Evaluation of Carotid Stenosis

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Page Contents

Introduction

CT scan and MRI are useful for evaluating the question of cerebral infarction which may occur as a consequence of carotid artery stenosis. Infarctions related to internal carotid artery stenosis may be deep, subcortical, or cortical. However, carotid stenosis may exist in the absence of infarction on MRI and CT. The definition of asymptomatic or symptomatic carotid artery stenosis is based upon the history and physical examination, depending on whether or not there are symptoms and signs of carotid territory ischemia. It is important to recognize that in the large clinical trials addressing management of carotid artery stenosis, the detection of "silent" infarcts on CT or MRI did not qualify the stenosis as symptomatic. In clinical practice, however, radiographical evidence of ischemia in the territory of a stenotic internal carotid artery, may affect management.

Four diagnostic modalities are used to directly image the internal carotid artery: cerebral angiography, carotid duplex ultrasound, computed tomograhic angiography (CTA) and magnetic resonance angiography (MRA). Each has unique advantages and disadvantages.

Conventional Transfemoral Cerebral Angiography

Cerebral angiography is the gold standard for imaging the carotid arteries. The development of intra-arterial digital subtraction angiography (DSA) reduces the dose of contrast, uses smaller catheters and shortens the length of the procedure. Although there is lower spatial resolution, DSA has largely replaced conventional angiography.1

The quality of the angiogram depends on selective catheterization of the carotid artery with at least two unimpeded views. Aortic arch injections alone are inadequate. Suboptimal studies can lead to misinterpretations as an irregular stenosis can be either under- or over-estimated in a single projection.

The methods of evaluating the degree of angiographic stenosis vary in technique and accuracy. In the randomized clinical trials evaluation the utility of endarterectomy in symptomatic patients, the two major surgical trials used different methods to measure carotid stenosis.2 The NASCET study measured a residual lumen diameter at the most stenotic portion of the vessel and compared this to the lumen diameter in the normal internal carotid artery distal to the stenosis.3 The ECST study measured the lumen diameter at the most stenotic portion of the vessel but compared this to the estimated probable original diameter at the site of maximum stenosis.40 Since the maximum stenosis is generally in the carotid bulb, a wider portion of the artery than that distally, a given stenosis would be more severe using the ECST method as compared to that of NASCET. ECST methodology requires an assumption of the true lumen, which increases the risk of inter-rater variability. Despite the need for uniformity in measurement if the results of clinical trials are to be generalized, many studies are interpreted using arbitary standards.4 One study found that in 74 percent of 57 angiograms, the degree of carotid stenosis reported by the radiologist was overestimated by an average of 24 percent when compared to a rigorous, precise measurement.5

Cerebral angiography allows study of the entire carotid artery system, providing information about tandem atherosclerotic disease, plaque morphology, and collateral circulation which may affect management.6 Pathologic evaluation of the plaque specimen provides the most useful data on plaquecomposition, which may have a bearing on prognosis.7,8

The disadvantages of angiography include its invasive nature, high cost and risk of morbidity and mortality. In a recent review of prospective studies using cerebral angiography, the risk of all neurologic complications was approximately 4% and the risk of serious neurologic complications or death was approximately 1% (range 0 - 5.7%).1 Cerebrovascular symptoms, advanced age, diabetes, hypertension, elevated serum creatinine and peripheral vascular disease increase the risk of morbidity. The size of the catheter, amount of contrast and procedure duration also affect the risk of complications.7

Carotid Duplex Ultrasound (CDUS)

Carotid duplex ultrasound is a non-invasive, safe, and relatively inexpensive technique for evaluation the carotid arteries. CDUS uses B-mode ultrasound imaging and Doppler ultrasound to detect focal increases in blood flow velocity indicative of high grade carotid stenosis.9,10,11

The peak systolic velocity is the most frequently used to gauge the severity of the stenosis, but the end diastolic velocity, spectral configuration, and internal/common carotid artery ratio provide additional information.12 Color Doppler flow technique may improve the efficiency of the test, but it has not been shown to improve accuracy.9,11,13,14

As an adjunct to CDUS, transcranial Doppler ultrasound (TCD) examines the major intracerebral arteries through the orbit and at the base of the brain and provides additional information regarding the intracranial hemodynamic consequences of high grade carotid lesions, such as the development of collateral flow patterns in the circle of Willis. TCD may be used to improve the accuracy of CDUS in identifying surgical carotid disease.15

CDUS is 91-94% sensitive and 85-99% specific in detecting a ssignificant stenosis of the internal carotid artery.9,10,11 Although limited, CDUS has utility in obtaining information about plaque composition. Intraplaque hemorrhage, which may increase the risk of embolism and impact on prognosis, can be visualized on high resolution B-mode.8,9,10,11,16,17 Moneta and colleagues found that that the ratio of ICA peak systolic velocity to the common carotid artery velocity accurately predicted a high grade stenosis amenable to surgery.18 Using published outcome data and receiver operator characteristic analysis, test criteria can be developed that maximize patient outcome for a specific clinical scenario.19,20

CDUS is less precise in determining stenoses of less than 50 percent, but this rarely impacts on its clinical utility.9,10 The absence of flow in the internal carotid artery may be due to occlusion, but hairline resdiual lumens can be missed on CDUS.21 Another limitation of ultrasound examination is that only the cervical portion of the internal carotid artery can be evaluated, although transcranial Doppler may provide some information about downstream vessels. Finally, the accuracy of CDUS relies heavily upon the experience and expertise of the ultrasonographer.10,11 Although important, it may be difficult for the clinician to know the accuracy of his local ultrasound laboratory. Accreditation by the Intersocietal Commission for the Accreditation of Vascular Laboratories (ICAVL), a multidisciplinary group assures that the ultrasound data meet certain criteria, including correlation against the gold standard of conventional angiography.

