TECHNICAL ASPECTS OF REVASCULARIZATION

Coronary artery by-pass grafting (CABG)

Contemporary CABG procedures carry a **1-2% peri-operative mortality, 0.3-10% risk of myocardial infarction, 2-4% of reoperation for bleeding, 1-4% of wound infection, 0.5-1% renal failure, 1-3% of stroke, and 0.5-3% mediastinitis**.[1-3] Five and 10-year survival rates with modern techniques are approximately 80% and 75%.[2] The beneficial effects of CABG may not last beyond 10 years after surgery, presumably due to the limited longevity of used grafts (Table 1). Grafting a coronary artery increases the risk of disease progression 3 to 6 times, especially in the right coronary artery.[4] Isolated elevations in cTnT >=7 upper reference limit (URL) and/or cTnI >=20 URL in the 48-h post-operative period may indicate the presence of prognostically significant peri-operative myocardial injury, and should prompt clinical evaluation to exclude Type 5 MI. Where ECG/angiography/imaging evidence of MI is available, lower levels of biomarker elevation (cTn x10 URL) should be considered for diagnosing prognostically significant myocardial injury, as per the Universal MI definition.[5] However, the clinically significant cut-offs for enzyme rise are not established,[6] and isolated biomarker release is not a feasible means of detecting prognostically relevant myocardial injury after surgery.[7]

Type of grafts

Saphenous vein grafts (SVGs) remain the most frequently used conduits in CABG. Despite advances in surgical techniques and pharmacotherapy, SVG failure rates remain high, often leading to repeat coronary revascularization (Table 1).[8] At 12-18 months after CABG, 17-25% of **vein grafts** have failed, and 34% of patients had at least one failed graft, [9, 10] while at 10 years only about half of saphenous vein grafts are patent, and of those only half are free of angiographic arteriosclerosis.[11] The **no-touch SVG harvesting** technique (minimal graft manipulation with preservation of vasa vasorum and nerves) theoretically reduces the risk of SVG failure,[8] but its superiority to conventional harvesting is not established.[12] Intermediate (30%–60%) SVG stenoses often progress rapidly. Stenting of intermediate SVG stenoses failed to improve outcomes; hence, treatment focuses on strict control of coronary artery disease risk factors. Perioperative aspirin and high-intensity statin administration are the cornerstones of secondary prevention after CABG. Redo CABG is associated with higher perioperative mortality compared with percutaneous coronary intervention (PCI); hence, the latter is preferred for most patients requiring repeat revascularization after CABG.[8] SVG PCI is limited by high rates of no-reflow and a high incidence of restenosis during follow-up.

Embolic protection devices reduce no-reflow and should be used when feasible.[8] Aortocoronary **saphenous vein graft aneurysms** occur with an approximate incidence of 0.07% as a late complication of CABG, but this is probably an underestimation. They are associated with significant morbidity and mortality since they grow with time and percutaneous or surgical management is recommended.[13]

The use of the **left internal thoracic artery (LITA)** to the LAD is superior to venous grafts (SVG) and the right internal thoracic artery is preferable to the radial to the best recipient vessel after the LAD (Table 2).[11, 14] **Bilateral internal thoracic artery grafting** is theoretically superior to single LITA, but this was not verified by the three RCTS published so far.[15] The largest of them, the ART randomized trial, demonstrated similar clinical outcomes for single and bilateral internal thoracic artery use at 1 year, but bilateral grafts were associated with a small absolute increase (1.3%) in the need for sternal wound reconstruction.[16] At 10 years, there was no significant between-group difference in the rate of death from any cause in the intention-to-treat analysis.[17] In retrospective analyses, bilateral internal thoracic artery grafting was associated with a reduced risk of repeat revascularization and an improvement in long-term survival compared to use of a single LITA. [18] The use of bilateral internal thoracic arteries is therefore promising, but the right internal thoracic artery may be associated with an increased risk of sternal wound infection compared to the radial artery without a clear benefit.[19] "Skeletonization" of ITA grafts is associated with a lower rate of sternal wound complications,[20] endoscopic harvesting is associated with reduced SVG patency, and no-touch technique of SVG harvesting that reduces endothelial injury has shown superior long-term patency when compared with conventional harvesting.[21] A difference in these surgical techniques may not become evident until 10 years, during which time >95% of ITAs remain patent, in contrast to only 32-71% of saphenous veins. LITA failure is associated with intermediate LAD stenosis without functional evidence of ischaemia, due to competitive flow, and grafting should be avoided in this setting.[22] Anterior ischemia in the presence of a patent anastomosed LITA may suggest subclavian steal syndrome, ie proximal subclavian stenosis.[23]

