Symposium: controversies in cerebrovascular disease 4. Appropriate imaging before carotid endarterectomy

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The question of which imaging method to use before performing carotid endarterectomy is a common and practical issue confronted by vascular surgeons. The imaging modalities of duplex ultrasonography, angiography, computed tomography (CT) and magnetic resonance angiography (MRA) have all been used in the preoperative assessment of the patient scheduled for carotid endarterectomy. This article focuses on these 4 modalities, with particular emphasis on the advantages and disadvantages of duplex ultrasonography versus angiography. The emergence of duplex ultrasonography as the sole preoperative imaging test has generated controversy among vascular surgeons and other specialists who deal with patients with carotid artery disease. Angiography, which has been the "gold standard" imaging test in the past and has been the reference standard in the large, randomized, controlled trials, imposes a small but definite risk of stroke and death. Duplex ultrasonography can be used as the sole preoperative imaging test on a selective basis, provided that there is institutional validation and ongoing quality assurance. Although MRA is not widely available, the combination of MRA and duplex ultrasonography can provide similar diagnostic accuracy to angiography in some institutions. Routine CT appears to be unnecessary but is useful in certain circumstances.

La question de la méthode d'imagerie à utiliser avant de procéder à une endartérectomie carotidienne est une question pratique à laquelle font souvent face les chirurgiens vasculaires. Les méthodes d'imagerie que sont l'échotomographie, l'angiographie, la tomographie assistée par ordinateur et l'angiographie par résonnance magnétique (ARM) ont toutes servi à l'évaluation pré-opératoire de patients qui doivent subir une endartérectomie carotidienne. Cet article porte avant tout sur ces quatre méthodes et particulièrement sur les avantages et les inconvénients de l'échotomographie par rapport à l'angiographie. L'émergence de l'échotomographie comme seule épreuve d'imagerie pré-opératoire a suscité la controverse chez les chirurgiens vasculaires et d'autres spécialistes qui traitent des patients atteints de maladies des artères carotides. L'angiographie, qui a été dans le passé l'«étalon or» des épreuves d'imagerie et la norme de référence dans le cadre d'importantes études contrôlées randomisées, présente un risque faible mais certain d'attaque et de mort. L'échotomographie peut servir de seule épreuve d'imagerie pré-opératoire de façon sélective à condition qu'il y ait validation par l'établissement et assurance continue de la qualité. Même si l'ARM n'est pas disponible partout, cette technique combinée à l'échotomographie peut produire un diagnostic aussi précis que l'angiographie dans certains établissements. La tomographie de routine ne semble pas nécessaire, mais elle est utile dans certains cas.

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Angiography has been the standard diagnostic imaging test since carotid endarterectomy was first performed in the mid-1950s. However, in the last 2 decades, progress in the development of other imaging modalities has increased the options available to vascular surgeons. These options include duplex ultrasonography, magnetic resonance angiography (MRA), computed tomography (CT), CT angiography, functional nuclear medicine scanning and CT brain mapping.[1–5] Recent large, prospective, randomized trials and other studies comparing different imaging methods have increased the controversy as to which are the most appropriate or most cost-effective imaging strategies.[2–4] This discussion will focus on the preoperative role of the more common modalities, specifically angiography, duplex ultrasonography and MRA, and on the role of routine CT scanning. Ultimately, however, the specific imaging modality or combination of modalities chosen will depend on the availability and quality of local institutional resources.

Angiography

To understand the role of the other modalities, the current status of angiography should be reviewed. Historically, conventional angiography has been the "gold standard" and has served as the imaging reference for the large prospective, randomized, controlled trials, such as the North American Symptomatic Carotid Endarterectomy Trial (NASCET)[2] and the Asymptomatic Carotid Atherosclerosis Study (ACAS) trial.[3] The clear benefit of angiography centres around the quality and reliability of imaging of the diseased carotid artery. The main disadvantage of angiography is related to its invasive nature and the associated complications. This risk is relatively low in most institutions but will vary somewhat according to local resources and personnel. Auditing these complications is essential to establish local stroke and death rates, which will clarify the decision as to the most appropriate imaging strategy.[4,5] In the ACAS trial, an apparent high stroke rate of 1.2% has generated controversy.[6] However, review of the literature reveals stroke rates varying from 0.0% to 5.4%.[3,6–9] In 1990, Hankey, Warlow and Sellar[6] reported a review of 15 studies involving 8300 angiographic examinations and reported a transient ischemic attack and stroke rate of 4%, with a permanent stroke rate of 1% and a death rate of less than 0.1%. In addition, systemic complications, including allergic reactions, chest pain, shortness of breath, nausea, headache and myocardial infarction ranged from 0.5% to 9.4%.[6] The occurrence of local site complications, including hematoma or leg ischemia, ranged from 0.6% to 20.8%.[6] Mani and colleagues[7] reported a major central nervous system complication rate of 0.8% in a review of 5000 cerebral angiographic examinations and noted a higher total complication rate for training hospitals (3.9%) versus nontraining hospitals (0.9%). In a recent prospective study, Dawson and associates[9] reported a local complication rate of 5% with no stroke complications in the series. The wide variation in the rate of stroke and other complications will obviously influence decision-making on a local level, notwithstanding the quality of the imaging itself, which may also vary on an institutional basis.

