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STATE-OF-THE-ART REVIEW

Update on Cardiac Catheterization in Patients With Prior Coronary Artery Bypass Graft Surgery

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JACC: CARDIOVASCULAR INTERVENTIONS CME/MOC/ECME

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CME/MOC/ECME Objective for This Article: Upon completion, the reader should be able to: 1) select optimal vascular access for patients with prior CABG; 2) evaluate strategies to prevent and treat distal embolization; 3) compare the outcomes of DES versus BMS in SVG PCI; 4) identify the optimal treatment strategy for acute graft failure; 5) select the optimal method of revascularization in patients with prior CABG; and 6) decide between native vessel versus graft PCI in prior CABG patients.

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ABSTRACT

Patients who undergo coronary bypass graft surgery often require subsequent cardiac catheterization and repeat coronary revascularization. Saphenous vein graft lesions have high rates for distal embolization that can be reduced with use of embolic protection devices. They also have high restenosis rates, which are similar with drug-eluting and bare-metal stents. Percutaneous coronary interventions of native coronary arteries is generally preferred over saphenous vein graft interventions, but can often be complex, requiring expertise and specialized equipment. Prolonged dual-antiplatelet therapy and close monitoring can help optimize subsequent clinical outcomes. (J Am Coll Cardiol Intv 2019;12:1635–49)
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Patients who undergo coronary artery bypass graft surgery (CABG) often require additional revascularization because of bypass graft failure or progression of native coronary artery disease (**Figure 1**) (1,2). Due to the high risk of redo CABG, coronary revascularization is performed by percutaneous coronary intervention (PCI) in nearly all prior CABG patients, but is associated with several challenges, both clinical (high-risk patient characteristics) and technical (such as treatment of failing bypass grafts, chronic total occlusions [CTOs], and severe calcification). We sought to provide an overview of novel developments in cardiac catheterization and PCI in prior CABG patients, as well as practical recommendations (**Central Illustration**).

ACCESS SITE SELECTION

Engagement of arterial grafts and saphenous vein grafts (SVGs) for angiography and/or PCI can be performed using either femoral or radial approach, however femoral access is associated with lower contrast and radiation dose (3). Although systematic

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HIGHLIGHTS

- Additional revascularization is often needed after coronary artery bypass graft surgery and carries increased risk.
- Optimal saphenous vein graft percutaneous coronary intervention requires embolic protection devices and vasodilators.
- If feasible, recanalization of the native coronary artery is preferred over bypass graft recanalization.
- Novel technical developments and pharmacotherapy are needed to improve outcomes after coronary bypass graft surgery.

reviews of mainly observational studies have suggested similar success with radial and femoral access, in the RADIAL CABG (RADIAL Versus Femoral Access for Coronary Artery Bypass Graft Angiography and Intervention) trial, diagnostic coronary angiography via radial access was associated with a higher mean contrast volume (142 ± 39 ml vs. 171 ± 72 ml; $p < 0.01$), longer procedure time (21.9 ± 6.8 min vs. 34.2 ± 14.7 min; $p < 0.01$), greater patient air kerma radiation exposure (1.08 ± 0.54 Gray vs. 1.29 ± 0.67 Gray; $p = 0.06$), and higher operator radiation dose (first operator 1.3 ± 1.0 mrem vs. 2.6 ± 1.7 mrem; $p < 0.01$) but higher patient satisfaction as compared with femoral access (4). In observational studies, however, radial access was associated with fewer vascular complications, and reduced hospital stay (4–6). If radial access is selected, the left radial artery should be used in most cases to facilitate engagement of the left internal mammary artery (LIMA) and the other bypass grafts. When graft engagement is challenging using radial access, early conversion to femoral access should be considered (7).

PHYSIOLOGICAL ASSESSMENT OF SVGs

Although fractional flow reserve (FFR) measurement is the standard of care for assessing intermediate native coronary artery lesions, its use in SVG lesions has been controversial (**Table 1**) (8–10) and is subject to important limitations. First, FFR of a SVG is the result of SVG flow, flow through the native coronary artery (unless the latter is occluded), and flow via collateral vessels; hence, FFR may be normal, even when a SVG has severe stenosis. Second, the variable rate of progression of SVG lesions affects the utility of physiological assessment in deciding to defer revascularization, and more data are warranted to determine the utility of physiological assessment (11–14).

INTERMEDIATE SVG LESIONS

As mentioned in the preceding text, in contrast to native coronary artery lesions, intermediate SVG lesions have high rates of progression, which limits the value of physiological assessment in this lesion subgroup. Despite promising early results with prophylactic stenting of such lesions in the VELETI (Moderate VEin Graft LEsion Stenting With the Taxus Stent and Intravascular Ultrasound) trial, the larger VELETI II trial did not show any improvement of clinical outcomes with stenting of intermediate SVG lesions as compared with medical therapy alone during 3-year follow-up (12–14). In addition to the 2 currently proven treatments to prevent SVG failure (aspirin and statins [15–18]), intensive low-density cholesterol lowering with Proprotein convertase subtilisin/kexin type 9 (PCSK9) inhibitors holds promise for preventing progression of SVG atherosclerosis and is currently being investigated for slowing the progression of intermediate SVG lesions (Alirocumab for Stopping Atherosclerosis Progression in Saphenous Vein Grafts [ASAP-SVG]; NCT03542110).

PREVENTION AND TREATMENT OF DISTAL EMBOLIZATION DURING SVG PCI

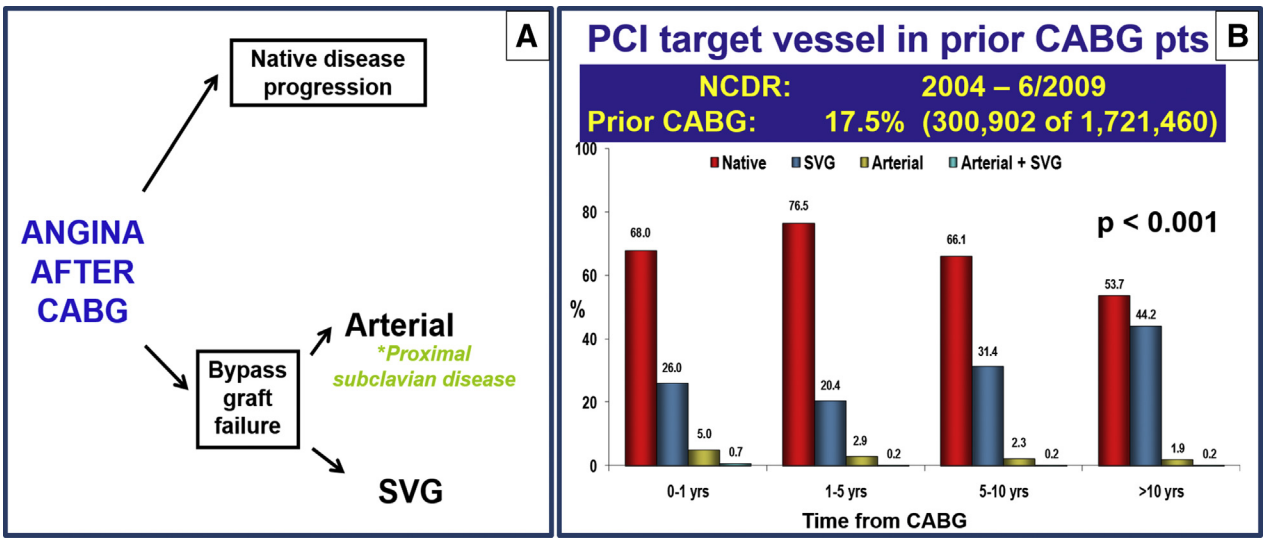
SVG PCIs represent approximately 6% of all PCIs performed in the United States (2,19). The 2 key limitations of SVG PCI are: 1) distal embolization and no reflow in the acute phase; and 2) high rates of restenosis and/or SVG disease progression during follow-up.

SVG PCI has high risk for no reflow, likely due to embolization of atheromatous material to the distal vasculature and intense vasospasm caused by microembolization of platelet-rich thrombi that release vasoactive agents resulting in microvascular obstruction (1,20). No reflow during SVG PCI has been associated with high risk of subsequent adverse cardiac events. Hong et al. (21) demonstrated that compared with patients who did not develop no reflow, those who did had higher risk for myocardial infarction (MI) (14.36% vs. 55.2%; $p = 0.036$) and death (13.33% vs. 52.19%; $p = 0.039$) during 5-year follow-up.

