Noninvasive Angiography for the Diagnosis of Carotid Artery Disease Using Doppler Ultrasound (Carotid Artery Doppler)

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SUMMARY To detect stenosis in the carotid artery with a bidirectional continuous-wave Doppler ultrasound device, the following non-invasive procedure, applied on 800 patients and compared with 294 angiograms of 186 patients, has proved to be about 90% reliable. Measurements of flow signals were taken over the terminal branches of the ophthalmic artery (supratrochlear and supraorbital arteries) and averaged. Compression of superficial temporal and facial arteries revealed flow direction and common carotid artery compression revealed the supplying blood vessel and the effectiveness of the circle of Willis. Measurements over the common carotid arteries were used to evaluate peripheral resistance. A set of eight criteria was used; the diagnostic value of each criterion was calculated by comparing 138 pathological Doppler findings in 123 patients with the angiograms. If reverse flow direction in supratrochlear or supraorbital artery was used alone, only 43% correct diagnoses would have resulted. A more severe stenosis is not necessarily correlated with a more weighted criterion; a subset of criteria is less efficient than the combination of all criteria. Application during 32 extracranial endarterectomies on 28 patients informed the surgeon immediately about the hemodynamic effect of the surgical intervention. Rethrombosis was diagnosed in two patients by postoperative Doppler examination.

Introduction

SCREENING METHODS to detect extracranial stenoses of cerebral vessels must fill the diagnostic gap between relatively fallible physical methods such as palpation and auscultation on one hand, and invasive techniques like angiography or xenon clearance on the other. The noninvasive application of bidirectional ultrasound devices has proved to be most promising in detecting these stenoses. These devices allow one to evaluate flow direction and give a semi-quantitative value of instantaneous velocity. Since the precise spatial relation between probe and vessel axis is not known, further maneuvers as part of the investigation are necessary to obtain maximum information. These procedures include compression of one or several feeding vessels while observing the flow reaction as a diagnostic criterion. Thus flow changes in the supraorbital artery on compression of the superficial temporal artery are used in the "Doppler ophthalmic test." Flow decrease in the supratrochlear (frontal medial) artery on compression of either the facial or the superficial temporal artery is well correlated with severe carotid artery obstruction. If reverse flow direction in supratrochlear or supraorbital artery is diagnosed in two patients by postoperative Doppler examination.

Anatomy and Hemodynamics

The ophthalmic artery is normally supplied by the intracranial portion of the internal carotid (fig. 1). Its terminal branches — the supratrochlear and supraorbital arteries (frontal medial and frontal lateral arteries) — anastomose with branches of the external carotid. A watershed exists between the distal ophthalmic branches and the superficial temporal artery in the supraorbital region and infra-orbitally with the facial artery, as well as with external carotid branches of the contralateral side. If an internal carotid artery is significantly stenosed, a pressure difference between internal and external carotid vessels may occur and the watershed may shift toward the intraorbital; thus retrograde flow can occur in the supratrochlear and/or supraorbital artery. The circle of Willis at the base of the brain is the most important communicating system through which pressure differences between the four main cerebral vessels are equalized. It is fully present in only about 25% of all people. If one carotid artery is severely stenosed, normal ophthalmic flow may still be present if the obstruction is compensated from the contralateral carotid or the vertebrobasilar system through the anterior or posterior communicating arteries. Since the internal carotid receives the larger portion of common carotid artery flow, an internal carotid obstruction can lead to markedly decreased common carotid artery flow. Reduced diastolic flow in the common carotid can be correlated with low cardiac output or increased peripheral resistance due to high intracranial pressure, local stenosis, or general diffuse arteriosclerosis.

Apparatus and Basic Examination Technique (Fig. 2)

