World J Surg
DOI 10.1007/s00268-017-4103-7

SCIENTIFIC REVIEW

Contemporary Management of Patients with Concomitant Coronary and Carotid Artery Disease

Mun J. Poi[1] · Angela Echeverria[1] · Peter H. Lin[1,2]

Abstract The ideal management of concomitant carotid and coronary artery occlusive disease remains elusive. Although researchers have advocated the potential benefits of varying treatment strategies based on either concomitant or staged surgical treatment, there is no consensus in treatment guidelines among national or international clinical societies. Clinical studies show that coronary artery bypass grafting (CABG) with either staged or synchronous carotid endarterectomy (CEA) is associated with a high procedural stroke or death rate. Recent clinical studies have found carotid artery stenting (CAS) prior to CABG can lead to superior treatment outcomes in asymptomatic patients who are deemed high risk of CEA. With emerging data suggesting favorable outcome of CAS compared to CEA in patients with critical coronary artery disease, physicians must consider these diverging therapeutic options when treating patients with concurrent carotid and coronary disease. This review examines the available clinical data on therapeutic strategies in patients with concomitant carotid and coronary artery disease. A treatment paradigm for considering CAS or CEA as well as CABG and percutaneous coronary intervention is discussed.

Introduction

Cardiovascular disease is one of the most common causes of death in developed countries, including the United States (U.S.). It is estimated that nearly 40% of all cardiovascular-related fatalities in the U.S. are due to myocardial ischemia caused by atherosclerotic coronary artery disease [1, 2]. As the result of systemic atherosclerotic progression, many patients with coronary artery occlusive disease are similarly inflicted with carotid artery occlusive disease. It is reported that stroke due to carotid artery atherosclerosis accounts for 18% of all cardiovascular-related fatalities in the U.S. [1, 2].

The presence of systemic atherosclerosis involving coronary artery or carotid artery occlusive disease is a common phenomenon in patients undergoing either coronary artery bypass grafting (CABG) or carotid endarterectomy (CEA). Among the patients undergoing CEA, it has been shown that 28% had severe coronary artery disease, which was indicated for CABG [3].

Similarly, hemodynamically significant carotid artery occlusive disease with greater than 80% luminal stenosis can be found in 12% of patients undergoing coronary revascularization [4–6]. Postoperative neurological complication following CABG is one of the most feared surgical complications, and frequency of postoperative stroke among patients undergoing CABG has been shown to range between 0.5 and 7% [7, 8]. It is well reported that carotid artery occlusive disease is an independent predictor of perioperative stroke in patients undergoing CABG [9–11].

✉ Peter H. Lin
plin@bcm.edu

1 Division of Vascular Surgery and Endovascular Therapy, Michael E. DeBakey Department of Surgery, Baylor College of Medicine, One Baylor Plaza, Houston, TX 77054, USA

2 University Vascular Associates, Los Angeles, CA, USA

Published online: 07 August 2017

Although numerous studies have convincingly demonstrated the efficacy and safety of preventive CEA for reducing the risk of stroke before CABG [10, 12–15], controversy exists regarding the benefit of prophylactic CEA in patients with asymptomatic carotid stenosis. Several researchers have suggested that CEA for asymptomatic carotid disease does not necessarily reduce the risk of stroke in patients undergoing CABG [16–21]. These conflicting perspectives may have been the result of heterogeneity of the patient population and their disease patterns, particularly related to factors including the severity of carotid stenosis and operative variables associated with coronary revascularizations.

Due in part to the complex factors contributing to the neurological complication, the management of carotid arterial stenosis in patients who undergo CABG remains has been a subject of debate. Commonly utilized treatment strategies have included simultaneous CEA-CABG, staged CEA followed by CABG, and staged CABG followed by CEA. Recent studies have highlighted the role of carotid artery stenting (CAS) before CABG and the use of off-pump CABG as a means to reduce perioperative ischemic stroke [22–25]. Despite theoretical benefits of each therapeutic approach, there remain no uniformly accepted treatment guidelines among physicians or surgeons who provide care to these patient cohorts.

The purpose of this article is to review various treatment strategies in patients who undergo CEA and CABG. Advances in endovascular treatment for carotid artery disease as well as surgical techniques with off-pump CABG have similarly increased the therapeutic armamentarium for these patients who require CEA and CABG. Rationales for these various treatment strategies as well as current literature to support their clinical applications are discussed. A proposed treatment algorithm encompassing these various treatment strategies is also provided.

Published treatment guidelines on CEA and CABG

Although current studies are inundated with studies with conflicting outcomes using various treatment strategies for patients requiring CEA and CABG, the American Heart Association (AHA) issued guidelines regarding the appropriateness of combined or synchronous CABG and CEA in 1998 [26]. Specifically, this treatment guideline addressed CABG patients with asymptomatic occlusive carotid disease. It is noteworthy that this guideline reflected a consensus view of experts who advocated that synchronous CEA and CABG is “acceptable but not proven” in patients with unilateral asymptomatic carotid lesions greater than 60% luminal stenosis where there is a proven operative stroke and death risk of less than 3%. For institutions where the operative stroke and death risk rates are greater than 3%, on the other hand, the clinical benefits and treatment efficacy of synchronous CEA and CABG were described as “uncertain” according to the AHA guidelines [3, 26].

The published guidelines by the AHA, however, did not fully resolve the controversy regarding the ideal treatment strategy for patients with high-grade carotid artery disease who require coronary revascularization. Debates continued regarding how to screen and identify patients with carotid occlusive disease before undergoing coronary revascularization. The American College of Cardiology (ACC) and American Heart Association (AHA) issued guidelines for CABG in 2004, which recommended a screening carotid ultrasound for those older than 65 years, individuals with left main coronary stenosis, peripheral vascular disease, or those with history of smoking, transient ischemic attack, stroke, or for the presence of carotid bruit on examination [27]. This carotid screening guideline would detect severe carotid stenosis (greater than 80%) in approximately 95% of patients undergoing CABG [27, 28]. In spite of the publication of this screening guideline, controversy abounds as authors conceded that these recommendations are based on a few observational studies and expert consensus, rather than any randomized studies. Many questioned the cost-effectiveness of screening carotid ultrasound in CABG patients for stroke prevention. Furthermore, the benefit of carotid screening in perioperative stroke or mortality reduction in the CABG population has not been proven in a large-scale clinical study [29, 30].

Prevalence and etiology of neurological complications following cardiac surgery

Ischemic stroke is by far one of the most feared complications following any surgical procedure, particularly cardiac operations. Neurological complications following CABG is associated with a mortality of 24.8% and mean hospital stay of 28 days for stroke survivors [10, 31, 32]. Studies have identified multiple risk factors for stroke in patients undergoing CABG, which include age, preoperative neurological symptoms, aortic arch disease, carotid bruit, diabetes, and degree of carotid stenosis. These widely ranged risk factors underscore the complex multifactorial etiologies which contribute to post-CABG neurological complications.

