Ultrasound evaluation of cerebrovascular steno-occlusive disease

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Carotid arteries

Introduction

The publication of the results of the European Carotid Surgery Trial (ECST) [(1)] and the North American Symptomatic Carotid Endarterectomy Trial (NASCET) [(2)] have highlighted the existence of a close link between the degree of carotid stenosis and the risk of stroke and the importance of accurate assessment of the degree of internal carotid artery (ICA) diameter reduction. More recent reports reiterate the importance of stenosis in patients with transient ischaemic attacks (TIA) [(3, 4)]. The number of strokes prevented by expedited carotid endarterectomy (CEA) or carotid artery stenting (CAS) (within 14 days of symptom onset) is significantly greater in patients with 70–99% stenosis compared with those with 50–69% stenosis [(3, 4)].

The NASCET and ECST trials did not originally report similar outcomes, due in large part to each trial using a different method for measuring stenosis severity (outer edge versus diameter) [(5)]. A 70% stenosis calculated using the NASCET criteria, for example, corresponds to an 83% stenosis calculated using the ECST technique since the diameter of the distal ICA is smaller than the estimated outer edge of the ICA at the stenosis [Figure 1].

After a reanalysis of the ECST results using the NASCET method, the outcomes of the two studies were similar [(6)].

Figure 1  Grading of internal carotid artery stenosis - NASCET vs ECST criteria.
The fundamental results achieved by the American and European trials have prompted an extensive worldwide effort to identify reliable and universally reproducible criteria to accurately grade ICA stenosis using Doppler ultrasound. The method relies mainly on velocity criteria and it has been used to provide national and international society consensus documents [(7-13)]. Several similarities can be found among the different consensuses, particularly a focal peak systolic velocity (PSV) >230 cm/s within the internal carotid artery stenosis and an internal carotid artery to common carotid artery (CCA) peak systolic velocity (ICA/CCA PSV) ratio >4, identify a ≥70% stenosis in symptomatic patients [(8, 9, 11, 13)].

**Indications for ultrasound examination of the carotid arteries**

The ultrasound detection and characterisation of severe carotid artery disease and preventive strategies like carotid endarterectomy can significantly reduce the incidence of stroke in at risk patients [(1, 7)]. However, it is not a cost effective strategy to screen asymptomatic patients in the community for carotid artery disease [(14)].

High risk patients are those with a history of stroke/transient ischaemic attack, neck bruits, peripheral arterial disease and coronary artery disease [(13)]. A duplex examination of the extracranial arteries should be mainly recommended in the following situations [(15)]:

- Patients with hemispheric neurological symptoms (i.e. stroke, transient ischaemic attack, amaurosis fugax).
- Evaluation of patients with cervical bruit.
- Patients with known coronary artery stenosis and/or peripheral arterial disease and/or proven carotid disease as per follow up.
- Asymptomatic patients ≥65 years old with cardiovascular risk factors (in particular hyperlipidaemia, arterial hypertension, diabetes mellitus, smoking).
- Patients scheduled for major cardiovascular surgical procedures (preoperative evaluation).
- Postoperative or post interventional patients after cerebrovascular revascularisation (e.g. carotid endarterectomy, stenting, etc.).
- Patients with symptoms of syncope or dizziness.
- Evaluation of pulsatile neck masses.
- Evaluation of non-hemispheric or unexplained neurological symptoms.
• Screening of high-risk patients, e.g. extra-carotid atherosclerosis, history of head and neck irradiation, known fibromuscular dysplasia (FMD), Takayasu arteritis or other extracranial vasculopathy.
• Neck trauma.
• Hollenhorst plaque (cholesterol embolus in retinal blood vessel) visualised on retinal examination.

Technical and methodological considerations

Ultrasound techniques can accurately depict arterial wall morphology using B-mode imaging and can simultaneously define carotid haemodynamics using colour Doppler flow and pulsed wave Doppler. Standard protocols should be used to ensure the reproducibility of the information collected [(16)].

The examination of extracranial vessels requires the use of B-mode and colour coded and/or power imaging with high frequency linear transducers. However, under particular circumstances such as in short and difficult necks, to investigate the very proximal or very distal carotid segments, to examine the vertebral arteries or in the presence of calcific arteries, lower frequency or curved array transducers may be necessary.

To detect a carotid stenosis, the highest peak systolic velocity is sought. The insonation angle should be ≤60°. The sample volume should be placed at and around the site of the narrowest region of an atherosclerotic lesion and can often be identified on colour Doppler flow as aliasing [Figure 2]. In addition to demonstrating elevated velocity at the site of the stenosis, colour Doppler detection of a poststenotic turbulence and a downstream demonstration of turbulence and/or ‘tardus parvus’ waveform [Figure 3 and 4] can further confirm and strengthen the diagnosis a significant (>70%) ICA stenosis.

Figure 2  B-mode and colour flow representation of a severe stenosis of the internal carotid artery with a focal increase in both PSV (326 cm/s) and end diastolic velocity (EDV) at the site of lumen reduction compared to the prestenotic values (a). The maximum lumen reduction and the colour velocity jet
(identified by aliasing) can be easily recognised and they can be used to place the sample volume of the spectral Doppler for velocity measurements (b).

Figure 3 Internal carotid artery stenosis with heterogeneous plaque and a 50-69% stenosis (a). On greyscale of the proximal ICA, there is irregular plaque which is hyperechoic, hypoechoic and anechoic. Plaque with anechoic spaces indicates heterogeneous plaque (b). Colour Doppler of the stenotic proximal ICA demonstrates aliasing associated with the narrowed segment. Distal to the stenosis there is widening of the artery with aliasing, red and blue indicating high velocity and simultaneous antegrade and retrograde flow (c). Spectral Doppler of the distal CCA before the bifurcation demonstrates a normal waveform. This velocity is used for the ICA:CCA ratio (d). ICA spectral Doppler before the stenosis demonstrates a normal waveform shape, no spectral broadening and a normal velocity (e). ICA spectral Doppler in the stenosis
demonstrates elevated velocity of the stenotic jet. In the jet there is no spectral broadening since turbulence occurs after the stenosis. This is the site of maximal velocity and is used for velocity and for the IC velocity of the IC:CC ratio (f). ICA spectral Doppler just beyond the stenosis demonstrates the appearance of spectral broadening with filling in of the envelope and mild forward and reverse flow. The velocity is elevated but is lower than the maximal velocity at the jet (g). ICA spectral Doppler further distal to the stenosis demonstrates more severe spectral broadening with filling in of the envelope, poor definition of the peak velocity envelope and mild forward and reverse flow. The velocity is still elevated but lower than the maximal velocity at the jet (h). ICA spectral Doppler further distal from the stenosis shows a ‘tardus parvus’ waveform with lower velocity than the rest of the ICA.
Figure 4  Severe stenosis of the internal carotid artery using B-mode (a). Colour imaging of the stenosis shows an increase in velocity in the stenosis indicated by aliasing with dissipation of the jet distally and flow separation with reverse
flow close to the artery wall (b). The spectral Doppler changes through the stenosis show normal peak velocity (PSV 58 cm/s) proximal to the stenosis (c) with an increase to 392 cm/s in the stenosis (d). Distal to the stenosis there is a jet in the centre of the artery (e). At the edge of the artery, reverse flow is observed (f). By opening up the sample volume to include the whole of the artery, the complex flow in the poststenotic region of the artery is demonstrated (g).