All examinations are performed on the prone patient. The probe of the bidirectional Parks 806 continuous-wave Doppler device is placed manually over the supratrochlear, supraorbital, and common carotid artery, respectively. The velocity signals which are not quantifiable but correlate with flow (called "flow signals") are monitored by stereo-earphones (acoustic flow signals) and on a three-channel recorder (direct flow signals). Aquasonic 2,000 gel serves for impedance adaptation between skin and ultrasound crystal. Acoustic and direct signals are used as a monitor to bring and hold the probe constantly in optimal position with max-
imum signals seen on the recorder. There is no "standard" position,11 because of anatomical variations. Additional compression tests are important for judging flow direction and the supplying vessel. Flow signals "toward" and "away" from the probe are registered on two separate channels. Average is performed with a PDP-12 digital computer, where the R-peak of the ECG triggers the add-up of each sweep. The R-peak is marked on the third recorder channel. After 20 cardiac cycles the result of the average is displayed on an oscilloscope from which the one with the larger integral (equal to mean flow) may be stored on digital tape for recall and comparison. For comparing small vessels only flow pulse amplitude is used, since diastolic flow has proved to be of no value as a diagnostic criterion. If measurements are taken from the larger cerebral vessels (common carotid or vertebral arteries), however, diastolic flow must be used, since a low value can indicate high peripheral resistance, even though flow pulse amplitude may be normal or increased. For data acquisition from patients during operations an analog tape is used. All functions are controlled by footswitches to leave the hands free for probe placement and compression tests. If both hands are needed for the compressions, the probe is fixed in a clamp held between the teeth.

Examination Procedure, Normal and Pathological Findings

The following set of eight criteria was used for the diagnosis of hemodynamic disturbances in the carotid artery:

1. Reverse flow direction in the supratrochlear artery.
2. Flow pulse amplitude difference between supratrochlear arteries of more than 40%.
3. Reverse flow direction in supraorbital artery.
4. Flow pulse amplitude difference between supraorbital arteries of more than 80%.
5. Pathological flow changes in supratrochlear arteries on common carotid artery compression (homolateral, contralateral, and both).
7. Time delay in rising phase of systolic pulse wave of more than 30 msec (supratrochlear and/or supraorbital arteries with/without compression of external carotid artery branches).
8. Shape of flow pulse in supratrochlear artery (absence of two systolic waves and/or incisura).

The criteria are numbered by their sequence of occurrence during the examination procedure described below. A synopsis of the criteria, normal and pathological (positive) findings are given in figure 3. Typical data obtained from a normal subject are shown in figure 4.

Supratrochlear (Frontal Medial) Artery and Compression of External Carotid Artery Branches

The flow signals are picked up in the medial angle of the eye with the probe in optimal position, averaged synchronously to the R-peak of the ECG, registered on the recorder, and stored. The superficial temporal artery is compressed over the zygomatic processus of the temporal bone, the facial artery over the mandibula before the masseter muscle and, if necessary, the infraorbital artery in the area of the foramen. Reactions to these compressions (homolateral and contralateral as required) are tested. Normally the signals remain constant or increase slightly, sometimes detectable only with stereo-earphones, thus indicating that the vessel is supplied from an intracranial artery. If the increase is well demonstrated on the recorder, another average with compression of the external carotid artery branches can be calculated. In pathological situa-


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<tr>
<th>normal</th>
<th>pathological</th>
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1. Flow signal changes in supratrochlear artery on compression of facial and superficial temporal arteries
   - No change or small increase
   - Decrease or change in direction indicates reverse flow direction

2. Flow pulse amplitude difference in supratrochlear arteries
   - Smaller: larger ± 0.8 to 1.0
   - Smaller: larger < 0.8

3. Flow signal changes in supratrochlear artery on compression of superficial temporal artery
   - Increase
   - Decrease or inversion in flow direction indicates reversed flow direction

4. Flow signal changes in supraorbital artery on compression of superficial temporal artery
   - Increase
   - Decrease or inversion in flow direction indicates reversed flow direction

5. Flow signal changes in supratrochlear artery on common carotid artery compression
   - Ipsilateral compression
   - Drastic decrease with no or small remaining signal (the latter indicates circle of Willis in function, anterior or posterior communicating arteries decompressible with compression of both common carotid arteries simultaneously) or decrease and inversion in flow direction and disapting flow signals after additional compression of internal carotid artery or contralateral common carotid artery
   - No influence or small decrease or inversion from retrograde to physiological flow direction
   - Contralateral compression
   - No influence or small increase (indicates anterior communicating artery in function)
   - Decrease

6. Flow signals of common carotid arteries
   - Diastolic flow at least one uncalibrated unit above zero
   - Diastolic flow near zero

7. Average time delay between R-peak of ECG and rising phase of systolic pulse wave in supratrochlear and supraorbital arteries (comparison of left-right, with-without compression of superficial temporal or facial arteries)
   - Delay difference smaller than 10 msec
   - Delay difference bigger than 30 msec