It is noteworthy that the incidence of neurological complications varies depending on the type of cardiac interventions. It is estimated that stroke occurs in 0.3–5.2% of patients undergoing cardiac surgery [33], 1.3% after cardiac catheterization [34, 35], 0.3% following percutaneous transluminal coronary angioplasty [36], 1.4–11.0% following percutaneous transluminal aortic valvuloplasty

[35], 3.2–4.2% after percutaneous mitral valvuloplasty [37, 38], and 9.0% after cardiac transplantation [39]. Specifically among patients who are older than 75 years of age, the risk of stroke can reach as high as 9% following CABG and 16% following valve replacement [40, 41]. In a prospective multicenter trial, Wolman and colleagues reported that ischemic stroke occurred in one out of every six patients who underwent coronary revascularization combined with intracardiac operation [42].

Utilizing a prospective database on 16,184 consecutive patients undergoing cardiac surgery, Bucerius and associates reported an overall incidence of stroke was 4.6% but varied depending on the surgical procedures [42]. Specifically, the incidence of stroke was 3.8% following CABG, 1.9% following beating heart CABG, 4.8% following aortic valve surgery, 8.8% following mitral valve surgery, 9.7% following double or triple valve surgery, and 7.4% following CABG and valve surgery. Other researchers conducted prospective studies of consecutive patients undergoing CABG and reported that the risk of major ischemic stroke ranged between 1 and 6% [43–45]. Using multivariate analysis, these authors have identified multiple factors, which were associated with an increased risk of stroke in patients undergoing cardiac surgery [14, 15, 46, 47]. These factors include age older than 60 years, greater than 50% carotid stenosis, prior stroke or transient ischemic attack, history of congestive heart failure, valvular disease, repeat heart surgery, postoperative atrial fibrillation, bypass time of more than 2 h, and prior myocardial infarction [15, 46–48].

Regarding possible pathogenic mechanisms of stroke during cardiac surgery, researchers have postulated various causes [46–49]. These mechanisms include cerebral flow compromise due to intraoperative hypotension with concomitant carotid artery occlusive disease, atheromatous emboli during aortic manipulation either during aortic cannulation or during application of the aortic side biting clamps for performing the aortocoronary saphenous vein graft anastomosis, air emboli, hemodynamic instability during cardiopulmonary bypass or inadequate intracerebral cross-perfusion. Despite the heterogeneity of these pathogenic mechanisms, many researchers believed that the stroke risk during CABG is related to the degree of carotid stenosis. In a meta-analysis, Naylor and associates reported that patients with no significant carotid disease had a 1.9% risk of stroke following CABG [50]. The risk of stroke increased to 3% in neurologically asymptomatic patients with unilateral 50–99% carotid stenosis, 5% in those with bilateral 50–99% carotid stenoses, and 7–11% in patients with carotid occlusion [50]. Although these authors suggested an association between significant carotid disease and post-CABG stroke, their study did not provide information regarding the laterality of cerebral ischemic events in relation to carotid stenosis. In patients who underwent CABG including left main stem coronary artery revascularization, the incidence of carotid artery disease and postoperative cerebrovascular complications was higher [51].

Contrary to these findings, other authors have proposed different mechanisms for post-CABG neurological complications, which were not related to the severity of carotid disease [49, 52]. Analyzing their institutional data of 1179 patients regarding post-CABG neurological events, Ricotta and associates reported a discrepancy between stroke distribution and site of carotid stenosis [49]. Additionally, most strokes occurred later than 24 h following CABG operation, suggesting that other potential causes such as atrial fibrillation or postoperative hypotension may have played a crucial role in post-CABG stroke [49]. Other researchers have found that proximal aortic calcification to be a predictor for post-CABG ischemic stroke irrespective of carotid disease, due in part to plaque embolization during aortic manipulation [52–54]. Additionally, radiological findings including aortic atheroma protrusion based on computed tomography (CT) scan or mobile aortic atheroma as detected by transesophageal echocardiography have also been shown to be associated with a 14% incidence of perioperative stroke [55, 56]. Lastly, Schoof and colleagues reported that, in patients with severe carotid stenosis or occlusion, the presence of an impaired cerebral autoregulatory reserve may contribute to increased stroke risk during cardiac surgery [57]. While these available data do not uniformly underscore a single pathogenic mechanism for post-CABG neurological complications, multiple randomized trials analyzing the efficacy of CEA have demonstrated that removing carotid plaque burden by CEA in patients with hemodynamically significant carotid disease will reduce the risk of ischemic stroke, including those who require coronary revascularization [58–60].

Potential treatment strategies for CEA and CABG

Various treatment strategies have been proposed to decrease the risk of post-CABG neurological complications in patients who require both carotid and coronary revascularization. Considering that carotid artery stenting has become an accepted treatment option for endovascular revascularization, this represents a potential treatment strategy for these patient cohorts. Consequently, available treatment strategies include the following options:

1. Combined or synchronous CABG and CEA during the same anesthetic setting,
2. Staged CEA first, followed by CABG,
3. Staged CABG first, followed by CEA,
4. Staged CAS first, followed by CABG,
5. CEA with off-pump CABG.

Despite multiple studies demonstrating the feasibility and safety of each of these treatment modalities, controversy exists as to which strategy can optimally reduce the risk of neurological adverse events following coronary revascularization. There are no randomized prospective studies with level 1 evidence to support the ideal treatment strategy. Although the consensus statement released by the American Heart Association acknowledged increased perioperative complications with synchronous carotid and coronary revascularization, it did not provide any recommendation for alternative management strategy for this subgroup of patients [27, 28]. Ongoing debates continue regarding the optimal timing and sequence of staged operations, particularly for those who require urgent reconstructions for either symptomatic carotid or coronary lesions during the same hospitalization.

Rationale for synchronous CEA and CABG

The combined or synchronous approach, first reported by Bernhard and colleagues in 1972, involves performing CEA, which was immediately followed by CABG under the same anesthesia [61]. Clinical studies have shown that advantages of the synchronous approach include: (a) decreased incidence of stroke and operative mortality for patients with symptomatic coronary and carotid artery diseases [23, 62], (b) decreased hospital cost and surgical procedural cost [23, 62], (c) shorter hospital length of stay [63], (d) acceptable operative morbidity and mortality [64], and (e) lower stroke risk on long-term follow-up [65, 66].

The synchronous approach is generally reserved for patients with severe symptoms involving both carotid and coronary vascular territories, such as those with severe stenosis (>90% luminal stenosis) or bilateral carotid occlusion. Van Der Grond and colleagues postulated that these patient cohorts are most likely to have impaired cerebral autoregulation due to chronic cerebral ischemia [67]. The authors suggested that when the cerebral autoregulation is impaired, the synchronous treatment with CEA and CABG should be considered as this subset of patients with cerebral hypoperfusion and ischemic metabolic changes distal to severe carotid stenosis are probably at high risk of stroke during CABG. This hypothesis, however, has not been validated by any clinical study.