ABBREVIATIONS AND ACRONYMS

BMS = bare-metal stents
CABG = coronary artery bypass graft surgery
CI = confidence interval
CTO = chronic total occlusion
DAPT = dual-antiplatelet therapy
DES = drug-eluting stents
EPD = embolic protection device
FFR = fractional flow reserve
IMA = internal mammary artery
LIMA = left internal mammary artery
MACE = major adverse cardiac events
MI = myocardial infarction
OR = odds ratio
PCI = percutaneous coronary intervention
SVG = saphenous vein grafts

FIGURE 1 Progression of Coronary Artery Disease in Patients With Prior CABG



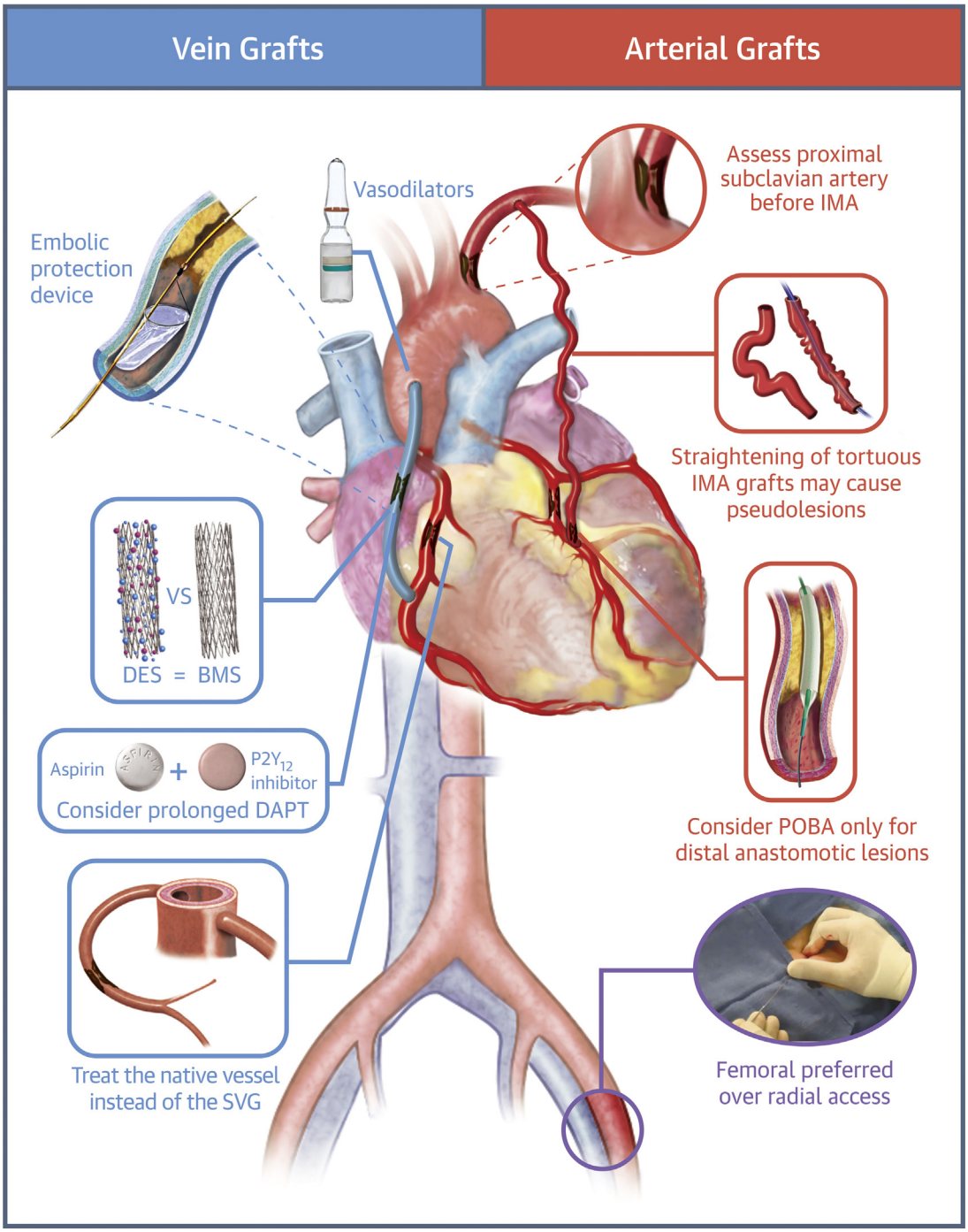
(A) Causes of angina in patients with prior CABG. **(B)** PCI target vessel in prior CABG patients during different time intervals from CABG. Image in **B** reproduced with permission from Brilakis et al. (2). CABG = coronary artery bypass graft surgery; NCDR = National Cardiovascular Data Registry; PCI = percutaneous coronary intervention; pts = patients; SVG = saphenous vein grafts.

Several strategies can be used to reduce the risk of distal embolization and no reflow (**Figure 2**). The only strategy that has been tested in randomized controlled trials is use of embolic protection devices. Other strategies include vasodilator administration, direct stenting (22), and use of undersized stents (23). Nicardipine is often preferred due to prolonged duration of action and less hypotensive effect and is often administered both before and after PCI. Other pharmacological agents such as adenosine, nitroprusside, and verapamil have also shown to prevent or improve no reflow events after intragraft administration (24–31). By contrast, platelet glycoprotein IIb/IIIa receptor inhibitors can cause harm during SVG intervention and should not be used routinely in SVG PCI (32). Laser may result in "vaporization" of thrombus and plaque components, potentially reducing the risk for distal embolization; however, it may lead to perforation, especially in highly angulated SVGs (33).

The only currently available embolic protection devices (EPDs) are filters: the FilterWire (Boston Scientific, Natick, Massachusetts) and the Spider (Medtronic, Santa Rosa, California) (**Table 2**) (34–40). Both require a distal landing zone for deployment; hence, they cannot be used in distal anastomotic lesions (unless the filter is deployed in the native coronary artery). The FilterWire is directly advanced through the target SVG lesion, whereas the Spider can be delivered over any guidewire advanced through the SVG lesion. A proximal occlusion device (Proxis, St. Jude Medical, Saint Paul, Minnesota) was discontinued in 2012, and a distal occlusion device (Guardwire, Medtronic) was discontinued in 2017.

In the first randomized controlled trial of EPD versus no EPD for SVG (SAFER [Saphenous vein graft Angioplasty Free of Emboli Randomized] trial) that randomized 801 patients, use of the Guardwire was associated with lower incidence of MI (8.6% vs. 14.7%; $p = 0.008$) and "no reflow" (3% vs. 9%; $p = 0.02$) (36). Given the results of the SAFER trial, subsequent EPD trials in SVG PCI compared one device with another. The FIRE (FilterWire EX Randomized Evaluation) trial compared the FilterWire with the GuardWire in 651 patients undergoing SVG-PCI. Thirty-day major adverse cardiac events (MACE) rates were similar between the 2 groups (9.9% of FilterWire EX group vs. 11.6% of GuardWire group; $p = 0.0008$ for noninferiority) (35). In the SPIDER (Saphenous vein graft Protection In a Distal Embolic protection Randomized) trial, the SpideRX filter was compared with FilterWire and GuardWire in 700 patients and was shown to be noninferior with comparable 30-day MACE rates (9.1% vs. 8.4%; $p = 0.01$ for noninferiority) (34). In a pooled analysis of 5 controlled trials and 1 registry evaluating EPDs in SVG-PCI, Coolong et al. (41) showed that the benefit of EPDs for reducing 30-day MACE was consistent across various degrees of SVG degeneration scores.

CENTRAL ILLUSTRATION **Cardiac Catheterization in Patients With Prior CABG: A Systematic Approach**



Xenogiannis, I. et al. J Am Coll Cardiol Intv. 2019;12(17):1635–49.

BMS = bare-metal stents; CABG = coronary artery bypass graft surgery; DAPT = dual-antiplatelet therapy; DES = drug-eluting stents; IMA = internal mammary artery; POBA = plain old balloon angioplasty; SVG = saphenous vein grafts.

TABLE 1 Published Studies on Bypass Graft Physiological Assessment

First Author (Year) (Ref. #)	Number of Patients	Objective	Major Findings
Aqel et al. (2008) (9)	10 patients with 10 SVG lesions with >50% stenosis	Access the physiological significance of SVG lesions with FFR	The sensitivity, specificity, PPV, NPV, and accuracy of FFR <0.75 for the detection of ischemia on stress MPI were 50%, 75%, 33%, 85%, and 70%, respectively
Di Serafino et al. (2013) (10)	233 patients with CABG and intermediate graft lesions (venous and arterial)	Compare the outcomes between FFR-guided and angiography-guided PCI	Patients with arterial graft stenosis had lower rates of MACE and TVF in the FFR-guided group. Patients with SVG stenosis had no significant difference for both MACE and TVF between the 2 groups
Almomani et al. (2018) (8)	33 patients with SVG lesions vs. 532 patients with native vessel disease	Compare the prognostic value of deferring intervention in lesions with FFR >0.8 in native coronary artery lesions vs. aortocoronary bypass grafts	MACE and TVF rates were significantly higher in the SVG group vs. the native vessel group (36% vs. 21%; p = 0.01 and 27% vs. 14%; p = 0.01)

CABG = coronary artery bypass surgery; FFR = fractional flow reserve; MACE= major adverse cardiac events; MPI = myocardial perfusion imaging; NPV = negative predictive value; PCI = percutaneous intervention; PPV = positive predictive value; SVG = saphenous vein graft; TVF = target vessel failure.