Multiple arterial grafts result in a lower rate of cardiac events compared to vein grafts.[24-26] **Radial artery** grafts may offer a patency comparable that of LITA when they are used to graft a vessel with >90% stenosis.[25, 27] In a meta-analysis of 6 RCTs (RADIAL), the use of radial artery grafts for CABG resulted in a lower rate of adverse cardiac events and a higher rate of patency at 5 years of follow-up, compared with the use of saphenous vein grafts.[24] The 10-year patency rate of the radial artery is also significantly higher than that of the free RITA and better than that of the SV (RAPCO-RITA RCT).[28] The only situation in which a **SVG** may have a better patency that an ITA graft is when used to bypass a moderately stenotic (50-70%) RCA, probably due to less competitive flow.[29] If one radial

artery has been used for coronary angiography or intervention, the contralateral one should be used for grafting, or, perhaps, the same one but at least 3 months after the coronary procedure.[30] Endoscopic vein graft harvesting is not inferior to open vein graft harvesting when performed by experienced operators (REGROUP trial).[31]

Diabetes does not appear to influence long-term patency of bypass grafts, either arterial or venous.[32] Bypassing ***intermediate lesions*** can result in more rapid progression of native vessel disease as well as accelerated graft failure, and FFR might be useful in identifying significant lesions that deserve bypass grafting. [33] A significant association between preoperative FFR and anastomotic arterial graft function at 6 months in CABG patients has been demonstrated. Arterial grafts to target vessels with FFR <0.78 had extremely high patency rate at 6 months.[34]

Off-pump beating heart bypass surgery

A reduced risk of stroke with off-pump beating heart bypass surgery (OPCAB), that was suggested by a meta-analysis, [35] has not been verified in the largest randomized trials so far. In RCTs, similar [36-38] or even worse outcomes (ROOBY trial)[39, 40] with OPCAB have been reported, and the issue of less effective revascularization with this approach has been raised with a resultant worse long-term survival compared to on-pump surgery.[41-43] Among patients with left main disease treated with CABG in the EXCEL trial, off-pump surgery was also associated with an increased risk of 3-year all-cause death compared with on-pump surgery.[44] Off-pump surgery may be protective against new-onset ventricular arrhythmias,[45] and reduces stroke when completely avoiding aortic manipulation by a no-touch, total arterial off-pump CABG.[46] In the elderly (>=75 years) no difference between the two modalities has been detected, but incomplete revascularization, irrespective of the type, was associated with worse survival (GOPCABE RCT).[47] Similar rates of the 30-day primary composite outcome were also observed and neurocognitive outcomes at 1 year were similar between the two modalities in prefrail and frail patients (FRAGILE RCT).[48] Dual antiplatelet therapy is recommended for off-pump CABG.[8]

Minimally invasive and robotic CABG

These mainly involve harvesting of a LIMA and off-pump anastomosis to LAD, and are currently under investigation.[2]

Shockwave therapy

Shockwave therapy has been shown to induce angiogenesis in the hibernating myocardium and trigger myocardial regeneration effects.[49] Direct cardiac shockwave therapy, in addition to coronary bypass surgery has been shown to improve LVEF and physical capacity in patients with ischaemic heart failure.[50]