8. Shape of averaged flow pulse signal of supratrochlear artery
   - 20 years old: 2 systolic waves, average well visible, 1 to 2 diastolic waves
   - 70 years old: 1 systolic wave, smeared or not visible increase, none or one diastolic wave
   - 6 Shape of averaged flow pulse signal of a 20 to 80 year old patient resembles the normal one of a 70 year old person

9. Average time delay between R-peak of ECG and rising phase of systolic pulse wave in supratrochlear and supraorbital arteries
   - Compression

Figure 3. Synopsis of criteria with normal and pathological range for carotid artery diagnosis. (Above baseline = physiological flow direction, below baseline = reverse flow direction.)
CAROTID ARTERY DOPPLER/Keller et al.

velocity flow signals and averages (20 cardiac cycles)

FIGURE 4. Normal findings in a healthy 22-year-old woman. Flow signals from the supratrochlear arteries are symmetrical, and no reactions are observed on compression of external carotid artery branches (2, 4 and 1, 3, respectively). On compression of a common carotid artery, a homolateral amplitude decrease occurs, whereas contralaterally no effect is noticed (5 and 6, respectively). Signals from the supraorbital artery cause flow increase (normal Doppler ophthalmic test). Common carotid arteries show diastolic flow well above zero. AST = arteria supratrochlearis, ASO = arteria supraorbitalis. 1 to 6 = compression localizations (see fig. 1), v = velocity (flow) signals, c = compression phase, I = uncalibrated unit, and t = time.

logical situations flow decrease or inversion of direction may be noted, indicating reverse flow direction. The detection of signals from the supraorbital is more difficult than from the normally stronger supratrochlear artery. There may be interference from branches of the maxillary or superficial temporal artery, thus producing a falsely pathological Doppler ophthalmic test. It must be pointed out that just one branch in the region of the supraorbital fissure with a flow increase during superficial temporal artery compression is sufficient for Criterion 3 to be normal. If the test is pathological, severe stenosis of the internal carotid artery often is found. If the average flow pulse amplitudes of left and right supraorbital arteries differ more than 80%, slightly disturbed carotid artery perfusion may also be suspected.

Supratrochlear Artery and Common Carotid Artery Compression

The next step in the examination is the observation of flow changes in the supratrochlear on compression of the common carotid arteries over two to four cardiac cycles. If the ophthalmic artery is supplied by the homolateral internal carotid, its compression is followed by a dramatic flow decrease. A small remaining signal in the physiological direction indicates that intracranial anastomoses are present. This can be further analyzed by compressing both carotid arteries simultaneously. If the remaining signal does not change, the posterior communicating arteries are more likely dominant; if it disappears, the anterior communicating artery is more likely dominant; if it decreases but does not disappear, both anterior and posterior communicating arteries are likely functioning. Sometimes, flow decrease and inversion of the small remaining signal are observed, usually indicating that external carotid artery branches from the contralateral side are feeding into the ophthalmic artery under the artificially disturbed hemodynamic conditions. The remaining flow signal may cease, if contralateral branches are then compressed in addition, e.g., superficial temporal or dorsal nasal artery. On contralateral carotid artery compression alone a small increase of the flow signal in the supratrochlear artery can be observed, also indicating that the anterior communicating artery is functioning. In pathological situations homolateral carotid compression can increase the flow signal in the supratrochlear artery, produce no change or lead to an inappropriately small decrease in flow signal. When isolated contralateral compression decreases flow signals, this can indicate severe carotid stenosis on the homolateral side, with the cross perfusion via the anterior communicating artery being temporarily interrupted by contralateral carotid compression. Inversion of flow direction during homolateral carotid artery compression with a backshift of the rising phase of the systolic pulse wave toward the R-peak of the ECG also indicates severely disturbed carotid artery perfusion, since in this case the
reduction of peripheral resistance by taking away all homolateral carotid artery branches allows even the reduced ophthalmic artery pressure to perfuse the terminal branches of the ophthalmic artery. If flow inversion occurs during superficial temporal or facial artery compression, then additional homolateral carotid compression may show that the internal carotid is still open, depending on whether the flow amplitude decreases or remains unchanged.