Despite the aforementioned trials and the American College of Cardiology/American Heart Association guideline recommendation to use EPDs in SVG PCI when technically feasible (Class I, Level of Evidence: B), EPDs remain underused: they were used in only 22% of patients undergoing SVG PCI in the United States (42-44) and in an even lower proportion in other countries, likely due to concerns over cost, prolongation of the procedure, and lack of expertise in use of those devices. The 2018 European Society of Cardiology/European Association for Cardio-Thoracic Surgery (ESC/EACTS) changed the EPD recommendation to Class IIa (Level of Evidence: B) from Class I (Level of Evidence: B) (45), referencing observational studies that did not find an association between EPD use and improved clinical outcomes (46,47). However, observational studies comparing EPD use versus no EPD use are subject to significant selection bias (higher risk lesions are more likely to be treated with an EPD), therefore their impact on clinical practice should be limited. Prospective, randomized trials of EPDs in SVG PCI would be optimal, but are unlikely to be performed. EPDs may not be required for in-stent restenotic lesions that have low risk for distal embolization (48). Recurrent SVG in-stent restenosis may respond to brachytherapy (49).

FIGURE 2 Strategies to Prevent Distal Embolization During SVG PCI

EPD = embolic protection devices; IC = intracoronary; SVG = saphenous vein grafts.

STENT SELECTION IN SVG PCI

Saphenous vein graft lesions have high rates of in-stent restenosis, which often presents as an acute coronary syndrome (50-52). Whether drug-eluting stents (DES) improve outcomes compared with bare-metal stents (BMS) in SVG lesions has been examined in 6 prospective randomized trials (**Table 3**) (50-59). During long-term follow-up, the 2 larger studies showed no difference between DES and BMS (54,56), and another showed worse outcomes with DES (59). In a meta-analysis of the 6 previously mentioned randomized trials by Kheiri et al. (60), there were no significant differences between DES and BMS in the long-term incidence of MACE, target lesion revascularization, target vessel revascularization, stent thrombosis, and all-cause mortality.

TABLE 2 Published Trials of EPDs in SVG Interventions

Study (Ref. #)	Year	Number of Cases	Primary Endpoint	EPD Event Rate (%)	Control Group Event Rate (%)	p Value Superiority
		EPD vs. No EPD				
SAFER (37)	2002	801	30-day composite of death, MI, emergency CABG, or TLR	(Guardwire) 9.6	16.5	0.004
		EPD vs. Another EPD		Test EPD Event Rate (%)	Control EPD Event Rate (%)	p Value Noninferiority
FIRE (35)	2003	651	30-day composite of death, MI or TVR	(Filterwire) 9.9	(Guardwire) 11.6	0.0008
SPIDER (presented at the 2005 TCT meeting)	2005	732	30-day composite of death, MI, urgent CABG, or TVR	(Spider) 9.1	(Guardwire 24% or Filterwire 76%) 8.4	0.012
PRIDE (37)	2005	631	30-day composite of cardiac death, MI, or TLR	(Triactiv) 11.2	(Filterwire) 10.1	0.02
CAPTIVE (38)	2006	652	30-day composite of death, MI, or TVR	(Cardioshield) 11.4	(Guardwire) 9.1	0.057
PROXIMAL (40)	2007	594	30-day composite of death, MI, or TVR	(Proxis) 9.2	(Guardwire 19% or Filterwire 81%) 10.0	0.006
AMETHYST (39)	2008	797	30-day composite of death, MI, or urgent repeat revascularization	(Interceptor Plus) 8.0	(Guardwire 72% or Filterwire 18%) 7.3	0.025

Triactiv is manufactured by Kensey Nash Corp. (West Whiteland Township, Pennsylvania), Cardioshield by MedNova (Galway, Ireland), and Interceptor Plus by Medtronic; other devices as in the text.

AMETHYST = Assessment of the Medtronic AVE Interceptor Saphenous Vein Graft Filter System; CAPTIVE = CardioShield Application Protects during Transluminal Intervention of Vein grafts by reducing Emboli; EPD = embolic protection device; FIRE = FilterWire EX Randomized Evaluation; MI = myocardial infarction; PRIDE = Protection During Saphenous Vein Graft Intervention to Prevent Distal Embolization; PROXIMAL = Proximal Protection During Saphenous Vein Graft Intervention; SAFER = Saphenous vein graft Angioplasty Free of Emboli Randomized; SPIDER = Saphenous Vein Graft Protection In a Distal Embolic Protection Randomized Trial; TLR = target lesion revascularization; TVR = target vessel revascularization; other abbreviations as in Table 1.

Because BMS and DES provide similar outcomes in SVGs, BMS should be preferred in countries with significant difference in the prices of DES and BMS.

There are several potential explanations for the failure of DES to improve outcomes as compared with BMS. First, the pathophysiology and physical history of SVG disease differs from that of native coronary arteries. Whereas atherosclerosis in coronary arteries takes decades to develop, accelerated atherosclerosis is observed in SVGs within months to years, often in a more concentric and diffuse pattern with less well-defined fibrous cap that likely responds differently to DES. Second, neoatherosclerosis occurs earlier in DES compared with

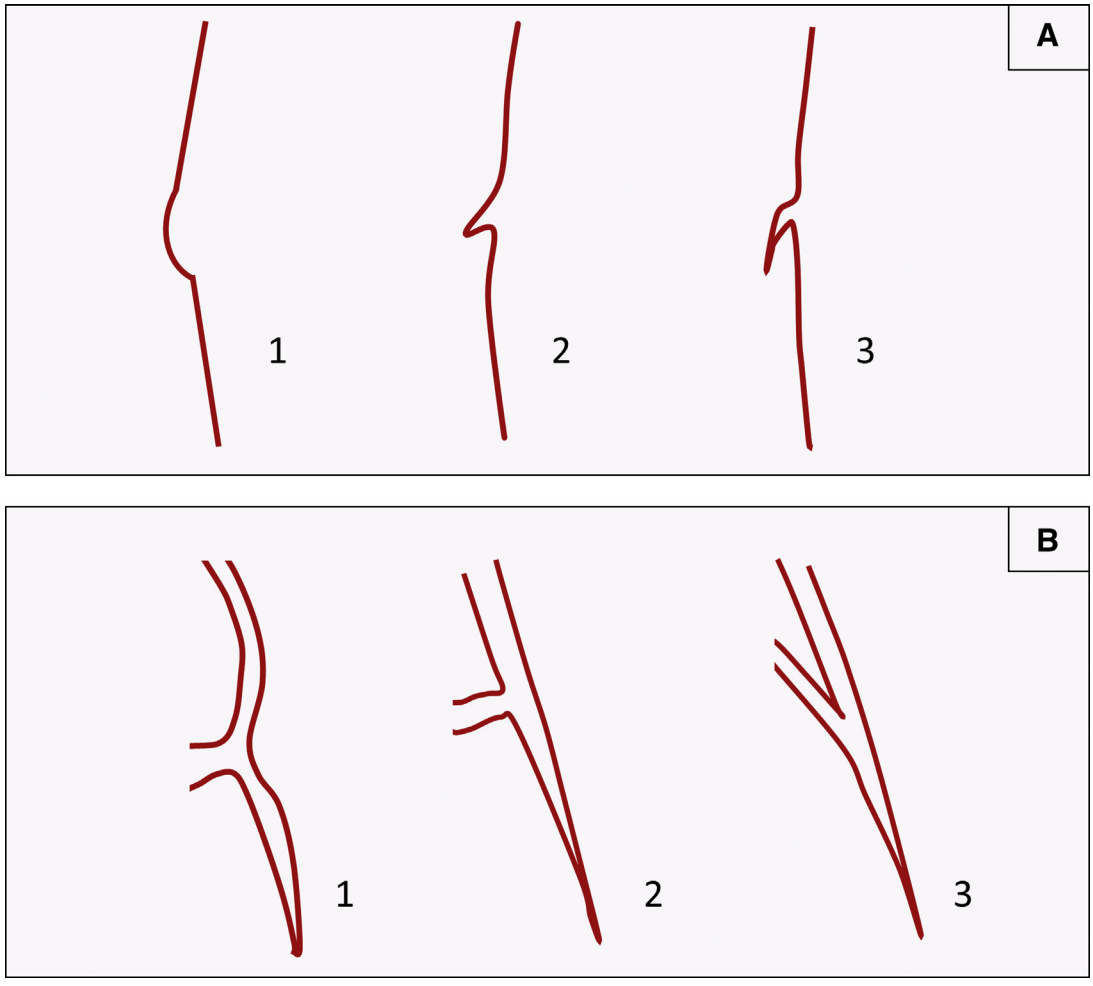
TABLE 3 Randomized Controlled Trials of DES Versus BMS in SVG Lesions

Study (Ref. #)	Year Published	N	Primary Endpoint	Drug-Eluting Stent Event Rate (%)	Bare-Metal Stent Event Rate (%)	p Value
RRISC (52,59)	2006	75	6-month angiographic restenosis	13.6	32.6	0.031
	2007		MACE at 32 months	58	41	0.130
SOS (50,55)	2009	80	12-month angiographic restenosis	9	51	<0.001
	2010	80	Target vessel failure at 35 months	34	72	0.001
ISAR-CABG (56,57)	2011	610	12-month composite of death, MI, and TLR	15	22	0.02
	2018	610	60-month composite of death, MI, and TLR	55.5	53.6	0.89
DIVA (54)	2018	597	12-month composite of cardiac death, target-vessel MI, and TVR	17	19	0.70
	2018	597	2.7-yr median follow-up—composite of cardiac death, target-vessel MI, and TVR	37	34	0.44
ADEPT (53)	2018	57	Late lumen loss at 6 months	0.47 ± 0.95 mm	0.53 ± 1.09 mm	0.86
Presented						
BASKET-SAVAGE*	2016	173	12-month composite of cardiac death, MI, and TVR	2.3	17.9	<0.001
BASKET-SAVAGE*	2016	173	36-month composite of cardiac death, MI, and TVR	12.4	29.8	0.0012

*Presented at the 2016 European Society of Cardiology meeting (Rome, Italy, August 30, 2016).