Other issues

The European System for Cardiac Operative Risk Evaluation, **logistic EuroSCORE and EuroSCORE II (www.euroscore.org)** and the **Society of Thoracic Surgeons STS score** (http://riskcalc.sts.org) that is probably more accurate in high risk patients (ACC/AHA SCAI 2021 GL on revascularization I B-NR), are useful guides for calculation of the intraoperative risk. Additional risk factors not quantified by the STS score are cirrhosis, frailty and malnutrition.[51] The prevalence of **severe carotid disease** (> 80% stenosis of the internal carotid artery) among patients undergoing **coronary artery bypass grafting is 6-12%,[52] but the optimum management of concomitant** carotid disease of this population remains controversial. Observational studies have suggested that a combined endarterectomy and CABG or staged carotid stenting followed by CABG is superior to staged endarterectomy followed by CABG at a later stage,[53, 54] but in the first RCT on the subject, although underpowered, no benefit of simultaneous CABG and carotid endarterectomy was seen.[55] In the ESC 2024 GL on aortic and peripheral diseases, carotid endarterectomy in general is now considered in stenosis > 70% (I A) or 50%(IIa A) in asymptomatic patients, and 60% (IIa B) in asymptomatic patients not at high surgical risk.[56]

In a pooled analysis of four large CABG trials, in the first 5 years after surgery, **women** were found to have worse cardiac and cerebrovascular outcomes than men. The difference in outcomes between the sexes was not evident after 75 years of age and was significantly affected by preoperative LVEF, but not by variations in the surgical technique used. [57]

Choice of the graft conduit and **peri-operative medication** are presented in Table 3. Evidence to support the Society of Thoracic Surgeons quality measure requiring ***β-blocker*** administration within 24 hours before CABG is uncertain in β–blocker–naive patients.[58] Perioperatively, β-blockers are useful for the prevention of AF after CABG, especially when initiated ≤72 hours postoperatively in high-risk patients (age >75 years, history of AF, longer aortic cross-clamp duration).[58] The use of ***calcium channel blockers*** for the first postoperative year, with dihydropyridines (eg, amlodipine or nifedipine) preferred over nondihydro-pyridines (eg, diltiazem or verapamil), may help limit radial artery graft spasm. duration).[58] Low-dose ***aspirin*** initiated within 6 hours after CABG and continued indefinitely improves graft patency and reduces future cardiovascular events.[58] In patients with ACS undergoing CABG, ***DAPT*** for 1 year is associated with a lower risk of death and cardiac events.[58, 59] DAPT decreases graft rate but at the expense of an increased risk of bleeding.[60] However, dual antiplatelet therapy may not be overall superior to aspirin alone in stable patients undergoing CABG,[61, 62] even after an acute coronary syndrome.[63] Aspirin and ticagrelor may result in increased SVG patency at one year compared to aspirin alone,[64] but in the benefit of dual therapy was not confirmed in a subsequent RCT.[65] The combination of

rivaroxaban 2.5 mg twice daily plus aspirin may reduce MACE.[66] Thus, the choice of antithrombotic therapy should be individualized, based on ischaemic and bleeding risks, and regularly reassessed.[59]

Sexual activity is allowed 6-8 weeks after CABG or non-coronary open heart surgery (IIa-C).[67]

Percutaneous coronary intervention (PCI)

The **in-hospital mortality** of PCI is estimated approximately **1%,** whereas **periprocedural infarction** (defined as increase in biomarkers >3 times the 99th percentile upper reference limit) **is 15%, ischemic stroke 0.1%, and emergency CABG** is required in **0.1-0.4%** of patients. [68-70] In the National Cardiovascular Data Registry report, PCI in-hospital mortality was 1.27%, ranging from 0.65% in elective PCI to 4.81% in ST-segment elevation myocardial infarction patients.[70] More recent data indicate a mortality of 1.08% and an inverse relationship between complications and operator and institutional volume.[68] In noanagenarians, however, a 10.6% 30-day mortality following PCI has been reported.[71] Older age, extreme body mass indexes, multivessel disease, a lower ejection fraction, unstable hemodynamic state or shock, several comorbidities (cerebrovascular disease, peripheral vascular disease, congestive heart failure, chronic obstructive pulmonary disease, diabetes mellitus, and renal failure), and a history of coronary artery bypass graft surgery are risk factors that increase mortality.[72]

General recommendations on PCI are presented in Tables 4 and 5.

