Clinical Implications of the Doppler Cerebrovascular Examination: A Correlation With Angiography

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SUMMARY A directional Doppler ultrasound cerebrovascular examination was compared with angiographical findings of 152 internal carotid arteries. The Doppler examination was abnormal in 36 of 38 (95%) arteries with occlusion or stenosis greater than 75%. Of 63 arteries with lesser degrees of stenosis, the Doppler examination identified only four. There were no false-positive Doppler examinations. If the decision to perform angiography had been predicated exclusively on the presence of abnormal Doppler findings, 61 of 101 (60%) carotid lesions of potential clinical significance would have been overlooked. While the Doppler ultrasound cerebrovascular examination is the most useful noninvasive technique available for the evaluation of certain specific categories of patients with cerebrovascular disease, the technique is based on hemodynamic alterations of pressure and flow, and cannot be expected to identify the relatively large number of non-hemodynamically significant carotid lesions that are still clinically significant as sources of emboli. This paper illustrates that in the routine evaluation of patients with symptomatic cerebrovascular disease, the Doppler examination should not play a part in the decision to proceed with angiography.

Clinical thromboemboli may originate from plaques which do not significantly narrow the carotid lumen, the clinician must be mindful that some patients with non-stenotic but nonetheless clinically significant lesions will perforce be found to have a normal Doppler examination.

The clinical implications of the Doppler cerebrovascular examination findings in 76 patients referred with suspected cerebrovascular disease, who also had conventional contrast angiography, constitute the basis of this report.

Methods

Patients

The clinical records, Doppler findings, and available angiograms of 227 consecutive patients with symptoms of cerebrovascular disease who were evaluated between January, 1974, and July, 1975, were reviewed for this study. Of this group, both angiograms and Doppler examinations of 76 patients (152 carotid arteries) were available for comparative analysis. There were 75 men and one woman; the average age was 59 years with a range of 43 to 82 years.

Doppler Examination Technique

Our modification of Brockenbrough's original technique of Doppler ultrasound assessment of ophthalmic artery directional flow has been the subject of a prior report.* In brief, this examination was based upon the fact that the ophthalmic artery served as a major conduit of collateral

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flow to the brain, via branches of the external carotid artery in the presence of hemodynamically significant stenosis (> 75%) or occlusion of the extracranial internal carotid artery. Normally, ophthalmic artery flow is out of the orbit through its three main branches (the supraorbital, frontal, and nasal arteries), and this flow can be monitored by means of a directional Doppler ultrasonic velocity detector. In a study of 100 normal subjects, the frontal artery had proved to be the most reliable indicator of ophthalmic arterial directional flow. The classic examination was accomplished by compression of the ipsilateral superficial temporal artery, which normally resulted in augmentation of flow in the frontal (or supraorbital) artery. Hemodynamically significant internal carotid artery obstruction may be associated with reversed flow in the frontal artery, which may be obliterated by superficial temporal artery compression. However, we have found that other branches of the ipsilateral or contralateral external carotid artery (facial, infraorbital) may be sources of reversed ophthalmic artery flow in a significant number of patients — 36% of 61 abnormal Doppler examinations in our series of 454 examinations. Consequently, systematic, selective compression of each of these vessels and transient common carotid compression (to detect intracranial collateral circulation), while simultaneously monitoring flow direction and characteristics at the frontal arteries, constitute the routine Doppler cerebrovascular examination in our laboratory. The overall accuracy of this technique in detecting hemodynamically significant internal carotid artery lesions is 98.7%.4

Utilizing an instrument with directional capability,* Doppler examinations were performed on both carotid systems in each patient, and the results recorded as "normal" or "abnormal" with respect to frontal artery flow direction and source.

### Angiographical Technique

The 76 patients likewise had four-vessel angiography performed by the transfemoral or transaxillary Seldinger catheterization technique. Views were obtained in multiple projections to assure adequate visualization of all brachiocephalic arteries, to allow accurate estimation of the degree of luminal stenosis, and to facilitate assessment of the surface characteristics of visualized lesions, such as irregularity or ulceration. Subtraction techniques were helpful in many instances.

Angiograms were obtained independently and without regard for the Doppler examination findings, on the basis of the usual clinical indications of symptoms, physical findings, and neurological status. For the purposes of this study, the apparent degree of stenosis of the luminal diameter of each internal carotid artery was estimated from the angiograms and assigned to one of four categories: "normal," "less than 75% stenosis," "greater than 75% stenosis," or "occluded." Angiographical interpretations were made without prior knowledge of the Doppler cerebrovascular examination findings.

### Results

Twenty-four internal carotid arteries were found to be occluded on angiograms; the Doppler cerebrovascular examination was abnormal in 23 of these arteries. Similarly an internal carotid artery stenosis greater than 75% of the luminal diameter was determined on angiograms of 14 vessels, 13 of which had a corresponding abnormal Doppler examination. Thus, the sensitivity of the Doppler examination for angiographically occlusive or highly stenotic lesions was 95%.

