studies with delayed-enhancement MRI confirming that there is irreversible injury in the myocardium associated with biomarker elevations and that the size of this injury correlates with the degree of elevation.⁷⁸⁵ Furthermore, a meta-analysis of 15 observational studies found that troponin elevations at any level were linked with worse in-hospital and long-term outcomes; elevations >3 times the upper limit of normal predicted even worse outcomes.²⁴² Other observational data, however, have raised concerns about whether the relationship is causal.^{786,787} A recent study found creatinine kinase-MB to correlate better with MRI-detected MI than troponin level.⁷⁸⁸ Definitions of PCI-related MI are being reevaluated by the Task Force for the Redefinition of Myocardial Infarction. Although there may be value for individual operators and hospitals to routinely measure cardiac biomarkers to track rates of PCI-related MI, at present there are not compelling data to recommend this for all PCI procedures.

5.11. Vascular Closure Devices: Recommendations

Class I

1. Patients considered for vascular closure devices should undergo a femoral angiogram to ensure their anatomic suitability for deployment. (*Level of Evidence: C*)

Class IIa

1. The use of vascular closure devices is reasonable for the purposes of achieving faster hemostasis and earlier ambulation compared with the use of manual compression.^{257,789–791} (*Level of Evidence: B*)

Class III: NO BENEFIT

1. The routine use of vascular closure devices is not recommended for the purpose of decreasing vascular complications, including bleeding.^{256,257,789–792} (*Level of Evidence: B*)

See Online Data Supplement 30 for additional data regarding vascular closure devices.

Vascular (arteriotomy) closure devices have been extensively reviewed,⁷⁹⁰ most recently in a 2010 AHA scientific statement,²⁵⁷ which issued several formal recommendations. The results of 4 meta-analyses have found that vascular closure devices decrease time to hemostasis compared with manual compression but do not decrease vascular complications, bleeding complications, or the need for blood transfusions.^{256,789,791,793} Future studies of vascular closure devices need to be randomized, include “high-risk” patients and “high-risk” anatomy, use blinded endpoint adjudication as much as possible, use well-defined and comprehensive complication endpoints, and be adequately powered to detect clinically important endpoints, particularly bleeding and vascular complications.

6. Postprocedural Considerations

Postprocedural considerations in patients undergoing PCI are discussed below and summarized in Table 14. Some recommendations and text regarding DAPT in Section 5.7.2 are intentionally repeated in this section for reader ease of use.

6.1. Postprocedural Antiplatelet Therapy: Recommendations

Class I

1. After PCI, use of aspirin should be continued indefinitely.^{560–563} (*Level of Evidence: A*)
2. The duration of P2Y₁₂ inhibitor therapy after stent implantation should generally be as follows:
 - a. In patients receiving a stent (BMS or DES) during PCI for ACS, P2Y₁₂ inhibitor therapy should be given for at least 12 months. Options include clopidogrel 75 mg daily,⁵⁷⁰ prasugrel 10 mg daily,⁵⁶⁷ and ticagrelor 90 mg twice daily.⁵⁶⁸ (*Level of Evidence: B*)
 - b. In patients receiving DES for a non-ACS indication, clopidogrel 75 mg daily should be given for at least 12 months if the patient is not at high risk of bleeding.^{208,212,571} (*Level of Evidence: B*)
 - c. In patients receiving BMS for a non-ACS indication, clopidogrel should be given for a minimum of 1 month and ideally up to 12 months (unless the patient is at increased risk of bleeding; then it should be given for a minimum of 2 weeks).⁵⁷² (*Level of Evidence: B*)
3. Patients should be counseled on the importance of compliance with DAPT and that therapy should not be discontinued before discussion with their cardiologist.²⁰⁸ (*Level of Evidence: C*)

Table 14. Postprocedural Recommendations for Patients Undergoing PCI

Recommendations	COR	LOE	References
Aspirin			
After PCI, use of aspirin should be continued indefinitely.	I	A	560–563
After PCI, it is reasonable to use aspirin 81 mg/d in preference to higher maintenance doses.	Ia	B	302,573–576
P2Y₁₂ inhibitors			
In patients receiving a stent (BMS or DES) during PCI for ACS, P2Y ₁₂ inhibitor therapy should be given for at least 12 mo. Options include clopidogrel 75 mg/d, prasugrel 10 mg/d, and ticagrelor 90 mg twice daily.	I	B	567,568,570
In patients receiving DES for a non-ACS indication, clopidogrel 75 mg/d should be given for at least 12 mo if patients are not at high risk of bleeding.	I	B	208,212,571
In patients receiving BMS for a non-ACS indication, clopidogrel should be given for a minimum of 1 mo and ideally up to 12 mo (unless the patient is at increased risk of bleeding; then it should be given for a minimum of 2 wk).	I	B	572
Patients should be counseled on the importance of compliance with DAPT and that therapy should not be discontinued before discussion with their cardiologist.	I	C	208
PPIs should be used in patients with a history of prior GI bleeding who require DAPT.	I	C	794
If the risk of morbidity from bleeding outweighs the anticipated benefit afforded by a recommended duration of P2Y ₁₂ inhibitor therapy after stent implantation, earlier discontinuation (eg, <12 mo) of P2Y ₁₂ inhibitor therapy is reasonable.	Ia	C	N/A
Use of PPIs is reasonable in patients with an increased risk of GI bleeding (eg, advanced age, concomitant use of warfarin, steroids, NSAIDs, <i>Helicobacter pylori</i> infection) who require DAPT.	Ia	C	794
Continuation of clopidogrel, prasugrel, or ticagrelor beyond 12 mo may be considered in patients undergoing placement of DES.	Ib	C	N/A
Routine use of a PPI is not recommended for patients at low risk of GI bleeding, who have much less potential to benefit from prophylactic therapy.	III: No Benefit	C	794
Exercise testing			
For patients entering a formal cardiac rehabilitation program after PCI, treadmill exercise testing is reasonable.	Ia	C	567,568
Routine periodic stress testing of asymptomatic patients after PCI without specific clinical indications should not be performed.	III: No Benefit	C	795
Cardiac rehabilitation			
Medically supervised exercise programs (cardiac rehabilitation) should be recommended to patients after PCI, particularly for patients at moderate to high risk, for whom supervised exercise training is warranted.	I	A	796–804
Secondary prevention (recommendations included from the 2011 AHA/ACC Secondary Prevention and Risk Reduction Therapy Guideline)⁸⁰⁵			
Lipid management with lifestyle modification and lipid-lowering pharmacotherapy			
Lifestyle modification	I	B	806,807
Statin therapy	I	A	344,806,808–810,810a
Statin therapy which lowers LDL cholesterol to <100 mg/dL and achieves at least a 30% lowering of LDL cholesterol	I	C	344,806,808–810,810a
Statin therapy which lowers LDL cholesterol to <70 mg/dL in very high-risk* patients	Ia	B	345,808–810,810a,811,812
Blood pressure control (with a blood pressure goal of <140/90 mm Hg)			
Lifestyle modification	I	B	813–817
Pharmacotherapy	I	A	813,818,819
Diabetes management (eg, lifestyle modification and pharmacotherapy) coordinated with the patient's primary care physician and/or endocrinologist	I	C	N/A
Complete smoking cessation	I	A	820–823

*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-HDL cholesterol ≥ 130 mg/dL with low HDL cholesterol [<40 mg/dL]), and 4) acute coronary syndromes.

ACS indicates acute coronary syndromes; BMS, bare-metal stent(s); COR, class of recommendation; DAPT, dual antiplatelet therapy; DES, drug-eluting stent(s); GI, gastrointestinal; HDL, high-density lipoprotein; LDL, low-density lipoprotein; LOE, level of evidence; N/A, not applicable; NSAID, nonsteroidal anti-inflammatory drug; PCI, percutaneous coronary intervention; and PPI, proton pump inhibitor.

Class IIa

1. After PCI, it is reasonable to use aspirin 81 mg per day in preference to higher maintenance doses.^{302,573–576} (Level of Evidence: B)
2. If the risk of morbidity from bleeding outweighs the anticipated benefit afforded by a recommended duration of P2Y₁₂ inhibitor therapy after stent implantation, earlier discontinuation (eg, <12 months) of P2Y₁₂ inhibitor therapy is reasonable. (Level of Evidence: C)

Class IIb

1. Continuation of clopidogrel, prasugrel, or ticagrelor beyond 12 months may be considered in patients undergoing placement of DES.^{567,568} (Level of Evidence: C)

Continued treatment with the combination of aspirin and a P2Y₁₂ inhibitor antagonist after PCI appears to reduce MACE.^{570,572} On the basis of RCT protocols, secondary prevention measures, and expert consensus opinion, aspirin 81 mg daily should be given indefinitely after PCI.

Likewise, P2Y₁₂ inhibitors should be given for a minimum of 1 month after BMS (minimum 2 weeks for patients at significant increased risk of bleeding)⁵⁸⁰ and for 12 months after DES and ideally in all patients who are not at high risk of bleeding.

The 2009 STEMI/PCI guidelines update¹⁰ listed the recommendation “if the risk of morbidity because of bleeding outweighs the anticipated benefit afforded by thienopyridine therapy, earlier discontinuation *should be considered*” as a Class I recommendation, although the language used, in part, was consistent with a Class IIa recommendation. To clarify the intent of the recommendation, as well as to acknowledge the inherent difficulties in weighing bleeding and stent thrombosis risks, the recommendation is designated a Class IIa recommendation, using the phrase “earlier discontinuation *is reasonable*.” Recommendations regarding P2Y₁₂ inhibitor discontinuation before elective or urgent CABG are provided in the “2011 ACCF/AHA Guideline for Coronary Artery Bypass Graft Surgery.”⁸²⁴

6.1.1. PPIs and Antiplatelet Therapy: Recommendations**Class I**

1. PPIs should be used in patients with a history of prior gastrointestinal (GI) bleeding who require DAPT.⁷⁹⁴ (Level of Evidence: C)

Class IIa

1. Use of PPIs is reasonable in patients with an increased risk of GI bleeding (eg, advanced age, concomitant use of warfarin, steroids, nonsteroidal anti-inflammatory drugs, *Helicobacter pylori* infection) who require DAPT.⁷⁹⁴ (Level of Evidence: C)

Class III: NO BENEFIT

1. Routine use of a PPI is not recommended for patients at low risk of GI bleeding, who have much less potential to benefit from prophylactic therapy.⁷⁹⁴ (Level of Evidence: C)

See Online Data Supplement 31 for additional data regarding the clopidogrel–PPI interaction.

PPIs are often prescribed prophylactically when clopidogrel is started to prevent GI complications such as ulceration and bleeding due to DAPT.⁸²⁵ There is pharmacodynamic evidence that omeprazole interferes with clopidogrel metabolism,^{826,827} but there is no clear evidence implicating other PPIs. However, even with omeprazole, there are no convincing data supporting an important clinical drug–drug interaction.⁸²⁶ The FDA communication about an ongoing safety review of clopidogrel advises that healthcare providers avoid the use of clopidogrel in patients with impaired *CYP2C19* function due to known genetic variation or drugs that inhibit *CYP2C19* activity. The FDA notes that there is no evidence that other drugs that reduce stomach acid, such as histamine-2 receptor antagonists (except cimetidine) or antacids, interfere with clopidogrel responsiveness. The COGENT (Clopidogrel and the Optimization of Gastrointestinal Events) trial randomized patients with DAPT to clopidogrel and omeprazole or clopidogrel and placebo, and while there was no difference in cardiovascular events between the 2 groups, GI events were halved in those randomized to omeprazole.⁸²⁸ It is reasonable to carefully evaluate the indication for PPI therapy in patients treated with clopidogrel, based on the presence or absence of the risk factors discussed above.⁷⁹⁴ The need for GI protection increases with the number of risk factors for bleeding. Prior upper GI bleeding is the strongest and most consistent risk factor for GI bleeding on antiplatelet therapy. Patients with ACS and prior upper GI bleeding are at substantial cardiovascular risk, so DAPT with concomitant use of a PPI may provide the optimal balance of risk and benefit. It should be noted that PPIs, by decreasing adverse GI effects related to clopidogrel, might decrease patients' discontinuation of clopidogrel. In patients in whom there is a clear indication for PPI therapy, some clinicians may choose to use a PPI other than omeprazole.

6.1.2. Clopidogrel Genetic Testing: Recommendations**Class IIb**

1. Genetic testing might be considered to identify whether a patient at high risk for poor clinical outcomes is predisposed to inadequate platelet inhibition with clopidogrel.⁸²⁹ (Level of Evidence: C)
2. When a patient predisposed to inadequate platelet inhibition with clopidogrel is identified by genetic testing, treatment with an alternate P2Y₁₂ inhibitor (eg, prasugrel or ticagrelor) might be considered.⁸²⁹ (Level of Evidence: C)

Class III: NO BENEFIT

1. The routine clinical use of genetic testing to screen patients treated with clopidogrel who are undergoing PCI is not recommended.⁸²⁹ (Level of Evidence: C)

On March 12, 2010, the FDA approved a new label for clopidogrel with a “boxed warning” about the diminished effectiveness of clopidogrel in patients with impaired ability to convert the drug into its active metabolite.⁸²⁹ Patients with decreased *CYP2C19* function because of genetic polymorphisms metabolize clopidogrel poorly and have higher rates of cardiovascular events after ACS and PCI than patients with

normal *CYP2C19* function. The warning also notes that tests are available to identify patients with genetic polymorphisms and that alternative treatment strategies should be considered for patients who are poor metabolizers. The clopidogrel boxed warning leaves the issue of whether to perform *CYP2C19* testing up to the individual physician. It does not specifically require genetic testing or other changes in evaluation or treatment and does not imply that there are solid evidence-based reasons for such actions. Rather, it serves to inform clinicians of genetic variations in response to clopidogrel and to emphasize that clinicians should use this knowledge to make decisions about how to treat individual patients. At the present time, the evidence base is insufficient to recommend routine genetic testing in patients undergoing PCI. There may be a potential role for genetic testing for patients undergoing elective high-risk PCI procedures (eg, unprotected left main, bifurcating left main, or last patent coronary artery).

6.1.3. Platelet Function Testing: Recommendations

Class IIb

1. Platelet function testing may be considered in patients at high risk for poor clinical outcomes.⁸²⁹ (*Level of Evidence: C*)
2. In patients treated with clopidogrel with high platelet reactivity, alternative agents, such as prasugrel or ticagrelor, might be considered.⁸²⁹ (*Level of Evidence: C*)

Class III: NO BENEFIT

1. The routine clinical use of platelet function testing to screen patients treated with clopidogrel who are undergoing PCI is not recommended.⁸²⁹ (*Level of Evidence: C*)

Platelet function testing to tailor antiplatelet therapy has received considerable interest. The GRAVITAS (Gauging Responsiveness With A VerifyNow Assay-Impact On Thrombosis And Safety) trial and several other ongoing trials test the concept that tailoring antiplatelet therapy based on platelet responsiveness assessed in an ex vivo P2Y₁₂ assay will improve cardiovascular outcomes.⁸³⁰ In GRAVITAS, treatment with high-dose clopidogrel for 6 months in patients with high platelet reactivity on standard-dose clopidogrel was not beneficial. At the present time, the evidence base is insufficient to recommend routine platelet function testing. The results of 2 ongoing trials (DANTE [Dual Antiplatelet Therapy Tailored on the Extent of Platelet Inhibition] and ARCTIC [Double Randomization of a Monitoring Adjusted Antiplatelet Treatment Versus a Common Antiplatelet Treatment for DES Implantation, and Interruption Versus Continuation of Double Antiplatelet Therapy, One Year After Stenting]) will provide further information on the issue (www.clinicaltrials.gov).

6.2. Stent Thrombosis

The majority of stent thrombosis occurs early (0 to 30 days after PCI). In broad clinical practice, the expected rate of early stent thrombosis is <1%, and beyond 30 days it is 0.2% to 0.6% per year.^{210,831} Acute stent thrombosis often presents as STEMI, and emergency revascularization is indicated.

Acute stent thrombosis is associated with mortality rates of 20% to 45%.⁸³² Survivors are also at risk of recurrent stent thrombosis.⁸³³

Mechanical and pharmacological factors are the most frequent cause of acute stent thrombosis. After the usual measures to restore flow in the infarct-related artery, it is important to consider the etiology of stent thrombosis as it pertains to further therapy and avoidance of recurrence. IVUS may identify factors such as an undersized stent, incomplete stent apposition, residual stenosis, or dissection and can guide subsequent treatment. The most common cause of acute stent thrombosis is nonadherence to DAPT; however, resistance to aspirin or thienopyridines and prothrombotic states such as congenital or acquired thrombophilic states (malignancy) are additional risk factors.^{834,835}

Given the poor prognosis of stent thrombosis and the uncertainties surrounding treatment, the importance of prevention must be emphasized. This includes ensuring compliance with DAPT and adequate stent sizing and expansion.⁸³⁶

6.3. Restenosis: Recommendations

Class I

1. Patients who develop clinical restenosis after balloon angioplasty should be treated with BMS or DES if anatomic factors are appropriate and if the patient is able to comply with and tolerate DAPT.⁸³⁷ (*Level of Evidence: B*)
2. Patients who develop clinical restenosis after BMS should be treated with DES if anatomic factors are appropriate and the patient is able to comply with and tolerate DAPT.^{838–840} (*Level of Evidence: A*)

Class IIa

1. IVUS is reasonable to determine the mechanism of stent restenosis.⁴⁹⁵ (*Level of Evidence: C*)

Class IIb

1. Patients who develop clinical restenosis after DES may be considered for repeat PCI with balloon angioplasty, BMS, or DES containing the same drug or an alternative antiproliferative drug if anatomic factors are appropriate and the patient is able to comply with and tolerate DAPT.⁴⁹⁵ (*Level of Evidence: C*)

6.3.1. Background and Incidence

After balloon angioplasty, mechanisms contributing to restenosis include smooth muscle cell migration and proliferation, platelet deposition, thrombus formation, elastic recoil, and negative arterial remodeling. Stents block elastic recoil and negative remodeling, and the predominant mechanism for restenosis after stent implantation is neointimal hyperplasia. Restenosis rates vary, depending on whether angiographic restenosis (defined as >50% diameter stenosis at follow-up angiography) or clinical restenosis (symptomatic and requiring target-lesion revascularization or target-vessel revascularization) is measured, as well as on patient characteristics, coronary anatomy considerations, and device type (balloon angioplasty, BMS, or DES). The incidence of angiographic restenosis rates for uncomplicated lesions treated in RCTs

ranges from 32% to 42% after balloon angioplasty^{463,464} and from 16% to 32% after BMS,^{463,464} and is generally <10% after DES.^{454,841} Less than half of patients with angiographic restenosis present with symptomatic, clinically relevant restenosis at 1-year follow-up, and a pooled analysis of 6186 patients from 6 trials of BMS showed target-lesion revascularization was performed in 12% and target-vessel revascularization in 14% at 1 year.^{842,843} Patients with clinical restenosis typically present with recurrent exertional angina, but 5% to 10% of patients present with acute MI and 25% with UA.^{844,845}

Factors associated with an increased risk of restenosis in various models include clinical setting (STEMI, ACS, daily angina), patient characteristics (diabetes, age <55 to 60 years, prior PCI, male sex, multivessel CAD), lesion location (unprotected left main, SVG), and procedural characteristics (minimum stent diameter ≤ 2.5 mm, total stent length ≥ 40 mm).^{778,846}

PCI strategies for treating restenosis after balloon angioplasty, BMS, and DES are reviewed in the following sections. In addition to repeat PCI, intensified medical therapy or CABG are often also reasonable strategies, dependent on initial treatment (eg, balloon angioplasty, BMS), pattern of restenosis, likelihood of recurrent restenosis, ability to intensify medical therapy, suitability for CABG, and patient preference. Repeat PCI with BMS or DES is not appropriate if the patient is not able to comply with and tolerate DAPT.

6.3.2. Restenosis After Balloon Angioplasty

For clinical restenosis after balloon angioplasty, stent implantation is superior to repeat balloon angioplasty or atheroablation devices. The REST (REstenosis STent) study showed that target-lesion revascularization rates were 10% for stent-treated patients and 27% for balloon-treated patients ($P=0.001$).⁸³⁷

6.3.3. Restenosis After BMS

In-stent restenosis is classified according to these angiographic characteristics: Pattern I includes focal lesions ≤ 10 mm in length; Pattern II is in-stent restenosis >10 mm within the stent; Pattern III includes in-stent restenosis >10 mm extending outside the stent; and Pattern IV is totally occluded in-stent restenosis.⁸⁴⁷ Treatment of in-stent restenosis with balloon angioplasty, repeat BMS, or atheroablation devices for Patterns I to IV resulted in 1-year target-lesion revascularization rates of 19%, 35%, 50%, and 83%, respectively. For clinical restenosis after BMS, repeat stenting with DES is preferred. Studies have demonstrated lower recurrent restenosis rates with DES compared with BMS or vascular brachytherapy.^{495,838–840}

6.3.4. Restenosis After DES

Clinical restenosis after placement of DES is becoming increasingly common due to the large numbers of patients who have been treated with DES. The predominant angiographic pattern for DES in-stent restenosis is focal (≤ 10 mm in length). Several biologic, mechanical, and technical factors may contribute to DES in-stent restenosis, including drug resistance, hypersensitivity, stent underexpansion, stent strut fracture, nonuniform stent strut coverage, gap in stent cover-

age, and residual uncovered atherosclerotic lesion. IVUS might be considered to determine the cause for in-stent restenosis and help guide treatment strategy. Interventionists may treat focal DES restenosis with balloon angioplasty and treat nonfocal DES restenosis with BMS, CABG, or repeat DES with the same or an alternative antiproliferative drug.^{848,849} Small, observational cohort studies have demonstrated angiographic restenosis rates of 25% to 30% with repeat DES either with the same or an alternative drug.^{495,849,850} There are no RCTs, and the most appropriate treatment of restenosis of DES remains unknown.

6.4. Clinical Follow-Up

At the time of discharge, patients are instructed to contact their physician or seek immediate medical attention if symptoms recur. Most physicians will give the patient instructions on return to work and timing of return to full activities. The importance of strict compliance with aspirin and P2Y₁₂ inhibitor therapy is ideally emphasized to the patient at the time of discharge and during follow-up visits.

Secondary prevention measures after PCI are an essential part of long-term therapy, reducing both future morbidity and mortality associated with CAD, and are discussed in Section 6.5. A follow-up visit after PCI is usually scheduled to assess the patient's clinical status, the patient's compliance with secondary prevention therapies, and the success of secondary prevention measures (eg, blood pressure control, low-density lipoprotein levels, smoking cessation). Routine, periodic stress testing of asymptomatic patients is not considered part of standard patient follow-up.

6.4.1. Exercise Testing: Recommendations

Class IIa

1. In patients entering a formal cardiac rehabilitation program after PCI, treadmill exercise testing is reasonable. (Level of Evidence: C)

Class III: NO BENEFIT

1. Routine periodic stress testing of asymptomatic patients after PCI without specific clinical indications should not be performed.⁷⁹⁵ (Level of Evidence: C)

Treadmill exercise testing before cardiac rehabilitation provides information about peak exercise capacity and heart rate, helping to stratify patients for the level of supervision during training, and seems reasonable for this purpose⁸⁵¹; nuclear imaging to assess ischemia in this context usually adds little.