Types of stents

Bare-meta stents **(BMS)** is superior to balloon, and drug-eluting stents (**DES)** is superior to BMS by decreasing target lesion revascularization.[73, 74] However, drug-coated balloons are superior to BMS in patients at bleeding risk.[75] There has been evidence from a meta-analysis that second-generation DES may also decrease mortality or the risk of MI compared to BMS,[76] but this was not confirmed in the NORSTENT trial,[77] or another individual patient data meta-analysis.[74] Early stent thrombosis (within the first 20 days) with second generation DES is <1% and thereafter 0.2-0.4% per year.[78] Uncovered struts and underexpansion are usually found in acute/subacute stent thrombosis, and neoatherosclerosis and uncovered struts in late/very late stent thrombosis.[79] There is evidence for a safety advantage of 2nd generation drug-eluting stents, such as everolimus-eluting, and biolimus-eluting stents, as compared with early generation DES, as detected in long-term (>1 year) follow-up,[80] especially in diabetics.[81]

Ultrathin-strut DES (<_70 lm) also reduce the risk of target lesion failure (defined as a composite of cardiac death, target-vessel myocardial infarction or clinically driven target

lesion revascularization), compared with conventional 2nd-generation thin-strut DES, with similar risks myocardial infarction, cardiac death, and all-cause mortality.[82]

DES with a **biodegradable polymer** and thin struts thickness (<81 μm) are theoretically attractive but they have not resulted in reduced stent thrombosis or MI compared to thin-strut everolimus- or zotarolimus-eluting conventional stents (81 and 91 μm, respectively),[83, 84] but this finding is not universal.[85] In patients at high risk for bleeding, a **polymer-free** umirolimus-coated stent has been found superior to a bare metal stent, with a 1-month course of dual antiplatelet therapy.[86] However, in subsequent trials, the value of polymer-free drug-coated stents compared to polymer-based or biodegradable stents zotarolimus-eluting stents was not established. [87-89]

The permanent presence of a metallic foreign body within the artery following stenting may cause vascular inflammation, restenosis, thrombosis, and neoatherosclerosis, and impair the physiological vasomotor function of the vessel and future potential of grafting the stented segment. **Bioresorbable** scaffolds have the potential to overcome these limitations and are under trial.[90 91] However, there has been evidence of increased stent thrombosis with a 1st generation thick-strut (150 μm poly-L-lactic acid-PLLA) bioresorbable, everolimus-eluting stent (Absorb BVS), with reported rates of 0.9% to 3% in 6 months to three years follow-up (ABSORB II, ABSORB Japan, ABSORB China, ABSORB III, EVERBIO II, AIDA, and TROFI II trials).[92] These unfavorable results were also observed at 5-years follo-up despite the improved implantation technique, with 3% greater absolute rate of target lesion failure.[93] Meta-analyses of these studies has confirmed a 2.4% stent thrombosis vs 0.6% with everolimus-eluting stents over 3 years.[94, 95] Other bioabsorabable stents are also in study, but no data refute their inferiority compared to conventional DES.[96]

The safety of drug-eluting stents in those with ***nickel allergy***, as well as the safety of ***MRI*** is now established.[97]

Duration of dual antiplatelet therapy

Duration of dual antiplatelet therapy depends on several factors and is still controversial (Tables 4 and 5, and Figures 1 and 2). Continuation of dual antiplatelet therapy beyond one year has not been found beneficial in randomized trials on both stable and unstable patients treated with 1st and 2nd generation DES. Treatment with dual antiplatelet therapy beyond 1 year after drug-eluting stent implantation reduces myocardial infarction and stent thrombosis, but at the expense of more bleeding events.[98] Thus, it may be associated with increased mortality because of an increased risk of non-cardiovascular mortality not offset by a reduction in cardiac mortality.[99] With 2nd generation DES even 1-3 months of dual antiplatelet therapy may reduce bleeding without affecting major cardiac events compared to 12-24 months therapy in both stable patients and after an ACS. In several RCTs (such as SMART-CHOICE, TWILIGHT-HBR, STOPDAPT-2, GLOBAL LEADERS, TICO, HOST-

EXAM, T-PASS, A-CLOSE, and others) discontinuation of aspirin with continued $P2Y_{12}$ inhibitor monotherapy has been found to reduce the risk of bleeding without increasing major adverse cardiovascular events when stopped 1 month or 3 months (when clopidogrel is used) after PCI, in both stable patients and after an acute coronary syndrome.[100-102] DAPT-based de-escalation in certain patients is associated with both decreased ischaemic and bleeding endpoints.[103] In patients requiring infinite antiplatelet therapy, clopidogrel appears superior to aspirin alone,[104, 105] but this has also been controversial.[106, 107]