Rationale for staged CEA and CABG

Numerous studies have found that combined or synchronous treatment of CEA and CABG resulted in higher stroke and death rates, due in part to several reasons [68, 69]. One factor is that synchronous CEA and CABG procedures are more technically challenging, from both a surgical and an anesthesia stand point, thereby resulting in greater perioperative complications. Another factor may be that combined operations result in excessive physiological and cardiovascular stress, resulting in greater hemodynamic fluctuations or instability during relatively long operative procedures. This notion was supported by a systemic review of 94 clinical studies, which noted that synchronous treatment carried a relative high morbidity and mortality rates with death or major stroke rate of 11.5% [20].

Many researchers favored the staged approach with CEA prior to CABG, due to perceived advantage of reduced operative time and minimize surgical complexity of two surgical procedures [4, 70, 71]. This approach is generally reserved for patients with stable coronary symptoms who can undergo the initial CEA procedure followed by a variable time interval of recovery before undergoing coronary revascularization.

Role of carotid artery stenting in patients undergoing CABG

Percutaneous stenting of carotid artery stenosis has emerged as an attractive treatment option compared to CEA. The clinical efficacy of CAS has been proven in several randomized trials to be equivalent to CEA [72–75]. Many have proposed that staged CAS followed by CABG may represent an acceptable treatment option to either staged or synchronous CEA and CABG. The theoretical advantages of CAS are related to the minimally invasiveness and avoidance of general anesthesia, which may reduce cardiac complications [76].

With regard to incorporating CAS treatment in patients who require CABG, there are three potential treatment strategies which include: (1) CAS followed by CABG several days or weeks later (staged procedures with separate anesthesia approach; (2) CAS under local anesthesia followed by CABG on the same day (same-day procedures with two anesthesia approaches); and (3) CAS followed by CABG in the same operating room under general anesthesia (same-day procedures under general anesthesia approach). Most published results utilized the staged approach in which CABG was performed several weeks following the initial CAS, as this staged approach allows for safe withholding of the anti-platelet agent prior to CABG. Patients underwent the same-day CAS and CAS requiring immediate anti-platelet regimens as soon as CABG is completed. Because an endovascular operating room is needed to allow CAS and CABG to be performed synchronously under the same anesthesia, only limited clinical series are available for such a treatment strategy [77–79].

Since there are no randomized trials comparing CAS to CEA for patients who require coronary revascularization, there are several observational studies which compared staged CAS plus CABG with a CEA plus CABG strategy [77, 80]. Van der Heyden and associates analyzed 356 patients who underwent CAS followed by CABG, with a mean interval of 22 days. All patients were neurologically asymptomatic, and an embolization protection device was used in only 40% of patients. At 30 days post-CABG, the stroke and death rate were 4.8%, myocardial infarction (MI) was 2% and the combined stroke, MI and death rate were 6.7% [80]. Long-term durability and a high rate of freedom from death and stroke were noted during the 5-year follow-up [80]. Another study similarly reported low peri-procedural complication rates in staged CAS followed by CABG [77]. Due to the favorable outcomes with percutaneous carotid stenting prior to CABG, these authors advocated CAS as a preferred treatment strategy compared to CEA prior to coronary revascularization [77, 80].

In a clinical study encompassing a 5-year institutional experience which compared CAS followed by open heart surgery (OHS) to combined CEA–OHS, Ziada and associates reported fewer strokes or MI at 30 days with the CAS–OHS approach (5 vs 19%, $p = 0.02$) despite the use of embolization protection device in only 14% of the patients [25]. The favorable outcome with CAS was further underscored by the fact that patients who underwent CAS had a higher risk profile with more unstable or severe angina (52 vs 27%, $p = 0.002$) and had a higher prevalence of symptomatic carotid disease (46 vs 23% $p = 0.002$) [25]. A recent meta-analysis of 11 published studies on CAS followed by CABG procedures reported similar 30-day risks of any stroke (4.2%), MI (1.8%) and combined stroke, MI and death (9.4%) when compared to the results from CEA–CABG strategies [19]. While these data showed comparable CAS–CABG outcomes compared to CEA–CABG cohorts, the author cautioned that the majority of patients who received CAS were largely asymptomatic neurologically (87%) and had unilateral carotid artery stenosis (82%) [19].

Utilizing the National Inpatient Sample database, Timaran and colleagues examined nationwide trends and outcomes of 27,084 procedures which comprised of combined CEA–CABG (96.7%) and CAS–CABG (3.3%) procedures [76]. The risk of postoperative stroke was significantly higher in the CEA–CABG group (3.9%) compared to the CAS–CABG group (2.4%), although no difference in the risk of combined stroke and death or in-hospital death was noted (5.2 vs 5.4%) [76]. The authors concluded that CAS might provide a safer carotid revascularization option for patients who require CABG [76]. Although CAS unquestionably has gained popularity due to its minimally invasiveness and perceived less anesthetic risks compared to traditional CEA, a consensus guideline published by the European Society for Vascular Surgery in 2009 underscored an important principle of this treatment modality, in which it recommended that CAS for carotid stenosis should only be performed for high-risk patients in high-volume institutions with proven low procedural complication rates [81].

Role of off-pump CABG in patients with carotid artery disease

Clinical evidence has suggested that the most important single cause of post-CABG stroke is thrombotic embolization from the aortic arch debris [82]. As the result, many physicians have refined surgical strategies and operative techniques to reduce the risk of embolization during aortic dissection, cannulation, and aortic cross-clamping. In a review article which analyzed 12 studies encompassing 324 synchronous CEA plus off-pump CABG procedures, these patient cohorts had better outcomes of stroke, MI or death (3.6%) compared to those who were treated with either combined or staged CEA and on-pump CABG. The operative mortality for synchronous CEA plus off-pump CABG was only 1.5%, and the risk of death or any stroke significantly reduced at 2.2% [83]. In a study which reported 38 patients who underwent synchronous CEA and off-pump CABG, the authors reported remarkable outcome with no postoperative neurological complications and an in-hospital death rate of 3% [84]. The clinical efficacy of synchronous CEA and off-pump CABG was similarly underscored by Chen and associates who reported their experience in 51 patients, who did not suffer any postoperative neurological or cardiac complications [85]. With a mean follow-up of 39 months, the operative mortality was 1.96% [85]. Several factors may have accounted for the clinical outcome of these studies. Off-pump CABG has been shown to result in reduced incidence of stroke compared to on-pump CABG due to decreased risk of embolization from aortic manipulation. Additionally, the devoid of extracorporeal circulation in off-pump CABG potentially minimizes the likelihood of systemic hypotension and possibly averts cerebral hypoperfusion [86].