Conversely, the advantages of angiography should be well understood in order to weigh its benefits when deciding which imaging modality is most appropriate. The key information provided by angiography is focused at or around the bulb and, most importantly, is the measurement of stenosis. There are different methods of measuring the degree of stenosis, and all have their inherent problems and variability.[5,10–16] One may measure only the minimal residual diameter (MRD) of the internal carotid stenosis, or use this MRD as a numerator and divide it by an appropriate denominator.[10–12,14] The denominator used will vary depending on the reference method chosen. The distal internal carotid artery has also been used, as in the NASCET and ACAS trials.[2,3] However, this most widely used "NASCET method" may not be applicable to all situations. For example, when the stenosis is very severe, the distal internal carotid artery may actually diminish in size, preventing its use as an appropriate denominator. In these patients, it has been suggested that a 95% stenosis be attributed to them.[11] Bladin and associates[14] found that the NASCET method was applicable in only 89% of cases. This method has also been criticized because it permits calculation of "negative stenoses" in which the bulb diameter is greater than the diameter of the distal internal carotid artery. In the series of Bladin and associates, calculation of angiographic stenosis with use of the NASCET method revealed negative stenoses in 9% of cases.[14]

Another denominator has been used, as reported in the European trial, that involves an estimate of the bulb size.[12] This bulb-based estimate is admittedly subjective and has been criticized on this basis.[13,15] An alternative method of measuring carotid stenosis has been put forward. It involves measuring the common carotid diameter and multiplying this value by 1.2.[15] The resultant measurement is called the carotid stroke index and has been suggested as a more objective index for assessing the size of the carotid bulb and a more widely applicable method of measurement.[14,15]

Regardless of the method, measuring stenosis has inherent variability with respect to intraobserver and interobserver reliability. Chikos and colleagues[16] reported a 90.4% intraobserver correlation and an 85.4% interobserver correlation for stenoses greater than 50%. However, as Strandness[5] and Hobson and Strandness[13] have emphasized, this variation may be higher in clinical practice, because radiologists do not conventionally use callipers to measure angiographic stenoses.

Another issue threatening angiography as the standard imaging technique relates to its lack of capability in identifying other carotid features, when assessed in comparative studies with operative specimens. With respect to ulceration, Streifler and colleagues[17] found that there was little agreement between angiography and surgical observation. They reported a sensitivity of 45.9% and specificity of 74.1%, with a positive predictive value of only 71.8%. They also noted that, in the literature, sensitivity ranged from 53% to 86%. Comerota and associates[18] has also commented on the inconsistency of angiography in identifying carotid ulceration. In addition, when compared with the measurement of the operative specimen, the angiographic measurement of stenosis has been reported to correlate poorly with those of duplex scanning and MRA.[19]

Examination of the arterial tree, both proximally and distally, has also been emphasized as a rationale for performing angiography before carotid endarterectomy. However, there appears to be little support in the literature for aortographic assessment for proximal arch disease as a reason to carry out angiography. In 1982, Goldstein and associates[20] reported, in a prospective study of 100 patients, that arch study influenced treatment in only 2 patients and did not support the routine use of arch aortography. In 1988, Moore and colleagues[21] also noted the lack of necessity for routine arch aortography and emphasized that clinical assessment will detect most of these cases of arch disease.