These findings cannot be generalized, and it should be noted that most of these studies had a mean duration of follow-up of one year. In an analysis of the DAPT study (30% of patients with stable CAD), patients who discontinued thienopyridine, either 12 months or 30 months after a percutaneous coronary intervention, were at an increased risk of an MI in the subsequent months mainly unrelated to stent thrombosis.[108] The optimum duration of dual antiplatelet therapy after stenting should be individualized, depending on condition treated, age of the patient, and comorbidities such as renal failure or history of prior myocardial infarction that affect the relative risk of adverse cardiac event and haemorrhage, while the type of stent used is not important with the new generation DES.[109-111] In patients with stable ischemic heart disease, the ACC/AHA/SCAI 2021 GL on revascularization recommend that, after consideration of recurrent ischemia and bleeding risks, select patients may safely transition to P2Y12 inhibitor monotherapy and stop aspirin after 1 to 3 months of dual antiplatelet therapy.[51] The DAPT score may also be used in this respect (see Chapter 28).[112, 113] In most patients, administration of DAPT for as long as 12 months may be not justified.[99] However, extended (12 months) DAPT duration may be beneficial following complex PCI procedures in high risk patients, following, especially, acute coronary syndromes.[114] In diabetics, 12 months DAPT is most probably indicated after an acute coronary syndrome and PCI.[115] In patients with AF and oral anticoagulation undergoing PCI, single anti-platelet therapy was not inferior to >=2 months dual anti-platelet therapy followed by single therapy thereafter.[116] Individualized duration of DAPT is recommended in patients with cancer with stable CAD, following revascularization, based upon thrombotic/ischaemic and bleeding risk, type and stage of cancer, and current cancer treatment (ESC 2022 GL on cardio-oncology, I C).[117] In patients >=75 years old, DAPT is generally discouraged beyond 12 months.[118] Thus, the optimum duration of triple therapy after stenting may differ on the basis of individual patient characteristics (and especially HAS-BLED score), stent, and drug characteristics (see also Chapter on ACS).[111, 119, 120] In stable patients with AF, monotherapy with a Xa inhibitor is appropriate one year after PCI.[121] Recommendations are provided in Chapter 28.

Patients on oral anticoagulants

Coronary angiography or PCI can be performed in patients on oral anticoagulation (warfarin or NOAC) and with additional anticoagulation, preferably through a radial access. For

elective PCI, there is no need of additional anticoagulation if the INR is >2.5. [122] In patients with stable CAD, no antiplatelet may be needed in addition to oral anticoagulation one year after stenting, but the issue is still controversial.[123] The management of patients on oral anticoagulants who are subjected to PCI is presented in Table 6 and also discussed in the Chapters on ACS and AF.

Technical Issues

General recommendations are provided in Tables 6-8.

Femoral and radial approach

Femoral artery ***pseudoaneurysms*** following PCI through the **femoral** artery constitute the most common femoral access complication following angiography, with an incidence ranging from 0.2% to 8%.[124] For small, stable pseudoaneurysms (<2 cm), observation with weekly duplex ultrasound until thrombosis occurs is appropriate. Ultrasound-guided compression should be considered if a pseudoaneurysm is >2 cm, has a short (<4 mm) neck width, is enlarging, is associated with significant pain, or occurs within 7 days of femoral access, or if continued anticoagulation is required. Compression is applied with the ultrasound probe in 10-minute cycles; an average of 37 minutes is required to achieve thrombosis. Patient discomfort may limit the procedure, and most patients require analgesia. The patient lies flat for 2-4 hours following compression. Repeat duplex ultrasound should be performed in 24-48 hours to verify that the pseudoaneurysm has not reopened. The success rate is 63-88%. Ultrasound-guided thrombin injection is preferred for larger aneurysms. Dilute thrombin is slowly injected into the pseudoaneurysm under duplex imaging and observed for thrombosis. Following successful thrombosis, the patient remains on bedrest for ≤12 hours. The procedural success rate is 93-97%, and the most common complication is distal embolization (0.5%).[125] Surgical repair may be necessary for pseudoaneurysms that are rapidly expanding, infected, or associated with skin necrosis or compressive symptoms such as ischemia or neuropathy.[124] Closure devices may decrease complications and short-term mortality even after elective intervention via femoral access.[126, 127] In patients undergoing PCI, bleeding is associated with increased in-hospital mortality that is highest with non-access site bleeding.[128] Pseudoaneurysm is the most common femoral access complication following angiography; incidence ranges from 0.2% to 8%.

