Eur J Vasc Endovasc Surg 12, 331–336 (1996)

Accuracy of Duplex Sonography before Carotid Endarterectomy — A Comparison with Angiography

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Objectives: *The aim of this prospective study was to contribute to the evaluation of the reliability of Duplex sonography (DS) before carotid endarterectomy (CEA).*
Design: *The study was performed prospectively in a university hospital setting.*
Methods: *Eighty-one consecutive patients aged 49–83 years were examined with DS and carotid angiography (CAG) before CEA. The results of the DS were judged as either confident, or CAG was assessed to be necessary preoperatively. The results from the DS and the CAG were then compared.*
Results: *DS was judged as confident in 148 of the 162 arteries examined. In none of these 148 arteries did CAG change patient management in any way, and the agreement between DS and CAG was good. In the remaining 14 arteries CAG was judged necessary, in 11 arteries because DS assessed the internal carotid artery (ICA) as occluded, which was confirmed by CAG in 10 arteries. In three arteries the reason was poor quality of the DS, however these three arteries were correctly assessed as severely diseased.*
Conclusions: *This study confirms that DS alone is sufficient in the preoperative evaluation before CEA, provided that CAG is performed whenever DS shows occlusion of the ICA, or when the quality of the DS is poor.*

Key Words: Carotid artery; Duplex sonography; Carotid angiography; Carotid artery stenosis; Doppler.

Introduction

Carotid angiography (CAG) has traditionally been considered the "gold standard" in the diagnosis and preoperative evaluation of extracranial carotid disease. During the last decade, however, CAG has been increasingly complemented by Duplex sonography (DS). In recent years, the question has been raised whether DS of the carotid arteries alone is sufficient in the evaluation before carotid endarterectomy (CEA), or whether CAG has to be performed preoperatively in all patients. Many authors claim DS to be reliable,[1–6] while others find it insufficient in this respect.[7] The question is of importance since CAG is an invasive procedure with discomfort for the patients and has potential risks.[8,9] Furthermore CAG is more expensive and time consuming. On the other hand, it is known that the results of the DS are operator dependent, which could introduce errors in investigation and interpretation of the results.[10,11]

The aim of this prospective study was to contribute to the evaluation of the reliability of DS in order to test the safety of management if patients, selected from the results of the DS, went to CEA without performing CAG preoperatively.

Material and Methods

Material

Eighty-one consecutive patients (22 women) aged 49–83 years (mean 68 years) were examined with DS and CAG, usually within a week before a planned CEA. In some patients, however, where CAG had been performed recently it was considered unnecessary to repeat the CAG. In these cases the initial CAG was used for comparison. The delay between CAG and DS was less than 1 week in 50 patients, and less than 1 month in 31 patients. Twenty-eight patients (34.5%) had had minor strokes, 32 (39.5%) transient ischaemic

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attacks (TIA), and 12 (15%) amaurosis fugax. Nine patients (11%), previously undergoing an endarterectomy on the symptomatic side, were operated on because of a contralateral asymptomatic severe stenosis.

Methods

Duplex sonography. All Duplex examinations were performed with the patient in the semi-supine position in a dental chair, by one of three well-experienced technicians. The examinations were performed according to the common routine in our laboratory, with an Acuson XP 10 (Acuson, Mountain View, CA, U.S.A.), using either a 7 MHz B-mode real-time linear scanner including a 5 MHz pulsed and colour-coded Doppler, or a 5 MHz B-mode real-time linear scanner including a 3.5 MHz pulsed and colour-coded Doppler. The pulsed Doppler was used to identify the common carotid artery (CCA), internal carotid artery (ICA), and external carotid artery (ECA), respectively, from their characteristic Doppler signals. For safe identification of the ECA, tapping on the temporal artery during Doppler examination of the ECA was also performed in all examinations. The vessels were visualised in several sagittal and transverse planes, and the presence or absence of plaques were noted. The colour-coded Doppler was used to localise areas with high flow velocities in the ICA, and the maximum flow velocity then sought and measured carefully with the pulsed Doppler. The angle between flow direction and Doppler signal was carefully corrected, and always kept below 65°. The degree of stenosis in the ICA was determined from the peak systolic velocity according to the equation:

$$y = 0.54 \cdot e^{0.021 \cdot x} \qquad (1)$$

where y = the peak systolic velocity in the ICA in m/s, and x = the degree of stenosis expressed as the diameter reduction in percentage.[12] A Doppler shift of 1 KHz corresponds to a flow velocity of 0.31 m/s. As stenosis below 30% does not increase the flow velocity,[12] the degree of stenosis was considered to be less than 30% whenever plaques were present, the vessel not severely diseased as judged from the B-mode picture, and the peak systolic velocity within normal limits (i.e. below 1 m/s). Whenever the ICA was patent, but the peak systolic velocity was 4.4 m/s or more, the degree of stenosis was estimated at 99%.