Another reported indication for angiography before carotid endarterectomy is examination of the arterial tree distal to the carotid bifurcation. Intracranial disease has been reported in 20% to 50% of patients who undergo angiography, with carotid siphon lesions being the most frequent.[22] However, several studies concur that the presence of intracranial disease does not impact on perioperative mortality, stroke morbidity or mortality, or long-term stroke rates after endarterectomy, although there is some suggestion of a decrease in long-term survival.[22,23] The incidence of intracranial aneurysms has been an issue. They have been reported in approximately 5% of cerebral angiograms.[24,25] The risk of bleeding is estimated to range from 10% to 17% over 5 years.[24] However, there are no documented cases of immediate postoperative hemorrhage and no support for performing angiography on this basis.[24,26]

In summary, although angiography is the imaging basis for the large, randomized, controlled trials, the benefits are not clearly supported in the literature. Furthermore, the disadvantages of expense, invasiveness and the small but definite risks of stroke and death are all well documented. It is these disadvantages that have generated interest in noninvasive diagnostic imaging. If the noninvasive diagnostic test can provide the same information to vascular surgeons as conventional angiography but without the risks, then the role for mandatory angiography becomes less clear.

Duplex ultrasonography

The advantages of duplex ultrasonography are that it is noninvasive, involves essentially no risk to the patient and is cost-effective. The disadvantages are that these tests are technologist-dependent, and the experience in the different centres is variable. In addition, duplex ultrasonography does not visualize arch or intracranial disease, is not applicable to all situations and was not the imaging standard used for the large, randomized, controlled trials.

The crucial argument against using duplex ultrasonography alone is the issue of reliability. The wide variability with respect to different technologists, equipment and centres, combined with the poor correlation in some of the large, randomized, controlled trials has led some to suggest that angiography must be used routinely.[4] However, angiography imposes a small but definite risk of stroke and death, whereas duplex scanning does not. Thus, the principal issues regarding the use of duplex scanning alone before carotid endarterectomy relate to the minimizing of risk and discomfort to the patient, as well as the additional cost of angiography versus duplex.[5] The decision to use duplex scanning alone before carotid endarterectomy must therefore be based on providing both a safe and reliable preoperative method of examination. To progress to a point where endarterectomies can be performed without angiography, an essential step will be institutional validation by comparing duplex ultrasonography and angiography. There appears to be growing support and experience published in the literature for this point of view.

Carotid endarterectomy based on duplex scanning alone was reported as early as 1979 by Von Reutern, Ortega-Schrkamp and Spillner.[27] In 1982, Blackshear and Connar[28] reported a series of 4 patients with allergies to the contrast medium used in

angiography. Since then, there have been numerous reports of carotid endarterectomy based on duplex scanning alone, with small series in the 1980s and larger series in the 1990s.[9,21,29–31] In 1988, Moore and colleagues[21] reported a small series of patients with endarterectomies based on duplex ultrasonography alone, which constituted only 14% of the total endarterectomy load at that time. He emphasized that endarterectomy could be done without angiography in patients in whom the use of contrast material would pose a significant risk, such as those with renal insufficiency or contrast allergy, or in patients in whom angiography may delay surgery.[21] Wagner and colleagues,[29] in 1991, reported a large series of 260 endarterectomies and noted that in the final year of their study, 68% of all endarterectomies were being done without angiography. Indications for angiography, which was then being done in a minority of patients, included: stenosis ranging from more than 70% to 80%, the presence of arch or intracranial disease, no visible end point, a technically difficult examination, recurrent stenosis, nonfocal symptoms, and physician or patient preference.[29] Finally, as part of this trend to use duplex scanning alone as the method of preoperative imaging, Dawson and associates[9] in 1993 reported a prospective study of 111 carotid arteries in 103 patients and found that clinical assessment and duplex scanning were sufficient in 93%. Of the remaining patients in whom angiography was thought to add significant information preoperatively, the situations included disease not limited in the bulb in 4 cases, questionable occlusions in 2 cases, inadequate examination in 1 case, and angiography showing distal occlusion in 1 other case.[9]

In summary, the lessons from the literature indicate that endarterectomy with duplex ultrasonography alone is feasible, with acceptable clinical results. However, the clinical scenario should be consistent, and duplex scanning will not replace angiography in all instances. The percentage of patients assessed by duplex scanning alone will vary according to local practices, personnel and resources. One important caveat is that validation of duplex scanning results on an institutional basis is absolutely critical; endarterectomy without angiography should not be performed without this type of quality assurance.[5] If NASCET criteria are to be used as a threshold test in the consideration for endarterectomy, correlation of the duplex measurements with the 70% stenosis defined by angiography should be established.[5,13,32] Moneta and colleagues[32] used the ratio of peak systolic velocity of the internal carotid artery (ICA) divided by the peak systolic velocity of the common carotid artery (CCA) (ICA/CCA ratio greater than 4) as an index correlating with the NASCET angiographic stenosis of greater 70%.