The **radial** access offers less vascular and bleeding complication rates, as well as lower mortality in patients with anemia, but at increased fluoroscopy times at the initial steps of the learning curve.[129-131] The use of a narrow J tipped, 1.5mm hydrophilic guidewire (‘Baby J’) has been shown to improved technical success.[132] Transradial catheterization and intervention may be performed regardless of the results of the Allen or Barbeau tests and in those with prior mastectomy.[97] The risk of artery occlusion with modern techniques ranges from 2.5 to 3.5%, but is usually asymptomatic.[133] The risk of peri-procedural stroke may be

increased with right but not left radial access.[134, 135] An extensive series from Japan has actually argued in favour of a reduced risk of stroke with radial (right or left) compared to femoral access intervention.[136] It probably preferable to avoid using the radial artery for at least 3 months after transradial access and to assess patency and flow characteristics with Doppler before use as a conduit. [30, 97, 137] A hemostasis duration of 2 hours offers the best balance for efficacy (prevention of radial artery occlusion) and safety (prevention of access site hematoma/rebleeding).[138]

In-stent restenosis

In a patient-level pooled analysis of RCTs, the 1-year rates of ischemia-driven target lesion revascularization (TLR) were 14.7%, 4.9%, and 2.5% with BMS, early-generation DES, and new-generation DES, respectively. Conversely, from 1 to 5 years, the respective cumulative rates of ischemia-driven TLR were 6.1%, 5.9%, and 4.4%.[139] Despite the substantial improvements in DES technologies, ISR and the need for target lesion revascularization still occur at a rate of 1%-2% per year with contemporary DES platforms.[140] The treatment of in-stent restenosis is challenging; high-pressure balloon pre-dilatation followed by drug-coated balloons may be used, but everolimus-eluting DES is the best options for DES restenosis.[140-145] Interestingly, although restenosis is an independent predictor of long-term survival in patients undergoing coronary stenting, revascularization has not been found to offer any advantage on survival. [146] New ischemic perfusion defects (usually silent) are expected in 23% of patients and 40% of them are due to disease progression not related to stents.[147]

Coronary bifurcations

The MEDINA classification is now the preferred classification scheme.[148] In coronary bifurcations, stenting of both the main vessel and side branch in bifurcation lesions may increase myocardial infarction and stent thrombosis risk compared with stenting of the main vessel only.[149 150] A two-stents strategy may be adopted with large (>=2.5 mm diameter) side branches.[151 152] For left main stem lesions, a stepwise provisional rather than systematic dual stenting appears to be preferable with lower target lesion revascularization (EBC MAIN RCT).[153]

Chronic total occlusions

Outcomes of chronic total occlusion (CTO) intervention have improved because of advancements in equipment and techniques. Antegrade wiring, antegrade dissection and reentry, and the retrograde approach are all complementary and necessary crossing strategies.[154, 155] However, despite initial evidence from registries,[156 157] observational and randomized trials have failed to demonstrate improved LV function or improved cardiovascular outcomes following successful recanalization of native, chronic total occlusions.[158-161] In the ISCHEMIA trial, the risks and benefits of invasive compared with

conservative were similar among patients with and without CCTA-determined CTOs (more frequent procedural MI, less frequent spontaneous MI, and significantly improved angina and dyspnea-related quality of life). In an observational comparison, successful CTO revascularization was associated with a high probability of lower cardiovascular death or MI (driven by lower MI).[162]