**Common Carotid Artery**

Flow signals from a normal common carotid artery show a diastolic flow well above zero. When peripheral resistance is high due to isolated stenosis or general diffuse arteriosclerosis, diastolic flow may drop to almost zero, thus contributing another diagnostic criterion. Flow pulse amplitude cannot be used, since it may be decreased, normal, or increased not only in the presence of these lesions, but also in the presence of high intracranial pressure. Aortic valve stenosis or insufficiency can also be responsible for low diastolic flow and must be excluded. Significant diastolic backflow is always associated with severe aortic insufficiency.

**Shape of the Averaged Flow Pulse Wave in Supratrochlear Artery**

The averaged flow signals taken from a healthy 20-year-old subject show two systolic waves, an incisura, and one or several diastolic waves. On 70-year-old subjects with no clinical signs of cerebrovascular failure and a normal cardiovascular system just one systolic wave, no incisura, and a small diastolic wave are observed. Thus, the two systolic waves and the incisura seem to correlate with vessel elasticity. If a patient less than 50 years old has a flow signal shape similar to that of a normal 70-year-old person, premature arteriosclerosis must be considered. We therefore use the shape of the averaged flow signal as an "age" parameter of the cerebrovascular system. Absent systolic waves are also seen in abnormal shunt situations, e.g., large arteriovenous malformations shunting from the external carotid artery into the jugular venous system.

**Results**

Carotid artery Doppler was used on 800 patients with symptoms of cerebrovascular failure, often prior to angiography. Of these patients, 186 underwent angiography of the carotid artery: 128 patients on the clinical relevant side, 58 patients on both sides, and five patients a second time after extracranial endarterectomy and suspicion of rethrombosis. Thirty-two extracranial endarterectomies on 28 patients and 12 bypass operations from the superficial temporal or facial artery compression, then additional homolateral carotid artery branches allows even the reduced ophthalmic artery pressure to perfuse the terminal branches of the ophthalmic artery. If flow inversion occurs during superficial temporal or facial artery compression, then additional homolateral carotid compression may show that the internal carotid is still open, depending on whether the flow amplitude decreases or remains unchanged.

**Diagnostic Criteria and Morphological Findings**

Carotid artery Doppler detected 138 pathological flow situations in 123 patients. The corresponding angiograms showed 110 obstructions, 11 processes distal from the ophthalmic artery (selective stenosis of ophthalmic, middle or anterior cerebral artery, persistent primitive trigeminal artery or enlarged posterior communicating artery with shunt into the vertebrobasilar system, and tumors), and 17 processes distal to a cortical branch of the middle cerebral artery were performed.

**Table 1**

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Rank No.</th>
<th>% Positive</th>
<th>% False-positive</th>
<th>% Positive Leading</th>
<th>% False-positive Leading</th>
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<tr>
<td>1</td>
<td>1</td>
<td>17</td>
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<td>4</td>
<td>19</td>
<td>2</td>
<td>3</td>
<td>1</td>
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Calculated from the quotient of "false-positive" and "positive" percent of cases, a lower rank corresponding to a lower quotient. Occurrence of criterion with best rank (percent of cases leading) on a given patient. Derived from 138 pathological Doppler diagnoses in 123 patients, corresponding to 110 obstructions, 11 processes distal to the carotid siphon, and 17 normal angiographical findings. Criterion 2 was present in 64% of the cases including 15% with false-positive findings compared with angiography, and in 33% of the cases, it was the criterion with best rank on a given patient including 11% with false-positive findings.

**Figure 5.** Frequency of occurrence and diagnostic rank of the individual criteria used in carotid artery Doppler. Derived from 138 pathological flow situations in 123 patients with the morphological findings taken from the angiograms. Criterion 2 occurred in 64% of cases corresponding to 11% occlusions, 14% filiform stenosis, 24% stenosis of moderate degree, and 15% without angiographical findings (see table 1).
Carotid Artery Doppler Compared With Angiography