The role of exercise testing to evaluate restenosis is much less certain. Although the presence of symptoms may not be a reliable means of detecting restenosis, there is no evidence that the detection of silent restenosis leads to improved outcome.^{852,853} Routine testing of all patients after PCI will also lead to many false-positive tests, particularly in the era of DES. As restenosis rates decline from 30% to 10%, the false-positive rate of stress imaging increases from 37% to 77%.⁸⁵⁴ A recent analysis of a national health insurance claims database and accompanying editorial find that stress testing after PCI is likely overused and rarely leads to repeat revascularization.^{855,856} In summary, there is no proven ben-

efit or indication for routine periodic stress testing in patients after PCI, and, thus, it is not indicated.^{8,851} In cases in which there is a clear clinical indication for stress testing in a patient after PCI, exercise ECG alone is an insensitive predictor of restenosis^{857,858}; therefore, stress imaging is the preferred stress test.⁸ In cases of recurrent angina after PCI in which the pretest likelihood of restenosis is high and repeat revascularization based on symptoms is likely indicated, most practitioners will proceed directly to cardiac catheterization rather than first obtain stress imaging.

6.4.2. Activity and Return to Work

The timing of return to physical activity depends on the presenting condition as well as previous functional status. For STEMI, for example, daily walking is encouraged immediately, and driving can begin within 1 week after uncomplicated MI if allowed by local motor vehicle laws.⁸⁵⁹ Sexual activity usually can be resumed within days, provided exercise tolerance is adequate, normally assessed by the ability to climb a flight of stairs.⁸⁵⁹ Similar recommendations have been issued for UA/NSTEMI.⁸⁶⁰ Patients with UA who have undergone successful revascularization and are otherwise doing well may return to physical activity on an accelerated schedule, usually within a few days.⁸⁶⁰

Return to work is more complex. Return to work rates after MI range from 63% to 94% and are confounded by factors such as job satisfaction, financial stability, and company policies.⁸⁶¹ The physical demands and degree of stress of a particular job require that recommendations be individualized. In the PAMI-2 (Primary Angioplasty in Myocardial Infarction) trial, patients were encouraged to return to work 2 weeks after primary PCI for STEMI, and no adverse events were reported.⁸⁶² In the RITA (Randomized Intervention Treatment of Angina) trial, revascularization with PCI led to earlier return to work compared with CABG, and subsequent employment rates were associated with relief of angina.¹⁰⁵ Many practitioners use graded exercise treadmill testing to determine the safety of activity and return to work by measuring the metabolic equivalent of task (MET) level achieved and comparing that level to energy levels required to perform different activities.⁸⁶³

6.4.3. Cardiac Rehabilitation: Recommendation

Class I

1. Medically supervised exercise programs (cardiac rehabilitation) should be recommended to patients after PCI, particularly for moderate- to high-risk patients for whom supervised exercise training is warranted.^{796–804} (Level of Evidence: A)

Participation in cardiac rehabilitation is associated with significant reductions in all-cause mortality (OR: 0.80, 95% CI: 0.68 to 0.93) and cardiac mortality.^{796,797} Reports from community-based surveys, which in general enroll older and higher-risk patients than clinical trials, have confirmed that participation in comprehensive rehabilitation is independently associated with a reduction in recurrent MI and reduced mortality.⁷⁹⁹ Cardiac rehabilitation is also associated with improvements in exercise tolerance, cardiac symptoms,

lipid levels, cigarette smoking cessation rates (in conjunction with a smoking cessation program), stress levels, improved medical regimen compliance, and improved psychosocial well-being.⁸⁰⁰ Cardiac rehabilitation is cost-effective as well.⁸⁶⁴ Physician referral may be the most powerful predictor of patient participation in a cardiac rehabilitation program.⁸⁶⁵

6.5. Secondary Prevention

The treatment of the patient does not end with PCI; secondary prevention measures are a critical component of patient management. Important secondary prevention measures were presented in detail in the “2006 AHA/ACC Guidelines for Secondary Prevention for Patients With Coronary and Other Atherosclerotic Vascular Disease”⁵⁶² and have recently been updated in the “AHA/ACCF Secondary Prevention and Risk Reduction Therapy for Patients With Coronary and Other Atherosclerotic Vascular Disease: 2011 Update.”⁸⁰⁵ The reader is referred to this document for detailed discussions of secondary prevention. Among the important recommendations are the following:

- Lipid management with lifestyle modification (Class I; Level of Evidence: B)^{805–807} and statin therapy are recommended. (Level of Evidence: A)^{344,806,808–810,810a} An adequate statin dose should be employed which reduces low-density lipoprotein cholesterol to <100 mg/dL AND achieves at least a 30% lowering of low-density lipoprotein cholesterol. (Class I; Level of Evidence: C)^{806–810,810a} It is reasonable to treat patients with statin therapy which lowers low-density lipoprotein cholesterol to <70 mg/dL in very high risk* patients. (Class IIa; Level of Evidence: C)^{345,808–810,810a,811,812} Patients who have triglycerides ≥200 mg/dL should be treated with statins to lower non-high-density lipoprotein cholesterol to <130 mg/dL. (Class I; Level of Evidence: B)^{344,809,810,866} In patients who are very high risk* and have triglycerides ≥200 mg/dL, a non-high-density lipoprotein cholesterol goal of <100 mg/dL is reasonable. (Class IIa; Level of Evidence: C)^{344,809,810,866}
- Blood pressure control with lifestyle modification (Class I; Level of Evidence: B)^{813–817} and pharmacotherapy (Class I; Level of Evidence: A),^{805,813,818,819} with the goal of blood pressure <140/90 mm Hg.
- Diabetes management (eg, lifestyle modification and pharmacotherapy), coordinated with the patient’s primary care physician and/or endocrinologist. (Class I; Level of Evidence: C)⁸⁰⁵
- Advising patients on the need for complete smoking cessation. (Class I; Level of Evidence: A)^{805,820–823}

7. Quality and Performance Considerations

7.1. Quality and Performance: Recommendations

Class I

1. Every PCI program should operate a quality-improvement program that routinely 1) reviews

*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.

quality and outcomes of the entire program; 2) reviews results of individual operators; 3) includes risk adjustment; 4) provides peer review of difficult or complicated cases; and 5) performs random case reviews. (*Level of Evidence: C*)

2. Every PCI program should participate in a regional or national PCI registry for the purpose of benchmarking its outcomes against current national norms. (*Level of Evidence: C*)

PCI quality and performance considerations are defined by attributes related to structure, processes, and risk-adjusted outcomes. Structural attributes include elements such as equipment, supplies, staffing, institutional and operator-level volumes, and the availability of electronic medical records. Processes include strategies for the appropriate patient, protocols for pre- and postprocedural care, appropriate procedural execution and management of complications, and participation in databases and registries for benchmarking performance of the program and individual operator. Risk-adjusted outcomes are the end result of these structures and processes of care, and when available are more reliable measures of quality than the institutional and individual operator volumes discussed in Section 7.4.

PCI process and outcomes assessments can be used for internal quality-improvement efforts and public reporting. Public reporting of institutional risk-adjusted outcomes is becoming more common. Although operator-level outcomes can be assessed and risk adjusted, the results are much less reliable due to lack of statistical power resulting from lower volumes. Any public reporting must use statistical methods that meet the high criteria established by the AHA Work Group.⁸⁶⁷

7.2. Training

The cognitive knowledge and technical skill required to perform PCI continue to grow. Details on the training required for interventional cardiology are found in the most recent ACCF Core Cardiology Training Statement.⁸⁶⁸

7.3. Certification and Maintenance of Certification: Recommendation

Class IIa

1. It is reasonable for all physicians who perform PCI to participate in the American Board of Internal Medicine interventional cardiology board certification and maintenance of certification program. (*Level of Evidence: C*)

The American Board of Internal Medicine established interventional cardiology board certification in 1999 as an “added qualification” to the cardiovascular disease board certification. Since 1990 all certificates from the American Board of Internal Medicine are time limited for a 10-year period and require all diplomats to participate in maintenance of certification to maintain their board-certified status. Maintenance of certification in interventional cardiology requires physicians to document a minimum of 150 interventional cases over the 2 years before expiration of the current certification, complete

self-assessment modules of their medical knowledge, participate in practice-based quality-improvement activities, and pass a secure, knowledge-based examination.^{869–871} For those who cannot meet the case volume requirement, an alternative option is to submit a log of 25 consecutive cases including patient characteristics and procedural outcomes. The maintenance of certification process is likely to change, as the American Board of Internal Medicine intends to evolve maintenance of certification from an episodic event that occurs once every 10 years to a more continuous process of continuous professional development.

7.4. Operator and Institutional Competency and Volume: Recommendations

Class I

1. Elective/urgent PCI should be performed by operators with an acceptable annual volume (≥ 75 procedures) at high-volume centers (>400 procedures) with on-site cardiac surgery.^{872,873} (*Level of Evidence: C*)
2. Elective/urgent PCI should be performed by operators and institutions whose current risk-adjusted outcomes statistics are comparable to those reported in contemporary national data registries. (*Level of Evidence: C*)
3. Primary PCI for STEMI should be performed by experienced operators who perform more than 75 elective PCI procedures per year and, ideally, at least 11 PCI procedures for STEMI per year. Ideally, these procedures should be performed in institutions that perform more than 400 elective PCIs per year and more than 36 primary PCI procedures for STEMI per year.^{872,874–877} (*Level of Evidence: C*)

Class IIa

1. It is reasonable that operators with acceptable volume (≥ 75 PCI procedures per year) perform elective/urgent PCI at low-volume centers (200 to 400 PCI procedures per year) with on-site cardiac surgery.⁸⁷² (*Level of Evidence: C*)
2. It is reasonable that low-volume operators (<75 PCI procedures per year) perform elective/urgent PCI at high-volume centers (>400 PCI procedures per year) with on-site cardiac surgery. Ideally, operators with an annual procedure volume of fewer than 75 procedures per year should only work at institutions with an activity level of more than 600 procedures per year. Operators who perform fewer than 75 procedures per year should develop a defined mentoring relationship with a highly experienced operator who has an annual procedural volume of at least 150 procedures per year. (*Level of Evidence: C*)

Class IIb

1. The benefit of primary PCI for STEMI patients eligible for fibrinolysis when performed by an operator who performs fewer than 75 procedures per year (<11 PCIs for STEMI per year) is not well established. (*Level of Evidence: C*)

Class III: NO BENEFIT

1. It is not recommended that elective/urgent PCI be performed by low-volume operators (<75 procedures per year) at low-volume centers (200 to 400 procedures per year) with or without on-site cardiac surgery. An institution with a volume of fewer than 200 procedures per year, unless in a region that is underserved because of geography, should carefully consider whether it should continue to offer this service.⁸⁷² (Level of Evidence: C)

Older observational evidence supported a volume-outcome relationship in PCI at both the institutional and operator level.⁸⁷³ However, this relationship is complicated and may be inconsistent across low-volume institutions or operators. More recent data on primary PCI suggest that operator experience may modify the volume-outcome relationship at the institutional level.^{876,878} Risk-adjusted outcomes remain preferable to institutional and individual operator volumes as quality measures.

Operator and hospital volume recommendations have been carried over from the 2005 PCI guideline. However, the writing committee recognizes that these volume recommendations are controversial. In addition, after extensive review of all relevant data, the writing committee believes that the LOE in support of all the above recommendations is best categorized as LOE C rather than LOE B as it has been in prior guidelines for some recommendations. We encourage the ACCF/AHA/ACP Clinical Competence and Training writing group for PCI and other expert writing groups to review this issue so that new recommendations can be considered by the next PCI guideline writing committee.

7.5. Participation in ACC NCDR or National Quality Database

Assessment of PCI quality and outcomes is important both at the level of the entire program and at the level of the individual physician. This requires collection of clinical and procedural data for PCI that allows regular comparison of risk-adjusted outcomes and complications with national benchmarks. The ACC NCDR CathPCI Registry is an example of a national registry to fulfill the goals of assessing and benchmarking quality and outcomes.

8. Future Challenges

Although this latest guideline reflects significant advancements in the field of PCI, there remain future challenges to the formulation and updating of guidelines for PCI. The proliferation of studies comparing the many newer drugs and devices with older therapies (or other newer therapies), often using different or novel study endpoints, endpoint definitions, and noninferiority designs, pose increasing challenges to objectively evaluating newer therapies and generating recommendations for their use. Numerous potential advances in the field of PCI, including intracoronary stem cell infusions for chronic and acute ischemic heart disease, designer drugs, novel intracoronary imaging technologies such as optical coherence tomography and virtual histology, new stent composition and designs (eg, drug-eluting, biodegradable, bifur-

cation), and drug-eluting balloons were considered for formal evaluation by the current writing committee, but it was thought that there were insufficient data at present to formulate any formal recommendations on these topics. These and other emerging technologies and treatments will need to be addressed in future PCI guidelines.

Finally, with this proliferation of new technology, the amount of data generated in the evaluation of these potential therapeutic advances will grow dramatically, adding significant challenges to future guideline generations. Of note, the Web site www.clinicaltrials.gov currently lists several hundred PCI-related clinical trials.

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KEY WORDS: AHA Scientific Statements ■ acute coronary syndromes ■ anticoagulants ■ antiplatelet agents ■ antiplatelet agents ■ arrhythmias, cardiac ■ coronary artery revascularization interventions: stents ■ coronary angiography ■ drug therapy ■ drug delivery systems ■ heart diseases ■ myocardial revascularization ■ platelet aggregation inhibitor ■ ultrasound

Appendix 1. Author Relationships With Industry and Other Entities (Relevant)—2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention

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 Number*
Glenn N. Levine (Chair)	Baylor College of Medicine—Professor of Medicine; Director, Cardiac Care Unit	None	None	None	None	None	None	None
Eric R. Bates (Vice Chair)	University of Michigan—Professor of Medicine	<ul style="list-style-type: none"> • Bristol-Myers Squibb • Daiichi-Sankyo • Datascope • Eli Lilly • Merck • Sanofi-aventis 	None	None	None	None	None	5.7.2 5.7.3 5.7.4.1 5.7.4.2 5.7.4.3 5.7.4.4 5.7.4.5 6.1 6.1.2 6.1.3
James C. Blankenship (Vice Chair)	Geisinger Medical Center—Director of Cardiology and Cardiac Catheterization Laboratories	None	None	None	<ul style="list-style-type: none"> • Abiomed • AstraZeneca • Boston Scientific • Conor Medsystems • Kai Pharmaceutical • Schering-Plough 	None	None	2.1 2.2 2.3 2.9.7 2.11 5.2.4 5.3 5.4.1 5.4.2 5.8.4 6.3
Steven R. Bailey	University of Texas Medical Center—Professor of Medicine and Radiology	<ul style="list-style-type: none"> • Volcano 	None	None	<ul style="list-style-type: none"> • Boston Scientific 	None	None	5.4.1 5.4.2
John A. Bittl	Munroe Heart-Interventional Cardiologist	None	None	None	None	None	None	None
Bojan Cercek	Cedars-Sinai Medical Center—Director, Coronary Care Unit	None	None	None	None	None	None	None
Charles E. Chambers	Penn State Milton S. Hershey Medical Center—Professor of Medicine and Radiology	None	None	None	None	None	None	None
Stephen G. Ellis	Cleveland Clinic Foundation—Section Head, Invasive and Interventional Cardiology	<ul style="list-style-type: none"> • Abbott Vascular • Boston Scientific • Cordis • Daiichi-Sankyo • Eli Lilly 	None	None	<ul style="list-style-type: none"> • Abbott Vascular 	None	None	2.2 2.11 5.7.2 6.1
Robert A. Guyton	Emory Clinic, Inc.—Professor and Chief, Division of Cardiothoracic Surgery	None	None	None	<ul style="list-style-type: none"> • Edwards Lifesciences 	None	None	2.1 2.2 2.3 2.9.7 2.11 5.2.4 5.3 5.5.5 6.2 6.3
Steven M. Hollenberg	Cooper University Hospital—Director, Coronary Care Unit	<ul style="list-style-type: none"> • Eisai 	None	None	None	None	None	5.7.4.3
Umesh N. Khot	CV Research Innovations, LLC—President/CEO	None	None	<ul style="list-style-type: none"> • Merck† 	None	None	None	4.6 5.7.3
Richard A. Lange	University of Texas Health Science Center at San Antonio—Professor of Medicine	None	None	None	None	None	None	None

(Continued)

Appendix 1. Continued

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 Number*
Laura Mauri	Brigham and Women's Hospital-Associate Professor of Medicine, Harvard Medical School	<ul style="list-style-type: none"> Abbott Conor Medsystems (Johnson & Johnson) Cordis Medtronic 	None	None	<ul style="list-style-type: none"> Lutonix 	<ul style="list-style-type: none"> Abbott Abiomed Boston Scientific Bristol-Myers Squibb Conor Medsystems Cordis Daichi-Sankyo Eli Lilly Medtronic Cardiovascular Sanofi-aventis 	<ul style="list-style-type: none"> Defendant, Conor, interpretation of clinical trial results, 2010 	2.9.7 5.2.3 5.3 5.4.2 5.5.1 5.5.2 5.5.4 5.5.5 5.6 5.7.2 5.7.3 5.8.2 5.8.4 5.8.5 5.11 6.1 6.1.2 6.1.3 6.2
Roxana Mehran	Columbia University Medical Center-Associate Professor of Medicine; Director, Data Coordinating Analysis Center	<ul style="list-style-type: none"> Abbott Vascular Abiomed AlphaMedical AstraZeneca Bracco BMS/sanofi-aventis DataScope Eli Lilly/Daichi-Sankyo Guerbet The Medicines Company Medtronic Vascular St. Jude 	None	None	None	None	None	4.7 5.1 5.2.4 5.3 5.4.1 5.4.2 5.5.1 5.5.2 5.6 5.7.2 5.7.3 5.7.4.1 5.7.4.2 5.7.4.3 5.7.4.4 5.7.4.5 5.8.3 5.8.4 5.11 6.1 6.1.1 6.1.2 6.1.3
Issam D. Moussa	Mayo Clinic-Professor of Medicine; Chair, Division of Cardiovascular Diseases	None	None	None	None	None	None	None
Debabrata Mukherjee	Texas Tech University-Chief, Cardiovascular Medicine	None	None	None	None	None	None	None
Brahmajee K. Nallamothu	University of Michigan-Assistant Professor of Medicine	None	None	None	None	None	None	None
Henry H. Ting	Mayo Clinic-Professor of Medicine; Assistant Dean for Quality	None	None	None	None	None	None	None

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

†Significant relationship.

Appendix 2. Reviewer Relationships With Industry and Other Entities (Relevant)—2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention

Peer Reviewer	Representation	Consultant	Speaker's Bureau	Ownership/ Partnership/ Principal	Personal Research	Institutional, Organizational, or Other Financial Benefit	Expert Witness
Deepak L. Bhatt	Official Reviewer—AHA	None	None	None	<ul style="list-style-type: none"> • AstraZeneca* • Bristol-Myers Squibb* • Eisai* • Eli Lilly • Ethicon* • The Medicines Company* • PLx Pharma† • Sanofi-aventis* 	None	None
Mauricio G. Cohen	Official Reviewer—AHA	<ul style="list-style-type: none"> • AstraZeneca* • Momenta Pharma • Xoma 	<ul style="list-style-type: none"> • Terumo Medical 	None	<ul style="list-style-type: none"> • Invitrox* 	None	None
John P. Erwin III	Official Reviewer—ACCF/AHA Task Force on Performance Measures	None	None	None	None	None	None
Kirk Garratt	Official Reviewer—SCAI	<ul style="list-style-type: none"> • Boston Scientific • Cordis/Johnson & Johnson • The Medicines Company 	<ul style="list-style-type: none"> • Boston Scientific • BMS/sanofi-aventis* • Daiichi-Sankyo/Eli Lilly* • Medtronic • The Medicines Company 	<ul style="list-style-type: none"> • Abbott Vascular • Boston Scientific 	None	None	None
Steven L. Goldberg	Official Reviewer—SCAI	<ul style="list-style-type: none"> • AGA 	<ul style="list-style-type: none"> • Bristol-Myers Squibb • Sanofi-aventis 	None	None	None	<ul style="list-style-type: none"> • Plaintiff, patient litigation, 2010
Alice K. Jacobs	Official Reviewer—ACCF/AHA Task Force on Practice Guidelines	None	None	<ul style="list-style-type: none"> • Wyeth* 	<ul style="list-style-type: none"> • Abbott Vascular* • Abiomed* • Accumetrics* • Cardiovascular Research Foundation (DSMB)† • Harvard Clinical Research Institute† • TIMI Study Group (DSMB)† 	None	None
G.B. John Mancini	Official Reviewer—ACCF Board of Governors	<ul style="list-style-type: none"> • GlaxoSmithKline • Merck • Pfizer • Sanofi-aventis 	None	None	<ul style="list-style-type: none"> • Merck* 	None	None

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Appendix 2. Continued

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W. Douglas Weaver	Official Reviewer—ACCF Board of Trustees	None	None	None	<ul style="list-style-type: none"> Boehringer Ingelheim (DSMB) Boston Scientific (DSMB) Duke Clinical Research Institute (Johnson & Johnson/Schering Plough)* GlaxoSmithKline NHLBI (DSMB) TIMI Study Group (Johnson & Johnson/Bayer—DSMB) 	None	None
Thomas M. Bashore	Content Reviewer	None	None	None	None	None	None
Christopher E. Buller	Content Reviewer	<ul style="list-style-type: none"> Abbott Vascular Toshiba Medical 	None	None	<ul style="list-style-type: none"> Novartis Regado Biosciences 	None	None
James A. Burke	Content Reviewer—ACCF Interventional Scientific Council	None	None	None	None	None	None
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T. Bruce Ferguson	Content Reviewer—ACCF Surgeons' Scientific Council	None	None	None	<ul style="list-style-type: none"> Novadaq Technologies* 	None	None
Victor A. Ferrari	Content Reviewer	None	None	None	<ul style="list-style-type: none"> NHLBI (DSMB)† National Institute for Aging/NIH (DSMB)† 	None	None
John G. Harold	Content Reviewer	None	None	None	None	None	None
Biswajit Kar	Content Reviewer	None	None	None	<ul style="list-style-type: none"> AstraZeneca† Boston Scientific† Medtronic† 	<ul style="list-style-type: none"> VA Cooperative Study† 	None
Morton J. Kern	Content Reviewer	<ul style="list-style-type: none"> Infraredex Merit Medical* 	<ul style="list-style-type: none"> St. Jude Medical* Volcano Therapeutics* 	None	None	None	None
Spencer B. King III	Content Reviewer	<ul style="list-style-type: none"> Celonova Biosciences† 	None	None	<ul style="list-style-type: none"> Merck (DSMB) Wyeth (DSMB) 	None	None
Frederick G. Kushner	Content Reviewer	None	None	None	<ul style="list-style-type: none"> Novartis† 	None	None
David J. Maron	Content Reviewer	None	None	<ul style="list-style-type: none"> Cardiovascular Care Affiliates* 	None	None	<ul style="list-style-type: none"> Plaintiff, acute coronary syndrome, 2010
Douglass A. Morrison	Content Reviewer	None	None	None	None	None	None

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R. Scott Wright	Content Reviewer	• Hoffman LaRoche*	None	None	None	None	None

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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*.

*Significant relationship.

†No financial benefit.