ADEPT = Comparison between the STENTYS self-apposing bare metal and paclitaxel-eluting coronary stents for the treatment of saphenous vein grafts; BASKET-SAVAGE = Basel Kosten Effektivitäts Trial–SAphenous Venous Graft Angioplasty Using Glycoprotein 2b/3a Receptor Inhibitors and Drug-Eluting Stents trial; BMS = bare-metal stents; DES = drug-eluting stents; DIVA = Drug-Eluting Stents vs. Bare Metal Stents In Saphenous Vein graft Angioplasty; ISAR-CABG = Is Drug-Eluting-Stenting Associated with Improved Results in Coronary Artery Bypass Grafts? trial; RRISC = Reduction of Restenosis In Saphenous vein grafts with Cypher™ sirolimus-eluting stent trial; SOS = Stenting Of Saphenous vein grafts trial; other abbreviations as in Tables 1 and 2.

FIGURE 3 SVG Morphologies



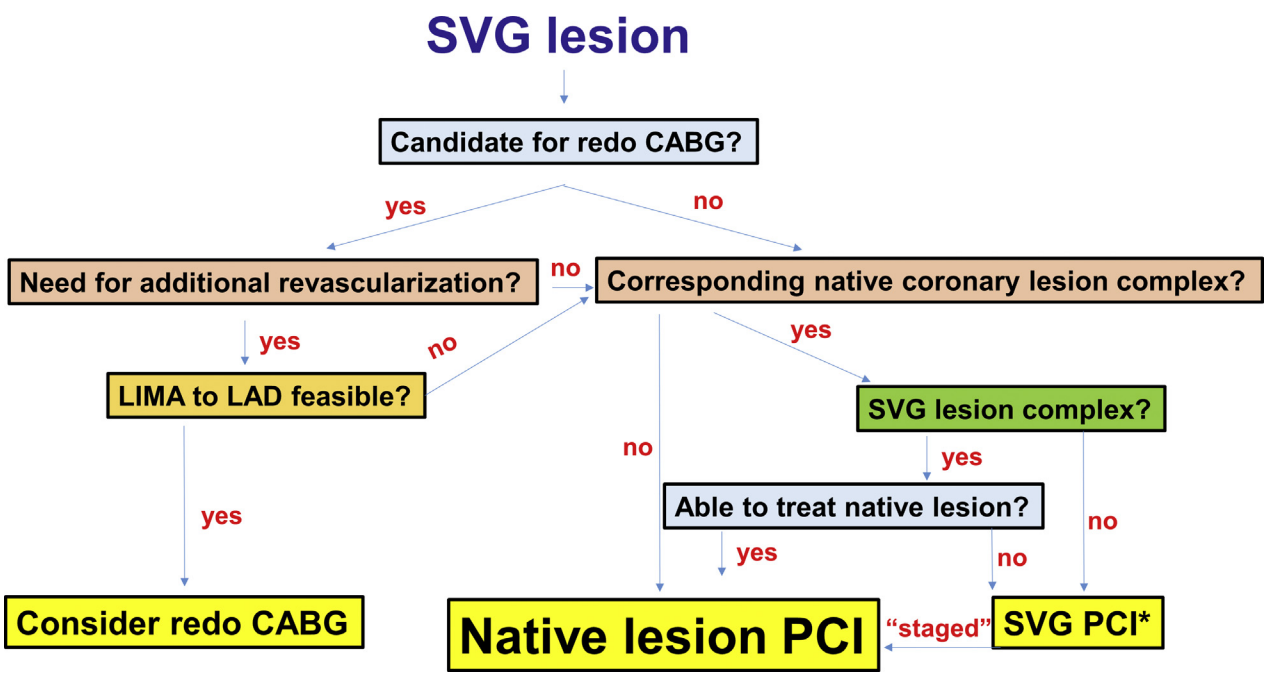
(A) Anatomic variants of the proximal cap of occluded saphenous vein grafts (SVGs): retrograde crossing should not be attempted in morphology #1 due to increased risk for perforation. **(B)** Anatomic variants of bypass graft distal anastomoses. Retrograde guidewire and equipment crossing is more likely to be challenging for morphology #3.

BMS, which may lead to a catch-up phenomenon (61,62). Third, thin-strut BMS may have lower risk for restenosis in SVGs than thicker strut stents that were used in most prior studies. Fourth, most DES versus BMS studies had mandatory angiography follow-up and were not blinded (50,52,53,57), which may bias outcomes in favor of DES (oculostenotic reflex). The DIVA (Drug-Eluting Stents vs. Bare Metal Stents In Saphenous Vein Graft Angioplasty) trial, the more recent randomized controlled trial that demonstrated no benefit of DES over BMS used blinding and did not mandate routine angiographic follow-up (54).

EARLY POST-OPERATIVE GRAFT FAILURE, ACUTE AND CHRONIC TOTAL SVG OCCLUSIONS

Graft failure during the early post-operative period occurs in up to 12% of the grafts, with approximately 3% of the patients developing symptoms (63). Graft occlusion rates are higher for vein grafts (3% to 12% before discharge) compared with radial artery (3% to 4%) and internal mammary artery (IMA) (1% to 2.5%) grafts (64). Potential causes include conduit defects, suboptimal anastomosis technique, poor native vessel runoff, and competitive flow with the native vessel.

FIGURE 4 Proposed Algorithm for the Selection of Target Vessel for PCI in Patients With Prior CABG



LAD = left anterior descending coronary artery; LIMA = left internal mammary artery; other abbreviations as in Figures 1 and 2.

Graft patency is higher when anastomosed to highly stenosed native coronary arteries: in a study of 164 patients who underwent pre-CABG FFR, graft occlusion at coronary angiography after 1 year was 8.9% for bypass grafts on functionally significant lesions (FFR <0.75) versus 21.4% for bypass grafts on lesions with FFR ≥0.75 (65). Conversely, there is an accelerated rate of disease progression in bypassed native coronary vessels, especially for non-left anterior descending artery vessels and when SVGs are used as compared with arterial grafts (66).

Unless the diagnosis of acute graft failure is made in the operating room, PCI is preferred for symptomatic graft failure. PCI is best performed in the corresponding native coronary artery instead of the bypass graft, if possible, in part because PCI of the graft anastomosis may lead to suture dehiscence and perforation (45). Redo CABG is recommended when coronary anatomy is not suitable for PCI, a large territory of myocardium is under jeopardy, multiple significant grafts are occluded, or in case of anastomotic lesions (46,67).

Acute SVG occlusions carry a high risk for short- and long-term adverse outcomes. Welsh et al. (68) demonstrated that prior CABG patients presenting with an ST-segment elevation myocardial infarction had similar outcomes compared with patients without prior CABG when the infarct-related artery was a native coronary artery; however, 90-day mortality was much higher in prior CABG patients whose culprit vessel was a SVG (19% vs. 5.7%; p = 0.05). Thrombosed SVGs often have large thrombotic burden which can be approached with thrombectomy and use of embolic protection devices (69). Aspiration thrombectomy is preferred over rheolytic thrombectomy to minimize the risk for distal embolization and adverse outcomes (70). Suction should be maintained until removal of the aspiration thrombectomy catheter from the guide catheter for optimal thrombus retrieval and reduction of the systemic thromboembolism risk. Occasionally, aspiration through a deeply intubated guide catheter or guide catheter extension (balloon-assisted deep intubation—BADI) may be required for retrieval of very large thrombi. Use of laser is another option for such patients, whereas thrombolytic administration has been associated with poor outcomes and is generally avoided (71).

ST-segment elevation myocardial infarction due to SVG obstruction can be very challenging to treat. Given the suboptimal results of thrombolytic therapy

TABLE 4 Major Studies Comparing Bypass Graft Versus Native Coronary Artery PCI

First Author (Year) (Ref. #)	N	Endpoint	Bypass Graft PCI	Native Coronary Artery PCI	p Value	Comments
Meliga et al. (2007) (88)	24	3-yr incidence of death, MI, TLR, and TVR	83.9%	81.8%	NS	
Tejada et al. (2009) (89)	91	1-yr MACE	15.1%	12.9%	0.8	
Varghese et al. (2009) (84)	142	No reflow	35%	24%	<0.001	After a mean follow-up of 2.5 ± 1.1 yrs, both groups of patients had similar incidence of MI, repeat PCI, and death.
		TIMI flow grade 3	80%	95%	<0.001	
Bundhoo et al. (2011) (86)	161	TVR	15%	4.9%	0.031	Mean follow-up: 13.5 ± 4.8 months. Graft-PCI was an independent predictor (HR: 3.73, 95% CI: 1.27 to 10.87; p = 0.016) of MACE.
		MACE	21.6%	8.9%	0.048	
Xanthopoulou et al. (2011) (90)	190	MACE	43.2%	19.6%	<0.001	Medial follow-up of 28 months.
		Cardiac death	19.3%	6.9%	0.008	
		Repeat revascularization	23.9%	12.7%	0.02	
Brilakis et al. (2011) (2)	300,902	In-hospital mortality	1.4%	0.9%	<0.001	The proportion of SVGs as PCI target vessels increases after 5 yrs and even more after 10 yrs from CABG. SVG PCI was an independent factor associated with higher in-hospital mortality (HR: 1.20, 95% CI: 1.10 to 1.30; p < 0.001).
Brilakis et al. (2016) (1)	11,096	In-hospital mortality	1.79%	0.83%	<0.001	
		5-yr mortality	24.39%	17.05%	<0.001	
Mavroudis et al. (2017) (87)	220	TVR	12.5%	3.6%	0.0004	
		Median survival	315 months	327 months	0.005	

CI = confidence interval; HR = hazard ratio; NS = nonsignificant; other abbreviations as in Tables 1, 2, and 3.

in occluded SVGs, PCI is the preferred reperfusion modality (71). Sometimes, identifying and engaging the grafts can be challenging, often requiring multiple catheters or aortography that may delay reperfusion (72). Use of embolic protection may be useful in such cases, although irreversible injury may have already occurred. SVG lesions are highly friable and rich in thrombus, and carry high risk for no reflow. Thrombolysis In Myocardial Infarction (TIMI) flow grade 3 post-PCI is achieved less frequently in patients who had SVG as the culprit vessel compared with patients who had a native coronary artery as the culprit vessel, and such patients had higher in-hospital and 30-day mortality and 1-year MACE rates (73,74).