In the study by Mishra and associates, synchronous CEA plus either on-pump or off-pump CABG was performed in 358 patients, which included 166 patients who had off-pump CABG and 192 patients with on-pump coronary revascularization [23]. The authors reported no differences in mortality or stroke between the two CABG approaches, with mortalities of 1.2% in the off-pump group and 1.6% in the on-pump group. Postoperative stroke rates of the off-pump and on-pump patients were 0 and 0.5%, respectively. Although these results suggest no significant difference in outcomes with either on-pump or off-pump CABG, the observed mortality and neurological morbidity rates in this study were lower than the published literature [8]. Several recent studies that analyzed the effect of off-pump CABG versus on-pump CABG in patients undergoing synchronous CEA and coronary revascularization have similarly noted the reduced incidence of postoperative stroke rate in off-pump CABG patients compared to on-pump CABG cohorts [31, 83, 87].

Contemporary studies based on multi-institutional database

In an effort to answer the question of whether patients should undergo staged versus synchronous carotid and coronary revascularization, various authors reported several studies analyzing contemporary large database [8, 13, 18, 83, 87]. Analyzing the Nationwide Inpatient Sample database during a recent 10-year period ending in 2007, Gospaldas from our institution compared the outcome of 6153 patients who underwent staged CEA and CABG versus 16,639 patients who underwent synchronous or combined procedures [87]. Within the synchronous approach, off-pump was performed in 5280 patients (31.7%) while 2004 patients (32.5%) underwent off-pump CABG in the staged group. While both staged and synchronous groups shared similar age, perioperative mortality and neurological complication rates, higher perioperative morbidities were noted in staged patients when compared to synchronous cohort, which included greater cardiac, wound, respiratory, and renal complications. When analyzing hospital length of stay, staged approach was independently associated with a longer hospital stay by 3.1 days ($p < 0.001$). This study was unique as it also analyzed treatment cost. Cost analysis using inflation-adjusted hospital charges showed that staged and synchronous strategy incurred a mean cost of \$118,801 ± 78,644 and \$98,106 ± 80,053, respectively (<0.001). Further assessment using risk-adjusted models indicated that staged procedures were independently associated with a \$23,328 higher hospital charge [87]. While this analysis showed no difference in mortality or neurological complications between the two groups, the study revealed greater benefits in the synchronous approach due to lower risk of overall complications and reduced hospital charges compared to the staged approach. Additionally, on-pump CABG was associated with greater stroke rates compared to off-pump CABG in the synchronous patients, a finding which was consistent with several other studies [84, 86].

In a similar clinical report which analyzed a large sample database, Prasad and colleagues examined the Society of Thoracic Surgeons (STS) database which included 745,769 patients who underwent CABG during a recent 5-year period [13]. Among them, 5732 patients had synchronous CEA and CABG, while 24,167 patients had staged CEA followed by CABG. The authors also identified a cohort of 15,757 patients who underwent CABG and had ultrasound-proven >75% carotid stenosis, but without any carotid intervention. The study revealed that synchronous approach yielded a significantly higher hospital length of stay, operative mortality, and in-hospital complications including stroke compared to those who either received staged CEA plus CABG or no carotid intervention. The negative operative treatment outcome for synchronous approach from this study was in contrast to other published series [8, 22, 31, 85, 88, 89]. Recognizing the potential weaknesses of this database analysis which included retrospective observational assessment of a large sample size without long-term data variables, the authors underscored the importance of better patient selection when considering synchronous approach for carotid and coronary revascularizations [13].

Studies based on systemic literature reviews or meta-analysis

The ideal treatment strategy for patients with carotid and coronary occlusive disease has been a subject of detailed analysis by many researchers in past decades [13, 19, 20, 77, 89]. In one of the early meta-analysis of 56 studies which reviewed three operative strategies in patients with concomitant coronary and carotid artery diseases including: (a) simultaneous CEA and CABG, (b) CEA followed by CABG, and (c) CABG followed by CEA [59], the authors reported a 10% perioperative stroke rate in patients who underwent CABG first followed by CEA. The stroke rate for patients undergoing combined CEA and CABG was reduced to 6%. For patients treated with CEA followed by CABG, their stroke rate was reduced even further to 5%. However, CEA followed by CABG showed the highest rates for perioperative myocardial infarction (11%) and death (9%), whereas those who underwent simultaneous CEA and CABG and CABG followed by CEA showed lower rates for perioperative myocardial infarction (5 and 3%, respectively) and death (6 and 4%, respectively) [59]. The report of this meta-analysis which demonstrated a potential beneficial role for combined treatment strategy was in contrast to a meta-analysis reported by Borger and associates who analyzed 16 studies including a total of 844 patients treated with combined CABG and CEA and 920 patients treated with staged approach [90]. The authors found a significantly higher risk in the composite endpoint, stroke, or death for patients undergoing combined CABG and CEA operations. Specifically, the crude event rates for stroke were 6.0 versus 3.2% for combined versus staged procedure, 4.7 versus 2.9% for death, and 9.5 versus 5.7% for stroke and death [90]. This report underscored the potential higher risk of stroke or death rate in the combined treatment strategy for CABG and CEA procedures. This finding was consistent with several other reviews which revealed that staged CEA followed by coronary revascularization has lower stroke rates compared to those undergoing synchronous CEA and CABG [91].

Naylor and associates have performed several literature reviews as well as meta-analysis regarding patients undergoing carotid and coronary revascularization [19–21, 50]. In one of their reports encompassing 59 studies before the year 2000, the authors observed that 91% of screened CABG patients did not have significant carotid occlusive disease, and the stroke risk in these patient cohorts was less than 2% [50]. In patients undergoing CABG who had asymptomatic unilateral 50–99% carotid stenosis, the risk of stroke was increased to 3%. The risk of stroke for patients with bilateral 50–99% carotid disease or unilateral carotid artery occlusion was increased to 5% and 7–11%, respectively [50]. The authors also analyzed 10 studies for a total of 111 patients who suffered stroke after CABG. Among them, 48% of these patients did not have particularly significant disease in either carotid (<50% stenosis), 20% had 50–99% unilateral stenosis, 20% had 50–99% bilateral stenosis, 7% carotid occlusion with <50% contralateral stenosis, and 4% an occlusion with >50% contralateral stenosis and 1% bilateral occlusion [50]. These data, together with those from CT scans and autopsy findings, suggest that only 50% of strokes in CABG patients may be attributed to carotid artery disease. The authors highlighted the importance of understanding the condition of aortic calcification, the choice of site and aortic clamping technique, and to use the off-pump surgical method, with the purpose of reducing non-carotid-related neurological complications [50].