We examined the correlation between Doppler velocities and the residual lumen diameters of internal carotid arteries from surgical pathological specimens to establish Doppler criteria for residual lumen diameter independent of percent stenosis. Peak systolic velocity(PSV), end-diastolic velocity(EDV), and carotid index(peak ICA velocity/CCA velocity) correlated with the residual lumen diameter. PSV >440 cm/sec, EDV >155 cm/sec, or carotid index >10 indicated a residual lumen diameter of < 1.5 mm (specificity 100% and sensitivity of 58%, 63% and 30%, respectively). By combining these criteria, the sensitivity increased to 72%. A PSV of >200 cm/sec combined with either an EDV >140 or a carotid index >4.5 has a sensitivity of 96% and a specificity of 61%.22

Transcranial Doppler (TCD)

Transcranial Doppler is often used in conjunction with carotid duplex ultrasonography (CDUS), to evaluate the hemodynamic significance of internal carotid artery (ICA) stenosis. We examined the sensitivity and specificity of TCD criteria in detecting a hemodynamically significant stenosis (residual lumen diameter £1.5 mm) at the origin of the ICA. For the transorbital approach, the strongest indicators of a residual lumen diameter £1.5 mm were reversed flow in the ipsilateral ophthalmic artery (OA) and a >50% peak systolic velocity difference between the carotid siphons (distal ICAs) in patients with unilateral ICA origin stenosis. They were 100% specific and 31% and 26% sensitive respectively.

For the transtemporal approach in patients with a unilateral stenosis, a >35% difference in ipsilateral middle cerebral artery (MCA) peak systolic velocity relative to the contralateral MCA, or a > 50% difference in contralateral anterior cerebral artery (ACA) peak systolic velocity relative to the ipsilateral ACA were 100% specific for identifying a residual lumen diameter of £1.5 mm. Sensitivities were 32% and 43% respectively. Irrespective of contralateral stenosis, a >35% difference in ipsilateral MCA peak systolic velocity relative to the ipsilateral posterior cerebral artery (PCA) had a 100% specificity and a 23% sensitivity for detecting a £1.5 mm minimal residual lumen diameter.23

Magnetic Resonance Angiography (MRA)

The MRA techniques most often used for evaluating the extracranial carotid arteries utilize either two dimensional time-of-flight (2D TOF) or MOTSA.10,24-26

MRA produces a reproducible three dimensional image of the carotid bifurcation with good sensitivity for detecting high grade carotid stenosis. Slow, turbulent and absent blood flow are poorly distinguished by MRA, therefore the degree of stenosis is consistently overestimated. Even normal or very mildly stenotic arteries may appear diseased on MRA as nonlaminar blood flow in the carotid bulb contributes to loss of signal intensity. Irregular stenoses which disturb flow are particularly susceptible to over-interpretation. Turbulent or complex flow in the artery proximal and distal to the stenosis also lead to overestimation of the length of the stenotic segment.10,25

MRA is more sensitive than it is specific for detecting high grade carotid stenosis. The majority of angiographic-MRA correlations have been performed using 2D TOF technique, and were consistent in that the degree of carotid stenosis was often overestimated for all ranges of stenosis. In different studies, sensitivity and specificity for 2D TOF MRA for predicting 50-99% angiographic stenosis varied between 73-100% and 59-99%, respectively.10,27-31 MRA also has difficulties similar to CDUS in distinguishing very severe stenosis from occlusion. Both false positive and false negatives may occur.29,31 Combined techniques of 3D and 2D TOF seem to improve the performance of MRA but are not routinely performed and probably increase test cost.10,24-26

Compared to CDUS, MRA is less operator dependent and does produce an image of the artery. However, it is more expensive and time-consuming. It is less readily available than CDUS and may not be performed if the patient is critically ill, unable to lie supine, or has claustrophobia, a pacemaker or ferromagnetic implants.10 In different series, up to 17% of MRA studies are incomplete because the patient could not tolerate the study or could not lie still enough to produce an image of adequate quality for interpretation.32

CT Angiography

Spiral CT provides an anatomic depiction of the carotid artery lumen and allows imaging of adjacent soft tissue and boy structures. The three dimensional reconstruction allows relatively accurate measurements of residual lumen diameter. CTA requires a contrast bolus comparable to that administered during a conventional angiogram. Therefore, impaired renal function is a relative contraindication for its use.

Choice of Imaging Test

Angiography has been considered the gold standard. However, angiography is a risky procedure and most patients with carotid ischemic symptoms do not have severe carotid stenosis.33,34 Therefore, patients are generally selected for angiography using one of the noninvasive tests. Both MRA and CDUS have better sensitivity than specificity. A number of studies have compared the sensitivity and specificity of both CDUS and MRA directly to angiography in the detection of surgical disease (Table 1).29,32,35,36

The combination of carotid ultrasound and MRA may obviate the need for conventional angiography in the presurgical assessment of patients with carotid artery disease, particularly when the tests agree.36,37 Some investigators have reported that the combination of ultrasound and MRA is not only cost effective,38but results in an overall error rate that is comparable to the interobserver reliability when two radiologists are presented with the same conventional angiogram revealing carotid artery disease.39

Bypassing angiography before surgery requires that noninvasive tests be highly specific as well as sensitive. TCD may be beneficial in this setting, increasing the specificity to carotid duplex ultrasound in detecting a < 1.5 mm residual lumen diameter.23

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