ACCF indicates American College of Cardiology Foundation; AHA, American Heart Association; DSMB, data safety and monitoring board; NHLBI, National Heart, Lung, and Blood Institute; NIH, National Institutes of Health; SCAI, Society for Cardiovascular Angiography and Interventions; and TIMI, Thrombolysis In Myocardial Infarction.

Appendix 3. Abbreviation List

ACS	=	acute coronary syndromes
AKI	=	acute kidney injury
BMS	=	bare-metal stent(s)
CABG	=	coronary artery bypass graft surgery
CAD	=	coronary artery disease
CKD	=	chronic kidney disease
CTO	=	chronic total occlusion
DAPT	=	dual antiplatelet therapy
DES	=	drug-eluting stent(s)
ECG	=	electrocardiogram
EF	=	ejection fraction
EPD	=	embolic protection device
FDA	=	US Food and Drug Administration
FFR	=	fractional flow reserve
GDMT	=	guideline-directed medical therapy
GI	=	gastrointestinal
GP	=	glycoprotein
IABP	=	intra-aortic balloon pump
IV	=	intravenous
IVUS	=	intravascular ultrasound
LAD	=	left anterior descending
LIMA	=	left internal mammary artery
LV	=	left ventricular
LVEF	=	left ventricular ejection fraction
MACE	=	major adverse cardiac event
MI	=	myocardial infarction
MRI	=	magnetic resonance imaging
NCDR	=	National Cardiovascular Data Registry
PCI	=	percutaneous coronary intervention
PPI	=	proton pump inhibitor
RCT	=	randomized controlled trial
SIHD	=	stable ischemic heart disease
STEMI	=	ST-elevation myocardial infarction
SVG	=	saphenous vein graft
TIMI	=	Thrombolysis In Myocardial Infarction
TMR	=	transmyocardial laser revascularization
UA/NSTEMI	=	unstable angina/non-ST-elevation myocardial infarction
UFH	=	unfractionated heparin

Appendix 4. Additional Tables/Figures

Appendix 4A. The NCDR CathPCI Risk Score System

Variable	Scoring Response Categories				Risk Score Calculation	
					Total Points	Risk of In-Patient Mortality (%)
Age	<60	≥60, <70	≥70, <80	≥80	0	0.0
	0	4	8	14	5	0.1
Cardiogenic shock	No	Yes			10	0.1
	0	25			15	0.2
Prior CHF	No	Yes			20	0.3
	0	5			25	0.6
Peripheral vascular disease	No	Yes			30	1.1
	0	5			35	2.0
Chronic lung disease	No	Yes			40	3.6
	0	4			45	6.3
GFR	<30	30–60	60–90	>90	50	10.9
	18	10	6	0	55	18.3
NYHA functional class IV	No	Yes			60	29.0
	0	4			65	42.7
PCI status (STEMI)	Elective	Urgent	Emergent	Salvage	70	57.6
	12	15	20	38	75	71.2
PCI status (no STEMI)	Elective	Urgent	Emergent	Salvage	80	81.0
	0	8	20	42	85	89.2
					90	93.8
					95	96.5
					100	98.0

CathPCI indicates catheterization percutaneous coronary intervention; CHF, congestive heart failure; GFR, glomerular filtration rate; NCDR, National Cardiovascular Data Registry; NYHA, New York Heart Association; and STEMI, ST-elevation myocardial infarction. Reproduced with permission from Peterson et al.²³⁶

Appendix 4B. The SCAI Lesion Classification System

Type I lesions (highest success expected, lowest risk)

1. Does not meet criteria for C lesion
2. Patent

Type II lesions

1. Meets any of these criteria for ACC/AHA C lesion
 - Diffuse (>2 cm length)
 - Excessive tortuosity of proximal segment
 - Extremely angulated segments, >90°
 - Inability to protect major side branches
 - Degenerated vein grafts with friable lesions
2. Patent

Type III lesions

1. Does not meet criteria for C lesion
2. Occluded

Type IV lesions

1. Meets any of these criteria for ACC/AHA C lesion
 - Diffuse (>2 cm length)
 - Excessive tortuosity of proximal segment
 - Extremely angulated segments, >90°
 - Inability to protect major side branches
 - Degenerated vein grafts with friable lesions
 - Occluded for >3 mo
2. Occluded

ACC indicates American College of Cardiology; AHA, American Heart Association; and SCAI, Society for Cardiovascular Angiography and Interventions. Reprinted with permission from Krone et al.⁸⁷⁹

Appendix 4C. Strategies to Reduce Radiation Exposure to Patient and Operator

Precautions to minimize exposure to patient and operator

- Use radiation only when imaging is necessary to support clinical care
- Minimize use of cine
- Minimize use of steep angles of x-ray beam
- Minimize use of magnification modes
- Minimize frame rate of fluoroscopy and cine
- Keep the image receptor close to the patient
- Utilize collimation to the fullest extent possible
- Monitor radiation dose in real time to assess patient risk-benefit during procedure

Precautions to specifically minimize exposure to operator

- Use and maintain appropriate protective garments
- Maximize distance of operator from x-ray source and patient
- Keep above-table and below-table shields in optimal position at all times
- Keep all body parts out of field of view at all times

Precautions to specifically minimize exposure to patient

- Keep table height as high as comfortably possible for operator
- Vary imaging beam angle to minimize exposure to any single skin area
- Keep patient's extremities out of beam

Appendix 4D. Patient Care Consideration Based on Procedural Radiation Dose

$K_{a,r}^*$	P_{KA}^\dagger	FT^\ddagger	Action
>5 Gray	>500 Gray cm ²	>60 min	Physician charts documentation about why exposure at this level occurred, documents whether multiple skin entry angles were used, assesses risk, educates patient about potential for skin injury, and arranges for appropriate follow-up within 30 d. Phone calls may be sufficient with an office visit arranged if issues/questions arise or a potential tissue injury is suspected.
≥10 Gray			Physician contacts radiation safety officer/medical physicist. The radiation safety officer/medical physicist should perform a detailed analysis of PSD. Document a) FOV, b) skin entrance port number, c) known geometry, with a "rough" geometric setup required. Educate patient about the potential for skin injury and document this in chart. Schedule an office visit in 2 to 4 wk.
PSD§ >15 Gray			If calculated PSD is indeed >15 Gray, the physician and/or radiation safety officer/medical physicist should contact hospital risk management within 24 h. Report the event to the Joint Commission and as needed to the appropriate State Department of Health.

* $K_{a,r}$ is total air kerma at reference point; $^\dagger P_{KA}$ is air kerma-area product; $^\ddagger FT$ is total fluoroscopy time, does not include cine; §PSD is peak skin dose, which requires calculations made by a qualified physicist.

FOV indicates field of view; and FT, fluoroscopy time.

Adapted with permission from Chambers et al.³¹⁷

Appendix 4E. General Considerations in Deciding Between Early Invasive Strategy and Initial Conservative Strategy

Early Invasive Strategy Generally Preferred	Initial Conservative Strategy Generally Preferred or Reasonable
<ul style="list-style-type: none"> • Recurrent angina or ischemia at rest or with low-level activities despite intensive medical therapy • Elevated cardiac biomarkers (TnT or TnI) • New or presumably new ST-segment depression • Signs or symptoms of heart failure • Hemodynamic instability • High-risk score (eg, GRACE, TIMI) • Sustained ventricular tachycardia • PCI within 6 mo • Prior CABG • Diabetes mellitus • Mild to moderate renal dysfunction • Reduced LV function (LVEF <40%) 	<ul style="list-style-type: none"> • Low-risk score (eg, GRACE, TIMI) • Absence of high-risk features • High risk for catheterization-related complications • Patient not a candidate for revascularization (with either PCI or CABG) • Patient prefers conservative therapy

CABG indicates coronary artery bypass graft surgery; GRACE, Global Registry of Acute Coronary Events; LV, left ventricular; LVEF, left ventricular ejection fraction; PCI, percutaneous coronary intervention; TIMI, Thrombolysis In Myocardial Infarction; TnI, troponin I; and TnT, troponin T.

Appendix 4F. Agents for Procedural Sedation and Analgesia

Drug	Clinical Effects	Dose	Onset	Duration	Comments
Midazolam	Sedation, anxiolysis. No analgesia.	Initial 0.5 to 1 mg IV, then titrated.	2 to 3 min	45 to 60 min	Reduce dose when used in combination with opioids. May produce paradoxical excitement. Reversible with flumazenil.
Fentanyl	Analgesia	50 mcg IV. May repeat every 3 min, titrate to effect.	3 to 5 min	30 to 60 min	Reduce dosing when combined with benzodiazepines. Reversible with naloxone.
Etomidate	Sedation, anxiolysis. No analgesia.	Sedation: 0.1 mg/kg IV; repeat if inadequate response.	<1 min	5 to 15 min	Respiratory depression may occur; institutional guidelines vary about administration to nonintubated patients by nonanesthesiologists. May cause myoclonus, nausea, and vomiting. Adrenocortical suppression occurs but is rarely of clinical significance. Not reversible.
Propofol	Sedation, anxiolysis. No analgesia.	Load 1 mg/kg IV; may administer additional 0.5 mg/kg doses as needed to enhance or prolong sedation.	<1 min	5 to 15 min	Frequent hypotension and respiratory depression; institutional guidelines vary concerning administration to nonintubated patients by nonanesthesiologists. Avoid with egg or soy allergies. Not reversible.
Reversal Agents					
Naloxone	Opioid reversal	0.4 to 2 mg IV	2 min	20 to 40 min	If shorter acting than reversed drug, serial doses may be required.
Flumazenil	Benzodiazepine reversal	0.2 mg IV. May repeat every 1 min up to 1 mg.	1 to 2 min	30 to 60 min	If shorter acting than reversed drug, serial doses may be required. Do not use in patients receiving long-term benzodiazepines, cyclosporine, isoniazid, lithium, propoxyphene, theophylline, or tricyclic antidepressants.

IV indicates intravenous.

2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention: A Report of the American College of Cardiology Foundation/American Heart Association Task Force on Practice Guidelines and the Society for Cardiovascular Angiography and Interventions
Writing Committee Members, Glenn N. Levine, Eric R. Bates, James C. Blankenship, Steven R. Bailey, John A. Bittl, Bojan Cercek, Charles E. Chambers, Stephen G. Ellis, Robert A. Guyton, Steven M. Hollenberg, Umesh N. Khot, Richard A. Lange, Laura Mauri, Roxana Mehran, Issam D. Moussa, Debabrata Mukherjee, Brahmajee K. Nallamothu and Henry H. Ting

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Data Supplement (unedited) at:

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Correction

In the article by Levine et al, “2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention,” which published ahead of print on November 7, 2011, and appeared in the December 6, 2011, issue of the journal (*Circulation*. 2011;124:e574–e651), several corrections were needed:

1. On page e608, in Table 12, last row, “Argatroban,” third column, “Patient Has Not Received Prior Anticoagulant Therapy,” the dosing for argatroban read, “350 mcg/kg bolus, then 15 mcg/kg per min IV infusion.” It has been changed to read, “350 mcg/kg bolus, then 25 mcg/kg per min IV infusion.”
2. On page e613, in the first column, first paragraph under section “5.10. Periprocedural MI Assessment: Recommendations,” the last 2 lines of the Class I recommendation read, “. . . creatinine kinase-MB and troponin I or T should be measured. . .” They have been changed to read, “. . . creatine kinase-MB and/or troponin I or T should be measured. . .” The corrected recommendation now reads,

In patients who have signs or symptoms suggestive of MI during or after PCI or in asymptomatic patients with significant *persistent* angiographic complications (eg, large side-branch occlusion, flow-limiting dissection, no-reflow phenomenon, or coronary thrombosis), creatine kinase-MB and/or troponin I or T should be measured. (*Level of Evidence: C*).

3. On page e613, in the first column, second paragraph under section “5.10. Periprocedural MI Assessment: Recommendations,” the parenthetical expression in the first and second lines of the Class IIb recommendation read, “. . . (creatinine kinase-MB and/or troponin I or T). . .” It has been changed to read, “. . . (creatine kinase-MB and/or troponin I or T). . .” The corrected recommendation now reads,

Routine measurement of cardiac biomarkers (creatine kinase-MB and/or troponin I or T) in all patients after PCI may be reasonable. (*Level of Evidence: C*).

These corrections have been made to the current online version of the article, which is available at <http://circ.ahajournals.org/content/124/23/e574>.

2011 ACCF/AHA/SCAI Guideline for Percutaneous Coronary Intervention—ONLINE AUTHOR LISTING OF COMPREHENSIVE RELATIONSHIPS WITH INDUSTRY AND OTHERS (October 2011)

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	Center	<ul style="list-style-type: none"> • Bracco • DataScope • Eli Lilly/Daichii Sankyo • Gilead • Guerbet • The Medicines Company • Medtronic Vascular • Regado Biosciences • sanofi-aventis/BMS • St. Jude Medical • Therox 					
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2011 ACCF/AHA/SCAI Percutaneous Coronary Intervention Guideline Data Supplements

Tables 1 to 15 pertain to the Revascularization Section

Data Supplement 1. Evidence for Survival Benefit After PCI or CABG (With LIMA Grafting to the LAD) in Patients With SIHD Who Are Receiving Medical Therapy and Are Suitable Candidates for Revascularization

Anatomic Subgroups	Evidence Supporting CABG for Survival	Evidence Supporting PCI for Survival	Evidence Supporting Superiority of Either CABG or PCI for Survival	Evidence Supporting Equivalence of CABG and PCI for Survival
Unprotected left main CAD	CASS Registry* (1,2) CASS† (3) VA Cooperative† (4,5) Yusuf et al.† (6) Dzavik et al.* (7)	None found	CABG better: Wu* (8) PCI better: None found	SYNTAX† (10) LE MANS† (11) Boudriot et al.† (12) Chieffo et al.* (13,14) Lee et al.* (15) Lee et al.§ (16) Naik et al.§ (17) White et al.* (18) Palmerini et al.* (19) Park et al.* (20) Sanmartín et al.* (21) Brener et al.* (22) Mäkikallio et al.* (23)
SYNTAX score <33			SYNTAX† (9)	
SYNTAX score ≥33			SYNTAX† (9)	
3-vessel disease with or without proximal LAD disease	For: Dzavik et al.* (7) ECSS† (24) Jones et al.* (25) MASS II* (26) Myers et al.† (27) Smith et al.* (28) SYNTAX† (9) Yusuf et al.† (6)	For: Dzavik et al.* (7) Smith et al.* (28) Against: Boden et al.† (29)	CABG better: Bair et al.* (30) Booth et al.† (31) Hannan et al.* (32) Hannan et al.* (33) Jones et al.* (25) MASS II* (26) Malenka et al.* (34)	Bravata et al.† (35) Daemen et al.† (36) Dzavik et al.* (7) ERACI II† (37) Mercado et al.† (38) RITA I† (39) Van Domburg et al.* (40)

2-vessel disease with proximal LAD disease	<i>For:</i> ECSS† (24) Jones et al.* (25) Smith et al.* (28) Yusuf et al.† (6)	<i>For:</i> Dzavik et al.* (7) Jones et al.* (25) Smith et al.* (28) <i>Against:</i> Boden et al.† (29)	<i>CABG better:</i> Hannan et al.* (32) Hannan et al.* (33) Hannan et al.* (41) Jones et al.* (25)	Berger et al.† (42) ERACI II† (37) Malenka et al.* (34)
2-vessel disease without proximal LAD disease	<i>For:</i> Smith et al.* (28)	<i>For:</i> Jones et al.* (25) Smith et al.* (28) <i>Against:</i> Boden et al.† (29) Cecil et al.† (43) Pitt et al.† (44)	<i>CABG better:</i> Bair et al.* (30) Booth et al.† (31) Dzavik et al.* (7) Hannan et al.* (41) Hannan et al.* (33) Jones et al.* (25)	Bravata et al.† (35) Daemen et al.† (36) Dzavik et al.* (7) Jones et al.* (25) Mercado et al.† (38) van Domburg et al.* (40)
1-vessel proximal LAD disease	<i>For:</i> Smith et al.* (28) <i>Against:</i> Greenbaum et al.* (45)	<i>For:</i> Jones et al.* (25) Smith et al.* (28) <i>Against:</i> Greenbaum et al.* (45)	<i>CABG better:</i> Hannan et al. (32)	Aziz et al.† (46) Ben-Gal et al.* (47) Bravata et al.† (35) Cisowski et al.§ (48) Diegeler et al.† (49) Drenth et al.† (50) Fraund et al.* (51) Goy et al.† (52,53) Greenbaum et al.* (45) Hong et al.† (54) Jaffery et al.† (55) Jones et al.* (25) Kapoor et al.† (56) MASS I† (57)
1-vessel disease without proximal LAD involvement	<i>Against:</i> Jones et al.* (25) Smith et al.* (28) Yusuf et al.† (6)	<i>Against:</i> Jones et al.* (25)	<i>PCI better:</i> Hannan et al.* (32) Jones et al.* (25)	Jones et al.* (25)

Multivessel CAD, DM present	<p><i>For:</i> MASS II† (58) Sorajja et al.* (59)</p> <p><i>No benefit:</i> BARI 2D† (60)</p>	<p><i>For:</i> MASS II† (58)</p> <p><i>No effect:</i> BARI 2D† (60) Sorajja et al.* (59)</p>	<p><i>CABG better:</i> BARI I† (61,62) Brener et al.* (63) Hlatky et al.† (64) Javaid et al.* (65) Malenka et al.* (34) Niles et al.* (66) Pell et al.* for 3-V CAD (67) Weintraub et al.† (68)</p>	<p>ARTS I* (69) Bair et al.* (30) Barsness et al.* (70) Bravata et al.† (35) CARDia† (71) Dzavik et al.* (7) MASS II† (58) Pell et al.* for 2-V CAD (67)</p>
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*Observational study, including articles on long-term follow-up, clinical trials not specified as randomized, comparative registry studies, comparative studies, prospective cohort studies, prospective observational studies, prospective registries, and prospective studies. †Randomized controlled trials, including meta-analyses. ‡Reviews (systematic or not). §Unknown study design.

ARTS indicates Arterial Revascularization Therapies Study Part; AWESOME, Angina With Extremely Serious Operative Mortality Evaluation; BARI I, Bypass Angioplasty Revascularization Investigation I; BARI 2D, Bypass Angioplasty Revascularization Investigation 2 Diabetes; CAD, coronary artery disease; CARDIA, Coronary Artery Revascularization in Diabetes; DM, diabetes mellitus; ECSS, European Coronary Surgery Study; ERACI II, Argentine Randomized Trial of Percutaneous Transluminal Coronary Angioplasty versus Coronary Artery Bypass Surgery in Multivessel Disease II; LAD, left anterior descending; LIMA, left internal mammary artery; MASS, Medicine, Angioplasty, or Surgery Study; RITA, Randomised Intervention Treatment of Angina; SIHD, stable ischemic heart disease; SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; V, vessel; and VA, Veterans Administration.

Data Supplement 2. Evidence for Relief of Unacceptable Angina in Subsets of Patients With SIHD Who are Receiving GDMT and Have Anatomy Suitable for Revascularization				
Anatomic Subgroups	Evidence Supporting CABG + GDMT for Angina	Evidence Supporting PCI + GDMT for Angina	Evidence Supporting Superiority of either CABG or PCI for Angina	Evidence Supporting Equivalence of CABG and PCI for Angina
Multivessel CAD	<p><i>Benefit:</i> Benzer et al.* (72) Bonaros et al.* (73) Favaroto et al.† (74) Hofer et al.* (75) Lukkarinen et al.* (76) MASS II† (26) RITA I† (77)</p>	<p><i>No benefit:</i> Lukkarinen et al.* (76)</p> <p><i>Benefit:</i> Benzer et al.* (72) COURAGE† (29,78) Hambrecht et al.‡ (79) Hofer et al.* (75) MASS II† (26) RITA I† (77) RITA II† (80) Wijeysundera et al.‡ (81)</p>	<p><i>CABG better:</i> Benzer et al.* (72) Bonaros et al.* (73) Lukkarinen et al.* (76) RITA I† (39)</p> <p><i>PCI better:</i> None found</p>	<p>Hofer et al.* (75) MASS II et al.† (26) Takagi et al.‡ (82)</p>
1-vessel CAD excluding the proximal LAD	No data found	<p>Hambrecht et al.† (79) Parisi et al.† (83) Pitt et al.† (44) Pocock et al.† (80)</p>	No data found	No data found

1-vessel CAD involving the proximal LAD	MASS I† (57)	Hambrecht et al.† (79) Parisi et al.† (83) Pitt et al.† (44) Pocock et al.† (80)	CABG better: Ben-Gal et al.* (47) Cisowski et al.† (48) Diegeler et al.‡ (49) Goy et al.† (52) Toutouzas et al.* (130) MASS I† (57)	Cisowski et al.† (84) Drenth et al.§ (85) Thiele et al.† (86)
Special Circumstances				
Patients with prior CABG and small or moderate sized area of ischemia	No data found	Gurfinkel et al.§ (87) Pfautsch et al.* (88) Subramanian et al.* (89)	CABG better: Weintraub et al.† (90)	Stephan et al.* (91)

*Observational study, including articles on long-term follow-up, clinical trials not specified as randomized, comparative registry studies, comparative studies, prospective cohort studies, prospective observational studies, prospective registries, and prospective studies. †Randomized controlled trials, including meta-analyses. ‡Reviews (systematic or not). §Unknown study design.

ARTS indicates Arterial Revascularization Therapies Study Part; AWESOME, Angina With Extremely Serious Operative Mortality Evaluation; BARI 2D, Bypass Angioplasty Revascularization Investigation 2 Diabetes; CABG, coronary artery bypass graft; CAD, coronary artery disease; CARDia, Coronary Artery Revascularization in Diabetes; COURAGE, Clinical Outcomes Utilizing Revascularization and Aggressive Drug Evaluation; GDMT, guideline-directed medical therapy; LAD, left anterior descending artery; LOE, level of evidence; MASS, Medicine, Angioplasty or Surgery Study; PCI, percutaneous coronary intervention; RITA, Randomised Intervention Treatment of Angina; SIHD, stable ischemic heart disease; and TIME, Trial of invasive versus medical therapy in elderly patients.