A report was made directly after the DS by the technician and one of two physicians for comparison with the CAG, giving information whether the ICA was patent or occluded, and the degree of stenosis in the ICA. Finally a general judgement of the findings was written, and preoperative CAG either judged to be necessary or unnecessary. CAG was judged to be necessary whenever the ICA was found to be occluded on DS, or when the quality of the DS was too poor for accurate interpretation.

Angiography. Fifty-one out of the 162 vessels (31.5%) were examined with arch angiography in right posterior oblique, anterior, and slightly oblique left lateral positions. In the remaining 111 vessels (68.5%) one right posterior oblique arch angiogram was performed, followed by selective common carotid arteriography in anterior and left or right lateral projections. Every carotid artery was thus visualised in three projections. Presence or absence of plaques were noted. The diameter of the stenosis and the prestenotic artery was measured on Digital Subtraction Angiography (DSA) films, using a millimetre scale and magnifying glass. The degree of stenosis was calculated from the radiographic view showing the most severe narrowing diameter reduction as:

$$\text{Diameter reduction in percent} = \frac{(b-a)}{b} \cdot 100 \qquad (2)$$

where a is the smallest diameter in the stenotic zone, and b is the diameter of the normal CCA proximal to the stenosis. All angiograms were reviewed by the same experienced radiologist, who was unaware of the results of the DS.

The equation used in calculation of the degree of stenosis from the peak systolic velocity was originally created with the use of a continuous-wave (C-W) Doppler.[12] We therefore found it of value to test the validity of the original algorithm when used with a pulsed Doppler, as in the present study. Thus the velocities from the present study were fitted to the angiographically measured degree of stenosis, and a new equation created for comparison with the original one.

Statistical analysis

The method suggested by Bland and Altman,[13] where the difference between two measurements is related to the mean value of the measurements was used in the comparison of DS and CAG in Fig. 1. The closest fit between the velocities as measured in the present study and the angiographically measured degree of stenosis was sought with exponential regression function.

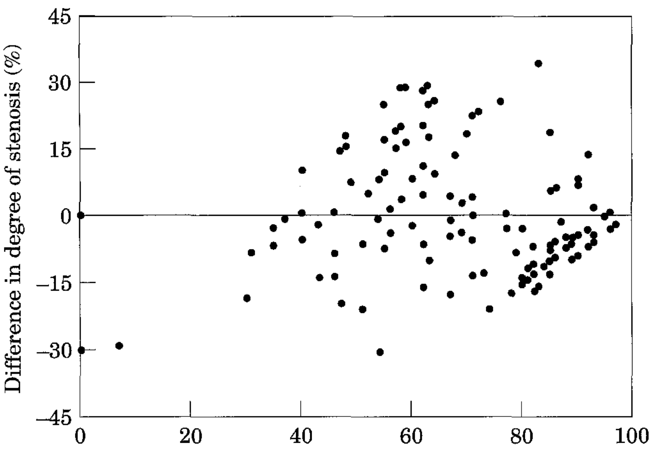

Fig. 1. Difference between the degree of stenosis as measured with carotid angiography and Duplex sonography (vertical axis) related to the mean degree of stenosis by the two methods (horizontal axis) in 131 arteries (the 17 arteries where Duplex gave a degree of stenosis less than 30%, and the 14 arteries where CAG was judged as requested have been excluded).

Results

In 157 of 162 arteries DS correctly demonstrated plaque. In the remaining five arteries, assessed as normal on CAG, DS was normal in three. In the two remaining arteries DS demonstrated the presence of plaque, in one confirmed at surgery as the patient underwent CEA in spite of the normal CAG. Preoperative angiography was recommended in 14 of the 162 arteries examined (8.5%), and in 12 of the 81 patients. In 11 of these 14 arteries the reason was that DS showed ICA to be occluded, which was confirmed by CAG in ten of the 11 arteries. In the remaining three arteries the reason was poor quality DS. In two of these three arteries it was not possible to estimate the degree of stenosis from the DS with accuracy (which were on both sides in the same patient). DS, however, correctly diagnosed the two vessels as severely diseased. In the remaining artery DS estimated the degree of stenosis to be 99% against 95% on CAG. Preoperative angiography was judged unnecessary in the remaining 148 of the 162 arteries examined (91.5%), and in 69 of the 81 patients. In 17 of these 148 arteries plaques were found to be present on DS, but with flow velocities within normal limits (i.e. below 1 m/s), and the degree of stenosis thus estimated to be less than 30%. CAG showed comparable results in three of these 17 arteries. Of the remaining 14 arteries CAG assessed one artery as normal, 10 arteries to have a stenosis between 30 and 49%, and three arteries a stenosis between 50 and 69%. One artery with a soft plaque, causing a severe narrowing of the lumen and a peak systolic velocity of only 0.1 m/s, was correctly assessed as subtotally occluded from the DS.