Because of high risk for restenosis, SVG CTOs should generally not be recanalized (Class III indication, Level of Evidence: C) (42), unless no other treatment options exist. Occluded SVGs can be used, however, for retrograde crossing of the corresponding native coronary artery if the occlusion morphology is favorable (**Figure 3**).

LEFT INTERNAL MAMMARY ARTERY AND ARTERIAL GRAFT PERCUTANEOUS CORONARY INTERVENTION

PCI of arterial grafts and especially of the LIMA is much less common than SVG PCI. The 2 main reasons are the better rates of LIMA patency over SVGs and possibly performance of redo CABG in cases of LIMA failure (**Figure 4**). Redo CABG is generally avoided in patients with a patent IMA graft to the left anterior descending coronary artery (75).

There should be high threshold for performing PCI through IMA grafts, given the high risk for ischemia and complications. Straightening of a tortuous LIMA during the advancement of guidewires and microcatheters may lead to pseudolesions (the so-called "accordioning effect"), that can lead to flow compromise and ischemia. Pseudolesions must be differentiated from vasospasm and dissection. Administration of intravenous vasodilators will be ineffective in the presence of the pseudolesions, which should correct with guidewire withdrawal (76). Deep guide intubation and use of guide catheter extensions may lead to IMA dissection and/or perforation (77,78). Despite the aforementioned limitations, PCI to IMA lesions has been associated with higher rates of restoration of TIMI flow grade 3 and lower rates of periprocedural complications compared with SVG PCI (79). IMA anastomotic lesions may be best treated with balloon angioplasty, whereas proximal and mid-segment lesions are stented in most cases (80). Gruberg et al. (81) analyzed 174 patients who underwent PCI of 128 IMA anastomotic lesions and found a higher need for repeat revascularization after stenting (33%) as compared with balloon angioplasty only (4.3%). Sharma et al. (82) also reported worse

outcomes with stenting compared with angioplasty alone at the anastomotic site (25% vs. 4.2%; p = 0.006) in 288 patients with 311 IMA lesions.

In patients with IMA grafts, the proximal subclavian artery should be evaluated, because severe lesions in this location could lead to coronary ischemia and even acute coronary syndromes (83). Subclavian artery stenting can be an effective treatment in such cases.

NATIVE CORONARY ARTERY PCI IN PRIOR CABG PATIENTS

Most PCIs (approximately two-thirds) performed in prior CABG patients are in native coronary artery lesions (2,84). Native coronary artery lesions in prior CABG patients are often complex, with high rates of calcification, tortuosity, and CTOs. The bypass grafts can often be used for retrograde crossing in such patients, although wiring upstream from the distal anastomosis can be challenging (**Figure 3**). Shortened guiding catheters are especially recommended for PCI of the distal native vessels through the IMA and also retrograde techniques. Advanced PCI techniques, such as use of atherectomy and CTO PCI are, therefore, often needed (85). Nevertheless, outcomes after native coronary artery PCI are better than outcomes post-SVG PCI in multiple series (**Table 4**) (1,2,84,86–90).

In patients presenting with SVG lesions, several operators advocate treating the native coronary artery instead, given the high short- and long-term risks of SVG PCI. The 2018 ESC/EACTS guidelines on myocardial revascularization state that PCI to a native vessel should be preferred over PCI of the bypass graft (Class IIa, Level of Evidence: C) (45). Decision making can be challenging, however, as the corresponding native coronary artery lesions are often complex to treat or even totally occluded (often CTOs). One approach is to treat the native coronary artery when it is simple or when both SVG PCI and native coronary PCI are complex, and there is local expertise in treating such lesions (**Figure 4**). This could also be done in a staged manner: the culprit SVG lesion is initially treated (especially for patients presenting with acute coronary syndromes who have complex native coronary artery lesions), followed by PCI of the native coronary artery weeks or months later (91). If the thrombosed SVG cannot be recanalized, PCI of the native coronary artery can sometimes be performed (92). Because SVGs that become occluded due to thrombus have very high rates of reocclusion, staged PCI of the corresponding native coronary artery should be considered after the initial procedure. In such cases, stenting the distal SVG anastomosis should be avoided, if possible, as it could hinder subsequent treatment of the native coronary vessel. This conceptually appealing approach will need to be validated in clinical studies.

Remaining flow in the SVG after successful native vessel PCI has been a source of concern because competitive flow from the SVG can lead to native stent thrombosis (93,94). Some operators advocate routine SVG coiling after treating the native coronary artery although robust data are missing (95).

COMPLICATIONS

Due to the need to engage and visualize the bypass grafts (and the often high complexity of treated lesions) angiography and PCI in prior CABG patients requires longer procedural and fluoroscopy time, higher radiation dose, and larger volume of contrast (96–98). As a result (and also because of worse baseline renal function), the risk for contrast nephropathy and possibly hemodialysis is increased in those patients who have had prior CABG compared with those who have not (93,97,99).

Even though coronary perforations were previously considered to be “innocent” complications in prior CABG patients due to pericardial adhesions preventing formation of a pericardial effusion and tamponade, it is now appreciated that they can be lethal events. Coronary perforation in prior CABG patients can lead to loculated hematomas resulting in cardiac chamber compromise and hemodynamic collapse (dry tamponade). In the OPEN-CTO (Outcomes, Patient Health Status, and Efficiency in Chronic Total Occlusion Hybrid Procedures) database, the perforation rate in post-CABG patients was approximately 7%. Four perforations that led to death occurred in the 365 patients with prior CABG (1.1%) (100). Such loculated effusions may require surgery or computed tomography-guided drainage for treatment. Prompt identification and treatment of coronary or graft perforation is, therefore, critical in prior CABG patients (101,102).

POST-PROCEDURAL ANTITHROMBOTIC THERAPY

Long-term dual-antiplatelet therapy (DAPT) is conceptually appealing in prior CABG patients, as they often have extensive, multilevel atherosclerotic disease and high risk for subsequent adverse cardiovascular events. In a meta-analysis of 22 studies comparing DAPT to aspirin alone following CABG,

DAPT was associated with lower cardiovascular mortality (odds ratio [OR]: 0.67; p = 0.02) and a trend toward lower all-cause mortality (OR: 0.78; p = 0.08), although there was no difference when the analysis was confined to randomized controlled trials. SVG occlusion up to 1 year after CABG was significantly lower with DAPT overall (OR: 0.64; p < 0.01) and in the subset of randomized controlled trials (OR: 0.58; p < 0.01). Importantly, patients who were treated with DAPT for >6 months had lower stroke rates (OR: 0.47; p = 0.04) but higher incidence of major bleeding (OR: 1.31; p = 0.03) (103).

In another meta-analysis of 9 randomized controlled trials, patients who received ticagrelor or prasugrel in addition to aspirin had lower mortality compared with patients taking clopidogrel and aspirin (relative risk: 0.49; 95% confidence interval [CI]: 0.33 to 0.71; p = 0.0002), whereas there was no significant difference when clopidogrel plus aspirin was compared with aspirin monotherapy (104). In a subanalysis of the PLATO (Platelet Inhibition and Patient Outcomes) trial, the reduction of the primary endpoint of cardiovascular death, MI, and stroke was not statistically significant in post-CABG patients (19.6% vs. 21.4%; adjusted hazard ratio: 0.91 [interquartile range: 0.67 to 1.24]) (105). Large, randomized trials are needed in order to clarify the usefulness of DAPT in different clinical settings (acute coronary syndromes vs. stable coronary artery disease) and the optimal antiplatelet combination.

In a study of 603 patients who underwent SVG PCI, those taking clopidogrel in addition to aspirin for more than 2 years had lower rates of MI or death during a 5-year follow-up after the cessation of clopidogrel, compared with patients who were taking clopidogrel for a shorter time period (106). In the DAPT (Dual Antiplatelet Therapy) study, patients who underwent SVG PCI had better outcomes with 30-month versus 12-month DAPT (107,108). Administration of DAPT for a longer duration than is usually recommended after native vessel PCI (generally 6 months for stable coronary disease and 1 year for acute coronary events) in patients undergoing SVG PCI, therefore, may be beneficial.