Data Supplement 3. RCTs of CABG Versus Balloon Angioplasty

					Acute Outcome		Late Outcome						
					Death %	Q Wave MI %	Death %	Q Wave MI %	Angina %	Repeat Revascularization %	Primary Endpoint	Primary Endpoint	Follow-Up in Years
Trial	No.	Age (y)	Female	CAD	CABG/ PCI	CABG/ PCI	CABG/ PCI	CABG/ PCI	CABG/ PCI	CABG/ PCI		CABG/ PCI	
BARI (62,92,93,94)	1,829	61	26%	MV	1.3/1.1	4.6/2.1	26.5/29	36/36	NA/NA	20/77*	D	26.5/29	10
EAST (95,96)	392	61	26%	MV	1.0/1.0	10.3/3.0*	17/21	19.6/16.6	12/20*	27/65*	D+MI+T	27.3/28.8	8 ^a
GABI (97)	359	NA	20%	MV	2.5/1.1	8/2.3*	22/25	9.4/4.5	26/29	59/83*	A	26/29	13 ^b
Toulouse et al. (98)	152	67	23%	MV	1.3/1.3	6.6/3.9	10.5/13.2	1.3/5.3	5.3/21.1*	9/29*	A	5.2/21.1*	5
RITA I (39, 77,99)	1,011	57	19%	SV/MV	1.2/0.8 RR: 0.88 (95% CI: 0.59 to 1.29)	2.4/3.5	9.0/7.7	7.4/10.8	52/78*	11/44*	D+MI+T	8.6/9.8	5

ERACI (100,101)	127	58	13%	MV	4.6/1.5	6.2/6.3	4.7/9.5	7.8/7.8	3.2/4.8	6/37*	D+MI+A+Revasc	23/53*	3
MASS (57,102)	142	56	42%	SV (LAD)	1.4/1.4	1.4/0	2.9/5.7	7/11	23/25	0/30*	D+MI+Revasc	3/24*	3
Goy et al. (52,53)	134	56	20%	SV (LAD)	0/0	0/0	2/9	4/15* RR: 2.6 (95% CI: 1.1 to 5.4; p=0.00004) ^c	29/26	9/38*	D+MI+Revasc	7.6/36.8*	5
CABRI (103,104)	1,054	60	22%	MV	1.3/1.3	N/A/N/A	2.7/3.9 RR: 1.42 (95% CI: 0.731 to 2.76; p=0.297)	3.5/4.9 RR: 1.42 (95% CI: 0.80 to 2.54; p=0.234)	10.1/13.9* RR: 1.54 (95% CI: 1.09 to 2.16; p=0.012)	9/36* RR: 5.23 (95% CI: 3.90 to 7.03; p<0.001)	D	2.7/3.9	1

*Statistically significant; ^aMortality and repeat revascularization at 8 y, other endpoints at 3 y; ^bMortality and repeat revascularization at 13 y, other endpoints at 1 y; ^cRelative risk for combined endpoint cardiac death and MI.

A indicates angina; BARI, Bypass Angioplasty Revascularization Investigation; CAD, coronary artery disease; CABG, coronary artery bypass graft; CABRI, Coronary Angioplasty versus Bypass Revascularization Investigation; CI, confidence interval; D, death; EAST, Emory Angioplasty versus Surgery Trial; ERACI, Argentine Randomized Trial of Percutaneous Transluminal Coronary Angioplasty versus Coronary Artery Bypass Surgery in Multivessel Disease; GABI, German Angioplasty Bypass Surgery Investigation; LAD, left anterior descending; MASS, Medicine, Angioplasty, or Surgery Study; MI, myocardial infarction; MV, multivessel; NA, not available; No., number; PCI, percutaneous coronary intervention; RITA, Randomized Intervention Treatment of Angina; Revasc, repeat revascularization; RR, relative risk; SV, single-vessel; and T, thallium defect.

Data Supplement 4. RCTs of CABG Versus BMS

						Death %	Q Wave MI %	Angina %	Repeat Revascularization %	Primary Endpoint	Primary Endpoint %	Follow-Up in Years
Trial	No.	Age (y)	Female	CAD	Enrollment Period	CABG/PCI	CABG/PCI	CABG/PCI	CABG/PCI		CABG/PCI	
SIMA (105)	121	59	21%	SV	1994-1998	4/2	4/5	5/9	8/24	D+MI+Rep Revasc	7/31*	2.4
AWESOME (106,107)	454	67	NA	MV	1995-2000	21/18	NA	NA	22/43*	D	21/20	5
MASS II (26)	408	60	32%	MV	1995-2000	25/24	10/13	NA	7.5/41.9	D+MI+Rep Revasc HR: 1.85 (95% CI: 1.39 to 2.47)	33/42*	10
ERACI II (101,108)	450	62	21%	MV	1996-1998	11.6/7.2	6.2/2.8	18/14	7.2/28.4*	D+MI+CVA+Rep Revasc	23.6/34.7*	5
SoS (109)	988	61	21%	MV	1996-1999	6.8/10.9* HR: 2.91 (95% CI: 1.29 to 6.53; p=0.01)	8.2/4.9	NA	6/21* HR: 3.85 (95% CI: 2.56 to 5.79; p<0.0001)	Rep Revasc	6/21*	6

ARTS I (110)	1205	61	24%	MV	1997-1998	7.6/8.0 RR: 1.05 (95% CI: 0.71 to 1.55; p=0.83)	5.6/6.7 RR: 1.19 (95% CI: 0.76 to 1.85; p=0.47)	NA	8.8/30.3* RR: 3.46 (95% CI: 2.61 to 4.60; p<0.001)	D+MI+CVA+Rep Revasc	21.8/41.7* RR: 1.91 (95% CI: 1.60 to 2.28; p<0.001)	5
Drenth et al. (50 , 85)	102	61	24%	SV	1997-1999	2/0	2/10	15/33	4/16	D+MI+CVA+Rep Revasc	14/29	4
Leipzig (49 , 111)	220	62	25%	SV	1997-2001	12/10 RR: 0.85 (95% CI: 0.37 to 1.93; p=0.54)	7/5 RR: 0.71 (95% CI: 0.20 to 2.43; p=0.46)	NA	10/32* RR: 3.18 (95% CI: 1.67 to 6.39; p<0.001)	D+MI+Rep Revasc	29/47* RR: 1.64 (95% CI: 1.13 to 2.42; p=0.02)	5
Myoprotect (112)	44	70	30%	MV	1998-2001	24/22	0/4	NA	5/30	D+MI+Rep Revasc	29/48*	1
Octostent (113)	280	60	29%	MV	1998-2000	2.8/0	4.9/4.4	13/22	4.2/15.2	D+MI+CVA+Rep Revasc	9.5/14.5 RR: 0.93 (95% CI: 0.86 to 1.02)	1
AMIST (114)	100	57	22%	SV	1999-2001	25/30	0/4	8/10	0/4	D+MI+Rep Revasc+T	28/34	1
Cisowski et al. (48 , 84)	100	54	17%	SV	2000-2001	0/3.6	0/0	0/20	0/20	D+MI	0/4	1
Kim et al. (115)	100	62	35%	SV	2000-2001	4.0/4.0	NA	6/19	2/14	NA	NA	1

*Statistically significant. AMIST indicates Angioplasty versus Minimally Invasive Surgery Trial; ARTS, Arterial Revascularization Therapies Study; AWESOME, Angina with Extremely Serious Operative Mortality Evaluation; BMS, bare-metal stent; CABG, coronary artery bypass grafting; CAD, coronary artery disease; CI, confidence interval; CVA, cerebrovascular accident; D, death; ERACI, Argentine Randomized Trial of Percutaneous Transluminal Coronary Angioplasty Versus Coronary Artery Bypass Surgery in Multivessel Disease; MASS, Medicine, Angioplasty, or Surgery Study; MI, myocardial infarction; MIDCAB, minimally invasive direct coronary artery bypass; MV, multivessel; NA, not available; Octostent, Long-term comparison of stenting versus off-pump; PCI, percutaneous coronary intervention; RITA, Randomized Intervention Treatment of Angina; RR, relative risk; Rep Revasc, repeat revascularization; SIMA, Stenting versus Internal Mammary Artery Study; SoS, Stent or Surgery; SV, single-vessel; and T, thallium defect.

Data Supplement 5. RCTs of CABG Versus DES

						Death %	MI %	Repeat Revascularization %	Primary Endpoint		RR and 95% CI	Follow-Up in Months
Trial	No.	Age (y)	Female	CAD	Enrollment Period	CABG/PCI	CABG/PCI	CABG/PCI		CABG/PCI		
Hong et al. (54)	189	61	36%	SV	2003	2.9/0	2.9/1.7	5.9/1.7	D, MI, Rep Revasc	11.7/4.3	N/A	6
Leipzig (86)	130	66	30%	SV	2003-2007	0/0	7.7/1.5*	0/6.2	D+MI+Rep Revasc	7.7/7.7	N/A	12
SYNTAX (116 , 117)	1800	65	22%	MV	2005-2007	6.7/8.6	3.6/7.1	10.7/19.7	D+MI+CVA+Rep Revasc	20.2/28.0	MACCE 12 mo follow-up; RR: 1.44 95% CI: 1.15 to 1.81	36

*Statistically significant. CABG indicates coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; CVA, cerebrovascular accident; D, death; MACCE, major adverse cardiac and cerebrovascular events; MI, myocardial infarction; N/A, not applicable; No., number of patients; MV, multivessel; PCI, percutaneous coronary intervention; RR, relative risk; Rep Revasc, repeat revascularization; SV, single vessel; and SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery.

Data Supplement 6. Hazard Ratios in Observational Studies Comparing PCI-DES to CABG

Study	Location	No. Patients (CABG/PCI)	Average Age (y)	Female Patients %	CAD	Enrollment Period	Combined Death/MI/CVA HR and 95% CI	Repeat Revascularization HR and 95% CI	MACCE HR and 95% CI	Follow-Up in Months
Park et al. (118)	Korea	1,495/1,547	62	29%	MVD	2003-2005	0.7* 0.53 to 0.91	2.56* 1.96 to 3.4	1.37* 1.16 to 1.63	31
Hannan et al. (33)	USA	7,437/9,964	66	30%	MVD	2003-2004	0.99 0.89 to 1.098	5.88* 5.31 to 6.51	2.89* 2.72 to 3.08	19
Briguori et al. (119)	Italy	149/69	65	29%	MVD	2002-2004	1.03 0.53 to 1.99	4.01* 1.67 to 9.60	1.48* 0.91 to 2.43	12
Yang et al. (120)	China	231/235	65	22%	MVD	2003-2004	0.7 0.33 to 1.49	13.26* 4.15 to 42.34	3.09* 1.80 to 5.30	25
Lee et al. (121)	USA	103/102	68	35%	MVD	2003-N/A	1.29 0.68 to 2.46	6.73* 2.06 to 21.95	2.25* 1.36-3.72	12
Yang et al. (122)	Korea	390/441	63	29%	MVD	2003-2004	0.75 0.43 to 1.31	4.26* 1.78 to 10.15	1.41* 0.93 to 2.13	12
Javaid et al. (65)	USA	701/979	65	33%	MVD	N/A	1.93 1.37 to 2.73	2.43* 1.73 to 3.41	2.44* 1.87 to 3.19	12
Varani et al. (123)	Italy	95/111	65	31%	MVD	2003-2005	0.47* 0.16 to 1.37	5.91* 1.39 to 25.6	1.52* 0.70 to 3.28	12
Tarantini et al. (124)	Italy	127/93	66	18%	MVD	2005-2005	0.56 0.20 to 1.56	1.91* 0.62 to 5.83	0.96* 0.48 to 1.92	24
Pooled HR							0.94	4.06	1.86	
							<i>p=0.66</i>	<i>p<0.001</i>	<i>p<0.001</i>	

*Statistically significant. CABG, coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; CVA, cerebrovascular accident; DES, drug-eluting stent; HR, hazard ratio; MACCE, major adverse cardiac and cerebrovascular events; MI, myocardial infarction; Mo, months; MVD, multivessel disease; N/A, not available; No, number; PCI, percutaneous coronary intervention, and y, year.

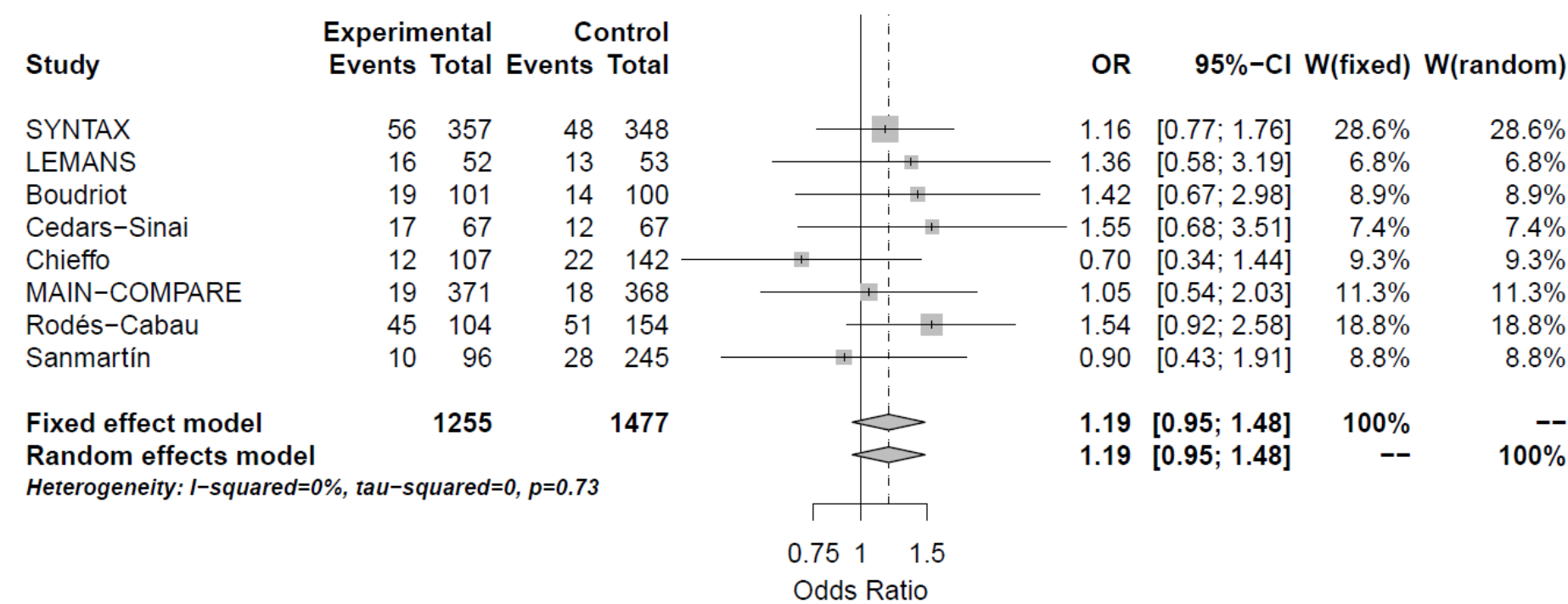
Data Supplement 7. Evidence from RCTs and Cohort Studies Comparing PCI with CABG for Unprotected Left Main CAD

Study	Type of Study/ Years of Recruitment	PCI/CABG No. of Patients	Early Results for PCI Versus CABG	1 to 5-Y Results for PCI Versus CABG
SYNTAX (10)	Randomized/2005-2007 45% of screened pts with LM disease not randomized, 89% of these had CABG	357/348	30-d outcomes not reported	3-y follow-up: MACCE 13.0% vs. 14.3% (p=0.60); repeat revascularization 20.0% vs. 11.7% (p=0.004); all-cause death 7.3% vs. 8.4% (change -0.2%, p=0.64).
LE MANS (11)	Randomized/2001-2004 65% of screened pts excluded as not suitable for both procedures	52/53	30-d outcomes: death 0% vs. 0%; MI 2% vs. 4% (p=NS) MACCE 2% vs. 14% (p=0.01) MAE RR: 0.78, p=0.006; MACCE RR: 0.88, p=0.03	1 y follow-up: death 2% vs. 8% (p=NS); MI 2% vs. 6% (p=NS); revascularization 30% vs. 10% (p=0.01); MACCE 32% vs. 26% (p=NS); MACCE RR: 1.09 (95% CI: 0.85 to 1.38); MAE RR: 0.89 (95% CI: 0.64 to 1.23)
Boudriot et al. (12)	Randomized/2003-2009 53% of screened pts excluded	100/201	Early outcomes not reported	12 mo outcomes: death 2.0% vs. 5.0% (p<0.001 for noninferiority); death, MI or revascularization 19.0% vs. 13.9% (p=0.19 for noninferiority)
Brener et al. (22)	Cohort/1997-2006	97/190	In-hospital outcomes: death 3% vs. 4% (p=NS)	3 y follow-up: survival 80% vs. 85%; OR: 1.42 (95% CI: 0.56 to 3.63; p=0.14)
Cedars-Sinai (15,17,18)	Cohort/2003-2005	67/67	30-d outcomes: death 2% vs. 5% (p=NS); MI 0% vs. 2% (p=NS); stroke 0% vs. 8% (p=0.03); MACCE 17% vs. 2%; (p<0.01)	1-2 y follow-up: propensity-adjusted HR for death HR: 1.93 (95% CI: 0.89 to 4.19; p=0.10), MACCE HR: 1.83 (95% CI: 1.01 to 3.32; p=0.05)
Chieffo et al. (13,14)	Cohort/2002-2004	107/142	In-hospital outcomes: death 0% vs. 2.1% (p=NS); MI 9.3% vs. 26.1% (p=0.0009); stroke 0% vs. 2% (p=NS)	5 y adjusted cardiac death OR: 0.50 (95% CI: 0.16 to 1.46; p=0.24), cardiac death or MI OR: 0.41 (95% CI: 0.15 to 1.06; p=0.06); death, MI, or stroke OR: 0.40 (95% CI: 0.15 to 0.99; p=0.04); TVR OR: 4.41(95% CI: 1.83 to 11.37; p=0.0004), MACCE OR: 1.58 (95% CI: 0.83 to 3.05; p=0.18)
MAIN-COMPARE (20,125)	Cohort/2000-2006	1102/1138	30-d outcomes not reported	5-y adjusted risk of death HR: 1.13 (95% CI: 0.88 to 1.44, p=0.35), combined adjusted risk of death, Q-wave MI, or stroke HR: 1.07 (95% CI: 0.84 to 1.37,p=0.59); TVR HR: 5.11 (95% CI: 3.52 to 7.42,p<0.001)
Mäkikallio et al. (23)	Cohort/2005-2207	49/238	30-d outcomes: death 2% vs. 7% (p=0.13)	1-y follow-up: death 4% vs. 11% (p=0.14); PCI vs. CABG (using 1° and 2° endpoint) HR: 2.1 (95% CI: 0.7 to 5.8, p= 0.180)

Palmerini et al. (19)	Cohort/2002-2005	157/154	30-d outcomes: death 3.2% vs. 4.5% (p=NS); MI 4.5% vs. 1.9%,(p=NS); revascularization 0.6% vs. 0.6% (p=NS)	1-2 y follow-up: death 13.4% vs. 12.3% (p=0.8); MI 8.3% vs. 4.5% (p=0.17); revascularization 25.5% vs. 2.6% (p=0.0001); PCI vs. CABG mortality HR: 0.95 (95% CI: 0.51 to 1.77, p=0.861); cardiac mortality HR: 0.99, (95% CI: 0.49 to 2.04, p=0.994); MI HR: 0.53 (95% CI: 0.21 to 1.32; p=0.170)
Rodés-Cabau et al. (126)	Cohort/2002-2008	104/145	30-d outcomes: MACCE 18.3% vs. 27.6%; death 6.7% vs. 8.3%; MI 12.5% vs. 17.2%; stroke 1.0% vs. 5.5% (all p=NS)	1-2-y follow-up: MACCE 43.3% vs. 35%; death 16.3% vs. 12.4%; MI 23.1% 19.3%; revascularization 9.6% vs. 4.8%; stroke 8.75 vs. 6.2% (all NS). Survival free of cardiac death or MI adjusted HR: 1.28 (95% CI: 0.64 to 2.56; p=0.47); MACCE-free survival adjusted HR: 1.11(95% CI: 0.59 to 2.0; p= 0.73).
Sanmartín et al. (21)	Cohort/2000-2005	96/245	30-d outcomes: MACCE after surgery 2.1% vs. 9.0% (p=0.03).	1-y follow-up: MACCE 10.4% vs. 11.4%, (p=0.50), repeat revascularization 5.2% vs. 0.8% (p=0.02)
Wu et al. (8)	Cohort/2000-2004	135/135	30-d outcomes: death 5.2% vs. 2.2% (p=0.33)	1-y follow-up: death 16.1% vs. 5.9% OR: 3.06 (95% CI: 0.99 to 9.45) 2-y follow-up: death 18.0% vs. 5.9%; HR: 3.1 (95% CI: 1.42 to 7.14; p=0.005); revascularization 37.3% vs. 6.3%; HR: 6.7; (95% CI: 3.0 to 14.3; p<0.001)

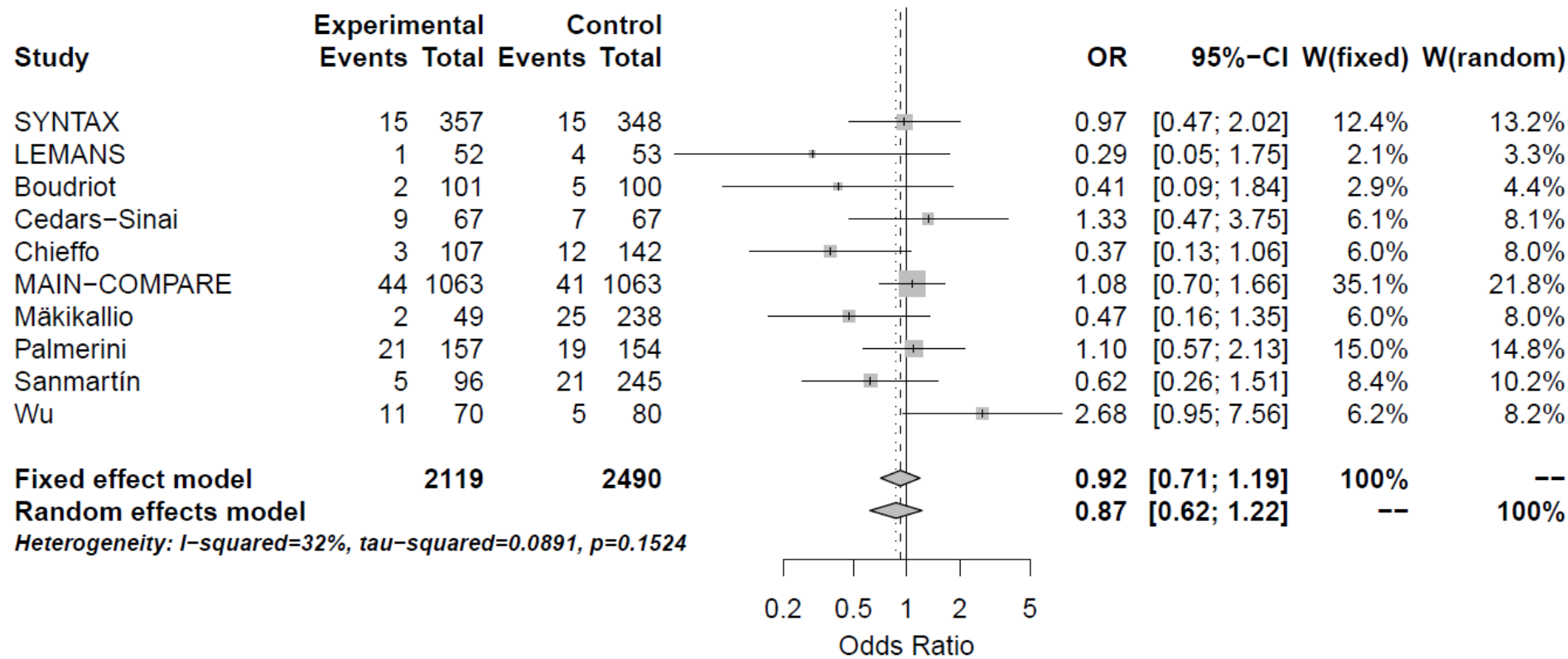
CABG indicates coronary artery bypass grafting; CI, confidence interval; d, day; HR, hazard ratio; LEMANS, Study of Unprotected Left Main Stenting Versus Bypass Surgery; LM, left main; MACCE, Major adverse cardiac and cardiovascular events; MAE, major adverse events; MAIN-COMPARE, Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty versus Surgical Revascularization; MI, myocardial infarction; NS, not significant; OR, odds ratio; pts, patients; PCI, percutaneous coronary intervention; RR, relative risk; SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; TVR, target vessel revascularization; and y, year.

