Efficiency in Carotid Revascularization Inventory and Instrumentation

Techniques and considerations for a patient-centered approach to carotid revascularization with CEA, TFCAS, and TCAR.

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Carotid revascularization is indicated for patients with internal carotid or carotid bifurcation occlusive disease to prevent stroke. Carotid endarterectomy (CEA) was first described in 1953 by Dr. Michael DeBakey and remains the primary treatment method for carotid occlusive disease. Carotid angioplasty was first described in the 1970s for the treatment of carotid atherosclerosis in patients with hostile neck anatomy or those at high medical risk. Since then, the latter technique has evolved to include carotid angioplasty and stenting under embolic protection via different approaches (transfemoral and transcarotid).

This article discusses considerations and tools for the three most commonly used carotid revascularization procedures: CEA, transfemoral carotid artery stenting (TFCAS), and transcarotid revascularization (TCAR).

PREOPERATIVE IMAGING

CTA

In patients with carotid stenosis, CTA of the arch and carotid arteries is used as the principal method to define the anatomy at the area of the carotid bifurcation while also providing information regarding common carotid artery (CCA) origin disease and disease distal to the carotid bifurcation and into the cranial vault. CTA also provides information regarding prior undiagnosed cerebral injury, which may provide insight into the risk that supposed asymptomatic plaque may portend. Additionally, CTA provides information regarding the anatomic location of the carotid bifurcation in relation to bony and soft tissue anatomy, providing insight into the challenge that surgically approaching a lesion may entail. Arch anatomy imaging provides information regarding access to the proximal CCA from a transfemoral approach; the length, depth, and course of the carotid artery will be displayed, which may impact direct carotid artery access for carotid stent placement via a transcarotid approach.

CTA is somewhat limited in the setting of severe calcification. Estimation of the degree of stenosis can be impacted by extensive calcification, but modern scanners allow mitigation of so-called blooming artifact and provide excellent correlation with degree of stenosis with subtraction angiography.[1] Because of the preintervention planning information it allows, CTA is almost always routinely performed in patients with reasonable renal function and known carotid stenosis.

MRA

MRA has proven useful in assessing for carotid stenosis; however, it requires increased time for acquisition and has resolution challenges that can often lead to overestimation of the degree of stenosis or a diagnosis of pseudo-occlusion of the carotid artery. MRA will provide information regarding the aortic arch anatomy, vessel tortuosity, anatomic location of the carotid bifurcation, area of stenosis, intracranial arterial disease, and possible “silent” cerebral infarction. MR evaluation of carotid disease can provide additional information regarding the plaque itself and presence of intraplaque hemorrhage, and it may allow characterization of plaque, providing perhaps some estimate of asymptomatic plaque risk. Although this imaging modality may prove useful in patients who cannot undergo CTA, it is not routinely used in assessing carotid disease and has not matched the accuracy of CTA in assessing the degree of stenosis and anatomy. Future increase in use of this technology will likely only occur if acquisition times are reduced and stenosis assessments improve.

Duplex Ultrasound

Duplex ultrasound (DUS) is a cost-effective, noninvasive tool to screen for carotid stenosis. It has relatively high sensitivity and specificity and is routinely used as an initial screening tool for carotid stenosis.[2] DUS can be challenging in patients with high lesions, extensive tortuosity, and significant calcification. Additionally, CTA or MRA provide better imaging and information in these cases. The question arises whether additional cross-sectional imaging is needed prior to revascularization in patients with high-quality diagnostic DUS. Given the current ease of performing additional axial imaging, it is likely beneficial to obtain the added information of CTA prior to planned revascularization of any method, even if the plan is to perform a CEA.[3] If stenting is being considered (whether TFCAS or TCAR), then cross-sectional imaging in addition to DUS is mandatory to assess the aortic arch anatomy, atherosclerotic burden, calcific burden of the plaque, and CCA and internal carotid artery (ICA) diameter and anatomy.

Combining Imaging Techniques: Is There a Time When You Don't Need More Than One Imaging Study?

In deciding whether a single imaging study is adequate prior to proceeding with revascularization, it is critical to understand the method of proposed treatment as well as the indication and physician-patient discussion regarding treatment. There are a number of studies reporting adequacy of carotid DUS alone for treatment of carotid stenosis, many published before 2000.[4,5] However, more recent authors have reported the safety of performing TCAR with DUS alone in the setting of symptomatic carotid stenosis and confirmed the safety of CEA with carotid DUS alone. This approach using a single imaging strategy is more commonly used and proposed in symptomatic patients and in those with contraindications to CTA imaging. Although the use of axial imaging is not always necessary, most carotid revascularizations are performed with some form of preoperative axial imaging beyond carotid DUS alone.