Sixty-three internal carotid arteries demonstrated angiographical evidence of stenosis less than 75%, but only four of these lesions were associated with a corresponding abnormal Doppler examination. The angiographical estimation of the degree of stenosis of these four lesions was 60%, 50%, 50%, and 30%. It is probable that these represent instances in which the true hemodynamic significance of the stenosis was greater than that implied by measurements taken from the angiograms. The remaining 59 carotid arteries with normal Doppler examinations all harbored lesions of potential clinical significance as sources of cerebral thromboemboli.

Fifty-one internal carotid arteries were normal on angiography, and all of these had a corresponding normal Doppler examination. There were no "false-positive" Doppler examinations (i.e., abnormal Doppler findings in view of a normal angiogram) (table 1).

### Comments

The results of this study confirmed the value of the Doppler cerebrovascular examination as a simple, inexpensive method of noninvasively detecting internal carotid artery lesions of hemodynamic significance (occlusion or stenoses >75%). The sensitivity of the technique in identifying lesions in this category was 95%

It would appear, however, that any attempt to select for angiography only those patients found to have an abnormal Doppler examination would result in the exclusion of a large number of patients with clinically significant and surgically correctable lesions. It has been suggested that the etiology of most transient ischemic attacks and a significant number of strokes may be cerebral thromboemboli emanating from plaques at the carotid bifurcation.1-19 Such lesions may or may not compromise the internal carotid artery to a degree sufficient to alter the pressure-flow relationships inherent in the production of an abnormal Doppler examination. In the present series, angiography demonstrated 101 internal carotid artery lesions of potential clinical significance; of this group, 24 arteries were occluded and, thus, would not be considered "operable" lesions by most vascular surgeons.

<table>
<thead>
<tr>
<th>Internal carotid artery angiogram</th>
<th>No. of arteries</th>
<th>Doppler examination</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>51</td>
<td>51</td>
</tr>
<tr>
<td>Stenosis &lt; 75%</td>
<td>63</td>
<td>59</td>
</tr>
<tr>
<td>Stenosis &gt; 75%</td>
<td>14</td>
<td>1</td>
</tr>
<tr>
<td>Occluded</td>
<td>24</td>
<td>1</td>
</tr>
<tr>
<td>Total</td>
<td>152</td>
<td>112</td>
</tr>
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*Directional Doppler Model 806 (Parks Electronics Inc, Beaverton, Oregon).
The remaining 77 lesions (14 stenoses > 75% and 63 stenoses < 75%) were all amenable to endarterectomy, and yet the Doppler examination was abnormal in only 17 instances. Thus, if the decision to perform angiography had been dictated solely by the Doppler examination, only 22% (17 of 77) of these potentially operable lesions would have been identified.

Several other investigators have reported similar findings in studies involving smaller numbers of patients. LoGerfo and Mason,10 utilizing a somewhat less complete, though similar, Doppler ultrasound technique, found normal Doppler examinations in 16 of 17 instances of internal carotid stenosis. Müller11 found that an abnormal Doppler examination correlated well with internal carotid thrombosis (14 of 15 cases showed reversed frontal artery flow), but only six of 18 stenoses were associated with an abnormal Doppler examination.

While we would disagree with the suggestion that the Doppler cerebrovascular examination may be routinely utilized in deciding whether or not to proceed with angiography,12,13 we do feel that the technique has a definite adjunctive value in the evaluation of patients with suspected cerebrovascular disease. In our experience, it seems to be helpful in five specific areas: evaluation of asymptomatic bruits, assessment before and after carotid endarterectomy, evaluation of ambiguous neurological or cerebrovascular symptoms, evaluation of patients with vertebrobasilar insufficiency, and mass screening of high-risk patients.

The value of "prophylactic" carotid endarterectomy in patients found to have asymptomatic carotid stenosis, prior to aortic aneurysmectomy, has been suggested.14 Since stroke occurring during operations on the abdominal aorta is probably secondary to the transient episodes of hypertension that may occur during these procedures, it would seem likely that the risk is limited primarily to those lesions of hemodynamic significance. Consequently, in the evaluation of asymptomatic carotid bruits found prior to planned major abdominal vascular procedures, it is our current policy to perform cerebral angiography only in those instances in which the cerebrovascular Doppler examination is abnormal. Whether endarterectomy is advisable for other patients with asymptomatic carotid lesions also remains to be clearly established. Some authorities now favor prophylactic operation in carefully selected younger patients with advanced carotid stenosis.1,11 The Doppler cerebrovascular examination appears to be an ideal method of screening these patients, and in deciding whether or not to proceed with angiography.

The Doppler cerebrovascular examination may be of decided value in the preoperative and postoperative evaluation of patients undergoing carotid endarterectomy. Prior to operation, the findings may be helpful in determining the operative priority of bilateral carotid stenoses. It is our feeling that the lesion of greater hemodynamic significance should be corrected initially, assuming that this may enhance the safety of the second procedure. In the postoperative period, normal flow direction in the ipsilateral frontal artery confirms the patency of the endarterectomy. The development of reversed flow, with or without an associated neurological deficit, is a reliable indication of occlusion of the endarterectomized vessel.