Findings of 191 angiograms from 186 patients (five patients with second angiogram after extracranial endarterectomy) are correlated with Doppler findings in table 3. Ninety-five obstructions (26 occlusions, 26 filiform stenoses, 23 stenoses of moderate degree, 11 multiple plaques, and nine kinkings) showed positive Doppler criteria, while in 52 patients both Doppler results and angiography showed undisturbed hemodynamics. Eleven times a process distal to the carotid siphon was diagnosed by Doppler and not verified by angiography; nine times such a process was present without any positive Doppler findings, 11 times there was no angiographical verification of a process proximal to the carotid siphon diagnosed by Doppler, but on some of these angiography was done only in one plane. One occlusion and 12 stenoses (three filiform, four multiple plaques, and three kinkings) had no Doppler criteria in the pathological range. Thus, correspondence with the angiographies was observed in 82% to 87% of cases, depending on where the 11 predicted processes distal from the carotid siphon were enrolled (false-positive, not used, positive). A comparison of angiograms and Doppler findings in patients with angiograms of both carotid arteries shows that 69% to 86% of lesions could be predicted correctly by Doppler, depending on whether the patients with disturbed carotid artery perfusion on both sides and no pathological Doppler findings in the less affected vessel are taken as false-negative or positive ("fair" correlation, table 4).

Carotid Artery Doppler During and After Extracranial Endarterectomy

After preparation of the carotid bifurcation the flow signals in the homolateral supratrochlear artery are measured. This is repeated after implantation of an internal shunt and after reclosure of the vessel. In this manner the surgeon is informed immediately about the effect of his intervention. Postoperative Doppler examinations reveal short-term and long-term hemodynamic effects of the surgery when compared with preoperative and intraoperative results. An immediate intraoperative increase of ophthalmic artery perfusion was observed in 23 of 28 patients, indicating...
TABLE 4  Reliability of Carotid Artery Doppler Versus Angiography (58 Patients With Angiograms of Both Carotid Arteries)

<table>
<thead>
<tr>
<th>Doppler findings</th>
<th>Morphological findings</th>
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<tbody>
<tr>
<td>Stronger affection</td>
<td>Weaker or no affection</td>
</tr>
<tr>
<td>15 affections on both sides</td>
<td>+</td>
</tr>
<tr>
<td>12 affections on one side only</td>
<td>+</td>
</tr>
<tr>
<td>10 affections on both sides, weaker one not diagnosed</td>
<td>+</td>
</tr>
<tr>
<td>13 without morphological affections on both sides</td>
<td>−</td>
</tr>
<tr>
<td>4 positive Doppler findings without morphological correlate</td>
<td>+</td>
</tr>
<tr>
<td>3 negative Doppler findings on both sides with morphological affections on both sides</td>
<td>−</td>
</tr>
<tr>
<td>1 negative finding on both sides with morphological affection on one side</td>
<td>−</td>
</tr>
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Minimal correlation: 40/58 = 69%; "fair" correlation: 50/58 = 86%. + = pathological Doppler or angiographical findings, − = normal Doppler or angiographical findings.

Twenty-eight patients had obstructions in both vessels.

that carotid artery perfusion must have increased as well. The findings persisted or increased even more during postoperative recovery. Two patients showed pathological Doppler criteria again on the first and third postoperative days, respectively. Suspicion of rethrombosis was confirmed in both patients by angiography and corrected by a second operative intervention. Five patients did not show an intraoperative increase of flow, either with the internal shunt or after reclosure of the vessel. In two of these patients a shift toward normal carotid artery perfusion was observed 24 hours later. In the remaining three patients no increase was noticed, and subsequent angiography in this group showed a good perfusion of the operated vessel, but poor filling of all vessels distal to the carotid siphon.

Carotid Artery Doppler and Bypass Operation

In 12 patients with nonoperable high-grade stenosis or occlusion of the carotid artery within the petrous bone or...
carotid siphon a bypass operation between superficial temporal and a cortical branch of the middle cerebral artery was performed. Six patients showed a discrete postoperative change in ophthalmic artery perfusion. In five cases the reverse flow direction observed preoperatively in the supraorbital artery changed to normal. In one patient with reverse flow direction in the supratrochlear and a preoperative flow decrease on facial artery compression, an inversion to physiological flow direction under the same compression maneuver observed after surgical intervention.

Demonstration of a Typical Case

Figure 7 shows the Doppler findings in a 51-year-old woman with hypertension, diabetes, obesity, and hyperlipidemia, who had a stroke with paresis of the left arm. Under physiotherapy recovery was rapid, and after a month only mild clinical symptoms of cerebrovascular disturbance were present. Carotid artery Doppler then indicated severe obstruction in the right internal carotid artery with Criteria 2, 4, and 5 being abnormal. The shape of the flow pulse wave showed no systolic waves and no incisura, so that premature arteriosclerosis also was suspected. Angiography revealed a high-grade stenosis of the right internal carotid just distal to the bifurcation. It was thought that surgical intervention might prevent an additional stroke. After preparation of the carotid bifurcation and implantation of an internal shunt, perfusion in the right supratrochlear artery increased immediately, was again reduced somewhat after reclosure of the vessel (probably due to a drop of blood pressure), and reached an amplitude similar to that with the internal shunt during postoperative recovery (fig. 8). All Doppler criteria with the exception of No. 8 have been normal since operation and no new stroke has occurred within the last two years.