Data Supplement 8. Forest Plot of 1-Year MACCE Rates After PCI or CABG for Unprotected Left Main CAD



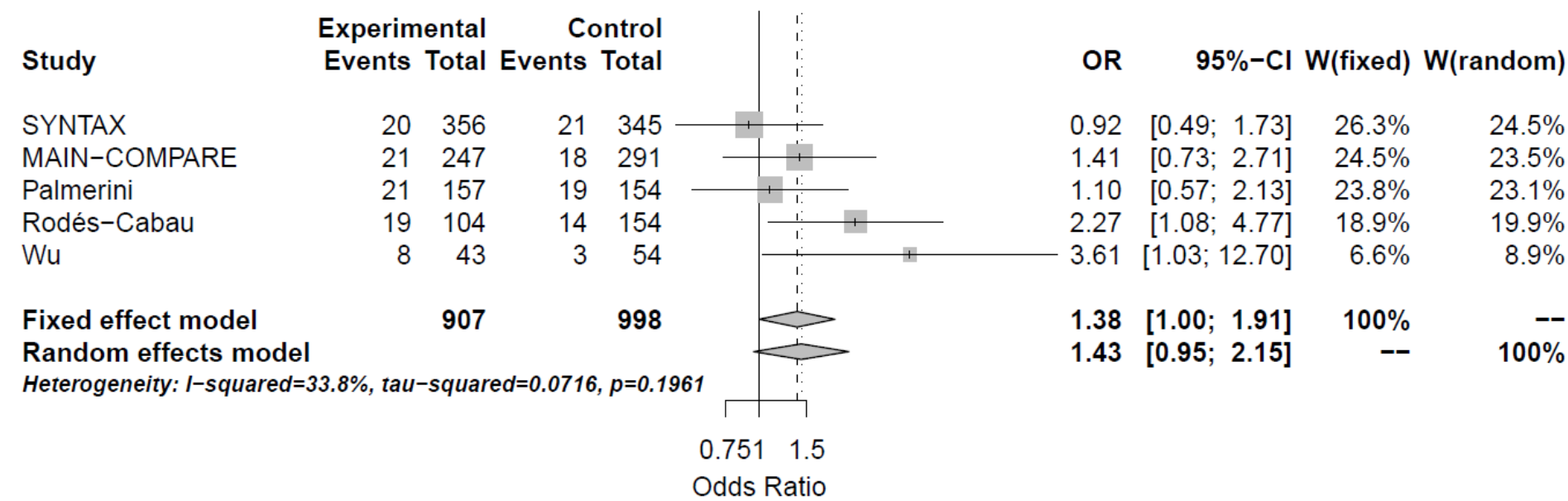
References: ([10](#),[11](#),[12](#),[13](#),[14](#),[15](#),[17](#),[18](#),[20](#),[125](#),[126](#)). OR >1 suggest an advantage of CABG over PCI.
CABG indicates coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; LEMANS, Study of Unprotected Left Main Stenting Versus Bypass Surgery; MAIN-COMPARE, Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty versus Surgical Revascularization; MACCE, major adverse cardiac and cerebrovascular event; OR, odds ratio; PCI, percutaneous coronary intervention; SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and W, weighted.

Data Supplement 9. Forest Plot of 1-Year Mortality Rates After PCI or CABG for Unprotected Left Main CAD



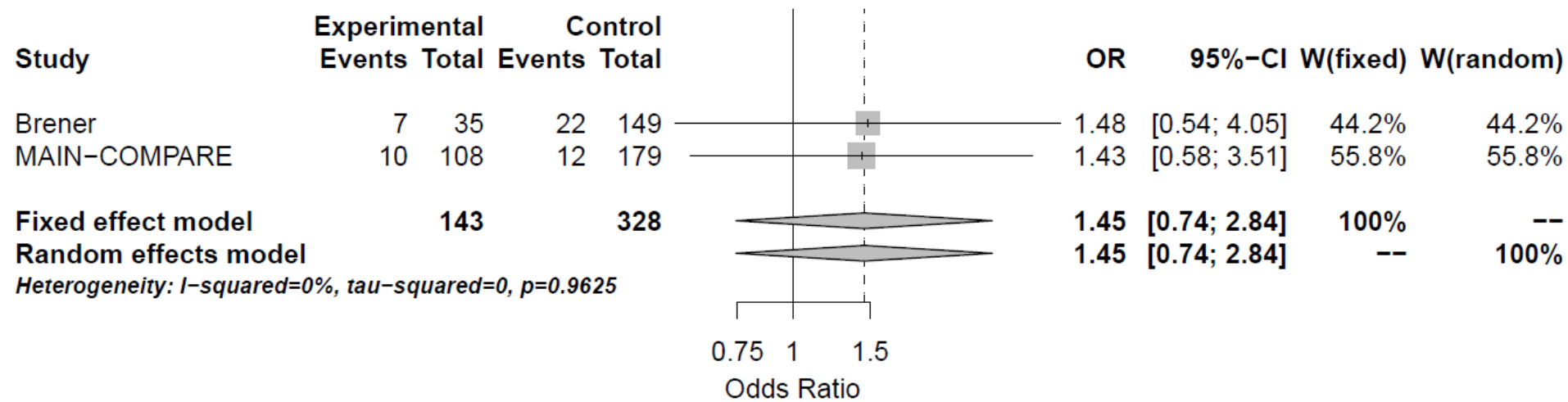
References: (8,10,11,12,13,14,15,17,18,19,20,23,125,126). OR >1 suggest an advantage of CABG over PCI.
CABG indicates coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; LEMANS, Study of Unprotected Left Main Stenting Versus Bypass Surgery;
MACCE, major adverse cardiac and cerebrovascular event; MAIN-COMPARE, Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous
Coronary Angioplasty versus Surgical Revascularization; OR, odds ratio; SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and W, weighted.

Data Supplement 10. Forest Plot of 2-Year Mortality Rates After PCI or CABG for Unprotected Left Main CAD



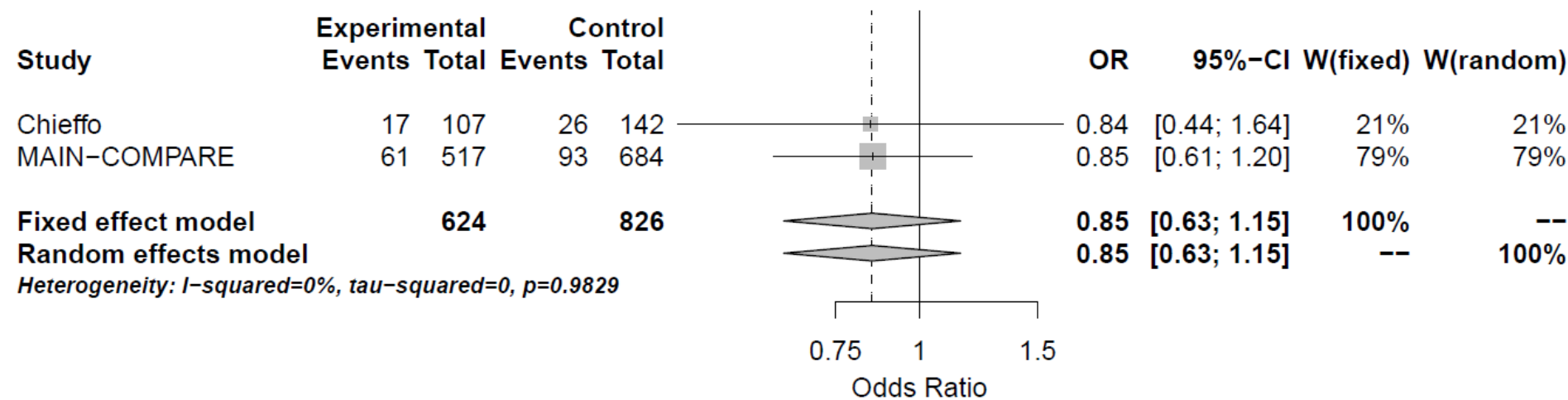
References: (8,11,19,20,125 126,127). OR >1 suggest an advantage of CABG over PCI.
CABG indicates coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; MAIN-COMPARE, Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty versus Surgical Revascularization; OR, odds ratio; PCI, percutaneous coronary intervention; SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and W, weighted.

Data Supplement 11. Forest Plot of 3-Year Mortality Rates After PCI or CABG (for Unprotected Left Main CAD)



References: (20, 22). OR >1 suggest an advantage of CABG over PCI.
CABG indicates coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; MAIN-COMPARE, Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty versus Surgical Revascularization; OR, odds ratio; PCI, percutaneous coronary intervention; and W, weighted.

Data Supplement 12. Forest Plot of 5-Year Mortality Rates After PCI or CABG for Unprotected Left Main CAD



References: (14,20). OR >1 suggest an advantage of CABG over PCI.
CABG indicates coronary artery bypass surgery; CAD, coronary artery disease; CI, confidence interval; MAIN-COMPARE, Revascularization for Unprotected Left Main Coronary Artery Stenosis: Comparison of Percutaneous Coronary Angioplasty versus Surgical Revascularization; OR, odds ratio; PCI, percutaneous coronary intervention; and W, weighted.

Data Supplement 13. Outcomes of PCI Versus CABG for Patients With Single-Vessel Coronary Disease Involving the Proximal Left Anterior Descending Artery

Author	Type of Study/ Years of Recruitment	Number of Patients PCI/CABG	Short-Term Results for PCI Versus CABG	Long-Term Results for PCI Versus CABG
Greenbaum et al. (45)	Retrospective cohort 1986-1994	754/149	At 1 y, HR for event-free survival for CABG to PCI: 0.20; p<0.0001	At 2 to 7 y, HR for event-free survival for CABG to PCI: 0.62; p=NS
Goy et al. (52,53,128)	Randomized 1994-1998	68/66	At 2.4 y: death, MI, revascularization 31% vs. 7% (p<0.001); death or MI 12% vs. 7%	At 5 y: death 9% vs. 3% (p=0.09). At 10 y: death 10% vs. 10% (p=1.0)
Cisowski et al. (48)	Randomized 2000-2001	50/50	At 6 mo: death or MI: 0% vs. 0%; revascularization 12% vs. 2% (p<0.05)	N/A
Diegeler et al. (49)	Randomized 1997- 2001	110/110	At 6 mo: death or MI 3% vs. 6% (p=NS); revascularization 29% vs. 8% (p=0.02)	N/A
Drenth et al. (50,85)	Randomized 1997-99	51/51	At 6 mo: death or MI 6% vs. 10% (p=NS); revascularization 4% vs. 8% (p=NS)	N/A
Reeves et al. (114)	Randomized 1999-2001	50/50	In-hospital: death or MI 0% vs. 0%	At 1.5 y: death 0% vs. 2% (p=NS); MI 4% vs. 0% (p=NS); revascularization 4% vs. 0% (p=NS). Survival analysis for MIDCAB vs. PTCA HR: 0.77 (95% CI: 0.38 to 1.57; p=0.47)
Thiele et al. (86)	Randomized 1997-2001	110/110	N/A	At 5 y: death 10% vs. 12% (p=0.54); MI 5% vs. 7% (p=0.46); revascularization: 32% vs. 10% (p<0.001)
Hong et al. (54)	Randomized 2003	119/70	In-hospital: death or MI 5.1% vs. 4.3% (p=1.00)	At 6 mo: death or MI: 6.8% vs. 10.1% (p=NS); revascularization 5.9% vs. 1.7% (p=NS)
MASS I (57,129)	Randomized	72/70	N/A	At 3 y: death, MI or revascularization 24% vs. 3% (p=0.006)
Fraund et al. (51)	Cohort 1998-2001	256/206	In-hospital death or MI 0.8% vs. 2 % (p=NS)	At 3 y: death or MI 4.7% vs. 5.8% (p=NS); revascularization 7.8% vs. 28.9% (p<0.01)
Ben-Gal et al. (47)	Matched cases from prospective cohort 2002-2003 (PCI were all DES)	83/83	30 d death: 0% vs. 1.1% (p=NS)	At 22 mo: death 1.1% vs. 5.5% (p=NS); revascularization 16.8% vs. 3.6% (p=0.005); independent predictors of MACE (Cox analysis) were assignment to the Cypher group (HR: 4.1; 95% CI: 1.26 to 13.16), multivessel disease (HR: 4.3; 95% CI: 1.44 to 13.16), and prior PCI (HR: 4.36; 95% CI: 1.28 to 14.90)
Toutouzas et al. (130)	Cohort	147/110	Inhospital: death or MI or revascularization 0% vs. 0%	At 2 y: death: 2.0% vs. 1.8% (p=NS); MI 0% vs. 0.9%; (p=NS); revascularization 2% vs. 0% (p=0.51)

CABG indicates coronary artery bypass graft; CI, confidence interval; d, day; DES, drug-eluting stents; HR, hazard ratio; MASS, Medicine, Angioplasty, or Surgery Study; MIDCAB, minimally invasive direct coronary artery bypass ;MI, myocardial infarction; mo, month; NS, not significant; PCI, percutaneous coronary intervention; PTCA, percutaneous transluminal coronary angioplasty and y, year.

Data Supplement 14. Cohort Studies Comparing CABG to PCI in Patients With Diabetes

Author	Type of Study/ Year of Recruitment	Number of Patients PCI/CABG	Long-Term Results for PCI Versus CABG
Barsness et al. (70)	Retrospective cohort 1984-1990	770 pts with diabetes total	At 5 y: Similar mortality for PCI and CABG pts: unadjusted 86% vs. 89%; p=NS; adjusted 92% vs. 93%
Weintraub et al. (68)	Cohort 1981-1994	834/1,805	At 10 y: death: 64% vs. 53%; p=0.045 for insulin-requiring pts with diabetes ONLY Insulin-requiring subgroup multivariate HR: 1.35; 95% CI: 1.01 to 1.79 for PTCA vs. CABG
Niles et al. (66)	Retrospective cohort 1992-1996	2,766 pts with diabetes total	At 2 y: higher mortality in PCI pts (HR: 2.0; p=0.038) with 3-vessel disease. Trend to higher mortality in PCI pts (HR: 1.3; p=0.2) with 2-vessel disease, compared to CABG
Van Domburg et al. (40)	Cohort 1970-1985	76/82	At 20 y: survival similar for PCI vs. CABG pts Mortality for CABG vs. PTCA RR: 1.03; 95% CI: 0.87 to 1.24
Brener et al. (63)	Retrospective cohort 1995-1999	265/2,054	At 6 y: deaths for NIDDM: 21% vs. 17%; p=0.008 Deaths for IDDM: 31% vs. 23%; p<0.0001 Unadjusted HR: 1.13; 95% CI: 1.0 to 1.4; p=0.07
Javaid et al. (65)	Retrospective cohort DES era	601 pts with diabetes total 344/257	At 1 y: death, stroke, MI, revascularization HR: 3.5; (p<0.001) for 2-vessel CAD HR: 4.8 (p<0.001) for 3-vessel CAD
Hueb et al. (58)	Cohort 1995-2000	120/221	At 5 y: incidence of cardiac death 11.1% vs. 11.8% (p=NS), revascularization 27.5% vs. 3.2% (p<0.001) The incidence of cardiac death was NS different between PCI and MT groups
Bair et al. (30)	Subset of large cohort 1992-2000	353/1,267	At 15 y: death HR: 0.81; p=0.03
Hannan et al. (33)	Subset of large cohort 2003-2004	2,844/3,256	At 18 mo: death HR: 1.03, p=0.75; death or MI HR: 1.19; p=0.07

CABG indicates coronary artery bypass graft; CAD, coronary artery disease; CI, confidence interval; DES, drug-eluting stent; HR, hazard ratio; IDDM, insulin-dependent diabetes mellitus; MI, myocardial infarction; MT, medical therapy; NIDDM, noninsulin-dependent diabetes mellitus; NS, not significant; pts, patients; PCI, percutaneous coronary intervention; PTCA, percutaneous transluminal coronary angioplasty; RR, relative risk, and y, year.

Data Supplement 15. RCTs of PCI With CABG in Patients With Multivessel CAD and Diabetes

Author	Type of Study in Year of Recruitment	Number of Patients PCI/ CABG	Primary Endpoint for PCI and CABG	Comments
SYNTAX (131)	Randomized 2005-2007	Overall 903/897 DM 231/221	DM: 12-mo death, stroke, MI, or revascularization: 26.0% vs. 14.2% (HR: 1.83, 95% CI: 1.22 to 1.73; p=0.003)	Criterion for noninferiority of PCI to CABG was not met in overall study.
CARDIa (71)	Randomized 2002-2007	DM 256/254	DM: 1-y death, stroke or MI: 13.0% vs. 10.5% (IOR: 1.25, 95% CI: 0.75 to 2.09; p=0.39)	Criterion for noninferiority of PCI to CABG was not met.
BARI 2D (60)	Prestratified/randomized to revascularization-medical therapy	DM 798/807	Death from any cause: <ul style="list-style-type: none">• Medical: 87.8%• Revascularization: 88.3%• P=0.97	5-y freedom from MACE: <ul style="list-style-type: none">• PCI vs. medical (77.0% vs. 78.9; p=0.15)• CABG vs. medical (77.6% vs. 69.5%; p=0.01)• interaction p=0.002
ARTS I (69 , 110 , 132)	Randomized 1997-1998	Overall 600/605 DM 112/96	Overall: 5-y overall freedom from death, stroke, or MI 18.2% vs. 14.9% (RR: 1.22; 95% CI: 0.95 to 1.58; p=0.14) DM: 1-y freedom from death, stroke, MI, or revascularization (63.4% vs. 84.4%; p< 0.001)	
MASS II (58)	Randomized 1995-2000	Overall 205/203 DM 56/59	DM: 1-y death 5.3% vs. 6.8% (p=0.5)	

*ARTS indicates Arterial Revascularization Therapies Study; BARI 2D, Bypass Angioplasty Revascularization Investigation 2 Diabetes; CABG, coronary artery bypass graft; CAD, coronary artery disease; CARDIA, Coronary Artery Revascularization in Diabetes; CI, confidence interval; DM, diabetes mellitus; HR, hazard ratio; LAD, left anterior descending artery; LOE, level of evidence; MACE, major adverse cardiac event; MASS II, Medicine, Angioplasty, or Surgery Study (MASS II); OR, odds ratio; MI, myocardial infarction; PCI, percutaneous coronary intervention; RR, relative risk; SYNTAX, Synergy Between Percutaneous Coronary Intervention with TAXUS and Cardiac Surgery; and y, year.

Data Supplement 16. Studies of Acetylcysteine for Prevention of Contrast Induced Nephropathy

Trial, Year	Study Drug / Comparator	Population	Primary Endpoint	Results	Statistics	Comments
ACT, 2011 (133)	Acetylcysteine vs. placebo	2,308 pts undergoing an angiographic procedure with at least one risk factor (age >70 y, chronic renal failure, diabetes mellitus, heart failure (LVEF<45%), or shock	CI-AKI 48 to 96 h after angiography	Acetylcysteine: 12.7%, placebo: 12.7%	p=0.97	No reduction in CI-AKI with Acetylcysteine vs. placebo
LIPSIA-N-ACC, 2010 (134)	Acetylcysteine vs. placebo	251 STEMI pts undergoing primary PCI	1) Occurrence of CI-AKI 2) reperfusion injury measured as myocardial salvage index by MRI	Endpoint 1) Acetylcysteine: 14%, placebo 20% Endpoint 2) Acetylcysteine 43.5, placebo	Endpoint 1) p=0.20 Endpoint 2) p=0.36	No clinical benefit with acetylcysteine with respect to development of CI-AKI and myocardial salvage index

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ACT indicates Acetylcysteine for Contrast-Induced Nephropathy Trial; CI-AKI, contrast-induced acute kidney injury; LVEF, left ventricular ejection fraction; LIPSIA-N-ACC, Leipzig Immediate Percutaneous Coronary Intervention Acute Myocardial Infarction N-ACC; MRI, magnetic resonance imaging; pts, patients; PCI, percutaneous coronary intervention; STEMI, ST-elevation myocardial infarction; and y, year.

Data Supplement 17. Studies Supporting the Minimization of Contrast Volume to Prevent Contrast Induced Acute Kidney Injury

Trial	Study Drug / Comparator	Population	Primary Endpoint	Results	Statistics	Comments
Marenzi, et al., 2009 (135)	Observational study to investigate the relationship between contrast volume and occurrence of CI-AKI	561 consecutive STEMI pts undergoing primary PCI	CI-AKI within 72 hours postprocedure	A higher volume of contrast media correlated to increased probability to develop CI-AKI: Q1: 10.9%, Q2: 13.6%, Q3: 17.1%, Q4: 27.5%		Volume of contrast media is correlated with incidence of CI-AKI
Laskey et al., 2007 (136)	Observational study into the usefulness of the ratio of contrast volume to creatinine clearance to predict CI-AKI	3,179 consecutive pts undergoing PCI	CI-AKI between 24 to 48 hours postprocedure	Volume to creatinine clearance ratio >3.7 was predictive of CI-AKI	OR 3.8, (95% CI: 2.0 to 7.3) p<0.01	Volume to creatinine clearance ratio can be used to determine maximum amount of contrast media

CI-AKI indicates contrast-induced acute kidney injury; OR, odds ratio; pts, patients; PCI, percutaneous coronary intervention; Q, quartile; and STEMI, ST-elevation myocardial infarction.

Data Supplement 18. Studies of Hydration to Prevent Contrast Induced Acute Kidney Injury

Trial	Study Drug/Comparator	Population	Primary Endpoint	Results	Statistics	Comments
Solomon et al., 1994 (137)	Half-isotonic saline vs. mannitol vs. furosemide	78 pts with chronic renal insufficiency undergoing cardiac angiography.	CI-AKI within 48 h	Saline: 11%, mannitol: 28%, furosemide: 40%	p=0.05	Hydration with saline provides protection against acute decreases in renal function.
Mueller et al., 2002 (138)	Isotonic Saline vs. half-isotonic saline	1620 pts undergoing elective or emergency PCI. Excluded if already on dialysis, had cardiogenic shock or mechanical ventilation.	CI-AKI within 48 h	Half-isotonic saline: 2.0% isotonic saline: 0.7%	p=0.04	Isotonic hydration is superior to half-isotonic hydration in the prevention of contrast-media associated nephropathy.
Trivedi et al., 2003 (139)	IV vs. oral prehydration	53 pts undergoing non-emergent cardiac catheterization. Excluded if CrCl <20mL/min, had decompensated heart failure, unacceptable risk of fluid overload as per primary physician or states of decreased effective arterial volume, e.g., nephritic syndrome, liver cirrhosis.	CI-AKI within 48 h	IV: 3.7% Oral: 34.6%	p<0.01	Intravenous hydration is preferable to oral hydration.