We also have found the Doppler examination helpful in the evaluation of patients with vague or nonspecific symptoms, such as headache, dizziness, or syncope, which are not typical of hemispheric or vertebrobasilar insufficiency. In our opinion, the finding of an abnormal cerebrovascular Doppler examination in these patients constitutes a firm indication for cerebral angiography, for such symptomatology may sometimes arise on a hemodynamic basis. As it is unlikely that symptoms of this nature would result from embolic phenomena, we would not be inclined to recommend angiography for this group of patients in view of a normal Doppler examination, unless intracranial pathology was suspected.

In the evaluation of patients with signs and symptoms of vertebrobasilar insufficiency or symptoms compatible with decreased "total cerebral perfusion," the demonstration by the Doppler examination of carotid artery lesions that are of hemodynamic significance has allowed a more confident expectation of improvement with carotid endarterectomy. Doppler ultrasound techniques also have demonstrated reversed vertebral artery flow in patients with the "subclavian steal" syndrome and the correction of abnormal hemodynamics by reconstructive surgery.14

Finally, we feel that the Doppler cerebrovascular examination has a definite investigational role in the screening and subsequent surveillance of the stroke-prone patient. The technique is inexpensive, may be performed repetitively without danger or discomfort to the patient, and is reproducible with regard to the presence or absence of hemodynamically significant internal carotid artery lesions. It is thus uniquely applicable to the task of monitoring the natural history of and the influence of therapy on extracranial occlusive cerebrovascular disease.

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Comparison of Local Blood Flow and Oxygen Availability at the Same Locus in the Ischemic Gerbil Brain

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SUMMARY Oxygen availability (O₂a) and local cerebral blood flow (CBF) as H₂ clearance were measured at the same point, taking advantage of the sensitivity of the platinized platinum electrode to both H₂ and O₂ in gerbils following ischemia made by transient bilateral carotid artery ligations. Both O₂a and CBF were zero during carotid ligation. During postischemic reperfusion there was a qualitative correlation between the two, with a tendency for the O₂a recovery to be less than that of CBF in the first hour and greater in the second hour. These differences in the time course of O₂a and cerebral blood flow may be accounted for by altered oxygen consumption in relation to tissue perfusion, or by altered oxygen sensitivity of the electrode. The results demonstrated the feasibility of making oxygen and flow measurements at the same point in tissue.

Introduction

CONTINUOUS MONITORING of the oxygen reduction current, called oxygen availability, at a chronically implanted polarographic electrode is relatively easily performed and is applicable in studies of regional cerebral vascular hemodynamics. Since it does not depend on indicator clearance, no steady state conditions apply to the measurement, and rapid changes are easy to demonstrate. Users of the method have generally presumed that it might alter oxygen delivery to the electrode. A critical evaluation of this problem has been prevented heretofore by the highly regional nature of the electrode measurement. There could never be assurance that the blood flow and oxygen tension were changing in exactly the same way at two points separated by only a few millimeters. Indeed, in our own work we have found that often they did not.

In this report we present some preliminary observations of flow and oxygen availability estimates made sequentially at the same point, taking advantage of the sensitivity of the platinized platinum electrode to both hydrogen and oxygen. It will be shown that although a qualitative relationship between local flow and oxygen availability is often present in ischemically injured brain tissue, this relationship may be significantly distorted in some cases by states of altered oxygen consumption or of electrode sensitivity.

Methods

Hydrogen/Oxygen Polarographic Cathode

These cathodes were 90% platinum/10% iridium sealed in glass with a bare tip 2 mm in length and 75 μm in diameter. The electrodes were platinized electrolytically in platinum chloride solution. The resulting coating of platinum black greatly increased the catalytic effect on hydrogen oxidation and hence of sensitivity to hydrogen. They were chronically implanted in the animal’s cortex with the glass insulation resting on the dura, anchored rigidly in place with dental acrylic attached to stainless steel screws in the frontal sinus. One electrode was placed in each hemisphere. Five days or more were allowed for tissue healing around the electrode. A separate Ag/AgCl reference for each cathode was placed subcutaneously. The electrodes were polarized at −600 mV, using a circuit similar to that described elsewhere.

For reasons discussed extensively elsewhere, the cathode current which is sensitive to changes in local P0₂ cannot be calibrated quantitatively. Following other users of the technique it was designated oxygen availability (O₂a). Under the conditions of these experiments in the resting, normally breathing gerbil an O₂a current in the range of 0.5 to 2.0 × 10⁻⁴ amp was usually obtained. When hydrogen was given by inhalation, tissue saturation and clearance were made evident by a negative current superimposed on the oxygen current, which was taken as the baseline.

Blood Flow Measurement

Measurements were recorded from each electrode simultaneously on two recorder channels, in order to optimize the baseline, range and sensitivity for oxygen and hydrogen independently. In order to minimize baseline
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