In their subsequent literature review of 97 articles encompassing 8972 patients undergoing either staged or synchronous carotid and coronary revascularizations, treatment outcomes following these two treatment modalities were analyzed [20]. Approximately 60% of patients undergoing either staged or synchronous procedures were neurologically asymptomatic, while 30–37% had bilateral 50–99% stenosis or contralateral carotid occlusion. The majority of patients in the synchronous treatment group (72%) were New York Heart Association grade 3 or 4, and 39% of these cohorts were classed as "urgent" while left main coronary artery disease was present in 25% of cases. The authors reported that synchronous approach had the highest operative mortality rate of 4.6%, while those treated with reversed staged approach (CABG followed by CEA) had the highest risk of ipsilateral stroke (5.8%) and stroke in general (6.3%) [20]. The risk of any operative stroke was lowest following staged approach (CEA followed by CABG, 2.7%). Myocardial infarction (MI) had the lowest perioperative risk in patients who underwent the reverse staged procedure (CABG followed by CEA, 0.9%) and the highest in those who underwent synchronous CEA and CABG treatment (6.5%). Death and any stroke were highest in patients undergoing synchronous CEA and CABG treatment (8.7%) and lowest following staged approach (CEA followed by CABG, 6.1%). The authors noted that, however, the benefit conferred by staging the operation was reduced when the risk of myocardial infarction was subsequently included in the analysis (synchronous = 11.5%, staged CEA–CABG = 10.2%). In a separate literature review by the same author group, it was demonstrated that recent CABG patients without significant carotid artery disease (<50% stenosis) had an operative stroke risk of approximately 1.8%. Unilateral (50–99%) and bilateral (50–99%) stenosis resulted in a 3.2 and 5.2% stroke risk, respectively [20]. Taken these results together, the authors concluded that there were no statistically significant differences between staged or synchronous strategies [20]. Additionally, these reviews suggest that carotid stenosis, by itself, may be a marker for other conditions, such as atherosclerotic disease of the aorta, which also may contribute to stroke risk during CABG surgery.

A multistate population-based study was reported by Brown and colleagues who assessed both the community-wide outcomes of combined CEA and CABG and the risk of adverse events. In their study, 10,561 CEAs were randomly selected using the Medicare database, of which 226 procedures were performed in combination with CABG in the same operative event. Only 12% of patients undergoing combined CEA and CABG had recent ipsilateral stroke or TIA, while 56% had had an asymptomatic carotid stenosis. The combined stroke and death rate was 17.7%. Proximal aortic arch atherosclerosis and symptomatic carotid stenosis were associated with perioperative neurological events. The authors identified several risk factors for higher mortality which included female sex, emergent CABG procedure, redo CABG operation, prolonged total pump time during CABG, presence of left main disease, and number of diseased coronary arteries. The study showed that strokes appeared to be associated with operative events. However, the patency of the carotid artery following stroke was not routinely assessed, and most strokes did not occur in the ipsilateral hemisphere of the CEA [9]. In an article by Das and colleagues who analyzed various strategies for the treatment of concomitant coronary artery disease and asymptomatic carotid artery stenosis as defined by greater than 50% luminal stenosis, the authors assessed four possible treatment strategies: (1) CABG in the presence of carotid stenosis, (2) synchronous CEA and CABG, (3) reverse (CABG followed by CEA in less than 3 months), and (4) prior staged (CEA followed by CABG in less than 3 months) [92]. The authors reported a significant reduction in stroke for prior versus combined procedures (1.5 vs 3.9%). The stroke rate in the prior stage also remained significantly lower compared with the other two groups, but when total risks of stroke and death were analyzed, similar results were found among the groups: prior 7.4%, reverse stage 7.2%, combined 8.4 and 11.5% in CABG in the presence of carotid stenosis.

Based on these literature reviews and meta-analysis, the vast majority of CABG patients with asymptomatic unilateral carotid stenosis can safely undergo coronary revascularization without any prophylactic carotid intervention. Undoubtedly, more data are needed to better identify patients with asymptomatic unilateral carotid stenosis who will benefit from prophylactic carotid intervention.

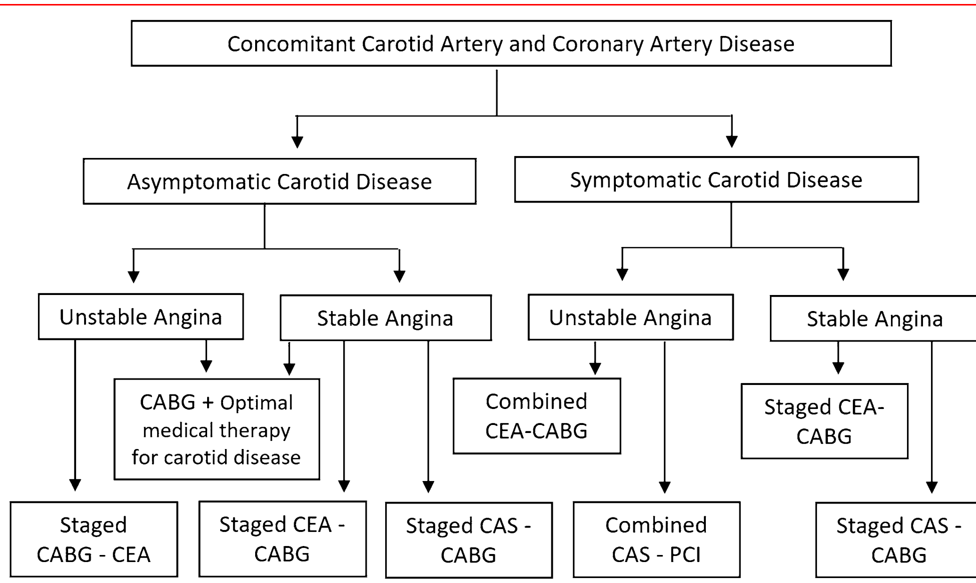
Proposed treatment paradigm in patients with carotid and coronary artery disease

Considering available data from published reports, the treatment indication for carotid artery stenosis in patients who require coronary revascularization must weigh in the status of neurological symptoms. While further clinical evidence is needed to support the ideal treatment approach for patients with coronary and carotid disease, we provide the following recommendations based on published literature:

- In patients with unilateral asymptomatic internal carotid artery disease (>60%) who require CABG, combined CABG and CEA is an acceptable but unproven treatment strategy. Patient life expectancy of at least 5 years or greater and perioperative stroke and death risk of less than 3% are needed to justify the combined treatment approach.
- In patients with bilateral internal carotid artery stenosis (>60%) who require coronary revascularization, combined CEA (on the side of the more severe stenosis) and CABG is an acceptable but unproven treatment modality. Greater than 5 years of life expectancy and less than 3% of perioperative stroke and death risk are needed to justify the combined procedures.
- In patients with internal carotid artery stenosis (>60%) and contralateral carotid occlusion who require CABG, there are no available data to support prophylactic CEA or CAS prior to coronary revascularization.
- In patients with symptomatic internal carotid artery stenosis (>60%) who require coronary revascularization for stable coronary disease, CAS is an acceptable but unproven treatment option. Procedural-related stroke rate of less than 3% is needed to justify this treatment strategy.