Bader et al., 2004 (140)	Bolus hydration during contrast media application vs. hydration 12 h before and after contrast media application.	39 pts with normal renal function undergoing cardiac catheterization. Excluded if pregnant, had uncontrolled hypertension, NYHA II-IV heart failure, liver failure or nephritic syndrome.	Change in GFR after 48 h	Change in GFR Bolus: -34.6±25.7 ml/min/1.73m ² Pre- and posthydration: -18.3±25.0 ml/min/1.73m ²	p<0.05	Hydration hours before and after exposure to contrast media is preferable to a bolus administration of saline immediately before or during contrast media exposure.
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CI-AKI indicates contrast-induced acute kidney injury; CrCl, creatinine clearance; GFR, glomerular filtration rate; h, hour; IV, intravenous; NYHA, New York Heart Association; pts, patients; and PCI, percutaneous coronary intervention.

Data Supplement 19. Studies of Periprocedural Statins to Reduce Adverse Outcome in PCI

Study Name	Author and Year	Study Type	Regimen	Study Size	Patient Population/Inclusion & Exclusion Criteria		Endpoints		P-Value	OR (CI)	Study Summary	Study Limitations
					<i>Inclusion Criteria</i>	<i>Exclusion Criteria</i>	<i>Primary Endpoint</i>	<i>Secondary Endpoint</i>				
<i>Statin-naïve</i>												
ARMYDA	Pasceri, 2004 (141)	RCT	Atorvastatin 40 mg/d starting 7 d before PCI	153	Chronic stable angina, elective PCI	ACS	Periprocedural MI (CPK > 2X normal)	1 mo MACE	0	0.25 (95% CI 0.08 to 0.80)	Pretreatment with statins for 1 wk decreases periprocedural MI	Definition of MI (although similar results with threshold 5X normal)
	Brigouri, 2004 (142)	Randomized	statin (atorvastatin, pravastatin, simvastatin) 3 d before PCI	451	Elective PCI	Positive CK or trop at entry	Periprocedural MI (CPK > 5X normal)		0.01	0.47 (95% CI: 0.26 to 0.86)	Pretreatment with statins for 3 d decreases periprocedural MI	Not blinded or placebo controlled
ARMYDA-ACS	Patti, 2007 (143)	RCT	Atorvastatin 80 mg 12 h before PCI and 40 mg preprocedure	171	NSTEMI	STEMI or NSTEMI that couldn't wait (hemodynamically unstable)	30 d MACE	Periprocedural MI (CPK > 3X normal)	0	0.25 (95% CI: 0.08 to 0.79)	In ACS, statins 12 hr before PCI decreases MACE	Definition of MI (although troponins were significant)
	Yun, 2008 (144)	RCT	Rosuvastatin 40 mg before PCI	445	ACS	Cardiogenic shock	Periprocedural MI (CPK > 2X normal)	1 mo MACE	0.04	0.49 (95% CI: 0.23 to 0.96)	In ACS, a single dose of statin before PCI decreases periprocedural MI.	
	Veselka, 2009 (145)	Randomized	Atorvastatin 80 mg/d starting 2d before PCI	200	Elective PCI	ACS, CRI (Cr > 150 mmol)	Periprocedural MI (CPK > 3X normal)		0.65	0.81 (95% CI: 0.33 to 1.98)	Pretreatment with statins for 2 d does not decrease periprocedural	Not blinded or placebo controlled

											MI.	
NAPLES II	Brigouri, 2009 (146)	Randomize d	Atorvastatin 80 mg d before PCI	668	Elective PCI of a de novo lesion	Instant restenosis	Periprocedural MI (CPK > 3X normal)	Inhospital MACE	0.01	0.56 (95% CI: 0.35 to 0.89)	Pretreatment with statins for 1 d decreases periprocedural MI	Not blinded or placebo controlled
STATIN STEMI	Kim, 2010 (147)	Randomize d	Atorvastatin 80 mg vs. 10 mg in ED before primary PCI for STEMI	171	STEMI	Cardiogenic shock or previous statins	30 d MACE	ST resolution, TIMI perfusion scores	0.26	0.52 (95% CI: 0.17 to 1.63)	Pretreatment with high-dose statins in STEMI may improve myocardial perfusion, but no hard outcome benefit	Underpowered (lower MACE than expected). Dose comparison, not placebo control
Reloading												
ARMYDA-RECAPTURE	Di Sciascio, 2009 (148)	RCT	On statins: reload atorvastatin 80 mg 12 h before PCI and 40 mg preprocedure	383	Elective PCI or NSTEMI	STEMI or NSTEMI that couldn't wait (hemodynamically unstable)	30 d MACE	Periprocedural MI (CPK > 3X normal)	0.04	0.36 (0.15 to 0.89)	Reloading in pts already on statins before PCI decreases MACE	Not blinded
Meta-analysis												
	Zhang, 2010 (149)	Meta-analysis	6 RCTs	2,088			Periprocedural MI			0.51 (0.38 to 0.67)	Pretreatment with statins before PCI reduces periprocedural MI.	Heterogeneity in trial design. 30 d MACE driven by MI in this area (low mortality, stroke, and early TVR)
	Winchester, 2010 (150)	Meta-analysis	10 RCTs	4,085, but not all had PCI			Periprocedural MI			0.59 (0.47 to 0.74)	Pretreatment with statins before PCI reduces periprocedural MI.	For short-term mortality, RR: 0.75 (95% CI: 0.16 to 3.58). Underpowered for this endpoint.

ACE indicates angiotensin-converting enzyme; ACS, acute coronary syndrome; ARMYDA, Atorvastatin for Reduction of MYocardial Damage during Angioplasty; CI, confidence interval; CK, creatine kinase; CPK, creatine phosphokinase; CRI, chronic renal insufficiency; ED, emergency department; MACE, major adverse cardiac event; MI, myocardial infarction; NAPLES, novel approaches for preventing or limiting events; NSTEMI, non-ST-elevation myocardial infarction; pts, patients; PCI, percutaneous coronary intervention; RCT, randomized control trial; RR, relative risk; STEMI, ST-elevation myocardial infarction; and TVR, target vessel revascularization.

Data Supplement 20. Data on Sites With No Onsite Surgical Backup

Author and Year	Study Type	Study Size (-) Indicates Without Onsite CABG Surgery (+) Indicates With Onsite CABG Surgery	Endpoints	OR/RR (95% CI); P-Value	Study Summary
	On-Site Surgery				
Wennberg et al., 2004 (151)	Medicare claims database 1121 hospitals	1,795 (-) 34,537 (+) 6,373 (-) 583,149 (+)	Primary PCI mortality Emergency CABG Elective PCI mortality Emergency CABG	OR 0.93 (0.80 to 1.08) OR 0.95 (0.73 to 1.22) OR 1.38 (1.14 to 1.67) OR 0.92 (0.73 to 1.17)	No difference non-primary/rescue PCI Worse outcome elective PCI
Carlsson et al., 2007 (152)	SCAAR PCI Registry 24 hospitals	8,838 (-) 25,525 (+)	30 d Mortality: 1.4 vs. 2.2% TIA/CVA: 0.3 vs. 0.4% emergency CABG: 0.1 vs. 0.2%	p<0.001 p=0.09 p=0.025	No difference in outcome More STEMI pts in (+)
Kutcher et al., 2009 (153)	NCDR PCI Registry 465 hospitals	8,736 (-) 299,425 (+)	Mortality Emergency CABG	OR 0.90 (0.72 to 1.14) OR 0.60 (0.37 to 0.98)	No difference in outcome
Tebbe et al., 2009 (154)	PCI Registry 36 hospitals	10,683 (-) 12,465 (+)	Mortality MACE MI TIA/CVA Emergency CABG	OR 0.99 (0.81 to 1.22) OR 1.08 (0.91 to 1.28) OR 1.24 (0.88 to 1.75) OR 1.30 (0.63 to 2.71) OR 1.17 (0.66 to 2.09)	No difference in outcome
Singh et al., 2009 (155)	4 trial meta-analysis	6,817	Mortality MI Emergency CABG	RR: 2.7 (0.6 to 12.9) RR: 1.3 (0.7 to 2.2) RR: 0.46 (0.06 to 3.1)	No difference in outcome
Sanborn et al., 2004 (156)	NRMI-3,-4 P-PCI Registry STEMI	1,874 (-) 24,890 (+)	Mortality: 3.7 vs. 4.8% MI: 1.1 vs. 1.5% CVA: 0.5 vs. 0.7%	p=0.07 p=0.19 p=0.44	No difference in outcome Transfer-outs not counted More likely to receive other meds.
Pride et al., 2009 (157)	NRMI-5 P-PCI Registry STEMI	1,655 (-) 1,768 (+)	Mortality: 3.3 vs. 3.8% MI: 0.9 vs. 1.0 %	p=0.44 p=0.76	No difference in outcomes with propensity analysis. Transfer bias.
Pride et al., 2009 (158)	NRMI-5 PCI Registry NSTEMI	1,282 (-) 1,282 (+)	Mortality: 1.0 vs. 1.3% MI: 0.2 vs. 0.8%	p=0.51 p=0.047	No difference in outcomes with propensity analysis. Transfer bias.
Hannan et al., 2009 (159)	New York State Registry STEMI	1,729 (-) 1,729 (+)	30-day mortality: 2.31 vs. 1.91% Emergency CABG: 0.23 vs. 0.69% 3-y mortality: 7.1 vs. 5.9%	p=0.40 p=0.046 p=0.07	No difference in outcomes with propensity analysis. Higher TVR rates and higher mortality in pts not undergoing PCI.

(-) indicates Without Onsite CABG Surgery; (+) indicates With Onsite CABG Surgery; CABG, coronary artery bypass graft; CI, confidence interval; CVA, cerebrovascular accident; MACE, major adverse cardiac event; MI, myocardial infarction; NCDR, National Cardiovascular Data Registry; NRMI, National Registry of Myocardial Infarction; OR, odds ratio; pts, patients; PCI, percutaneous coronary intervention; P-PCI, primary percutaneous coronary intervention; SCAAR, Swedish Coronary Angiography and Angioplasty Registry; STEMI, ST-elevation myocardial infarction; TIA, transient ischemic attack; and TVR, target vessel revascularization.

Data Supplement 21. Studies of Radial Access PCI

Author/Study	Study Population	Endpoint	Radial Access Endpoint %	Femoral Access Endpoint %
Brueck et al. , 2009 (160)	1,024 pts randomized equally to femoral versus radial access.	Vascular complications	0.58%	3.71%
Jolly et al. , 2009 (161)	Meta-analysis	Bleeding complications	0.05%	2.3%
Pristipino et al. , 2009 (162)	Observational study of 1,052 pts.	Bleeding and vascular complications	1.9%	4.2%
Rao et al. , 2008 (163)	NCDR database observational study of 593,094 pts	Vascular complications	0.19%	0.7%
Jaffe et al. , 2007 (164)	200 octogenarians	Vascular complications	5%	26%
Louvard et al. , 2004 (165)	377 octogenarians	Vascular complications	1.6%	6.5%
Agostoni et al. , 2004 (166)	Meta-analysis	Access site complications	0.3%	2.8%
Jolly et al. , 2011 (167)	7,021 pts with ACS for catheterization/PCI randomized to radial versus femoral access.	Death, MI, stroke, or non-CABG related major bleeding at 30 d	3.7%	4.0%

ACS indicates acute coronary syndrome; CABG, coronary artery bypass graft; d, day; MI, myocardial infarction; NCDR, National Cardiovascular Data Registry, pts, patients; and PCI, percutaneous coronary intervention.

Data Supplement 22. Studies of Cardiogenic Shock in the Elderly

Author and Year	Study Type	Patient Population Number of Patients (%)	Study Size	Endpoints	Results HR/ RR (95% CI), P-Value	Study Summary
Dzavik et al. , 2005 (1993-1998) (168)	SHOCK RCT subgroup	56/302 (19%) ≥75 y old	ERV - 24 (12 PCI) IMS - 32	30 d mortality	ERV = 75% IMS = 53% RR: 1.41	Multiple testing, small sample size. ERV pts: lower LVEF, more women, more anterior MI, 6 did not undergo revascularization
Dauerman et al. , 2001 (1986-1997) (169)	Worcester Heart Attack Registry cohort	310 ≥65 y old	ERV - 26 IMS - 284	Inhospital mortality	ERV = 56% IMS = 77% p=0.02	
Dzavik et al. , 2003 (1993-1997) (170)	SHOCK Registry	277/865 (32%) ≥75 y old	ERV - 62 (45 PCI) IMS - 215	30 d mortality	ERV = 48% IMS = 81% p=0.0003 RR: 0.46 (95% CI 0.28 to 0.75)	Similar mortality as younger pts

Antoniucci et al. , 2003 (1995-2001) (171)	Florence PCI Registry	71/205 (35%) ≥75 y old	PCI - 71	Mortality	6 mo: 51%	Higher mortality than younger pts (51% vs. 25%)
Dauerman et al. , 2003 (1990-2000) (172)	Northern New England PCI Registry	74/310 (24%) ≥75 y old	PCI - 74	Mortality	Inhospital: 47%	Higher mortality than younger pts (46.7% vs. 34.5%)
Prasad et al. , 2004 (1991-2000) (173)	Mayo PCI Registry	61 ≥75 y old	PCI - 61	Mortality	Inhospital: 44% 30 d: 47%	
Zeymer et al. , 2004 (1994-2001) (174)	ALKK PCI Registry	1,333 Average age 63.9±12.6 y)	N/A	Mortality	Inhospital: 63% for pts ≥75 y	14% incidence of "shock"
Klein et al. , 2005 (1998-2002) (175)	NCDR PCI Registry	143 70 to 79 y old 74 ≥ 80 y old	PCI - 217	Mortality	Inhospital: 64% Inhospital: 81%	
Migliorini et al. , 2006 (1995-2004) (176)	Florence PCI Registry	104/280 (37%) ≥75 y old	PCI - 104	Mortality	30 d: 49% 6 mo: 56%	Second report, same center
Amin et al. , 2009 (1999-2005) (177)	Rush/Cook County Registry	80/310 (26%) ≥75 y old	ERV – 29 (15 PCI) IMS - 51	Mortality (follow-up not stated)	HR: 0.56 (0.32 to 0.99)	Higher mortality than younger pts
Lim et al. , 2009 (2004-2007) (178)	Melbourne Interventional Group Registry	45/143 (32%) ≥75 y old	PCI - 45	Mortality	Inhospital: 42% 30 d: 43% 1y: 53%	Similar mortality in older pts as younger pts (43% vs. 36%, respectfully)

ALKK indicates Arbeitsgemeinschaft Leitender Kardiologischer Krankenhausärzte; CI, confidence interval; d, day; ERV, early revascularization; HR, hazard ratio; IMS, initial medical stabilization; LVEF, left ventricular ejection fraction; mo, month; MI, myocardial infarction; NCDR, National Cardiovascular Data Registry; pts, patients; PCI, percutaneous coronary intervention; RCT, randomized controlled trial; RR, relative risk; SHOCK, SHould we emergently revascularize Occluded Coronaries in cardiogenic shock; and y, years.

Data Supplement 23. Studies of Fractional Flow Reserve Assessment for Intermediate Coronary Lesions

Study Name	Author(s)/Year Published	Study Type	Study Size	Inclusion/Exclusion Criteria	Primary Endpoint	Results/Coronary Artery Bypass Graft P-Values	Summary/Conclusions
DEFER (179)	Bech et al. , 2001	RCT	325 pts	Elective PCI 3 groups based on </≥0.75FFR (deferral, performance, and reference groups)	Absence of cardiac events by 24 mo	Same event in pts with FFR ≥0.75 with PCI or deferred	In pts with SVCAD and no document ischemia, FFR identifies those benefit from PTCA
DEFER (180)	Pijls et al. , 2007	RCT	325 pts	Elective PCI SVD with 3 groups (deferral, performance, and reference groups) based on </≥0.75FFR	Absence of cardiac events by 60 mo	Similar to 2 y follow-up No benefit with PCI if FFR ≥0.75	In pts with SVCAD and no document ischemia, FFR identifies those benefit from PTCA
FAME (181)	Tonino et al. , 2009	RCT	1,005 pts (DES)	MVD PCI with angiography PCI only vs. angiography and FFR ≤0.80	1 y death, MI, or repeat	18.3% in angiography group; 13.2% in FFR group (p=0.02)	FFR guided PCI in MVD pts improves 1 y composite endpoints-death, MI, and

					revascularization		revascularization.
FAME (182)	Pijlis et al., 2010	RCT	1,005 pts (DES)	MVD pts with angiography PCI only or angiography and FFR ≤ 0.80	1 y death, MI, or repeat revascularization	22.4% angiography group; 17.9% in FFR group (p=0.08)	FFR guided PCI in MVD pts improves 2 y composite endpoints-death, MI, and revascularization.
(FFR vs. IVUS) (183)	Nam et al., 2010	NRCT	167 pts	40-70% PCI of stenosis with IVUS $MLA \leq 4.0\text{cm}^2$ or FFR ≤ 0.8	1 y death, MI, or repeat revascularization	No difference: 3.6% FFR vs. 3.2% IVUS.	No difference in events; more PCI's in IVUS group (91.5%) vs. FFR (33.7%) (p<0.001)
(LM) (184)	Courtis et al., 2009	NRCT	142 consecutive pts	LM 30 to 60% or indeterminate. FFR < 0.75 revascularization recommended, > 0.80 medical therapy recommended, or 0.75 to 0.80 either recommended.	14 mo follow-up MACE	13% medical vs. 7% revascularization. Death or MI 6 vs. 7%, respectively.	FFR may be helpful but DM and dose of adenosine may influence decision.
(LM) (185)	Hamilos et al., 2010	NRCT	213 pts (209 with follow-up)	Equivalent LM FFR < 0.80 surgery; 0.80 medical therapy	Event free survival 3 y follow-up; 5 y estimated.	74.2% medical therapy versus 82.8% surgery (p=0.48)	FFR is beneficial for equivocal LM lesions in deciding need for revascularization.

DEFER indicates Deferral Versus Performance of Balloon Angioplasty in Patients Without Documented Ischemia; DES, drug eluting stent; DM, diabetes mellitus; FAME, Fractional Flow Reserve Versus Angiography for Multivessel Evaluation; FFR, fractional flow reserve; IVUS, intravascular ultrasound; LM, left main; MACE, major adverse cardiac event; MI, myocardial infarction; MLA, mean lesion area; MVD, multivessel disease; NRCT, nonrandomized controlled trial; pts, patients; PCI, percutaneous coronary intervention; PTCA, percutaneous transluminal coronary angioplasty; RCT, randomized controlled trial; SVCAD, single-vessel coronary artery disease, SVD, saphenous vein disease; and y, year.

Data Supplement 24. RCTs and Relevant Meta-Analyses of Glycoprotein IIb/IIIa Inhibitors in Trials of PCI

Trial	Study Drug / Comparator	Population	Primary Endpoint	Results	Statistics	Comments
Primarily Elective PCI (Without Routine Clopidogrel Pretreatment)						
EPISTENT (186)	Abciximab vs. placebo	2,399 pts undergoing elective PCI	Death, MI or UTVR at 30 d	5.3% (stent+abciximab) vs. 10.8% (stent+placebo) HR: 0.48	95% CI: 0.33 to 0.69; p<0.001	
ESPRIT (187)	Eptifibatide (double bolus) vs. placebo	2,064 predominantly non-ACS pts undergoing planned stent implantation	Combination of death, MI, UTVR and thrombotic bailout GP IIb/IIIa inhibitor therapy within 48 h after randomization.	6.6% (95% CI 8.7 to 12.4%) with treatment vs. 10.5% (95% CI 5.1 to 8.1%) for pts on placebo. RR: 0.63	95% CI: 0.47 to 0.84; p=0.0015	18% of pts with ACS within 48 h or acute STEMI within 7 d before randomization.
Juergens et al. (188)	Tirofiban (standard dose) vs. placebo	894 pts undergoing planned PCI with stenting	TIMI major bleeding	No differences in major bleeding <u>Death, MI or UTVR at 30 d:</u> 3.9% vs. 3.9%	p=NS <u>Death, MI or UTVR at 30 d:</u> p=NS	
Elective (Stable) and Urgent (ACS) Patients Enrolled (Without Routine Clopidogrel Pretreatment)						
EPILOG (189)	Abciximab vs. placebo	2,792 pts with stable ischemia or unstable angina	Death, MI or UTVR at 30 d	5.2% in abciximab with low dose heparin group vs. 11.7% in placebo group. HR: 0.43	95% CI: 0.30 to 0.60; p<0.001	

ACS/High Risk (Without Routine Clopidogrel Pretreatment)						
CAPTURE (190)	Abciximab (administered for 18 to 24 h before PCI) vs. placebo	1,265 pts with “refractory unstable angina” undergoing PCI 18 to 24 h after diagnostic catheterization	Death, MI or UTVR at 30 d	11.3% in abciximab vs. 15.9% in placebo group.	p=0.012	Significant reduction in MI rate both before and during PCI with abciximab therapy. No difference in 6 mo composite endpoint.
EPIC (191)	Abciximab vs. placebo	Pts at high risk for abrupt vessel closure	Death, MI, UTVR, IABP or unplanned stent placement at 30 d	Bolus only: 11.4% Bolus + infusion: 8.3% Placebo: 12.8%	p=0.009 overall; p=0.008 for bolus + infusion vs. placebo	
RESTORE (192)	Tirofiban (standard dose) vs. placebo	2,139 pts with ACS undergoing PTCA or DCA	Death, NFMI, UTVR, or stent placement at 30 d	10.3% vs. 12.2%	p=0.160	Composite endpoint was statistically lower at 2 and 7 d follow-up (but not at the 30 d primary endpoint).
STEMI (Without Routine Clopidogrel Pretreatment)						
On-TIME 2 (193)	Tirofiban (high-dose bolus) vs. placebo	936 pts with STEMI treated with prehospital drug/placebo undergoing primary PCI.	Residual ST-segment deviation 1 h after PCI	3.6 mm in pts treated with high-dose bolus tirofiban vs. 4.8 mm in placebo group.	p=0.003	No significant reduction in clinical endpoints in the phase 2 (blinded) study; analysis of combined phase 1 (open label) and phase 2 data did demonstrate reduced clinical endpoints at 30 d.
ACE (194,195)	Abciximab vs. placebo	400 pts with STEMI undergoing primary PCI with stenting.	Death, NFMI, TVR and CVA at 1 mo	4.5% in abciximab group vs. 10.5% in stent only group OR: 0.41	95% CI: 0.17 to 0.97; p=0.041	1 y cardiovascular mortality 5.0% vs. 10.5% (p=0.040).
ISAR-2 (196)	Abciximab vs. placebo	401 pts undergoing stenting within 48 h after onset of AMI.	Late lumen loss after stenting	1° endpoint: N/A	p=0.038	Death, reinfarction and TLR at 30 d 5.0% in abciximab group vs. 10.5% in placebo group.
CADILLAC (197,198)	Abciximab vs. placebo	2,082 pts with STEMI undergoing primary PCI.	Death, reinfarction, disabling CVA, and TVR at 6 mo	<u>1 mo:</u> 4.6% in abciximab group vs. 7.0% in placebo. RR: 0.65 <u>1 y:</u> 16.9% in abciximab group vs. 18.4% in placebo group RR: 0.92	<u>1 mo:</u> 95% CI: 0.46 to 0.93; p=0.01 <u>1 y:</u> 95% CI: 0.76 to 1.10; p=0.29	Composite results of abciximab vs. placebo for entire study population only reported at 1 mo and 1 y.
ADMIRAL (199)	Abciximab vs. placebo	300 pts with STEMI undergoing primary PCI with stenting.	Death, reinfarction, or UTVR	6.0% in abciximab group vs. 14.6% in placebo group. OR: 0.41	95% CI: 0.18 to 0.93; p=0.01	
RAPPORT	Abciximab vs. placebo	483 pts with STEMI	Death, NFMI or TVR at 6	28.2% in abciximab group vs.	p=0.97	7 and 30 d secondary endpoints