Magnetic resonance angiography (MRA)

MRA is another imaging modality that has been used before performing carotid endarterectomy. Advantages of this technique are that it is noninvasive, requires no contrast medium, allows visualization of the intracranial and arch areas, and provides images similar to conventional angiograms. The disadvantages include expense, variable resolution, and issues with respect to patient compliance and metal artefact. Several comparative studies have recently been reported.[33–37] Also, different techniques, involving 2-dimensional and 3-dimensional time of flight, as well as multiple overlapping thin-slab acquisition and source imaging techniques, have been described more recently with improved results.[35] However, the techniques do not appear to be standardized, and there are different thresholds for detecting carotid stenosis. Nevertheless, in general, MRA appears to have fairly good sensitivity (83% to 100%) and specificity (74% to 99%).[37] Signal loss has been a consistent problem, though less so in more recent reports.[34] This may result in overestimation of the extent of stenosis, resulting in high-grade stenotic lesions being erroneously reported as occluded arteries.[34] On the basis of studies in which MRA has been combined with duplex ultrasonography, there appears to be a growing consensus that MRA and duplex scanning may replace angiography.[33–37] In 1995, Kent and associates,[36] using decision analysis, found that duplex scanning and MRA could replace conventional angiography, and that this combination provided the lowest long-term morbidity, mortality and most favourable cost-effective investigation. In a recent retrospective review comparing duplex ultrasonography and MRA, Muto and colleagues[37] found that discrepancies between the 2 tests did not alter decision-making and that duplex alone with clinical evaluation is reliable and cost-effective.

Computed tomography

Routine CT has also been reported to be a reasonable imaging modality for assessment before carotid endarterectomy. Reported advantages are that it provides clinical correlation, may influence the timing of the endarterectomy, may provide information with respect to intracranial disease and may allow detection of the silent infarct. The disadvantages include cost and the fact that routine use may not influence treatment. Pos-

itive CT has been reported both in asymptomatic and symptomatic groups. Cao and associates[38] noted in the literature that the incidence of positive CT scans in patients with symptoms is high (67% to 77% in patients with stroke, and 14% to 47% in those with transient ischemic attacks), but the percentage of positive scans in patients without symptoms is also significant (13% to 21%). With respect to CT and the timing of endarterectomy, Whittemore and colleagues[39] reported a small series of patients with small, fixed deficits who underwent endarterectomy within 30 days with acceptable clinical results. Ricotta and colleagues[1] noted that CT was helpful in treatment planning for patients with acute deficits but not for those scheduled for elective endarterectomy. Piotrowksi and colleagues[40] reported that in patients with stable deficits endarterectomy could be done within 6 weeks after CT.

The issue of silent infarcts has been raised in terms of their being a manifestation of carotid disease.[38,41,42] Norris and Zhu[41] reported in 1992 that 19% of patients with asymptomatic stenosis had positive CT scans. Brott and associates,[42] reporting on CT findings in patients in the ACAS, found a 15% incidence of silent infarcts, although the prognostic importance of these lesions is not clear. Cao and associates[38] reported that positive CT scans were associated with an increased risk of stroke and death. Furthermore, Martin and colleagues[43] noted that routine CT before endarterectomy did not influence treatment in a 5-year prospective study of 469 patients. Also, the cost for preoperative CT was over $500 000 and was not found to be cost-effective.[43] This group did not detect any unsuspected intracranial condition and concluded that recognition of clinically silent infarcts does not influence the postoperative morbidity.[43]

Summary

Angiography appears to be an imperfect standard for patient assessment for carotid endarterectomy but still forms the basis for preoperative assessments in large, randomized, controlled trials. Duplex ultrasonography, with validation, can selectively replace angiography. MRA appears to be an evolving technique with imaging similar to that of conventional angiography but without the risks. The use of MRA and duplex ultrasonography appears to be limited by availability and cost but has proven comparable to conventional angiography in some institutions. Routine CT appears to be unnecessary but may be useful in selected circumstances. The individual approach to the patient will vary with local resources, practice and personnel. Institutional complication rates with respect to angiography should be audited, and validation for duplex scanning against angiography is necessary before proceeding to the use of duplex alone before endarterectomy.

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