Figure 1 outlines the various treatment strategies for patients with coronary and carotid disease for consideration of either staged or combined interventions. For those patients with symptomatic carotid artery stenosis who require CABG, a staged treatment approach of CEA

Fig. 1 Potential treatment strategies for patients with concomitant coronary artery disease and carotid artery disease



followed by CABG may be considered in the setting of stable angina, while a combined strategy of CEA and CABG should be reserved for those with acute coronary syndrome. For patients with asymptomatic unilateral carotid stenosis who requires coronary revascularization for stable coronary disease, various carotid treatment strategies including medical therapy alone or CAS can also be considered. For patients with acute coronary syndrome or unstable coronary disease, immediate coronary revascularization with either subsequent staged carotid intervention or combined carotid intervention should be offered. Given the increased availability of endovascular hybrid operating suite in many institutions, synchronous treatment strategies for coronary and carotid revascularization can be expanded to CAS or CEA treatment in conjunction with CABG or percutaneous coronary intervention (PCI) [93].

Conclusions

The ideal treatment strategy for severe carotid and coronary artery disease remains elusive based on current published data. The majority of patients who require coronary and carotid interventions have unilateral carotid disease who are asymptomatic neurologically. It remains a subject of debate whether prophylactic carotid interventions can definitively benefit the survival rate. Ongoing controversy also exists regarding the optimal timing of carotid revascularization in patients with concomitant coronary and carotid disease. Recent advances in endovascular technologies have supported the utility of carotid stenting as an acceptable treatment strategy for carotid revascularization. This percutaneous carotid intervention has become a latest armamentarium for physicians in treating patients who require coronary and carotid revascularization. The role of optimal medical therapy with risk factor modification must also be considered when treating patients with coronary and carotid occlusive disease. Given these multitudes of therapeutic considerations, a randomized clinical trial is undoubtedly needed to address the optimal treatment modality for patients with these concomitant diseases.

References

1. Lloyd-Jones D, Adams R, Carnethon M et al (2009) Heart disease and stroke statistics—2009 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Circulation 119:e21–e181
2. Roger VL, Go AS, Lloyd-Jones DM et al (2011) Heart disease and stroke statistics—2011 update: a report from the American Heart Association. Circulation 123:e18–e209
3. Brown KR (2003) Treatment of concomitant carotid and coronary artery disease. Decision-making regarding surgical options. J Cardiovasc Surg (Torino) 44:395–399
4. Hertzer NR, Loop FD, Taylor PC, Beven EG (1978) Staged and combined surgical approach to simultaneous carotid and coronary vascular disease. Surgery 84:803–811
5. Hertzer NR, Mascha EJ (2006) A personal experience with coronary artery bypass grafting, carotid patching, and other factors influencing the outcome of carotid endarterectomy. J Vasc Surg 43:959–968
6. Salasidis GC, Latter DA, Steinmetz OK, Blair JF, Graham AM (1995) Carotid artery duplex scanning in preoperative assessment for coronary artery revascularization: the association between peripheral vascular disease, carotid artery stenosis, and stroke. J Vasc Surg 21:154–160 **(discussion 61-2)**
7. Fukuda I, Gomi S, Watanabe K, Seita J (2000) Carotid and aortic screening for coronary artery bypass grafting. Ann Thorac Surg 70:2034–2039
8. Kougias P, Kappa JR, Sewell DH et al (2007) Simultaneous carotid endarterectomy and coronary artery bypass grafting: results in specific patient groups. Ann Vasc Surg 21:408–414
9. Brown KR, Kresowik TF, Chin MH et al (2003) Multistate population-based outcomes of combined carotid endarterectomy and coronary artery bypass. J Vasc Surg 37:32–39
10. Cambria RP, Ivarsson BL, Akins CW et al (1989) Simultaneous carotid and coronary disease: safety of the combined approach. J Vasc Surg 9:56–64
11. Rosamond W, Flegal K, Furie K et al (2008) Heart disease and stroke statistics—2008 update: a report from the American Heart Association Statistics Committee and Stroke Statistics Subcommittee. Circulation 117:e25–e146
12. Ozatik MA, Gol MK, Fansa I et al (2005) Risk factors for stroke following coronary artery bypass operations. J Card Surg 20:52–57
13. Prasad SM, Li S, Rankin JS et al (2010) Current outcomes of simultaneous carotid endarterectomy and coronary artery bypass graft surgery in North America. World J Surg 34:2292–2298. doi:10.1007/s00268-010-0506-4
14. Ricotta JJ, Wall LP (2003) Treatment of patients with combined coronary and carotid atherosclerosis. J Cardiovasc Surg (Torino) 44:363–369
15. Ricotta JJ, Wall LP, Blackstone E (2005) The influence of concurrent carotid endarterectomy on coronary bypass: a case-controlled study. J Vasc Surg 41:397–401 **(discussion-2)**
16. Baiou D, Karageorge A, Spyt T, Naylor AR (2009) Patients undergoing cardiac surgery with asymptomatic unilateral carotid stenoses have a low risk of peri-operative stroke. Eur J Vasc Endovasc Surg 38:556–559
17. Ghosh J, Murray D, Khwaja N, Murphy MO, Walker MG (2005) The influence of asymptomatic significant carotid disease on mortality and morbidity in patients undergoing coronary artery bypass surgery. Eur J Vasc Endovasc Surg 29:88–90
18. Li Y, Walicki D, Mathiesen C et al (2009) Strokes after cardiac surgery and relationship to carotid stenosis. Arch Neurol 66:1091–1096
19. Naylor AR (2009) Does the risk of post-CABG stroke merit staged or synchronous reconstruction in patients with symptomatic or asymptomatic carotid disease? J Cardiovasc Surg (Torino) 50:71–81
20. Naylor AR, Cuffe RL, Rothwell PM, Bell PR (2003) A systematic review of outcomes following staged and synchronous carotid endarterectomy and coronary artery bypass. Eur J Vasc Endovasc Surg 25:380–389
21. Naylor R, Cuffe RL, Rothwell PM, Loftus IM, Bell PR (2003) A systematic review of outcome following synchronous carotid endarterectomy and coronary artery bypass: influence of surgical and patient variables. Eur J Vasc Endovasc Surg 26:230–241
22. Chiappini B, Dell' Amore A, Di Marco L, Di Bartolomeo R, Marinelli G (2005) Simultaneous carotid and coronary arteries