(200)		undergoing primary PCI.	mo	28.1% in placebo group.		of death, MI or UTVR were statistically lower with abciximab.
De Luca, 2005 meta-analysis (201)	Abciximab vs. placebo	STEMI pts undergoing primary PCI or lytic therapy.	30 d mortality	Primary PCI trials only: 2.4% in abciximab group vs. 3.4% in placebo group. OR: 0.68	95% CI: 0.47 to 0.99; p=0.047	
De Luca et al., 2009 meta-regression analysis (202)	GP IIb/IIIa vs. placebo (or bivalirudin)	16 RCTs of primary PCI, including HORIZONS and BRAVE-3.	30 d mortality	2.9% in GP IIb/IIIa vs. 2.8% in placebo (or bivalirudin group). OR: 0.96	95% CI: 0.76 to 1.22; p=0.75	Reinfarction 1.9% in GP IIb/IIIa group vs. 1.5% in placebo group (p=0.22); Major bleeding 4.1% in GP IIb/IIIa group vs. 2.7% in placebo group (p=0.0004); trend toward mortality benefit when HORIZONS not included in analysis (OR: 0.78; 95% CI: 0.58 to 1.04); strong relationship present between patient risk profile and mortality benefit from GP IIb/IIIa.
Pre-Cath Lab Administered GP IIb/IIIa (“Facilitated PCI”)						
On-TIME 2 (193)	Tirofiban (high bolus dose) vs. placebo	936 pts with STEMI treated with prehospital drug/placebo undergoing primary PCI	Residual ST-segment deviation 1 h after PCI	3.6 mm in high- bolus tirofiban vs. 4.8 mm in placebo.	p=0.003	No significant reduction in clinical endpoints in the phase 2 (blinded) study; analysis of combined phase 1 (open label) and phase 2 data did demonstrate reduced clinical endpoints at 30 d
FINESSE (203)	Abciximab	Abciximab administered pre-cath lab (including at “spoke” hospital) vs. abciximab+1/2 dose lytic administered in pre-cath lab vs. abciximab in the cath lab.	Death, VF, cardiogenic shock, and CHF at 90 d	Abciximab-facilitated 10.5% vs. 10.7% abciximab in cath lab.	p=0.86	No significant difference in 90 d mortality
RELAX-AMI (204)	Abciximab administered in ER (early group)vs. abciximab in cath labafter coronary angiography (late group)	210 pts with STEMI undergoing primary PCI	Preintervention TIMI flow grade	TIMI3 flow: 24% in early group vs. 10% in late group.	p=0.001	1 mo LVEF better in ER-treated (early group) pts (51% vs. 47% in late group pts; p=0.01)
Keeley et al.,	GP IIb/IIIa administered in	9 trials of GP IIb/IIIa therapy,	Numerous endpoints studied	In analysis of only GP IIb/IIIa		

2006 Meta-analysis (205)	ER or ambulance vs. GP IIb/IIIa in cath lab	as well as lytic and combination therapy trials		trials, no differences in death, NFMI or UTVR		
Montalescot et al., 2004 Meta-analysis (206)	GP IIb/IIIa administered in ER or ambulance vs. GP IIb/IIIa in cath lab	6 trials enrolling 931 pts treated with abciximab or tirofiban	TIMI flow grade 2 or 3 on first angiogram	41.7% early group vs. 29.8% in late group. OR: 1.69	95% CI: 1.28 to 2.22; p<0.001	Early administration reduced overall mortality from 4.7% to 3.4%; (OR: 0.72; 95% CI: 0.37 to 1.40; p=0.42)
Head-to-Head Comparisons						
EVA-AMI (207)	Eptifibatide vs. abciximab	427 pts with STEMI treated with primary PCI	>70% resolution of ST-segment elevation at 60 min after PCI	62.6% after eptifibatide vs. 56.3% after abciximab.	N/A	
FATA (208) (209)	Tirofiban (high- dose) vs. abciximab	692 pts with STEMI undergoing primary PCI	≥70% ST-segment resolution at 90 min	67.05% after tirofiban vs. 70.45% after abciximab (change -3.4%)	Change CI: -10.35 to +3.56, falling beyond the predefined change ± 10% equivalence boundaries	30 d MACE 2.8% in tirofiban group vs. 1.8% in abciximab group (p=0.34)
MULTISTRATE GY (210)	Tirofiban (high dose) vs. abciximab	722 pts with STEMI undergoing primary PCI	≥50% ST-segment resolution at 90 min	85.3% in tirofiban infusion vs. 83.6% in abciximab infusion.	p<0.001 for noninferiority	30 d MACE similar (4.0% in tirofiban vs. 4.3% in abciximab; p=0.85)
STRATEGY (211)	Tirofiban (high dose) vs. abciximab	175 pts with STEMI undergoing primary PCI	<u>1° endpoint:</u> N/A (see comments) <u>2° endpoint:</u> MACE at 30 d	30-d Death/reinfarction/stroke/urgent TVR 3% vs. 8%	p=0.33	Pts were randomized to tirofiban + drug-eluting stent or to abciximab + bare metal stent, confounding interpretations of primary and secondary endpoints
Danzi et al. (212)	Tirofiban (high dose) vs. abciximab	100 pts undergoing primary PCI	Change in infarct-zone wall motion score index at 30 d assessed by echocardiography.	<u>Tirofiban:</u> 2.18 at baseline to 1.95 at 30 d <u>Abciximab:</u> 2.20 at baseline to 1.99 at 30 d	p=0.67	Ejection fractions at 1 mo were similar in the two groups
TARGET (213,214)	Tirofiban (standard dose) vs. abciximab	2,398 pts undergoing elective or urgent PCI (STEMI excluded)	Death, MI, or UTVR within 30 d.	7.6% vs. 6.0% HR: 1.26	95% CI: 1.01 to 1.57; p=0.038	In subgroup analysis, tirofiban worse in ACS pts (9.3% vs. 6.3%; p=0.002) but not in pts without ACS (4.5% vs.5.6%; p=0.32)
De Luca et al., Meta-analysis of randomized primary PCI trials (215)	Small molecules vs. abciximab	2,107 pts with STEMI undergoing primary PCI	30 d mortality	2.0% small molecule vs. 2.2% abciximab	p=0.66	Similar post-PCI TIMI flow grade 3 (89.8% small molecule vs. 89.1% abciximab; p=0.72) and ST-segment resolution (68.2% small molecule vs. 67.8% abciximab; p=0.66)

Gurm et al., Meta-analysis of randomized primary PCI trials (216)	Small molecules vs. abciximab	2,138 pts undergoing primary PCI	30 d mortality rates, reinfarction rates, and major bleeding rates assessed	<u>Death:</u> 1. small molecule vs. 2.3% abciximab OR: 0.84 <u>Reinfarction:</u> 1. small molecule vs. 1.2% abciximab OR: 1.22 <u>Major Bleeding:</u> 1. small molecule vs. 1.3% abciximab OR: 1.21	<u>Death:</u> 95% CI: 0.46 to 1.55; p=0.58 <u>Reinfarction:</u> 95% CI: 0.51 to 2.91; p=0.69 <u>Major Bleeding:</u> 95% CI: 0.58 to 2.49; p=0.61	
IC vs. IV Administration						
EASY-MI (217)	IC vs. IV abciximab	105 pts with STEMI undergoing primary PCI	<u>1° endpoint:</u> PAI ≥95% 10 min after bolus administration. <u>2° endpoints:</u> numerous acute and 6 mo angiographic and MRI-assessed outcomes	<u>1° endpoint:</u> 53% IC vs. 54% IV <u>2° endpoints:</u> no difference in myocardial blush grade, peak release of cardiac biomarkers, necrosis size, myocardial perfusion or LVEF	<u>1° endpoint:</u> p=1.00	
Thiele et al. (218)	IC vs. IV abciximab	154 pts with STEMI undergoing primary PCI	Infarct size and extent of microvascular obstruction (expressed as percent of LV) as assessed by MRI at 2 days	<u>Infarct size:</u> 15.1% IC abciximab vs. 23.4% IV abciximab <u>Microvascular obstruction:</u> 1.1% vs. 3.5%	<u>Infarct size:</u> p=0.01 <u>Microvascular obstruction:</u> p=0.01	<u>MACE at 30 days:</u> 5.2% IC abciximab vs. 15.6% IV abciximab (p=0.06)
Galache Osuna et al. (219)	IC bolus vs. IV bolus abciximab	137 pts undergoing PCI	Death, MI or need for revascularization at 1 y	8.5% IC abciximab bolus vs. 6.2% IV abciximab bolus.	p=NS	
Bellandi et al. (220)	IC vs. IV abciximab; IC administration was <i>distal</i> to lesion	45 pts with STEMI undergoing primary PCI	Salvage index and LV function recovery as assessed by SPECT	<u>Salvage index:</u> 0.66 vs. 0.4 <u>LVEF recovery:</u> 14.7% vs. 8%	<u>Salvage index:</u> p=0.003 <u>LVEF recovery:</u> p=0.013	
Intracoronary bolus administration of	IC vs. IV abciximab	43 pts with ACS or prior lytic-treated STEMI undergoing PCI	Coronary bed platelet GP IIb/IIIa receptor occupancy	<u>After 1st bolus:</u> 94% vs. 51%	<u>After 1st bolus:</u> p<0.001	Corrected TIMI frame count post-PCI better with IC administration (18 vs. 25;

eptifibatide during percutaneous coronary stenting for non ST elevation myocardial infarction and unstable angina (221)				After 2 nd bolus: 99% vs. 91%	After 2 nd bolus: p=0.001	p=0.007)
Wu et al. (222)	IC vs. IV tirofiban (standard dose)	118 elderly pts with STEMI or NSTEMI-ACS	1° endpoint not specified; numerous angiographic and clinical endpoints assessed	<u>TIMI 3 after PCI:</u> 89.7% study group vs. 71.9% control <u>TMPG grade 3 after PCI:</u> 84.5% study group vs. 66.7% control <u>Composite 30 d MACE:</u> 1.7% study group vs. 7.0% control <u>30 d LVEF:</u> 67.4% study group vs. 60.7% control	<u>TIMI 3 after PCI:</u> p=0.016 <u>TMPG grade 3 after PCI:</u> p=0.026 <u>Composite 30 d MACE:</u> p=0.350 <u>30 d LVEF:</u> p=0.033	
GP IIb/IIIa After Clopidogrel Pretreatment						
BRAVE-3 (223)	Abciximab vs. placebo	800 pts with STEMI undergoing PCI within 24 hours of symptom onset	SPECT-measured infarct size	15.7±17.2% in abciximab group vs. 16.6±18.6% placebo group	p=0.47	
ISAR-REACT (224)	Abciximab vs. placebo	2,159 pts undergoing elective PCI	Death, MI or UTVR at 30 d	4% abciximab vs. 4% placebo; RR: 1.05	95% CI: 0.69 to 1.59; p=0.82	
ISAR-SWEET (225)	Abciximab vs. placebo	701 pts with diabetes undergoing elective PCI	Death or MI at 1 y	8.3% abciximab vs. 8.6% placebo RR: 0.97	95% CI: 0.58 to 1.62; p=NS	
ISAR-REACT 2 (226)	Abciximab vs. placebo	2,022 “high-risk” ACS pts undergoing PCI	Death, MI or UTVR at 30 d	8.9% abciximab vs. 11.9% placebo; RR: 0.75	95% CI: 0.58 to 0.97; p=0.03	RR: 0.71 in troponin positive pts; RR: 0.99 in troponin negative pts
ISAR-SMART 2 (227)	Abciximab vs. placebo as part of a 2 x 2 randomization	502 pts undergoing small vessel elective PCI	Incidence of restenosis. Secondary endpoint of death or MI at 1 y	Secondary endpoint of death or MI at 1 y: 8.8% abciximab vs. 6.8% placebo; RR: 1.33	95% CI: 0.71 to 2.50; p=0.37	
ADVANCE	Tirofiban (high dose) vs.	202 pts undergoing elective	Death, NFMI, UTVR or	20% tirofiban vs. 35% placebo;	95% CI: 0.29 to	Pts pretreated with either

(228)	placebo	or urgent PCI (1/3 with stable angina; half with ACS)	bailout GPI therapy at median of 185 d	HR: 0.51	0.88; p=0.01	ticlopidine or clopidogrel Death/MI/TVR at 6 mo lower (HR: 0.57; 95% CI: 0.99 to 0.33; p=0.048)
TOPSTAR (229)	Standard dose tirofiban vs. placebo	109 pts undergoing elective PCI	Incidence and amount of troponin release after 24 h	<u>Incidence:</u> 48% tirofiban vs. 69% placebo. <u>Amount (48 h):</u> 0.0291tirofiban vs. 0.036 placebo	<u>Incidence:</u> p<0.05 <u>Amount (48 h):</u> p=NS	Variably defined primary endpoint(s) in manuscript with no amount of troponin release at 24 h listed in results.
Pannu et al., Meta-analysis (230)	GP IIb/IIIa vs. placebo	5,303 pts undergoing PCI	Death, MI or TVR	OR: 0.84	95% CI: 0.58 to 1.22; p=0.35	

ACE indicates Abciximab and Carbostent Evaluation; ACS, acute coronary syndrome; AIDA STEMI, Abciximab Intracoronary versus intravenously Drug Application in ST-Elevation Myocardial Infarction;_ADMIRAL, Abciximab before Direct Angioplasty and Stenting in Myocardial Infarction Regarding Acute and Long-Term Follow-up; ADVANCE, Additive Value of tirofiban administered with the high dose bolus in the prevention of isChEmic complications during high-risk coronary angioplasty; AMI, acute myocardial infarction; BRAVE; Bavarian Reperfusion Alternatives Evaluation; CADILLAC, Controlled Abciximab and Device Investigation to Lower Late Angioplasty Complications; cath, catheterization; CI, confidence interval; CVA, cerebrovascular accident; DCA, directional coronary atherectomy; EASY-MI, EArly Discharge after Transradial Stenting of CoronarY Arteries in Acute Myocardial Infarction;_EPIC, Evaluation of 7E3 for the Prevention of Ischaemic Complications; EPILOGUE, Evaluation in PTCA (percutaneous transluminal coronary angioplasty) to Improve Long-term Outcome with abciximab GP IIb/IIIa blockade; EPISTENT, Evaluation of Platelet IIb/IIIa Inhibition in STENTing; ER, emergency room; ESPPRIT, Ehnahnce Suppression of the Platelet IIb/IIIa Receptor with Integrilin Therapy; EVA-AMI; Eptifibatide vs. Abciximab in Primary PCI for Acute STEMI; FATA, Facilitated Angioplasty with Tirofiban or Abciximab; FINESSE, Facilitated Intervention With Enhanced Reperfusion Speed to Stop Events; GP, glycoprotein; GPI, glycoprotein inhibitors; HORIZONS; Harmonizing Outcomes with RevascularIZatiON and Stents; HR, hazard ratio; IC, intracoronary; ISAR; Intracoronary Stenting and Antithrombotic Regimen; ISAR-REACT; Intracoronary Stenting and Antithrombotic Regimen: Rapid Early Action for Coronary Treatment; ISAR-SMART, Intracoronary Stenting or Angioplasty for Restenosis Reduction in Small Arteries; ISAR-SWEET, Intracoronary Stenting and Antithrombotic Regimen: Superior Way to Eliminate Elevated Thrombotic Risk in Diabetics; IV, intravenous; LVEF, left ventricular ejection fraction; MACE, major adverse cardiac event; MI, myocardial infarction; MRI, magnetic resonance imaging; NFMI, nonfatal myocardial infarction; NS, not significant; NSTEMI-ACS; non-ST-elevation acute coronary syndrome; ON-TIME; Ongoing tirofiban in myocardial infarction evaluation; pts, patients; PCI, percutaneous coronary intervention; PTCA, percutaneous transluminal coronary angioplasty; RAPPORT, ReoPro and Primary PTCA Organization and Randomized Trial; RCT, Randomized control trials; RELAX-AMI, Randomized Early versus Late AbciXimab in Acute Myocardial Infarction; RESTORE, Randomized Efficacy Study of. Tirofiban for Outcomes and Restenosis; RR, relative risk; SPECT, single photon emission computed tomography; STRATEGY, Single High Dose Bolus Tirofiban and Sirolimus Eluting Stent vs. Abciximab and Bare Metal Stent in Myocardial Infarction; STEMI, ST-elevation myocardial infarction; TARGET, Do Tirofiban and ReoPro Give Similar Efficacy Outcomes? TIMI, Thrombolysis In Myocardial Infarction; TMPG, TIMI myocardial perfusion grades; TOPSTAR, Troponin in Planned PTCA/Stent Implantation With or Without Administration of the Glycoprotein IIb/IIIa Receptor Antagonist Tirofiban; TVR, target vessel revascularization; UTVR, urgent target vessel revascularization; and VF, ventricular fibrillation.

Data Supplement 25. Studies of No-Reflow Therapies During PCI

Author and Year	Study Type	Study Size	Clinical Setting	Patient Population/Inclusion & Exclusion Criteria				Endpoints			Conclusions	Comments
					<i>Drug</i>	<i>Delivery</i>	<i>Dose</i>	<i>Death (PCI, CABG)</i>	<i>MI (PCI, CABG)</i>	<i>TIMI 3 flow (PCI, CABG)</i>		
Calcium Blockers												
Piana et al., 1994 (231)	Cohort	28	Vein grafts and native coronaries	Post-PCI TIMI flow <3 without mechanical obstruction	Verapamil	Guide or distal perfusion catheter	Mean 234 mcg	2	3.6% Q-wave and 28.6% CK-MB >50 IU/L	80%	"nearly 90% of pts respond promptly to IC verapamil"	

Weyrens et al., 1995 (232)	Cohort	24	Vein grafts and native coronaries	Post-PCI TIMI 0-I flow with patent treatment site	Diltiazem	Distal perfusion catheter	500 to 2500 mcg boluses	0	4% CK > 3 x normal	96%	"Diltiazem led to prompt improvement in coronary flow in most pts."	
Kaplan et al., 1996 (233)	Cohort	15	SVGs	Post-PCI TIMI flow <3 without mechanical obstruction	Verapamil	Guide or distal perfusion catheter	250 to 1250 mcg	0	6% MI (CK-MB > 25 IU/L)	88%	"IC verapamil is successful in improving no-reflow in all cases"	IC nitroglycerine was of no benefit whatsoever.
Huang et al., 2006 (234)	Cohort	72	Vein grafts and native coronaries	Post-PCI TIMI flow <3 without mechanical obstruction	Nicardipine	Guide or distal perfusion catheter	Mean 460 mcg	1.4%	4.2%	98.6%	"favorable safety and efficacy profile"	
Adenosine												
Fischell et al., 1998 (235)	Cohort	11	SVGs	Post-PCI "slow- or no-reflow" (Mean TIMI flow = 1)	Adenosine	N/A	Mean of 12 boluses	0	75% CPK > normal	90%	"intra-graft adenosine is promising"	
Sdringola et al., 2000 (236)	Cohort	11	SVGs	Post-PCI "slow- or no-reflow" without mechanical obstruction	Adenosine	Via guide catheter	>120 mcg in 11; < 120 mcg in 9	0	40% CPK > 3 x normal	82% with > 120 mcg adenosine; 33% with < 120 mcg adenosine	"intra-graft adenosine promises to be safe and effective"	
Barcin et al., 2004 (237)	Cohort	21	Vein grafts and native coronaries	Post-PCI TIMI flow <3 without mechanical obstruction	Adenosine	Guide (n =12), distal catheter (n=9)	Mean 98 mcg	N/A	15%	30%	"adenosine and nitroprusside is safe and potentially more effective than adenosine alone"	
Nitroprusside												
Hillegass et al., 2001 (238)	Cohort	19	Vein grafts and native coronaries	Post-PCI TIMI flow <3 without mechanical obstruction	Nitroprusside	Via guide catheter	Mean 435 mcg	0	N/A	75%	"nitroprusside is a safe and efficacious agent to treat no-reflow"	
Adenosine and Nitroprusside												

Barcin et al., 2004 (237)	Cohort	20	Vein grafts and native coronaries	Post-PCI TIMI flow <3	Adenosine and nitroprusside	Guide (n=9), distal catheter (n=11)	Adenosine mean 71 mcg and nitroprusside mean 285 mcg	N/A	10%	60%	"adenosine and nitroprusside is safe and potentially more effective than adenosine alone"	
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CABG indicates coronary artery bypass graft; CK-MB, creatine kinase-myocardial band; CPK, creatine phosphokinase; IC, intracoronary; IU, international units; L, liter; mcg, microgram; MI, myocardial infarction; N/A, not applicable; pts, patients; PCI, percutaneous coronary intervention; SVG, saphenous vein grafts; and TIMI, Thrombolysis In Myocardial Infarction.

Data Supplement 26. Impact of Successful Versus Failed Recanalization of Chronic Total Occlusions on Long Term Survival

Study Name	Study Type	No. of Patients	Procedure Success	Duration of Follow-Up, y	Survival %			PCI Success as Predictor of Survival	
					PCI Success	PCI Failure	P-Value	HR (95% CI)	P-Value
Suero JA et al. (239)	Retrospective	2,007	74.4%	10	73.5	65.0	0.001	0.7 (0.5 to 0.8)	<0.0003
Hoye A et al. (240)	Retrospective	874	65.1%	5	93.5	88.0	0.02	0.58 (0.34 to 0.98)	0.04
Prasad A et al. (241)	Retrospective	1,262	51 to 73%	10	N/A	N/A	N/A	1.16 (0.90 to 1.50)	0.25
Safley DM et al. (242)	Retrospective	2,608	71 to 75%	5	88.9	80.2	<0.001*	0.61 (0.42 to 0.89)	<0.05*

* The difference in survival is significant only for patients who underwent successful recanalization of a left anterior descending artery CTO.
 CI indicates confidence interval; CTO, chronic total occlusion; PCI, percutaneous coronary intervention, and y, year.

Data Supplement 27. RCTs of Balloon Angioplasty Versus Stenting for Chronic Total Occlusions

Trial	No. of Patients	Reocclusion			Restenosis			TVR		
		PTCA	Stent	P-Value	PTCA	Stent	P-Value	PTCA	Stent	P-Value
SICCO (243)	114	26%	16%	0.058	74%	32%	<0.001	42%	22%	0.025
GISSOC (244)	110	34%	8%	0.004	68%	32%	0.0008	22%	5%	0.04
Mori et al. (245)	96	11%	7%	0.04	57%	28%	0.005	49%	28%	<0.05
SPACTO (246)	85	24%	3%	0.01	64%	32%	0.01	40%	25%	NS
TOSCA (247)	410	20%	11%	0.02	70%	55%	<0.01	15%	8%	0.03

STOP (248)	96	17%	8%	NS	71%	42%	0.032	42%	25%	NS
PRISON (249)	200	7%	8%	0.99	33%	22%	0.14	29%	13%	<0.0001
SARECCO (250)	110	14%	2%	0.05	62%	26%	0.01	55%	24%	0.05

PTCA indicates percutaneous transluminal coronary angioplasty; TVR indicates target vessel revascularization; SICCO, Stenting in Chronic Coronary Occlusion; GISSOC, Gruppo Italiano di Studi sulla Stent nelle Occlusioni coronariche; NS, not significant; SPACTO, Stent vs. Percutaneous Angioplasty in Chronic Total Occlusion; TOSCA, Total Occlusion Study of Canada; SARECCO, Stent or Angioplasty after Recanalization of Chronic Coronary Occlusions; STOP, Stents in Total Occlusion for Restenosis Prevention; and PRISON, Primary Stenting of Occluded Native Coronary Arteries. Table adapted from Stone et al. (251).