Whether anticoagulation can reduce bypass graft failure and improve clinical outcomes after CABG remains controversial. In a substudy of COMPASS (Cardiovascular OutcoMes for People Using Anticoagulation StrategieS) trial, the combination of 2.5 mg of rivaroxaban twice per day with aspirin did not reduce the incidence of graft failure in patients with prior CABG compared with aspirin administration alone (113 [9.1%] vs. 91 [8.0%]; OR: 1.13; 95% CI: 0.82 to 1.57; p = 0.45). It also did not reduce the composite endpoint of cardiovascular death, MI, and stroke (12 [2.4%] vs. 16 [3.5%], hazard ratio: 0.69; 95% CI: 0.33 to 1.47; p = 0.34) (109).

CONCLUSIONS

Prior CABG patients undergoing cardiac catheterization have increased risk for complications and often require complex procedures. Several new studies have advanced our understanding of the optimal approach to cardiac catheterization and PCI in these high-risk patients.

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REFERENCES

1. Brilakis ES, O'Donnell CI, Penny W, et al. Percutaneous coronary intervention in native coronary arteries versus bypass grafts in patients with prior coronary artery bypass graft surgery: insights from the veterans affairs clinical assessment, reporting, and tracking program. J Am Coll Cardiol Intv 2016;9:884–93.

2. Brilakis ES, Rao SV, Banerjee S, et al. Percutaneous coronary intervention in native arteries versus bypass grafts in prior coronary artery bypass grafting patients: a report from the National Cardiovascular Data Registry. J Am Coll Cardiol Intv 2011;4:844–50.

3. Rigattieri S, Sciahbasi A, Brilakis ES, et al. Meta-analysis of radial versus femoral artery approach for coronary procedures in patients with previous coronary artery bypass grafting. Am J Cardiol 2016;117:1248–55.

4. Michael TT, Alomar M, Papayannis A, et al. A randomized comparison of the transradial and transfemoral approaches for coronary artery bypass graft angiography and intervention: the RADIAL-CABG trial (RADIAL Versus Femoral Access for Coronary Artery Bypass Graft Angiography and Intervention). J Am Coll Cardiol Intv 2013;6:1138–44.

5. Bundhoo SS, Earp E, Ivanauskiene T, et al. Saphenous vein graft percutaneous coronary intervention via radial artery access: safe and effective with reduced hospital length of stay. Am Heart J 2012;164:468–72.

6. Rathore S, Roberts E, Hakeem AR, Pauriah M, Beaumont A, Morris JL. The feasibility of percutaneous transradial coronary intervention for saphenous vein graft lesions and comparison with transfemoral route. J Intervent Cardiol 2009;22:336–40.

7. Cooper L, Banerjee S, Brilakis ES. Crossover from radial to femoral access during a challenging percutaneous coronary intervention can make the difference between success and failure. Cardiovasc Revasc Med 2010;11:266. e5–8.

8. Almomani A, Pothineni NV, Edupuganti M, et al. Outcomes of fractional flow reserve-based deferral in saphenous vein graft narrowing. Am J Cardiol 2018;122:723–8.

9. Aqel R, Zoghbi GJ, Hage F, Dell'Italia L, Iskandrian AE. Hemodynamic evaluation of coronary artery bypass graft lesions using fractional flow reserve. Catheter Cardiovasc Interv 2008;72:479–85.

10. Di Serafino L, De Bruyne B, Mangiacapra F, et al. Long-term clinical outcome after fractional flow reserve- versus angio-guided percutaneous coronary intervention in patients with

intermediate stenosis of coronary artery bypass grafts. Am Heart J 2013;166:110–8.

11. Abdel-Karim AR, Da Silva M, Lichtenwalter C, et al. Prevalence and outcomes of intermediate saphenous vein graft lesions: findings from the stenting of saphenous vein grafts randomized-controlled trial. Int J Cardiol 2013;168:2468–73.

12. Rodes-Cabau J, Bertrand OF, Larose E, et al. Comparison of plaque sealing with paclitaxel-eluting stents versus medical therapy for the treatment of moderate nonsignificant saphenous vein graft lesions: the moderate vein graft lesion stenting with the Taxus stent and intravascular ultrasound (VELETI) pilot trial. Circulation 2009; 120:1978–86.

13. Rodes-Cabau J, Bertrand OF, Larose E, et al. Five-year follow-up of the plaque sealing with paclitaxel-eluting stents vs medical therapy for the treatment of intermediate nonobstructive saphenous vein graft lesions (VELETI) trial. Can J Cardiol 2014;30:138–45.

14. Rodes-Cabau J, Jolly SS, Cairns J, et al. Sealing intermediate nonobstructive coronary saphenous vein graft lesions with drug-eluting stents as a new approach to reducing cardiac events: a randomized controlled trial. Circ Cardiovasc Interv 2016;9:e004336.

15. Collaborative overview of randomised trials of antiplatelet therapy–II: maintenance of vascular graft or arterial patency by antiplatelet therapy. Antiplatelet Trialists' Collaboration. BMJ 1994; 308:159–68.

16. Goldman S, Copeland J, Moritz T, et al. Saphenous vein graft patency 1 year after coronary artery bypass surgery and effects of antiplatelet therapy. Results of a Veterans Administration Cooperative Study. Circulation 1989;80:1190–7.

17. Kulik A. Secondary prevention after coronary artery bypass graft surgery: a primer. Curr Opin Cardiol 2016;31:635–43.

18. Okrainec K, Platt R, Pilote L, Eisenberg MJ. Cardiac medical therapy in patients after undergoing coronary artery bypass graft surgery: a review of randomized controlled trials. J Am Coll Cardiol 2005;45:177–84.

19. Dehmer GJ, Weaver D, Roe MT, et al. A contemporary view of diagnostic cardiac catheterization and percutaneous coronary intervention in the United States: a report from the CathPCI Registry of the National Cardiovascular Data Registry, 2010 through June 2011. J Am Coll Cardiol 2012;60:2017–31.

20. Lee KW, Norell MS. Management of 'no-reflow' complicating reperfusion therapy. Acute Card Care 2008;10:5–14.

21. Hong YJ, Jeong MH, Ahn Y, et al. Intravascular ultrasound findings that are predictive of no reflow after percutaneous coronary intervention for saphenous vein graft disease. Am J Cardiol 2012;109:1576–81.

22. Leborgne L, Cheneau E, Pichard A, et al. Effect of direct stenting on clinical outcome in patients treated with percutaneous coronary intervention on saphenous vein graft. Am Heart J 2003;146: 501–6.

23. Hong YJ, Pichard AD, Mintz GS, et al. Outcome of undersized drug-eluting stents for percutaneous coronary intervention of saphenous vein graft lesions. Am J Cardiol 2010;105:179–85.

24. Grygier M, Araszkiewicz A, Lesiak M, Grajek S. Intracoronary adenosine administered during aortocoronary vein graft interventions may reduce the incidence of no-reflow phenomenon. A pilot randomised trial. Kardiol Pol 2014;72:126–33.

25. Hillegass WB, Dean NA, Liao L, Rhinehart RG, Myers PR. Treatment of no-reflow and impaired flow with the nitric oxide donor nitroprusside following percutaneous coronary interventions: initial human clinical experience. J Am Coll Cardiol 2001;37:1335–43.

26. Kaplan BM, Benzuly KH, Kinn JW, et al. Treatment of no-reflow in degenerated saphenous vein graft interventions: comparison of intracoronary verapamil and nitroglycerin. Cathet Cardiovasc Diagn 1996;39:113–8.

27. Kapoor N, Yalamanchili V, Siddiqui T, Raza S, Leesar MA. Cardioprotective effect of high-dose intragraft adenosine infusion on microvascular function and prevention of no-reflow during saphenous vein grafts intervention. Catheter Cardiovasc Interv 2014;83:1045–54.

28. Michaels AD, Appleby M, Otten MH, et al. Pretreatment with intragraft verapamil prior to percutaneous coronary intervention of saphenous vein graft lesions: results of the randomized, controlled vasodilator prevention on no-reflow (VAPOR) trial. J Invasive Cardiol 2002;14: 299–302.

29. Sdringola S, Assali A, Ghani M, et al. Adenosine use during aortocoronary vein graft interventions reverses but does not prevent the slow-no-reflow phenomenon. Catheter Cardiovasc Interv 2000; 51:394–9.

30. Sharma S, Lardizabal JA, Singh S, Sandhu R, Bhambi BK. Intra-graft abciximab and verapamil combined with direct stenting is a safe and effective strategy to prevent slow-flow and no-reflow phenomenon in saphenous vein graft lesions not associated with thrombus. Recent Pat Cardiovasc Drug Discov 2012;7:152–9.

31. Zoghbi GJ, Goyal M, Hage F, et al. Pretreatment with nitroprusside for microcirculatory protection in saphenous vein graft interventions. J Invasive Cardiol 2009;21:34–9.

32. Roffi M, Mukherjee D, Chew DP, et al. Lack of benefit from intravenous platelet glycoprotein IIb/IIIa receptor inhibition as adjunctive treatment for percutaneous interventions of aortocoronary bypass grafts: a pooled analysis of 5 randomized clinical trials. Circulation 2002;106:3063–7.

