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Carotid endarterectomy (CEA) was shown to be superior to “best” medical therapy for stroke prevention in patients with severe atherosclerotic carotid stenosis in both the North American Symptomatic Carotid Endarterectomy Trial (NASCET) and the Asymptomatic Carotid Atherosclerosis Study (ACAS), and is currently being compared to carotid stent-assisted angioplasty (CAS) in the Carotid Revascularization Endovascular Stent Trial (CREST). The efficacy of both CEA and CAS is highly dependent on low procedural morbidity (< 5%) and producing a durable repair with a low incidence of recurrent stenosis or occlusion.

Duplex ultrasonographic surveillance of patients after both CEA and CAS procedures has demonstrated an incidence of > 50% diameter residual or recurrent stenosis in the range of 4 to 22%. Severe, progressive stenosis warranting reintervention is in the range of 4 to 5% following both procedures; although the long-term outcomes after CAS are less known. In the SAPHIRE (Stenting and Angioplasty with Protection in Patients at High Risk for Endarterectomy) trial, carotid revascularization was repeated ( $p = .04$ ) more frequently after CEA (4.5%) than following CAS (0.6%).<sup>1</sup>

Color duplex ultrasonography is an accurate method to confirm patency and grade re-stenosis severity following CAS procedures. Carotid duplex ultrasonography using high-resolution (7–10 MHz transducer frequency) B-mode imaging, power Doppler imaging, and pulsed-Doppler velocity spectrum analysis provides detailed anatomic and hemodynamic information of the extra-cranial carotid artery bifurcation. Carotid stents are readily imaged, and with the use of serial studies, a number of abnormalities can be identified including: stent thrombosis, in-stent stenosis, stent deformity, stent separation from the wall, and stent migration. The threshold criteria for < 50% diameter-reduction stent stenosis has not been defined but several vascular groups have recommended using a higher peak systolic velocity (PSV) value of 150 cm/s rather than 125 cm/s commonly used (University of Washington criteria) for atherosclerotic lesions. Deployment of stent alters the compliance of the carotid segment producing a stiffer artery segment which theoretically results in an increase in PSV in the stented artery. Typically, blood flow in the stent is laminar with areas of disturbed flow identified at the proximal and distal stent orifices. The ratio of PSV along the length of the stent should be less than 2. Following CAS, stent apposition to the carotid wall and plaque can be determined using transverse and sagittal scanning views. Poor stent apposition may be associated with an increased incidence of stent failure.

Serial duplex ultrasound studies have confirmed that both positive (stent-expansion) and negative (stent lumen reduction–myointimal hyperplasia) re-modeling occurs.<sup>2</sup> Self-expanding stent diameters increase after deployment most marked in the mid-stent region. The extent of stent expansion was less in the region of calcified plaques. Neointimal thickening is a common finding and in-stent thickness increased up to 12 months and stabilized thereafter. The anatomic result of these complex interactions is an increase in PSV (mean of  $75 \pm 27$  cm/s at 1 day to  $101 \pm 37$  cm/s at 1 year;  $p < .001$ ) in the stent indicating a dominance of negative remodeling secondary to neointimal proliferation. The development of carotid-stent stenosis is associated with lumen reduction, elevation of flow velocity, and post-stenotic flow disturbance. Velocity criteria for grading stenosis severity vary in the literature. At the University of South Florida noninvasive vascular laboratory, if color Doppler imaging of the CAS segment is normal, a PSV < 150 cm/s indicates less than 50% stenosis. Duplex testing within 1-month following 65 CAS procedures with angiograms showing 20% residual stenosis measured a mid-stent PSV of  $100 \pm 27$  cm/s (range: 52–145 cm/s) and a stent PSV ratio of  $1.19 \pm 0.3$  (range: 0.8–1.5). A PSV from 150 to 300 cm/s indicates a 50 to 75% stenosis, and high-grade (> 75%) stenosis is associated with a PSV > 300 cm/s and an end-diastolic velocity at the stenosis > 125 cm/s. High-grade internal carotid artery (ICA) or stent re-stenosis (> 75–80% DR; end-diastolic velocity > 125–140 cm/s), may be caused by progressive myointimal hyperplasia or atherosclerosis and these lesions increase the risk of thrombosis and ipsilateral stroke.

Considering the potential for recurrence of carotid stenosis, duplex surveillance after CEA or CAS is recommended. Testing intervals of 6 months are sufficient to detect development of restenosis, and follow 50 to 75% stenotic lesions for progression. In the majority of patients, however, the main reason for duplex surveillance is to identify progression of contralateral > 50% ICA stenosis, rather than to detect restenosis of the CEA or CAS site. An early duplex scan of the CAS site within 1 month is useful to exclude residual stenosis. A progressive stenosis to > 75% diameter reduction (PSV > 300 cm/s; diastolic velocity, > 125 cm/s; ICA/common carotid artery ratio, > 4) should prompt consideration for re-intervention. Duplex scanning every 1 to 2 years after carotid intervention appears to be adequate when no stenosis is identified within the first postoperative year, and < 50% DR contralateral stenosis is present. Surveillance every 6 months is indicated in patients with residual or recurrent ipsilateral stenosis and contralateral ICA occlusion. The development of hemispheric symptoms in the presence of > 50% DR ICA or CAS stenosis, or asymptomatic disease progression to a high-grade stenosis (> 75–80% DR, end-diastolic velocity > 140 cm/s), should prompt a recommendation of surgical or endovascular (stent-assisted angioplasty) intervention in appropriate patients.

The yield (ie, intervention rate for severe stenosis) of duplex surveillance after CEA (3–5%) is less than after CAS (6–10%).<sup>3,4</sup> Progression of contralateral disease, however, is five times more common. A policy of duplex ultrasound surveillance and reintervention for high-grade stenosis is associated with a low (< 1% per year) incidence of ipsilateral hemispheric, disabling stroke. The majority of patients after CEA or CAS have duplex scans indicating bilateral < 50% stenosis, and annual follow-up is appropriate.

#### References

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#### NOTES