Discussion

Carotid artery Doppler as a noninvasive and fast examination method allows detection of hemodynamically significant obstructions (occlusions, filiform or moderate-grade stenoses) in the carotid artery between its intrathoracic origin and the branching of the ophthalmic artery intracranially with about 90% reliability. Almost the same accuracy can be expected when bilateral occlusive disease occurs. When Criterion 1 or 6 was positive, Doppler diagnosis always was correct (20% of cases). Criteria 3, 5, and 7 are of approximately equal value, having a high probability of correlation with morphological findings (43% of cases including 6% false-positive cases). Criteria 2 and 4 gave merely an indication that hemodynamics in the internal carotid artery were out of the normal range (37% of cases including 14% false-positive cases). When three or more positive criteria were present on a given patient, Doppler diagnosis also was always correct (21% of cases). A more severe stenosis is not necessarily correlated with a better ranked criterion, e.g., Criterion 2 (Rank 6) alone was found to be positive on 3% of patients with filiform stenoses or occlusions. There seems to be a good correlation between diagnostic rank of a criterion and the degree of an obstruction, but there is little correlation between the degree of a stenosis and the occurrence of any particular criterion. This can be explained by the physiological experience that not only the degree of stenosis but also the function of the circle of Willis and the control capability of the cerebrovascular system are responsible for the compensation mechanism. The interpretation of the criteria is also influenced by the patient's age, history, and clinical picture, especially in those cases with weak-positive criteria. In a differential diagnostic scheme a negative result can be used in the "per exclusionem" sense. Doppler examination can provide answers to the following questions:

1. Are transient or established symptoms of cerebrovascular failure caused by a carotid artery stenosis?
2. What is the hemodynamic significance of an extracranial stenotic murmur with or without cerebral symptoms?
3. What is the hemodynamic effect of an extracranial endarterectomy (both intraoperatively and for postoperative follow-up)?
4. Are there "silent" stenoses (e.g., found during a general checkup or before an endarterectomy of other vessels)?

Since false-negative results may occur, angiography is always indicated, when the clinical history and examination
strongly suggest cerebrovascular failure and the patient's condition permits further therapy. Angiography is also necessary to localize an obstruction to decide about the operative procedure.

Single or a subset of criteria is obviously less sufficient for proper diagnosis than the combination of all eight, especially if those of better diagnostic rank are eliminated. If reversal of flow direction in supratrochlear or supraorbital artery is used as diagnostic criteria alone, only 43% correct diagnoses resulted in our series (i.e., 25 instead of 32 occlusions, 21 instead of 31 filiform stenoses, and 13 instead of 47 other than filiform stenoses). This is less than other authors have described11, 14, 16, 26 and may once again be explained by the fact that not only the degree of a stenosis but also the function of the circle of Willis are responsible for the compensating mechanism.19, 28 Common carotid artery compression provides very reliable information (Rank No. 3) not only in those cases with stenotic processes, but also with intracranial anastomosis and shunts. Elimination of carotid artery compression would certainly diminish the value of the method. Since mechanical loosening of a thrombus might occur, however, it is not without risks. If there are enough indications for a stenosis from other criteria, this compression test is not necessary (three or more other criteria fulfilled, reverse flow in supratrochlear artery, or low diastolic flow in common carotid). We have applied common carotid artery compression over two or four cardiac cycles on 2,000 patients since 1970 and observed three minor complications in the form of transient ischemic attacks with the symptoms disappearing after 20 minutes. Tooze et al.27 did not notice any severe complication with the carotid compression test under EEG control on 2,500 patients. To avoid bradycardia or other rhythm complications, only partial compression is performed initially. When a frequency alteration occurs, compression is attempted further proximally, and when no change in heart action is observed, full compression is performed.