CEA

CEA remains the cornerstone treatment for asymptomatic and symptomatic carotid occlusive disease, validated by numerous clinical trials across the years. Important preoperative considerations, which can alter the surgical approach and complication rates, include prior neck surgery, radiation, prior cranial neck injuries, limited neck mobility, high carotid bifurcation lesions (≥ C2 vertebral body), and high-risk medical comorbidities. The standard approach involves positioning the patient with the neck hyperextended and head turned to the contralateral side; performing an incision along anterior border of the sternocleidomastoid muscle (SCM); mobilizing the SCM and internal jugular laterally, dividing the facial vein; and establishing control of the CCA, ICA, external carotid artery (ECA), and superior thyroid artery. Surgeons need to isolate the CCA with caution to preserve the vagus nerve and avoid injury to the recurrent laryngeal nerve. Care also needs to be taken in dividing the facial vein and elevating the anterior belly of the digastric muscle to avoid injury to the hypoglossal nerve. Branches crossing the hypoglossal nerve need to be carefully dissected and divided to allow mobilization of the nerve and exposure of the distal ICA to ensure dissection and exposure of this vessel above the area of disease in the ICA. Once the vessels have been exposed and the patient anticoagulated, endarterectomy can begin. Standard exposure necessitates self-retaining retractors such as a Weitlaner or Henley retractor to allow freedom of the surgeons' hands to perform dissection. It is often necessary for an assistant to hold retractors to ensure adequate exposure.

Patch Material

Typically, longitudinal arteriotomy is most commonly followed by endarterectomy and patch angioplasty. Primary versus patch closure of the carotid artery post-endarterectomy has been evaluated in multiple studies, and primary closure is not recommended as it is associated with increased restenosis and increased perioperative and long-term stroke rate.[6] No difference has been shown in outcomes between the various patch materials, such as bovine pericardium, prosthetic (Dacron or polytetrafluoroethylene), and autogenous vein.[7,8] A smaller subset of surgeons perform eversion CEA (ECEA), which involves transection of the ICA, eversion ICA endarterectomy, and reimplantation. ECEA is useful for focal bifurcation lesions and tortuous/redundant carotid, and it is thought to reduce clamp times, reduce suture line bleeding, and avoid using a prosthetic patch. Studies have shown similar perioperative and long-term outcomes between standard CEA and ECEA. Although a transverse incision along the neck crease can be used for cosmetic reasons, this approach offers no real exposure advantage, and care must be taken to avoid injuring the greater auricular nerve.

Neuromonitoring During CEA

With regard to neuromonitoring, many different modalities have been used: local/regional anesthesia, ICA stump pressures, electroencephalography, somatosensory-evoked potential monitoring, cerebral oximetry, and transcranial Doppler. These modalities are used to assess whether cerebral ischemia during carotid clamping is significant enough to warrant shunting. An alternative to this selective application of shunting approach is to routinely place a shunt at the time of the procedure. Studies have failed to show any significant difference in perioperative stroke rates between selective and routine shunting.[9] No monitoring technique has proven more effective than another, and a team with a routine for approaching monitoring and shunting is important to success. Shunts should be readily available in the operating room, and monitoring equipment should be arranged ahead of time so it is available to be used and interpreted during CEA. Communication between the operative team and the anesthesia team (which should include the team performing the monitoring) is critical to success as well so that there is understanding of when the ICA is clamped and unclamped and when shunt insertion is completed; this allows the surgeon to know if the monitoring strategy indicates need for a shunt and be aware of the neurologic or monitored response to shunt insertion.

Difficult-to-Reach Plaque and Conversion to TCAR

Most high plaques can be reached with the standard approach via extension of the incision posterior to the angle of the mandible behind the parotid gland, mobilization of the hypoglossal nerve, division of the posterior belly of the digastric, and division of the occipital artery. More aggressive maneuvers such as lateral mandibulotomy, nasotracheal intubation and mandibular subluxation, and division of the styloid process and its associated ligaments are rarely used nowadays with the availability of carotid stenting. In rare cases where the carotid disease is high enough that a distal ICA clamp cannot be secured, carotid stenting should be considered. Conversion to TCAR can be performed by extending the incision caudally and dissecting the CCA at the base of the neck, allowing this portion of the vessel to be used as an access point for TCAR. On the rare occasion where conversion to TCAR cannot be achieved, distal control can be achieved with a 4- or 4.5-mm dilator, balloon catheter, or Fogarty catheter (Edwards Lifesciences).