The difference between the degree of stenosis as estimated on DS and CAG in 131 arteries is given in Fig. 1. The 17 arteries with a stenosis below 30% as determined by DS, as well as the 14 arteries where CAG was judged to be requested, have been excluded. Of the five arteries assessed as normal on CAG, DS was normal in three arteries. Plaques were present in two, with a degree of stenosis of less than 30% in one artery, and of 30% in the other one. In both these arteries the presence of plaque was obvious from the DS examination. As the one patient with 30% ICA stenosis had ipsilateral symptoms, and the plaque appearance was heterogeneous on DS, endarterectomy was performed and the findings from the DS confirmed at surgery.

The original equation (created from measurements with C-W Doppler), and the new equation created from the velocities in the present study (measured with pulsed Doppler), are shown in Fig. 2. The 11 arteries judged as occluded on DS, and the sub-occluded artery with very low flow velocity were excluded when performing the fit between the peak systolic velocities and the angiographically measured degree of stenosis. As seen there is good agreement between the two curves. The new equation created was:

$$y = 0.39 \cdot e^{0.026 \cdot x} \quad (3)$$

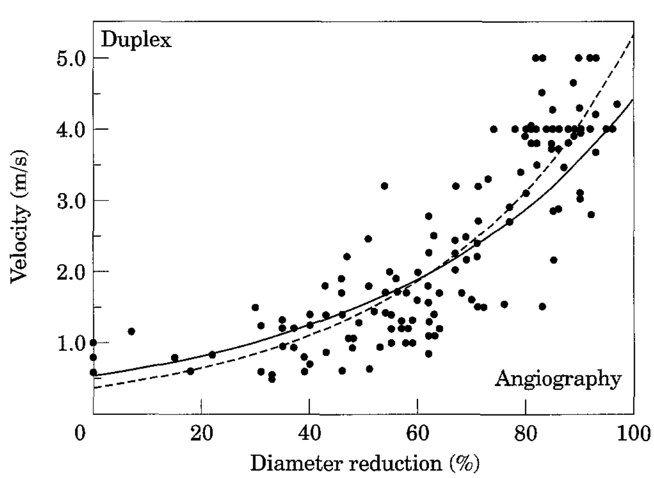

Fig. 2. Comparison between the original equation created with C-W Doppler (---), and the new equation developed from the velocities measured with pulsed Doppler in the present study (—). (●) actual velocities measured, used in creating the new equation. There is a close relationship between the two curves.

Discussion

In the present study DS was assessed as confident in the preoperative evaluation of a great majority of the patients examined, and in none of these patients did CAG result in a change in management. In only 8.5% of all arteries examined CAG was considered necessary, mostly because DS had assessed the ICA as occluded. Thus DS was confirmed as a highly valid method in the preoperative evaluation before CEA, and could safely be used as the sole preoperative examination.

CAG has traditionally been considered as the "gold-standard" in evaluation of extracranial carotid disease before CEA. The method has, however, several major disadvantages, such as risks of complications, patient discomfort, and high costs. An overall incidence of complications of 8.5% has been reported, the most frequent being local haematoma,[8] and an incidence of neurological complications between 2.6 and 4%, and of permanent neurological deficit between 0.33 and 1%.[8,9] Furthermore, CAG gives no information about plaque morphology, a matter of increasing interest. In contrast, DS can be performed without known complications or discomfort, and the method has recently been suggested as the method of choice in the preoperative evaluation of extracranial carotid artery disease. Crew *et al.*[14] reported the results of 65 CEAs performed with DS but without preoperative CAG, and found that the non-invasive assessment correlated well with the findings at surgery. Some other studies have compared the result of DS with a subsiding CAG,[2,4] while others have analysed the consequences of performing CEA without a preoperative CAG at all.[1,3,5,6]

One advantage of CAG, as compared to DS, is the additional information about the arch vessels and the intracranial circulation. However, a study of 1000 angiograms revealed intrathoracic abnormalities in only 1.8%.[15] Of these the majority were suspected because of unequal arm blood pressures, and no unsuspected arch lesion were found to cause symptoms after CEA had been performed. Significant intracranial lesions are also rare, with an incidence of siphon stenosis of 6%, and of intracranial aneurysm of 2%.[16] However, the presence of an intracranial lesion did not alter patient management, and was not related to the incidence of subsequent neurological symptoms or mortality.[17] Thus, the documentation of an arch lesion or an intracranial lesion is not essential, and the presence of an arch or intracranial lesion would rarely alter patient management.