33. Niccoli G, Belloni F, Cosentino N, et al. Case-control registry of excimer laser coronary angioplasty versus distal protection devices in patients with acute coronary syndromes due to saphenous vein graft disease. Am J Cardiol 2013;112:1586–91.

34. Dixon S. Saphenous vein graft protection in a distal embolic protection randomized trial. Paper presented at: Transcatheter Cardiovascular Therapeutics; October 17-21, 2005; Washington, DC.

35. Stone GW, Rogers C, Hermiller J, et al. Randomized comparison of distal protection with a filter-based catheter and a balloon occlusion and aspiration system during percutaneous intervention of diseased saphenous vein aorto-coronary bypass grafts. Circulation 2003;108:548–53.

36. Baim DS, Wahr D, George B, et al. Randomized trial of a distal embolic protection device during percutaneous intervention of saphenous vein aorto-coronary bypass grafts. Circulation 2002; 105:1285–90.

37. Carrozza JP Jr, Mumma M, Breall JA, Fernandez A, Heyman E, Metzger C. Randomized evaluation of the TriActiv balloon-protection flush and extraction system for the treatment of saphenous vein graft disease. J Am Coll Cardiol 2005;46:1677–83.

38. Holmes DR, Coolong A, O'Shaughnessy C, et al. Comparison of the CardioShield filter with the guardwire balloon in the prevention of embolisation during vein graft intervention: results from the CAPTIVE randomised trial. EuroIntervention 2006;2:161–8.

39. Kereiakes DJ, Turco MA, Breall J, et al. A novel filter-based distal embolic protection device for percutaneous intervention of saphenous vein graft lesions: results of the AMEthyst randomized controlled trial. J Am Coll Cardiol Intv 2008;1: 248–57.

40. Mauri L, Cox D, Hermiller J, et al. The PROXIMAL trial: proximal protection during saphenous vein graft intervention using the Proxis Embolic Protection System: a randomized, prospective, multicenter clinical trial. J Am Coll Cardiol 2007; 50:1442–9.

41. Coolong A, Baim DS, Kuntz RE, et al. Saphenous vein graft stenting and major adverse cardiac events: a predictive model derived from a pooled analysis of 3958 patients. Circulation 2008;117: 790–7.

42. Levine GN, Bates ER, Blankenship JC, et al. 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. J Am Coll Cardiol 2011;58:e44–122.

43. Lee M, Kong J. Current state of the art in approaches to saphenous vein graft interventions. Interv Cardiol 2017;12:85–91.

44. Mehta SK, Frutkin AD, Milford-Beland S, et al. Utilization of distal embolic protection in saphenous vein graft interventions (an analysis of 19, 546 patients in the American College of Cardiology-National Cardiovascular Data Registry). Am J Cardiol 2007;100:1114–8.

45. Neumann FJ, Sousa-Uva M, Ahlsson A, et al. 2018 ESC/EACTS guidelines on myocardial revascularization. Eur Heart J 2019;40:87–165.

46. Brennan JM, Al-Hejily W, Dai D, et al. Three-year outcomes associated with embolic protection in saphenous vein graft intervention: results in 49 325 senior patients in the Medicare-linked National Cardiovascular Data Registry CathPCI Registry. Circ Cardiovasc Interv 2015;8:e001403.

47. Paul TK, Bhatheja S, Panchal HB, et al. Outcomes of saphenous vein graft intervention with and without embolic protection device: a comprehensive review and meta-analysis. Circ Cardiovasc Interv 2017;10:e005538.

48. Ashby DT, Dangas G, Aymong EA, et al. Effect of percutaneous coronary interventions for in-stent restenosis in degenerated saphenous vein grafts without distal embolic protection. J Am Coll Cardiol 2003;41:749–52.

49. Mishra S, Wolfram RM, Torguson R, et al. Comparison of effectiveness and safety of drug-eluting stents versus vascular brachytherapy for saphenous vein graft in-stent restenosis. Am J Cardiol 2006;97:1303–7.

50. Brilakis ES, Lichtenwalter C, de Lemos JA, et al. A randomized controlled trial of a paclitaxel-eluting stent versus a similar bare-metal stent in saphenous vein graft lesions the SOS (Stenting of Saphenous Vein Grafts) trial. J Am Coll Cardiol 2009;53:919–28.

51. Lichtenwalter C, de Lemos JA, Roesle M, et al. Clinical presentation and angiographic characteristics of saphenous vein graft failure after stenting: insights from the SOS (stenting of saphenous vein grafts) trial. J Am Coll Cardiol Intv 2009;2:855–60.

52. Vermeersch P, Agostoni P, Verheye S, et al. Randomized double-blind comparison of sirolimus-eluting stent versus bare-metal stent implantation in diseased saphenous vein grafts: six-month angiographic, intravascular ultrasound, and clinical follow-up of the RRISC trial. J Am Coll Cardiol 2006;48:2423–31.

53. IJsselmuiden AJJ, Simsek C, van Driel AG, et al. Comparison between the STENTYS self-apposing bare metal and paclitaxel-eluting coronary stents for the treatment of saphenous vein grafts (ADEPT trial). Neth Heart J 2018;26:94–101.

54. Brilakis ES, Edson R, Bhatt DL, et al. Drug-eluting stents versus bare-metal stents in saphenous vein grafts: a double-blind, randomised trial. Lancet 2018;391:1997–2007.

55. Brilakis ES, Lichtenwalter C, Abdel-Karim AR, et al. Continued benefit from paclitaxel-eluting compared with bare-metal stent implantation in saphenous vein graft lesions during long-term follow-up of the SOS (Stenting of Saphenous Vein Grafts) trial. J Am Coll Cardiol Intv 2011;4:176–82.

56. Colleran R, Kufner S, Mehilli J, et al. Efficacy over time with drug-eluting stents in saphenous vein graft lesions. J Am Coll Cardiol 2018;71:1973–82.

57. Mehilli J, Pache J, Abdel-Wahab M, et al. Drug-eluting versus bare-metal stents in saphenous vein graft lesions (ISAR-CABG): a randomised controlled superiority trial. Lancet 2011;378:1071–8.

58. Sosa A, Chao H, Guerra A, et al. Paclitaxel-eluting vs. bare metal stent implantation in saphenous vein graft lesions: very long-term follow-up of the SOS (Stenting of Saphenous vein grafts) trial. Int J Cardiol 2015;186:261–3.

59. Vermeersch P, Agostoni P, Verheye S, et al. Increased late mortality after sirolimus-eluting stents versus bare-metal stents in diseased saphenous vein grafts: results from the randomized DELAYED RRISC trial. J Am Coll Cardiol 2007;50:261–7.

60. Kheiri B, Osman M, Abdalla A, Ahmed S, Bachuwa G, Hassan M. The short- and long-term outcomes of percutaneous intervention with drug-eluting stent vs bare-metal stent in saphenous vein graft disease: an updated meta-analysis of all randomized clinical trials. Clin Cardiol 2018;41:685–92.

61. Yahagi K, Kolodgie FD, Otsuka F, et al. Pathophysiology of native coronary, vein graft, and in-stent atherosclerosis. Nat Rev Cardiol 2016;13:79–98.

62. Yazdani SK, Otsuka F, Nakano M, Ladich E, Virmani R. Pathology of saphenous vein grafts. Intervent Cardiol Clin 2013;2:241–9.

63. Zhao DX, Leacche M, Balaguer JM, et al. Routine intraoperative completion angiography after coronary artery bypass grafting and 1-stop hybrid revascularization results from a fully integrated hybrid catheterization laboratory/operating room. J Am Coll Cardiol 2009;53:232–41.

64. Thielmann M, Massoudy P, Schmermund A, et al. Diagnostic discrimination between graft-related and non-graft-related perioperative myocardial infarction with cardiac troponin I after coronary artery bypass surgery. Eur Heart J 2005;26:2440–7.

65. Botman CJ, Schonberger J, Koolen S, et al. Does stenosis severity of native vessels influence bypass graft patency? A prospective fractional flow reserve-guided study. Ann Thorac Surg 2007;83:2093–7.

66. Yoon SH, Kim YH, Yang DH, et al. Risk of new native-vessel occlusion after coronary artery bypass grafting. Am J Cardiol 2017;119:7–13.

67. Thielmann M, Sharma V, Al-Attar N, et al. ESC Joint Working Groups on Cardiovascular Surgery and the Cellular Biology of the Heart Position Paper: perioperative myocardial injury and infarction in patients undergoing coronary artery bypass graft surgery. Eur Heart J 2017;38:2392–407.

68. Welsh RC, Granger CB, Westerhout CM, et al. Prior coronary artery bypass graft patients with ST-segment elevation myocardial infarction treated with primary percutaneous coronary intervention. J Am Coll Cardiol Intv 2010;3:343–51.

69. Abdel-Karim AR, Banerjee S, Brilakis ES. Percutaneous intervention of acutely occluded saphenous vein grafts: contemporary techniques and outcomes. J Invasive Cardiol 2010;22:253–7.

70. Ali A, Cox D, Dib N, et al. Rheolytic thrombectomy with percutaneous coronary intervention for infarct size reduction in acute myocardial infarction: 30-day results from a multicenter randomized study. J Am Coll Cardiol 2006;48:244–52.