The question arises whether Doppler examination has a place in the management of patients with transient ischemic attacks (TIA). Since angiography should be performed whether or not the patient is in a state where endarterectomy is justifiable, any "screening" method can be omitted. However, since not every TIA is a consequence of a lesion in the extracranial internal carotid artery, we feel more justified in performing angiography knowing about impaired carotid hemodynamics. We are sometimes reluctant to perform angiography when Doppler results are within normal range. Furthermore, if the patient is operated on, preoperative as well as intraoperative findings are important to evaluate the effect of surgical intervention and to detect postoperative complications such as early or late rethrombosis.26

Some authors deny any screening value of carotid artery Doppler because periodic Doppler examinations do not prevent a possible stroke.28 Low-grade stenosis cannot be diagnosed and can still be the source of an embolus. Even medium-grade stenoses are found with only about 90% probability. Failure is possible particularly in those cases with multiple lesions, e.g., high-grade stenosis of the internal carotid in combination with occlusion of the middle or anterior cerebral arteries. Thus the method is not infallible. Nonetheless, in comparison with other noninvasive techniques (thermometry, ophthalmodynamography, brain scintigraphy) it is one of the best methods for detecting carotid artery stenosis when preventive treatment is still possible. If Doppler findings point strongly to a hemodynamic disturbance even in the absence of clinical symptoms or a typical history, we often perform angiography.6, 29 On the other hand, a firm diagnosis can be made in situations where angiography is contraindicated at the time. If a patient deteriorates after heart surgery or a cerebrovascular operation in spite of normal Doppler findings, the postoperative complications can be interpreted more precisely by excluding rethrombosis without a second angiogram and reoperation.

Mol and Rijcken28 discussed further criteria (ratios of flow pulse amplitude to end-diastolic value in the common carotid, or of amplitude of common carotid to amplitude of supratrochlear artery flow). In our experience these criteria do not add to the diagnostic reliability of our procedure, especially since variations are observed when the probe is pressed with different force against the skin, which sometimes cannot be avoided. Furthermore, we do not believe that selective measurements over internal and external carotid arteries in the bifurcation area can be made with sufficient accuracy concerning the spatial relationship between probe and vessel.29 It is not possible to insure that measurements are taken from the target vessel, since anatomical variations in location of the bifurcation and in the branching direction of the internal carotid are considerable, thus often providing false results.11 We feel, therefore, that pulsed Doppler devices offer greater promises than continuous-wave units in developing criteria for quantifying the degree of "low diastolic flow" in the common carotid artery.30, 81 Furthermore, there is no need to measure several vessels simultaneously, since the "physiological" state of a patient hardly changes so much that criteria may change from normal to pathological during an examination.

A bypass operation between the superficial temporal and middle cerebral artery does not necessarily change the hemodynamics in the distant ophthalmic artery.32 Since a relatively small vessel is used, local hemodynamics may change significantly while no effect is observed in the ophthalmic artery or its terminal branches. Nevertheless, in five patients with reverse flow direction in the supraorbital artery before operation, a normal Doppler ophthalmic test in the postoperative recovery phase was found. Thus a hemodynamic equilibrium of low stability could be postulated, so that a small intracranial change in blood pressure led to a change in ophthalmic artery perfusion, and part of the "watershed" was shifted out of the orbit. However, carotid artery Doppler is not an adequate method to assess the positive hemodynamic effect of this operation. If the probe is placed on the bypass itself, more information could probably be obtained on the flow situation.

Carotid artery Doppler in its present state does not replace angiography, since exact localization of an obstruction is beyond its range. Exact localization probably will be possible in the near future by Doppler angiography.82 The examination requires experience not only in signal interpretation but also in positioning of the ultrasound probe over small and large vessels. Good knowledge of cerebro
vascular anatomy and pathophysiology is necessary to avoid overinterpretation and misinterpretation. If these conditions are fulfilled, it is a valuable noninvasive method which facilitates the decision for or against angiography in critical cerebrovascular situations and in evaluation of the undiagnosed patient. It helps to judge the effect of an extracranial endarterectomy and to detect a postoperative complication before its clinical manifestation. It is especially reliable when the same investigator does the entire examination on a given patient. The examination is quickly performed (average, 20 minutes). If applied in everyday routine checkups in the way blood pressure measurements are used, many potential stroke patients could be diagnosed and treated appropriately before a stroke or even a TIA occurs.20,94

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