Results on angina relief and QoL have been rather controversial. The EUROCTO RCT showed improved symptom relief and quality of life after PCI as compared with medical,[163] whereas the DECISION-CTO RCT showed no difference,[160] although a meta-analysis of the two trials showed an improvement in QoL.[163] In the recent ORBITA-CTO RCT in patients with symptomatic single-vessel CTO, PCI for CTO improved angina beyond placebo.[164] However, with just 50 patients, this trial was relatively small, all patients were treated in specialized centers by experienced operators, and patients with the most complex CTO features were also excluded from the study. Thus, until robust evidence emerges, attempting to treat a CTO is neither safer nor more effective than medical therapy alone for reducing CV death or MI, and that an invasive strategy for true CTOs remains an antianginal procedure.[165]

Complex calcified lesions

Various techniques including cutting balloon, rotational atherectomy, lithotripsy balloon and orbital atherectomy are now available for crossable lesions. However, in the ECLIPSE RCT, routine treatment with orbital atherectomy before stenting did not increase minimal stent area or reduce the rate of target vessel failure at 1 year compared with a balloon angioplasty-based approach.[166] If the wire cannot cross the lesion, crossing with a microcatheter or laser may be tried.[167]

Small vessels

Coronary arteries with a diameter <3 mm are prone to higher rates of restenosis and stent thrombosis.[168, 169] Ultra-thin-strut stents,[170] and drug-coated balloons may be useful in this setting.[145, 171]

Saphenous vein grafts

PCI for SVG accounts for more than 5% of all procedures.[172] It is limited by a risk of distal embolization and higher rates of repeat revascularization compared with redo CABG. DES do not provide superior patency than bare-metal stents for treatment of SVG lesions at 5 years, and their superiority even at 12 months is controversial. [173, 174] In patients with prior CABG presenting with graft failure, currentguidelines recommend PCI of the bypassed native coronary artery. However, in PROCTOR RCT, SVG PCI was associated with improved 1-year clinical outcomes compared with native vessel PCI (80% of them CTOs).[175]

Chronic kidney disease

In patients with chronic kidney disease DES are preferred.[176] ***Contrast-induced nephropathy***

is associated with a worse outcome, but the incidence is low (1.2%) and the incidence of sustained renal injury even lower.[177] Caution is needed in patients with creatinine>=2 mg/dL or an eGFR <30mL/min/1.73m^2, and hydration with sodium chloride to maintain a urine output >150 ml/h is probably the only protective measure with the strongest evidence. Assuming optimal contrast media administration, no prophylaxis is necessary for patients with eGFR >30 mL/min/1.73 m^2.[178] Adjunctive pharmacotherapy, such as acetylcysteine or sodium bicarbonate, have not been demonstrated to effectively prevent or treat contrast-induced nephropathy.[179, 180] Statins are protective, and statin loading with atorvastatin 80 mg within 24 hour preprocedure,[181] or rosuvastatin (40-10 mg)[182, 183] should be given in statin-naïve patients. In addition, inorganic nitrate in the form of potassium nitrate capsules (KNO_3: 6 mmol each giving 12 mmol in total equivalent to 744 mg of nitrate) once daily for a total of 5 days with the first dose taken prior to coronary angiography has been shown to improve kidney function in patients at risk (NITRATE-CIN RCT).[184] More importantly, the smallest amount of contrast should be used (<350 mL), and an isosmolar contrast (290 mOsm/kg) is indicated for high-risk patients, whereas low-osmolar agents (700-850 mOsm/kg) are reasonable in moderate-risk patients. Recommendationsn are provided in Table 7, and Figure 3.

Elderly

Coronary artery disease is a major cause of morbidity and mortality in patients ≥80 years of age and PCI, when feasible, is more attractive than CABG in this setting.[185] A patient-centered approach, taking into account health status, functional ability and frailty, cognitive skills, and patient preferences is essential when considering revascularization for older adults with CAD.