disease: staged or combined surgical approach? J Card Surg 20:234–240
23. Mishra Y, Wasir H, Kohli V et al (2004) Concomitant carotid endarterectomy and coronary bypass surgery: outcome of on-pump and off-pump techniques. Ann Thorac Surg 78:2037–2042 **(discussion 42-3)**
24. Trehan N, Mishra M, Kasliwal RR, Mishra A (2000) Surgical strategies in patients at high risk for stroke undergoing coronary artery bypass grafting. Ann Thorac Surg 70:1037–1045
25. Ziada KM, Yadav JS, Mukherjee D et al (2005) Comparison of results of carotid stenting followed by open heart surgery versus combined carotid endarterectomy and open heart surgery (coronary bypass with or without another procedure). Am J Cardiol 96:519–523
26. Biller J, Feinberg WM, Castaldo JE et al (1998) Guidelines for carotid endarterectomy: a statement for healthcare professionals from a Special Writing Group of the Stroke Council American Heart Association. Circulation 97:501–509
27. Eagle KA, Guyton RA, Davidoff R et al (2004) ACC/AHA 2004 guideline update for coronary artery bypass graft surgery: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (committee to update the 1999 guidelines for coronary artery bypass graft surgery). Circulation 110:e340–e437
28. Eagle KA, Guyton RA, Davidoff R et al (1999) ACC/AHA guidelines for coronary artery bypass graft surgery: executive summary and recommendations: a report of the American College of Cardiology/American Heart Association Task Force on Practice Guidelines (committee to revise the 1991 guidelines for coronary artery bypass graft surgery). Circulation 100:1464–1480
29. Berens ES, Kouchoukos NT, Murphy SF, Wareing TH (1992) Preoperative carotid artery screening in elderly patients undergoing cardiac surgery. J Vasc Surg 15:313–321 **(discussion 22-3)**
30. Brener BJ, Brief DK, Alpert J et al (1984) A four-year experience with preoperative noninvasive carotid evaluation of two thousand twenty-six patients undergoing cardiac surgery. J Vasc Surg 1:326–338
31. Chiti E, Troisi N, Marek J et al (2010) Combined carotid and cardiac surgery: improving the results. Ann Vasc Surg 24:794–800
32. Bucerius J, Gummert JF, Borger MA et al (2003) Stroke after cardiac surgery: a risk factor analysis of 16,184 consecutive adult patients. Ann Thorac Surg 75:472–478
33. Sila CA (1991) Neuroimaging of cerebral infarction associated with coronary revascularization. AJNR Am J Neuroradiol 12:817–818
34. Davidson CJ, Mark DB, Pieper KS et al (1990) Thrombotic and cardiovascular complications related to nonionic contrast media during cardiac catheterization: analysis of 8,517 patients. Am J Cardiol 65:1481–1484
35. Davidson CJ, Skelton TN, Kisslo KB et al (1988) The risk for systemic embolization associated with percutaneous balloon valvuloplasty in adults. A prospective comprehensive evaluation. Ann Intern Med 108:557–560
36. Galbreath C, Salgado ED, Furlan AJ, Hollman J (1986) Central nervous system complications of percutaneous transluminal coronary angioplasty. Stroke 17:616–619
37. Holmes DR Jr, Nishimura RA, Reeder GS, Wagner PJ, Ilstrup DM (1989) Clinical follow-up after percutaneous aortic balloon valvuloplasty. Arch Intern Med 149:1405–1409
38. Nishimura RA, Holmes DR Jr, Reeder GS (1990) Percutaneous balloon valvuloplasty. Mayo Clin Proc 65:198–220
39. Hotson JR, Enzmann DR (1988) Neurologic complications of cardiac transplantation. Neurol Clin 6:349–365
40. Craver JM, Weintraub WS, Jones EL, Guyton RA, Hatcher CR Jr (1988) Predictors of mortality, complications, and length of stay in aortic valve replacement for aortic stenosis. Circulation 78:I85–I90
41. Wareing TH, Davila-Roman VG, Daily BB et al (1993) Strategy for the reduction of stroke incidence in cardiac surgical patients. Ann Thorac Surg 55:1400–1407 **discussion 7-8**
42. Wolman RL, Nussmeier NA, Aggarwal A et al (1999) Cerebral injury after cardiac surgery: identification of a group at extraordinary risk. Multicenter Study of Perioperative Ischemia Research Group (McSPI) and the Ischemia Research Education Foundation (IREF) Investigators. Stroke 30:514–522
43. Breuer AC, Furlan AJ, Hanson MR et al (1983) Central nervous system complications of coronary artery bypass graft surgery: prospective analysis of 421 patients. Stroke 14:682–687
44. Coffey CE, Massey EW, Roberts KB et al (1983) Natural history of cerebral complications of coronary artery bypass graft surgery. Neurology 33:1416–1421
45. Shaw PJ, Bates D, Cartlidge NE et al (1985) Early neurological complications of coronary artery bypass surgery. Br Med J (Clin Res Ed) 291:1384–1387
46. Libman RB, Wirkowski E, Neystat M et al (1997) Stroke associated with cardiac surgery. Determinants, timing, and stroke subtypes. Arch Neurol 54:83–87
47. Reed GL 3rd, Singer DE, Picard EH, DeSanctis RW (1988) Stroke following coronary-artery bypass surgery. A case-control estimate of the risk from carotid bruits. N Engl J Med 319:1246–1250
48. Barbut D, Caplan LR (1997) Brain complications of cardiac surgery. Curr Probl Cardiol 22:449–480
49. Ricotta JJ, Faggioli GL, Castilone A, Hassett JM (1995) Risk factors for stroke after cardiac surgery: Buffalo Cardiac-Cerebral Study Group. J Vasc Surg 21:359–363 **(discussion 64)**
50. Naylor AR, Mehta Z, Rothwell PM, Bell PR (2002) Carotid artery disease and stroke during coronary artery bypass: a critical review of the literature. Eur J Vasc Endovasc Surg 23:283–294
51. Vigneswaran WT, Sapsford RN, Stanbridge RD (1993) Disease of the left main coronary artery: early surgical results and their association with carotid artery stenosis. Br Heart J 70:342–345
52. Roach GW, Kanchuger M, Mangano CM et al (1996) Adverse cerebral outcomes after coronary bypass surgery. Multicenter Study of Perioperative Ischemia Research Group and the Ischemia Research and Education Foundation Investigators. N Engl J Med 335:1857–1863
53. Blauth CI (1995) Macroemboli and microemboli during cardiopulmonary bypass. Ann Thorac Surg 59:1300–1303
54. Blauth CI, Cosgrove DM, Webb BW et al (1992) Atheroembolism from the ascending aorta. An emerging problem in cardiac surgery. J Thorac Cardiovasc Surg 103:1104–1111 **(discussion 11-2)**
55. Katz ES, Tunick PA, Rusinek H et al (1992) Protruding aortic atheromas predict stroke in elderly patients undergoing cardiopulmonary bypass: experience with intraoperative transesophageal echocardiography. J Am Coll Cardiol 20:70–77
56. Taggart DP, Westaby S (2001) Neurological and cognitive disorders after coronary artery bypass grafting. Curr Opin Cardiol 16:271–276
57. Schoof J, Lubahn W, Baeumer M et al (2007) Impaired cerebral autoregulation distal to carotid stenosis/occlusion is associated with increased risk of stroke at cardiac surgery with cardiopulmonary bypass. J Thorac Cardiovasc Surg 134:690–696
58. Moore WS (2003) Resolved: NASCET and ACAS need not be repeated: the affirmative position. Arch Neurol 60:775–778
59. Moore WS, Barnett HJ, Beebe HG et al (1995) Guidelines for carotid endarterectomy. A multidisciplinary consensus statement from the Ad Hoc Committee, American Heart Association. Circulation 91:566–579
60. Nicolaides AN, Kakkos SK, Griffin M et al (2005) Severity of asymptomatic carotid stenosis and risk of ipsilateral hemispheric