The accuracy of DS is very operator dependent. In a 3 year multicentre study the accuracy was found to improve with increasing experience in all the centres involved.[10] Thus it is necessary to evaluate the quality of DS locally, before performing CEA based on DS alone. In the present study DS was assessed to be sufficient in preoperative evaluation in about 90% of the examined arteries. Of those where CAG was felt to be necessary the reason was ICA occlusion in 11 arteries, and poor quality of the DS in only three. As a comparison, Ranaboldo *et al.*[3] performed CEA without CAG in 45% of 98 patients, but found in the end of the study period CAG to be requested in less than 30%. Dawson *et al.*[4] found CAG unnecessary in 93% of patients, Chervu and Moore[5] in 63%, and finally Horn *et al.*[6] in 67%. The different incidence of CAG in these studies may partly be explained in different experience with the DS method, although difference in patient material and treatment policy might also have played a part. In the present study CAG changed the patient management in only one patient, where DS assessed the ICA to be occluded, whereas CAG revealed an open ICA with a severe stenosis. CAG would, however, have been performed under all circumstances in this patient, as this is our policy whenever the ICA is assessed as occluded on DS. The fact that 10 out of 11 occluded arteries were correctly assessed with DS has not changed our policy on this point. In all patients where DS was judged as confident the operators' findings were consistent with the DS result. On the other hand, one patient assessed as normal on CAG, was operated upon based on the DS examination. As seen in the comparison of the degree of stenosis as measured with DS and CAG in Fig. 1 there are discrepancies which may have several explanations. The angiographic estimation of stenosis is not without difficulties. The estimate is based on the relation between the smallest arterial diameter in the stenotic zone, and the normal vessel diameter. Firstly, this assumes an axisymmetric stenosis, but plaque development is often asymmetric.[18] In contrast, the peak systolic velocity as measured with Doppler is theoretically related to the cross sectional area of the stenosis. Secondly, it is problematic to define the normal vessel diameter angiographically. These factors can contribute to differences in degree of stenosis as measured with DS and CAG, not necessarily in disfavour of DS.

In the present study the smallest diameter in the stenotic zone was compared to the diameter of the normal CCA proximal to the stenosis, as the original equation for calculation of stenosis from the peak systolic velocity in the ICA was created from this comparison.[12] In the North American Symptomatic Carotid Endarterectomy Trial (NASCET) the diameter of the ICA distal to the stenotic zone was used,[19] and in the European Carotid Surgery Trial (ECST) an assumed diameter of the normal carotid bulb.[20] The conclusion of both trials was that patients with stenoses of 70–99% benefit from a carotid endarterectomy. However, as the diameter of the distal ICA is normally smaller than that of the proximal ICA, the angiographically calculated degree of stenosis from the two trials are not equal.[21] All three angiographic methods for estimation of the degree of stenosis have disadvantages, the method used in the present study probably fewest. With the NASCET method, collapse of the ICA distal to a tight stenosis may influence the estimation, and overlapping vessels as well may cause problems. The major disadvantage of the ECST method is the difficulty to assess the bulb lumen. In contrary, the lumen of the CCA is usually well defined, free of overlapping vessels, and seldom affected by severe atheroma. Also, the CCA method is the most reproducible of the three methods.[22] Evaluation of the angiograms performed in the present study by all three methods revealed a close agreement between the method used in this study and the ECST method (mean difference in degree of stenosis 3% ± 6), whereas the agreement to the NASCET method was poor (mean difference 19% ± 12). In 13 of the 162 arteries examined in the present study (8%) DS and CAG disagreed whether the degree of stenosis was at least 70%. Of these 13 arteries, however, seven were in the range of 70–75% stenosis on either DS or CAG. Thus in only six arteries a major disagreement between DS and CAG regarding the 70% limit were seen. In a study of Chicos *et al.*[23] there was disagreement around the 70% limit in 7.5% of examined ICAs, when three observers examined the angiograms (recalculated values). Thus the rate of disagreement around the 70% limit between DS and CAG is in the same magnitude as the interobserver variability in assessment of stenosis on carotid angiograms.

In conclusion DS is a valid method for evaluation of stenoses in the carotid arteries, and could safely be used as the only investigation before CEA in selected cases. When the quality of the DS is poor, or if DS shows occlusion of the ICA, CAG should be performed as well. It is, however, of importance that DS are performed by well-experienced operators with at least 1–2 years of experience.

Acknowledgement

This study was supported by the Faculty of Medicine, Lund University, Lund, Sweden, and the Swedish Medical Research Council (no 00759 and no 00660).

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Accepted 17 January 1996