Retrograde Carotid Stenting

Although not common, some patients present with tandem innominate or common carotid lesions in addition to the carotid bifurcation lesion. There may be indirect evidence (eg, parvus tardus waveforms) of a proximal tandem lesion on DUS, but cross-sectional imaging provides the best delineation of inflow anatomy. In cases where a proximal lesion must be addressed prior to or at the same time as CEA, our preference is retrograde stenting of these lesions at the time of CEA. Through a standard CEA incision, stenting has been performed either prior to or after endarterectomy. There are advantages and disadvantages to both approaches, but care must be taken to avoid damage to the stent if performed initially. Adequate anticoagulation must be maintained to ensure the stent remains thrombus free throughout the procedure. When stenting is performed after the endarterectomy is completed, avoid elevating plaque at the proximal endpoint of the endarterectomy. In instances like this, it can be helpful to tack the proximal endpoint of the endarterectomy to better ensure passage of equipment in the true lumen. We favor adequately sized balloon-expandable or self-expanding covered stents to reduce the potential for embolic debris from the interstices of the stent. Stents should be placed across the entire area of disease, even extending slightly into the aortic arch lumen to ensure complete lesion coverage. The ICA is routinely clamped during this intervention to reduce stroke risk potential.

TFCAS

TFCAS initially emerged as a less invasive technique for carotid revascularization in medically or anatomically high-risk patients, usually performed under local anesthesia with minimal or no sedation. Prior to undertaking TFCAS, cross-sectional imaging is necessary to evaluate the anatomy of the aortic arch and its underlying atherosclerotic disease and the calcific burden and tortuosity in the CCA and ICA. Transfemoral stenting should be avoided in complex aortic arches, extensive atherosclerotic disease of the aortic arch, significant tortuosity at the stent landing zone, and circumferential or extensive eccentric calcification that might prevent adequate stent expansion.

Transfemoral stenting involves aortic arch navigation, cannulation of the CCA with an introducer sheath, crossing of the lesion, and either deployment of a distal embolic protection device or proximal occlusion of the

CCA with balloon occlusion of the ECA (proximal protection). This is followed by lesion crossing, angioplasty, stent deployment with potential application of poststent angioplasty for residual stenosis, and ultimately, filter recapture or proximal protection release.

It is important to have a variety of shaped catheters, from a simple curved vertebral catheter to a complex curved catheter (eg, Vitek, Cook Medical). A variety of self-expanding carotid stent sizes should be available for deployment, with the stent sized usually 1 to 2 mm larger than the target CCA. Tapered stents have been used to accommodate for CCA-ICA mismatch.

Stent size (diameter and length) should be predetermined based on preprocedure axial imaging. Prestenting balloon angioplasty should be slightly undersized compared to the size of the distal ICA, while poststent angioplasty should not be larger than the ICA size. Some interventionalists avoid poststent dilation completely because of the increased risk associated with embolic debris released during poststenting dilation. A variety of monorail, 0.014-inch, wire-compatible balloons should be available to accommodate predilation and postdilation needs. Normally, balloons between 3 to 5.5 mm in diameter with lengths from 30 to 40 mm are adequate to accommodate most anatomies. Because carotid angioplasty can result in bradycardia and even asystole, hypotension may occur, and many operators prophylactically give anticholinergic medication (atropine or glycopyrrolate) to mitigate that effect.

In patients with hostile groins or severe iliac tortuosity or occlusive disease and unfavorable arch anatomy, transradial and transbrachial upper extremity access have emerged as potential alternatives to TFCAS. Furthermore, right upper extremity access can be advantageous in patients with left ICA lesions and bovine arch anatomies. Preliminary studies have shown acceptably low rates of cerebral thromboembolic and access site complication. Preprocedural axial imaging allows identification of patients who would likely benefit from the access points used for the procedure, and decision-making to proceed with this approach should be made ahead of time based on preoperative imaging.