71. Reiner JS, Lundergan CF, Kopecky SL, et al. Ineffectiveness of thrombolysis for acute MI following vein graft occlusion (abstr). Circulation 1996;94 Suppl I:I570.

72. Poon K, Roati A, Walters DL. Saphenous vein graft intervention discussion on acute vein graft occlusion intervention. J Am Coll Cardiol Intv 2011;4:1250. author reply 1250–1.

73. Brodie BR, VerSteeg DS, Brodie MM, et al. Poor long-term patient and graft survival after primary percutaneous coronary intervention for acute myocardial infarction due to saphenous vein graft occlusion. Catheter Cardiovasc Interv 2005;65:504–9.

74. Gaglia MA Jr, Torguson R, Xue Z, et al. Outcomes of patients with acute myocardial infarction from a saphenous vein graft culprit undergoing percutaneous coronary intervention. Catheter Cardiovasc Interv 2011;78:23–9.

75. Ibanez B, James S, Agewall S, et al. 2017 ESC guidelines for the management of acute myocardial infarction in patients presenting with ST-segment elevation: the Task Force for the management of acute myocardial infarction in patients presenting with ST-segment elevation of the European Society of Cardiology (ESC). Eur Heart J 2018;39:119–77.

76. Goel PK, Agarwal A, Kapoor A. "Concertina" effect during angioplasty of tortuous right and left coronary arteries and importance of using over-the-wire system: a case report. Indian Heart J 2001;53:87–90.

77. Tajti P, Karatasakis A, Karmpaliotis D, et al. Retrograde CTO-PCI of native coronary arteries via left internal mammary artery grafts: insights from a multicenter U.S. registry. J Invasive Cardiol 2018;30:89–96.

78. Ichimoto E, De Gregorio J. Successful deployment of polytetrafluoroethylene-covered stent to seal left internal mammary artery graft perforation due to guide catheter extension system. Cardiovasc Revasc Med 2016;17:574–7.

79. Januszek RA, Dziewierz A, Siudak Z, Rakowski T, Dudek D, Bartus S. Predictors of periprocedural complications in patients undergoing percutaneous coronary interventions within coronary bypass grafts. Cardiol J 2018 Apr 19 [E-pub ahead of print].

80. Dash D. An update on coronary bypass graft intervention. Heart Asia 2014;6:41–5.

81. Gruberg L, Dangas G, Mehran R, et al. Percutaneous revascularization of the internal mammary artery graft: short- and long-term outcomes. J Am Coll Cardiol 2000;35:944–8.

82. Sharma AK, McGlynn S, Apple S, et al. Clinical outcomes following stent implantation in internal mammary artery grafts. Catheter Cardiovasc Interv 2003;59:436–41.

83. Dimas B, Lindsey JB, Banerjee S, Brilakis ES. ST-segment elevation acute myocardial infarction due to severe hypotension and proximal left subclavian artery stenosis in a prior coronary artery bypass graft patient. Cardiovasc Revasc Med 2009;10:191–4.

84. Varghese I, Samuel J, Banerjee S, Brilakis ES. Comparison of percutaneous coronary intervention in native coronary arteries vs. bypass grafts in patients with prior coronary artery bypass graft surgery. Cardiovasc Revasc Med 2009;10:103–9.

85. Kirtane AJ, Doshi D, Leon MB, et al. Treatment of higher-risk patients with an indication for revascularization: evolution within the field of contemporary percutaneous coronary intervention. Circulation 2016;134:422–31.

86. Bundhoo SS, Kalla M, Anantharaman R, et al. Outcomes following PCI in patients with previous CABG: a multi centre experience. Catheter Cardiovasc Interv 2011;78:169–76.

87. Mavroudis CA, Kotecha T, Chehab O, Hudson J, Rakhit RD. Superior long term outcome associated with native vessel versus graft vessel PCI following secondary PCI in patients with prior CABG. Int J Cardiol 2017;228:563–9.

88. Meliga E, Garcia-Garcia HM, Kukreja N, et al. Chronic total occlusion treatment in post-CABG patients: saphenous vein graft versus native vessel recanalization-long-term follow-up in the drug-eluting stent era. Catheter Cardiovasc Interv 2007;70:21–5.

89. Tejada JG, Velazquez M, Hernandez F, et al. Percutaneous revascularization in patients with previous coronary artery bypass graft surgery. Immediate and 1-year clinical outcomes. Int J Cardiol 2009;134:201–6.

90. Xanthopoulou I, Davlouros P, Tsigkas G, Panagiotou A, Hahalis G, Alexopoulos D. Long-term clinical outcome after percutaneous coronary intervention in grafts vs native vessels in patients with previous coronary artery bypass grafting. Can J Cardiol 2011;27:716–24.

91. Xenogiannis I, Tajti P, Burke MN, Brilakis ES. Staged revascularization in patients with acute coronary syndromes due to saphenous vein graft failure and chronic total occlusion of the native vessel: a novel concept. Catheter Cardiovasc Interv 2019;93:440–4.

92. Brilakis ES, Banerjee S, Lombardi WL. Retrograde recanalization of native coronary artery chronic occlusions via acutely occluded vein grafts. Catheter Cardiovasc Interv 2010;75:109–13.

93. Dautov R, Manh Nguyen C, Altisent O, Gibrat C, Rinfret S. Recanalization of chronic total occlusions in patients with previous coronary bypass surgery and consideration of retrograde access via saphenous vein grafts. Circ Cardiovasc Interv 2016;9:e003515.

94. Pereg D, Fefer P, Samuel M, et al. Native coronary artery patency after coronary artery bypass surgery. J Am Coll Cardiol Intv 2014;7:761–7.

95. Nguyen-Trong PK, Alaswad K, Karmpaliotis D, et al. Use of saphenous vein bypass grafts for retrograde recanalization of coronary chronic total occlusions: insights from a multicenter registry. J Invasive Cardiol 2016;28:218–24.

96. Michael TT, Karmpaliotis D, Brilakis ES, et al. Impact of prior coronary artery bypass graft surgery on chronic total occlusion revascularisation: insights from a multicentre US registry. Heart 2013;99:1515–8.

97. Teramoto T, Tsuchikane E, Matsuo H, et al. Initial success rate of percutaneous coronary intervention for chronic total occlusion in a native coronary artery is decreased in patients who underwent previous coronary artery bypass graft surgery. J Am Coll Cardiol Intv 2014;7:39–46.

98. Toma A, Stahli BE, Gick M, et al. Long-term follow-up of patients with previous coronary artery bypass grafting undergoing percutaneous coronary intervention for chronic total occlusion. Am J Cardiol 2016;118:1641–6.

99. Berry C, Pieper KS, White HD, et al. Patients with prior coronary artery bypass grafting have a poor outcome after myocardial infarction: an analysis of the VALsartan in acute myocardial iNfarcTion trial (VALIANT). Eur Heart J 2009;30:1450–6.

100. Sapontis J, Salisbury AC, Yeh RW, et al. Early procedural and health status outcomes after chronic total occlusion angioplasty: a report from the OPEN-CTO registry (Outcomes, Patient Health Status, and Efficiency in Chronic Total Occlusion Hybrid Procedures). J Am Coll Cardiol Intv 2017;10:1523–34.

101. Karatasakis A, Akhtar YN, Brilakis ES. Distal coronary perforation in patients with prior coronary artery bypass graft surgery: the importance of early treatment. Cardiovasc Revasc Med 2016;17:412–7.

102. Wilson WM, Spratt JC, Lombardi WL. Cardiovascular collapse post chronic total occlusion percutaneous coronary intervention due to a compressive left atrial hematoma managed with percutaneous drainage. Catheter Cardiovasc Interv 2015;86:407–11.

103. Cardoso R, Knijnik L, Whelton SP, et al. Dual versus single antiplatelet therapy after coronary artery bypass graft surgery: an updated meta-analysis. Int J Cardiol 2018;269:80–8.

104. Verma S, Goodman SG, Mehta SR, et al. Should dual antiplatelet therapy be used in patients following coronary artery bypass surgery? A meta-analysis of randomized controlled trials. BMC Surg 2015;15:112.

105. Brilakis ES, Held C, Meier B, et al. Effect of ticagrelor on the outcomes of patients with prior coronary artery bypass graft surgery: insights from the PLATelet inhibition and patient outcomes (PLATO) trial. Am Heart J 2013;166:474–80.

106. Sachdeva A, Bavisetty S, Beckham G, et al. Discontinuation of long-term clopidogrel therapy is associated with death and myocardial infarction after saphenous vein graft percutaneous coronary intervention. J Am Coll Cardiol 2012;60:2357–63.

107. Mauri L, Kereiakes DJ, Yeh RW, et al. Twelve or 30 months of dual antiplatelet therapy after drug-eluting stents. N Engl J Med 2014;371:2155–66.

108. Yeh RW, Secemsky EA, Kereiakes DJ, et al. Development and Validation of a Prediction Rule for Benefit and Harm of Dual Antiplatelet Therapy Beyond 1 Year After Percutaneous Coronary Intervention. JAMA 2016;315:1735–49.

109. Lamy A, Eikelboom J, Sheth T, et al. Rivaroxaban, aspirin, or both to prevent early coronary bypass graft occlusion: the COMPASS-CABG study. J Am Coll Cardiol 2019;73:121–30.

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