IVUS and OCT

Intracoronary imaging may be necessary for the detection of vumnerable plaques that may constitute an indication for PCI.[186] Intravascular ultrasound (IVUS) should be considered to assess the severity of unprotected left main lesions (ESC/EACTS 2018 GL on revascularization, IIa-B),[187] The value of optical coherence tomography (OCT) is rather debatable in this respect, [188-190] but OCT seems to be useful for PCI of bifurcations,[191] and for calcified lesions.[192] In the RENOVATE-COMPLEX-PCI RCT, intravascular imaging-guided PCI with either IVUS or OCT led to a lower risk of composite of cardiac death, MI, or TLR than angiography-guided PCI of complex lesions.[193] and in a subsequent meta-analysis IVUS-guided PCI was associated with a reduction in ischemia-driven target lesion revascularization.[194] IVUS was also superior to angiography in complex coronary bifurcation lesions treated with the 2-stent DK crush technique (DKCRUSH VIII RCT),[193] and an updated meta-analysis suggested reductions in the rates of cardiac and all-cause mortality after imaging-guided left-main PCI.[195] However, in the ORBITA and IVUS-CHIP RCTs in

main stem or complex lesions unprotected left main coronary artery disease, IVUS-guided PCI has showed no additional benefit over angiography-guided PCI.[196, 197]
For **FFR** and **iFR** see the Chapter on Stable CAD.

Other issues

There has been some evidence that concomitant ***balloon counterpulsation*** may improve long-term outcomes in high-risk patients undergoing PCI.[198, 199] PCI should be performed by operators with a ***workload*** of at least 75 cases per year in an institution performing more than 400 and certainly not less than 200 cases per year. However, although operator volume may not be associated with mortality following PCI, [200] and operator volume is not associated with long-term outcomes among patients surviving the index hospitalization.[201]

The treatment of symptomatic ***myocardial bridge*** refractory to beta blockers remains a clinical challenge. PCI has been associated with reports of stent fracture, stent thrombosis, and perforation during stent deployment, and CABG may be preferable. However, these concerns may be reliably mitigated using second-generation DES, accurate stent sizing aided by detailed intravascular imaging, and preferential use of high radial strength platforms.[202] Restenosis still likely occurs more frequently with PCI for myocardial bridge than for atherosclerotic lesions, and in this case CABG is indicated. Furthermore, the mechanisms underlying myocardial bridging are multifactorial, and most patients should be treated conservatively as they are asymptomatic. For those with persistent symptoms despite tailored medical therapy, surgical myotomy or CABG may be considered in preference to intervention, but these approaches carry procedural risks and lack robust comparative data.[203]

Recommendations for assessment and life-style changes after revascularization are provided in Table 8.

On-site ***surgical back-up*** is no more mandatory for elective PCI, provided there have been plans for rapid transport to a cardiac surgery operating room in a nearby hospital (Table 9).[204, 205] Rates of in-hospital mortality and emergency CABG for primary and nonprimary PCI appear similar at centers with and without on-site surgery (CPORT and MASS COMM trials and VA CART Program).[206 207] No further monitoring is needed after non-urgent PCI,[208] and same day discharge following PCI is safe in low-risk patients.[209]

Recent evidence also suggest a shorter ***nothing by- mouth*** time before the cardiac catheterization procedure, continuation of medications (except for perhaps *ACE inhibitors/ARBs* in those with eGFR <60 mL/min) previously recommended to hold before the procedure (such as ***metformin*** in patients with no or mild renal impairement), avoidance of the use of ***opiates*** as part of the sedation cocktail in young patients (but potential use in the elderly in the place of benzodiazepines), and not requiring ***allergy prophylaxis*** in those with shellfish

allergy.[97] ***Iodine*** is present throughout the body (eg, thyroid hormones, amino acids) and therefore cannot be an allergen. ***Women*** have worst outcomes than men.[210]

Hybrid Coronary Revascularization

Hybrid coronary revascularization (defined as the planned combination of LIMA-to-LAD artery grafting and DES of ≥1 non-LAD coronary arteries) is reasonable in patients with heavily calcified proximal aorta or poor target vessels for CABG (but amenable to PCI) or unfavorable LAD artery for PCI (i.e., excessive vessel tortuosity or chronic total occlusion. It can also be considered as an alternative to multivessel PCI or CABG in an attempt to improve the overall risk–benefit ratio of the procedures.[211] Available evidence is limited,[212] but in one randomized comparison, hybrid coronary revascularization had similar 5-year all-cause mortality when compared with conventional coronary bypass grafting (POL-MIDES trial).[213]

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