Particularly for patients with distal carotid filters, some form of debris aspiration should be available as there are times when significant debris can obstruct the filter and retrieval is complicated. The ability to aspirate some of the debris trapped in the filter should reduce embolic potential.

Although not mandatory, three-dimensional (3D) image fusion overlay has been used during TFCAS to delineate aortic arch anatomy based on preoperative CTA and MRA and merged with two-dimensional on-table fluoroscopic images. This has been shown to reduce contrast exposure and time to cannulate the CCA. Similarly, 3D fusion has been used with TCAR and has shown a reduction in contrast dose and radiation.[10,11]

TCAR

FDA-approved in 2015, TCAR is a relatively novel hybrid approach for carotid revascularization that offers threefold cerebral embolic protection by avoiding wire manipulation in the aortic arch, initiating flow reversal with proximal CCA clamping, and eliminating lesion crossing before embolic protection is employed. Studies have shown similar perioperative stroke rates to CEA, with lower operative times and cranial nerve injuries. However, these data have only been through observational studies, and direct head-to-head comparisons have not been performed; thus, additional data with randomized trials are sorely needed.

Patient positioning and preparation are similar to CEA. Initially, a transverse incision is made at the base of the neck over the SCM and centered between the two heads of the SCM. The jugular vein and vagus nerve are identified and protected during the procedure. The CCA is then identified medial to and slightly deeper than the jugular vein and dissected for a length of 3 cm. The CCA is cannulated and the sheath inserted. Reversal of flow is initiated via a dynamic filtering system returning blood to the femoral vein after passing through a filtration system. The CCA is clamped proximal to the sheath, and the lesion is then crossed with a 0.014-inch wire, predilated, and stented. TCAR anatomic criteria includes length of at least a 5-cm working distance between the CCA access site and carotid bifurcation; the CCA must also be free of disease at the access site and have a diameter at least 6 mm. The stent is sized usually 1 to 2 mm larger than the target CCA, and the angioplasty should match the ICA size. Sizing for balloon dilation and stent placement should be predetermined based on axial imaging.

Similar to TFCAS, TCAR was initially reserved for patients with high medical, surgical, or anatomic risks; however, in 2022 TCAR use expanded to include patients at standard surgical risk. Generally, TCAR should be avoided if the patient has anatomy that does not meet the anatomic criteria, a circumferentially calcified lesion, or thrombotic plaque that is at high risk for embolization through the stent tines. For patients with unfavorable TCAR anatomy, specifically a short (< 5 cm) clavicle-to-carotid bifurcation distance, a 6-mm prosthetic graft (usually Dacron) can be sewn end-to-side to the CCA to extend the working distance to the carotid bifurcation. After stent delivery, the conduit is ligated. This is rarely necessary in the presence of other viable options for carotid revascularization but can be a valuable tool if CEA and TFCAS are not ideal options.

Furthermore, some surgeons deploy TCAR (ie, stenting via the transcarotid or transcervical route) but use a distal filter for embolic protection rather than the dynamic flow reversal system (Enroute transcarotid neuroprotection system, Silk Road Medical). New devices are emerging that combine dynamic flow reversal with distal filter protection during transcervical carotid stenting, but these are still part of clinical trials. Similar to TFCAS, a variety of balloon diameters with monorail design and 0.014-inch wire compatibility should be available for TCAR. A variety of self-expanding carotid stent lengths and diameters should also be available.

MEDICATIONS

For patients undergoing any of these procedures, vasoactive drugs and the ability to initiate these drugs rapidly should be readily available. Asystole and severe bradycardia along with hypotension and, in some instances, hypertension can create extremely stressful situations, and preparation for immediate action and drug delivery in these situations is critical. Heparin should be readily available for use as well, and the ability to monitor the anticoagulation efficacy is critical to success. For stenting in particular, patients should be administered dual antiplatelet agents, and if allergic reactions to these drugs is a problem, then glycoprotein IIb/IIIa inhibitors should be considered.

CONCLUSION

With the emergence and evolution of different techniques for carotid revascularization, it is important to consider the patient's medical, surgical, and anatomic factors and adopt a patient-centered approach for carotid revascularization. Fortunately, modern-day vascular centers are equipped with all the tools and sufficiently proficient specialists to pick the best treatment algorithm for the individual patient, whether that is medical therapy, a minimally invasive endovascular procedure, open surgical revascularization, or a hybrid of these options. ■

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