ischaemic events: results from the ACSRS study. Eur J Vasc Endovasc Surg 30:275–284
61. Bernhard VM, Johnson WD, Peterson JJ (1972) Carotid artery stenosis. Association with surgery for coronary artery disease. Arch Surg 105:837–840
62. Akins CW, Hilgenberg AD, Vlahakes GJ et al (2005) Late results of combined carotid and coronary surgery using actual versus actuarial methodology. Ann Thorac Surg 80:2091–2097
63. Kolh PH, Comte L, Tchana-Sato V et al (2006) Concurrent coronary and carotid artery surgery: factors influencing perioperative outcome and long-term results. Eur Heart J 27:49–56
64. Brow TD, Kakkar VV, Pepper JR, Das SK (1999) Toward a rational management of concomitant carotid and coronary artery disease. J Cardiovasc Surg (Torino) 40:837–844
65. Gaudino M, Glieca F, Alessandrini F et al (1999) Individualized surgical strategy for the reduction of stroke risk in patients undergoing coronary artery bypass grafting. Ann Thorac Surg 67:1246–1253
66. Plestis KA, Ke S, Jiang ZD, Howell JF (1999) Combined carotid endarterectomy and coronary artery bypass: immediate and long-term results. Ann Vasc Surg 13:84–92
67. van der Grond J, Balm R, Kappelle LJ, Eikelboom BC, Mali WP (1995) Cerebral metabolism of patients with stenosis or occlusion of the internal carotid artery. A 1H-MR spectroscopic imaging study. Stroke 26:822–828
68. Kaul TK, Fields BL, Riggins LS, Wyatt DA, Jones CR (2000) Coexistent coronary and cerebrovascular disease: results of simultaneous surgical management in specific patient groups. Cardiovasc Surg 8:355–365
69. Khaitan L, Sutter FP, Goldman SM et al (2000) Simultaneous carotid endarterectomy and coronary revascularization. Ann Thorac Surg 69:421–424
70. Carrel T, Stillhard G, Turina M (1992) Combined carotid and coronary artery surgery: early and late results. Cardiology 80:118–125
71. Hertzer NR, Loop FD, Beven EG, O'Hara PJ, Krajewski LP (1989) Surgical staging for simultaneous coronary and carotid disease: a study including prospective randomization. J Vasc Surg 9:455–463
72. Fiehler J, Jansen O, Berger J et al (2008) Differences in complication rates among the centres in the SPACE study. Neuroradiology 50:1049–1053
73. Knur R (2009) Carotid artery stenting: a systematic review of randomized clinical trials. Vasa 38:281–291
74. Lal BK, Brott TG (2009) The carotid revascularization endarterectomy vs. stenting trial completes randomization: lessons learned and anticipated results. J Vasc Surg 50:1224–1231
75. Mantese VA, Timaran CH, Chiu D, Begg RJ, Brott TG (2010) The carotid revascularization endarterectomy versus stenting trial (CREST): stenting versus carotid endarterectomy for carotid disease. Stroke 41:S31–S34
76. Timaran CH, Rosero EB, Smith ST et al (2008) Trends and outcomes of concurrent carotid revascularization and coronary bypass. J Vasc Surg 48:355–360 **(discussion 60-1)**
77. Mendiz O, Fava C, Valdivieso L et al (2006) Synchronous carotid stenting and cardiac surgery: an initial single-center experience. Catheter Cardiovasc Interv 68:424–428
78. Palombo G, Stella N, Faraglia V et al (2009) Safety and effectiveness of combining carotid artery stenting with cardiac surgery: preliminary results of a single-center experience. J Cardiovasc Surg (Torino) 50:49–54
79. Versaci F, Reimers B, Del Giudice C et al (2009) Simultaneous hybrid revascularization by carotid stenting and coronary artery bypass grafting: the SHARP study. JACC Cardiovasc Interv 2:393–401
80. Van der Heyden J, Suttorp MJ, Bal ET et al (2007) Staged carotid angioplasty and stenting followed by cardiac surgery in patients with severe asymptomatic carotid artery stenosis: early and long-term results. Circulation 116:2036–2042
81. Liapis CD, Bell PR, Mikhailidis D et al (2009) ESVS guidelines. Invasive treatment for carotid stenosis: indications, techniques. Eur J Vasc Endovasc Surg 37:1–19
82. Djaiani GN (2006) Aortic arch atheroma: stroke reduction in cardiac surgical patients. Semin Cardiothorac Vasc Anesth 10:143–157
83. Fareed KR, Rothwell PM, Mehta Z, Naylor AR (2009) Synchronous carotid endarterectomy and off-pump coronary bypass: an updated, systematic review of early outcomes. Eur J Vasc Endovasc Surg 37:375–378
84. Beauford RB, Saunders CR, Goldstein DJ (2003) Off pump concomitant coronary revascularization and carotid endarterectomy. J Cardiovasc Surg (Torino) 44:407–415
85. Chen XJ, Chen X, Xie DH, Shi KH, Xu M (2009) Preliminary results of combined carotid endarterectomy and off-pump coronary artery bypass grafting in patients with coexistent carotid and coronary artery diseases. Chin Med J (Engl) 122:2951–2955
86. van Dijk D, Spoor M, Hijman R et al (2007) Cognitive and cardiac outcomes 5 years after off-pump vs on-pump coronary artery bypass graft surgery. JAMA 297:701–708
87. Gopaldas RR, Chu D, Dao TK et al (2011) Staged versus synchronous carotid endarterectomy and coronary artery bypass grafting: analysis of 10-year nationwide outcomes. Ann Thorac Surg 91:1323–1329 **(discussion 9)**
88. Venkatachalam S, Gray BH, Mukherjee D, Shishehbor MH (2011) Contemporary management of concomitant carotid and coronary artery disease. Heart 97:175–180
89. Venkatachalam S, Shishehbor MH (2011) Management of carotid disease in patients undergoing coronary artery bypass surgery: is it time to change our approach? Curr Opin Cardiol 26:480–487
90. Borger MA, Fremes SE, Weisel RD et al (1999) Coronary bypass and carotid endarterectomy: does a combined approach increase risk? A metaanalysis. Ann Thorac Surg 68:14–20 **(discussion 1)**
91. Zacharias A, Schwann TA, Riordan CJ et al (2002) Operative and 5-year outcomes of combined carotid and coronary revascularization: review of a large contemporary experience. Ann Thorac Surg 73:491–497 **discussion 7-8**
92. Das SK, Brow TD, Pepper J (2000) Continuing controversy in the management of concomitant coronary and carotid disease: an overview. Int J Cardiol 74:47–65
93. Serruys PW, Morice MC, Kappetein AP et al (2009) Percutaneous coronary intervention versus coronary-artery bypass grafting for severe coronary artery disease. N Engl J Med 360:961–972