Data Supplement 28. Clinical Trials of DES Versus BMS for Chronic Total Occlusions

Trial	Study Type	No. of Patients		Restenosis			Reocclusion			TVR		
		BMS	DES	BMS	DES	P-Value	BMS	DES	P-Value	BMS	DES	P-Value
Ge L et al. (252)	Retrospective	259	122	33.3%	9.2%	<0.001	6.5%	2.5%	NS	29%	9%	<0.001
Nakamura S et al. (253)	Retrospective	120	60	32%	2%	0.001	6%	0%	0.001	30%	3%	0.001
Kelbaek H et al. (254)	Retrospective	63	64	38%	0%	<0.001	N/A	N/A	N/A	33.3%	4.7%	<0.001
Werner GS et al. (255)	Retrospective	61	61	55%	11.7%	<0.001	21.7%	1.7%	<0.001	32%	6%	<0.001
PRISON II (256)	Randomized	100	100	41%	11%	<0.0001	13%	4%	0.04	22%	8%	0.009
ACROSS/TOSCA-4 (257)	Prospective, single arm	N/A	200	N/A	22.6%	N/A	N/A	2.9%	-	N/A	9.8%	-

ACROSS/TOSCA-4 indicates Approaches to Chronic Occlusions With Sirolimus-Eluting Stents/Total Occlusion Study of Coronary Arteries; BMS, bare metal stent; CTO, chronic total occlusion; DES, drug eluting stent; N/A, not applicable; No, number; PRISON II, Primary Stenting of Totally Occluded Native Coronary Arteries; and TVR, target vessel revascularization

Data Supplement 29. Studies of Embolic Protection Devices for Saphenous Vein Graft PCI

Study Name	Aim of Study	Study Type	Study Size	Patient Population/ Inclusion & Exclusion Criteria		Endpoints		Statistical Analysis (Results)	P-Values & 95% CI	OR HR RR	Study Summary
				Inclusion Criteria	Exclusion Criteria	Primary Endpoint	Secondary Endpoint				

SAFER (258)	To reduce embolization using a balloon-occlusion system.	Randomized multicenter	801	Angina, ischemia and >50% stenosis in SVG	Recent MI, SVG <3 or >6 mm	MACE (Death, MI, emergency CABG or TVR within 30 d)	CK-MB >3x ULN	Superiority design	0.40 to 0.88; p<0.004	RR: 0.58	9.6% embolic protection device vs. 16.5% placebo
FIRE (259)	To compare the ability of a filter-based system to reduce embolization during SVG intervention with that of a balloon occlusion system.	Randomized multicenter	651	Planned stenting of SVG stenosis	Recent MI, SVG age <6 mo	MACE (Death, MI, TVR within 30 d)	CK-MB >8x, >3x or >1x ULN	Noninferiority design	0.55 to 1.33; p=0.53	HR: 0.86	9.9% (filter) vs. 11.6% (balloon)
PROXIMAL (260)	To compare the ability of proximal occlusion system to reduce embolization during SVG intervention with that of an EPD.	Randomized multicenter	594	Planned stenting of SVG stenosis	Recent MI, SVG age <2 mo	MACE (Death, MI, emergency CABG or TVR within 30 d)		Noninferiority design	0.3 to 1.57; p=0.782	OR: 0.91	9.2% (test-proximal protection when possible, distal when not) vs. 10.0% (control group – distal protection whenever possible)

CABG indicates coronary artery bypass graft; creatine kinase-myocardial band; d, day; EPD, embolic protection device; FIRE, Filter Wire EX Randomized Evaluation; MACE, major adverse cardiac event; MB, myocardial bands; MI, myocardial infarction; PROXIMAL, Proximal Protection During Saphenous Vein Graft Intervention; SAFER, Saphenous Vein Graft Angioplasty Free of Emboli Randomized; SVG, saphenous vein graft; TVR, target vessel revascularization; and ULN, upper limit of normal.

Data Supplement 30. Major Reviews, Meta-Analyses and Studies of Vascular Closure Devices

Study Name	Author/ Year/ Journal	Aim of Study	Study Type	Study Size	Patient Population/ Inclusion/Exclusion	End-points	Statistics	Results/ P-Values	Conclusions/Comments
JACC State-of-the-art paper	Dauerman et al., 2007 JACC (261)	Review and critical analysis of VCD	Review and critical analysis	N/A	Diagnostic catheterization or endovascular procedure	N/A	N/A	N/A	<u>Select Manuscript Conclusions:</u> 1. VCD reliably shortens time to hemostasis and thus allows earlier patient ambulation. 2. Concerns that VCD outcomes are worse are “not supported by review of published meta-analysis, multicenter registries, and longitudinal registries”. 3. The largest registry study to date suggested a significant decrease in complications with VCD; “it is possible this reduction in complications is directly related to the VCD or alternatively reflects a reluctance by the operator to use a VCD” in certain situations. 4. Pts believed to be at high risk for VCD use have been routinely excluded from pivotal studies leading to VCD approval. 5. For PCI pts, “contemporary data support a neutral effect on complications”.
AHA Scientific Statement	Patel et al., 2010 Circulation	AHA Scientific Statement	Review and critical	N/A	Diagnostic catheterization or endovascular	Various complications	N/A	N/A	<u>Select Manuscript Conclusions:</u> 1. Existing literature on VCDs emanates largely from small and moderate clinical trials (100 to 650 pts). Many of these studies were

	(262)	on VCD	analysis		procedure				<p>single-center trials and enrolled predominantly low and medium-risk pts. These studies were likely underpowered to detect differences in the rates of infrequent vascular complications. Other studies lacked defined allocation concealment, blinded outcome assessment and/or intention-to-treat analyses.</p> <p>2. Overall, nonrandomized observational data appear to confirm the efficacy of VCDs, but provide no definitive evidence as to their safety compared to manual compression or to each other.</p> <p>3. The results of observational registry data and meta-analyses highlight that devices may have different effects, and these clinical effects may not be easily identified in the small randomized trials conducted in populations that may be lower risk than those in clinical use.</p> <p><u>Recommendations/Guidelines</u></p> <p>1. Pts considered for deployment of arteriotomy closure devices at the femoral artery site should undergo a femoral angiogram with identification of sheath insertion site and other features (atherosclerosis, calcification, etc.) to ensure anatomical suitability for their use (Class I, Level of Evidence: C).</p> <p>2. Facilities with standard manual compression regimens should aim to achieve the reported low vascular complication rates (< 1%), in pts undergoing uncomplicated 5-Fr diagnostic angiography. (Class I, Level of Evidence: C).</p> <p>3. Use of arteriotomy closure devices is reasonable following invasive cardiovascular procedures performed via the femoral artery to achieve faster hemostasis, shorter duration of bed rest and possibly improved patient comfort. The use of these devices should be weighed against the risk of increased complications in certain patient subsets and also take into account body habitus, location of arteriotomy, size and condition of the parent vessel, sheath size, and presence or absence of systemic disease in the patient (Class IIA – Level of Evidence: B). This recommendation is based on a meta-analysis and several small scale trials. However, in these studies there are trends towards higher rates of complications. (Class IIa, Level of Evidence: B).</p> <p>4. Arteriotomy closure devices should not be utilized routinely to reduce vascular complications in pts undergoing invasive cardiovascular procedures via the femoral artery approach (Class III, Level of Evidence: B).</p> <p>5. Complications encountered during or following deployment of arteriotomy closure devices should be collected systematically either as part of local quality efforts or national registries (such as the ACC-NCDR) and systematically reported to the FDA (Class I – Level of</p>
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									Evidence: C).
Management of Pts Undergoing Percutaneous Coronary Revascularization – AHA statement	Levine et al., 2003 Ann Intern Med (263)	AHA commissioned statement to review management of pts undergoing PCI, including identification and prevention of complications.	Review and critical analysis	PCI-related articles	PCI procedures	N/A	N/A	N/A	<p><u>Select Manuscript Conclusions:</u></p> <ol style="list-style-type: none"> 1. VCDs are associated with a risk for vascular complications that is often similar to that seen with manual compression. These complications include pseudoaneurysm, bleeding and hematoma, infection, arterial stenosis or occlusion, and venous thrombosis. 2. Most series report an incidence of major complications ranging from approximately 1% to 5%. 3. Several reports in the surgical literature suggest that vascular closure devices are associated with a higher incidence of large pseudoaneurysms and pseudoaneurysms. Not amenable to ultrasound compression therapy, greater loss of blood and need for transfusions, higher incidence of arterial stenosis or occlusion, more extensive surgical repair, and higher incidence of groin infections compared with manual compression.
N/A	Biancari et al., 2010 AHJ (264)	Assess efficacy of VCD	Meta-analysis of randomized studies	31 prospective randomized studies; 7,528 pts	Diagnostic catheterization or endovascular procedure	Various complications including groin hematoma, bleeding, pseudoaneurysm, blood tx, vascular complications	Meta-analysis	<p><u>Overall in PCI cohort (VCD vs. no VCD):</u></p> <ul style="list-style-type: none"> • Groin bleeding: 3.6 vs. 2.4% OR: 1.76 (95% CI: 0.27 to 5.20) • Blood Tx: 0.6 vs. 0.4% OR: 1.17 (95% CI: 0.44 to 3.15) • Pseudoaneurysm: 2.6% vs. 2.5% (95% CI: 0.70 to 1.66; p=1.08) • Lower limb/vascular complication: 	<p><u>Select Study Conclusions:</u></p> <ol style="list-style-type: none"> 1. VCD decreases time to hemostasis. 2. VCD not associated with decreased bleeding complications. 3. Numerically more lower limb ischemia and other arterial ischemic complications and need of surgery for vascular complications with VCD. 4. Significantly more groin infections with VCD. 5. Analysis of only more recent studies (2000 onward) did not demonstrate benefits of VCD (other than time to hemostasis). 6. No individual device showed significant benefits.

								<div>0.3 vs. 0% (95% CI: 0.82 to 13.60; p=3.34)</div> <div><ul style="list-style-type: none">• Vascular surgery: 1.0 vs. 0.5% (95% CI: 0.89 to 3.56; p=1.79)• Numerically more groin infections and vascular surgeries• Time to hemostasis with VCD 38 min shorter (27 to 48 min)</div> <div><u>Adverse events after diagnostic cath or PCI in studies published from 2000 onward:</u></div> <div><ul style="list-style-type: none">• Groin bleeding: 4.0% vs. 0.9% Fixed RR: 3.49 (95% CI: 0.62 to 19.08)• Blood Tx: 0.7% vs. 0.8% Fixed RR: 0.78 (95% CI: 0.35 to</div>
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								<div>1.71)</div> <ul style="list-style-type: none">• Lower limb/vascular complication: 0.3% vs. 0 .0% Fixed RR: 3.07 (95% CI: 0.50 to 13.10)• Pseudoaneurys m: 0.7 vs. 1.1% OR: 0.69 (95% CI: 0.38 to 1.23)• Vascular surgery: 0.6% vs. 0.3% Fixed RR: 1.76 (95% CI: 0.74 to 4.20)• Time to hemostasis with VCD 43 min shorter (31 to 55) <div>All studies</div> <ul style="list-style-type: none">• Groin bleeding RR: 1.75 (95% CI: 0.83 to 3.71) with CVD• Risk of lower limb ischemia,	
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								arterial stenosis, and/or device entrapment in femoral artery RR: 3.28 (95% CI: 0.92 to 11.74) • Groin infection RR: 2.48 (95% CI: 1.14 to 5.43) with VCD	
N/A	Koreny et al., 2004 JAMA (265)	Meta-analysis of VCD safety and efficacy	Meta-analysis of randomized trials	30 studies; 4,000 pts	Pts undergoing diagnostic or interventional coronary procedures	Various vascular complications	Meta-analysis	<u>RR for complication with VCD:</u> • Groin hematoma: 1.14 (95% CI: 0.86 to 1.51) • Bleeding: 1.48 (95% CI: 0.88 to 2.48) • AV fistula: 0.83 (95% CI: 0.23 to 2.94) • Pseudoaneurysm: 1.19 (95% CI: 0.75 to 1.88) <u>Time to hemostasis with VCD:</u> • 17 min shorter	<u>Select Study Conclusions:</u> 1. The quality of individual trials was “fair” and there were “many of poor methodological quality”, 2. Time to hemostasis was shorter (though notable heterogeneity in the data). 3. Generally no difference in complications; there was “reason for concern that (VCDs) may increase the risk of hematoma and pseudoaneurysm.” 4. Sensitivity analysis did not reveal significant differences in the devices studied.

								<p>with VCD</p> <p><u>RR for complications with CVD analyzed on in trials that used explicit intention-to-treat approaches:</u></p> <ul style="list-style-type: none"> • Hematoma: 1.89 (95% CI: 1.13 to 3.15) • Pseudoaneurysm: 5.40 (95% CI: 1.21 to 24.5) 	
N/A	Nikolsky et al., 2004 JACC (266)	Meta-analysis of VCD vascular complications	Meta-analysis of randomized, case-control, and cohort studies	30 studies; 37,066 pts	Pts undergoing percutaneous coronary procedures	Vascular complications (composite of numerous complications)	Meta-analysis	<p><u>PCI - all studies:</u> VCD OR: 1.11 (95% CI: 0.94 to 1.33)</p> <p><u>PCI - randomized studies only:</u> VCD OR: 1.35 (95% CI: 0.67 to 1.98)</p> <p><u>PCI using GP IIb/IIIa:</u></p> <ul style="list-style-type: none"> • Angio-Seal OR: 1.17 (95% CI: 0.87 to 1.58) • Perclose OR: 1.05 (95% CI: 	<p><u>Selected Study Conclusions:</u></p> <ol style="list-style-type: none"> 1. In PCI studies, no difference in composite endpoint of vascular complications with VCD compared to manual compression. 2. In PCI studies, no statistically significant difference in vascular complications with either Angio-Seal or Perclose when compared to manual compression; higher complication rate with VasoSeal compared to manual compression. 3. No difference in vascular complication rates with VCD (vs. manual compression) in the setting of PCI using GP IIb/IIIa inhibitors.

								0.77 to 1.44)	
N/A	Vaitkus et al., 2004 J Invasive Cardiol (267)	Meta-analysis of VCDs to detect any differences in VCDs	Meta-analysis of prospective randomized trials	16 studies; 5,048 pts	Pts undergoing invasive coronary procedures	“Major” complications	Meta-analysis	<ul style="list-style-type: none">• Overall analysis of VCDs: OR: 0.89 (95% CI: 0.86 to 0.91)• PCI only pts: OR: 1.00 (95% CI: 0.96 to 1.03)• PCI pts only treated with AngioSeal: OR: 0.51 (95% CI: 0.45 to 0.58)• PCI pts only treated with Perclose: OR: 1.0 (95% CI: 0.13 to 7.48)• PCI pts only treated with VaoSeal: OR: 1.18 (95% CI: 1.16 to 1.20)	<u>Select Study Conclusions:</u> 1. VCDs may be associated with a reduction in risk of complications following invasive coronary procedures, but significant differences may exist among individual devices.

N/A	Marso et al., 2010 JAMA (268)	Bleeding with VCD	Retrospective registry data of NCDR-CathPCI Registry	1.5 million pts	Pts undergoing PCI	Bleeding (drop hdb > 3 g/dL, blood Tx, prolongation of hospital stay)	Bleeding risk adjustment, propensity score, multinomial regression, etc.	<u>Unadjusted rates:</u> <ul style="list-style-type: none"> No VCD: 2.8% VCD: 2.1% (p<0.001) <u>Adjusted rates:</u> <ul style="list-style-type: none"> No VCD: 2.7%; VCD: 2.5% OR: 0.77 (95% CI: 0.73 to 0.80); NNT=148 	<u>Select Study Conclusions:</u> <ol style="list-style-type: none"> largest evaluation of registry data. VCD associated with significantly lower bleeding rates, particularly among pts at greatest risk for bleeding. found bleeding less likely with VCD. <u>Writing Group Author Caveats:</u> <ol style="list-style-type: none"> Registry analyses could not take in to account VCD deployment failure and complications related to VCD (infection, vascular damage, neuropathy, etc.). Data is nonrandomized, and hemostasis method would presumably occur after sheathogram, thus likely there was selection bias in who did or did not receive a VCD that study could not account for.
N/A	Hoffer et al., 2003 J Vasc Interv Radiol (269)	Review article	Systematic review	N/A	Pts undergoing diagnostic and therapeutic percutaneous procedures	N/A	N/A	N/A	<u>Select Review Conclusions:</u> <ol style="list-style-type: none"> Closure devices can rapidly establish hemostatis in the presence of anticoagulation and antiplatelet agents. In pts undergoing therapeutic. interventions, VCD complication rates were similar to manual compression. There is an increased prevalence of infectious and embolic complications with VCD (though not likely to be found statistically significant given low absolute numbers). No device is dramatically different with regard to efficacy and complications.

ACC-NCDR indicates American College of Cardiology-National Cardiovascular Data Registry; AHA, American Heart Association; cath, catheterization; CVD, cardiovascular disease; FDA, Food and Drug Administration; NCDR, National Cardiovascular Data Registry; NNT, number needed to treat; OR, odds ratio; pts, patients; PCI, percutaneous coronary intervention, RR, relative risk; tx, toxicity; and VCD, vascular closure device.

Data Supplement 31. Studies That Have Evaluated Potential Clopidogrel–PPI Interaction

Study	Design and Number of Patients	Conclusions	Comments
Gilard et al. (270)	Observational N=105	Omeprazole decreased the inhibitory effects of clopidogrel as assessed by VASP.	Small, pilot study
Gilard et al. (271)	Double-blind, Placebo-controlled N=124	Omeprazole decreased clopidogrel inhibitory effect on platelet P2Y12 as assessed by VASP.	<ol style="list-style-type: none"> Clinical endpoints not evaluated Short study duration (7 d) Single PPI (omeprazole) evaluated

Pezalla et al. (272)	Observational N=1,010	High PPI exposure in pts taking clopidogrel was associated with a higher MI rate vs. placebo.	<ol style="list-style-type: none"> 1. Poorly defined categories (i.e., clopidogrel adherence, low vs. high PPI exposure) 2. Confounding variables (high PPI exposure with more comorbidities)
Kreutz et al. (273)	Retrospective Cohort N=16,690	Concomitant use of a PPI and clopidogrel compared with clopidogrel alone was associated with a higher rate of major adverse cardiovascular events within 1 y after coronary stent placement.	<ol style="list-style-type: none"> 1. Retrospective analysis
Dunn et al. (274)	Retrospective post hoc analysis N=2,116	PPI use independently associated with 28-d and 1-y endpoints.	<ol style="list-style-type: none"> 1. Interaction analysis did not demonstrate effect of PPI use on randomized therapy 2. PPI therapy was assessed only at study entry.
Small et al. (275)	Open-label Crossover N=26	Lansoprazole decreased IPA after clopidogrel dose but not prasugrel.	<ol style="list-style-type: none"> 1. Single PPI (lansoprazole) studied 2. Healthy subjects 3. Pharmacodynamics studied—no clinical implications
Siller-Matula et al. (276)	Case-Control N=300	Pantoprazole and esomeprazole are not associated with impaired response to clopidogrel.	<ol style="list-style-type: none"> 1. Nonrandomized 2. Possible confounding 3. Pharmacodynamics studied—no clinical implications
Ho et al. (277)	Retrospective Cohort N=8,205	Use of PPI and clopidogrel after hospital discharge for ACS was associated with an increased risk of adverse outcomes.	<ol style="list-style-type: none"> 1. Demographics limited to male veterans 2. Cause-specific mortality unavailable 3. Causality not established 4. Possible confounding
Juurlink et al. (278)	Observational N=13,636	Omeprazole attenuates the effects of clopidogrel as compared to pantoprazole or esomeprazole.	<ol style="list-style-type: none"> 1. Comorbid conditions and nonprescription medications unknown 2. Possible miscoding and confounding 3. Patient adherence unknown
Sibbing et al. (279)	Case-Control N=268	Concomitant therapy with PPI other than pantoprazole in pts receiving clopidogrel following AMI associated with loss of benefit and increased risk of reinfarction.	<ol style="list-style-type: none"> 1. Underpowered 2. Platelet function measured at single time point 3. Pharmacodynamic technique (MEA) 4. Pharmacodynamics studied—no clinical implications
Medco reanalysis (280)	Retrospective analysis N=16,690	PPIs interfere with clopidogrel and this interaction is apparent with each of the most commonly prescribed PPIs.	<ol style="list-style-type: none"> 1. Retrospective analysis was based on medical and pharmacy claims
FAST MI (281)	Genetic analysis N=2,208	The use of omeprazole, or any other proton-pump inhibitor, had no effect on the clinical response to clopidogrel.	<ol style="list-style-type: none"> 1. Subgroup analysis 2. Forced statistical modeling 3. Observational
Dallas VA database (282)	Retrospective N=533	Concomitant use of PPI(s) with clopidogrel was associated with an increased risk of MACE post-PCI.	<ol style="list-style-type: none"> 1. Retrospective 2. Observational
Gaspar et al. (283)	Retropsective N=922	PPI prescription in addition to aspirin and clopidogrel was not associated with a worse prognosis in pts with ACS.	<ol style="list-style-type: none"> 1. Retrospective 2. Observational

TRITON-TIMI 38 Trial (284)	Post hoc subgroup analysis N=13,608	In a large population of subjects treated with clopidogrel or prasugrel, the use of a PPI was not associated with an increased risk of cardiovascular events.	1. Retrospective 2. Subgroup
PRINCIPLE TIMI 44 (285)	Post hoc subgroup analysis N=201	PPI was not associated with increased risk of adverse clinical outcomes for pts treated with clopidogrel or prasugrel. There was a trend towards a modest attenuation of the antiplatelet effects of both clopidogrel and prasugrel with PPI use.	1. Retrospective 2. Subgroup
COGENT (286)	RCT	At 390 d 67 cardiovascular events—a composite of CV death, nonfatal MI, CABG or PCI, or ischemic stroke—occurred in the placebo group and 69 in the omeprazole group, with superimposable event curves.	Trial stopped early as sponsor went bankrupt No evidence of clopidogrel-PPI interaction

ACS indicates acute coronary syndrome; AMI, acute myocardial infarction; COGENT, Clopidogrel and the Optimization of Gastrointestinal Events; CV, cardiovascular; IPA, inhibition of platelet aggregation; MACE, major adverse cardiac event; MEA, multiple electrode platelet aggregometry; MI, myocardial infarction; pts, patients; PPI, proton pump inhibitor; PRINCIPLE-TIMI 44, Prasugrel In Comparison to Clopidogrel for Inhibition of Platelet Activation and Aggregation-TIMI 44; TRITON-TIMI 38, Trial to Assess Improvement in Therapeutic Outcomes by Optimizing Platelet Inhibition with Prasugrel-TIMI 38 trials; and VASP, vasodilator-stimulated phosphoprotein. Adapted with permission from Allen et al. [\(287\)](#).

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