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Noninvasive Techniques in the Evaluation of Arterial Disease

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This paper reviews noninvasive technology currently being applied in clinical peripheral vascular laboratories for the evaluation of obstructive arterial disease in the lower extremities and in the cerebral circulation. Lower extremity, arterial insufficiency can be assessed by pressures measured with a Doppler flowmeter or by oscillometric tracings obtained with a Pulse Volume Recorder. Carotid artery stenosis is studied by: 1) ocular pneumoplethysmography, which indirectly measures ophthalmic artery pressure; 2) oculoplethysmography, which compares pulse arrival time at the two eyes; and 3) the Doppler ophthalmic test, which detects the flow pattern in the ophthalmic artery. The main uses of the tests are to evaluate asymptomatic carotid murmurs, to screen high risk groups, and to aid postoperative follow-up.

Introduction

THE development of noninvasive diagnostic procedures represents a major step forward in the evaluation and management of arteriosclerosis obliterans. Although contrast angiography remains the best way of anatomic visualization, the new techniques provide supplemental physiological data previously not available. The modern hardware provides the clinician with sensitivity of detection and recording capabilities previously found only in sophisticated research facilities.

Lower Extremity Examination

Doppler flowmeter

The development of the Doppler ultrasound velocity detector or flowmeter has been the most important step in modern instrumentation for peripheral vascular diagnosis.[1] A narrow ultrasound beam (5-10 MHZ) is generated by the probe and penetrates fluid and tissues. When the signal is reflected off stationary cells, the returning beam has the same frequency as the original, which produces cancellation in the electronic circuit. But when the beam is reflected by moving red blood cells in a vessel, there is a resulting shift in frequency proportional to the velocity of the cells (the Doppler principle). The meter detects the change in frequency and converts it to an audible sound, the pitch of which is proportional to the velocity. It is possible to obtain a graphic tracing with any type of chart recorder. Some Doppler flowmeters are capable of differentiating flow toward and flow away from the probe.

The gradient or decrease in pressure produced by a lesion is the parameter most frequently studied in the evaluation of occlusive arterial disease. After blood pressure cuffs have been applied at the thigh, the upper calf, and ankle, pressures are measured at these levels, using the Doppler flowmeter to detect the systolic endpoint when blood starts to move beyond the cuff. The resulting pressure values are then compared with the brachial pressure (where arm

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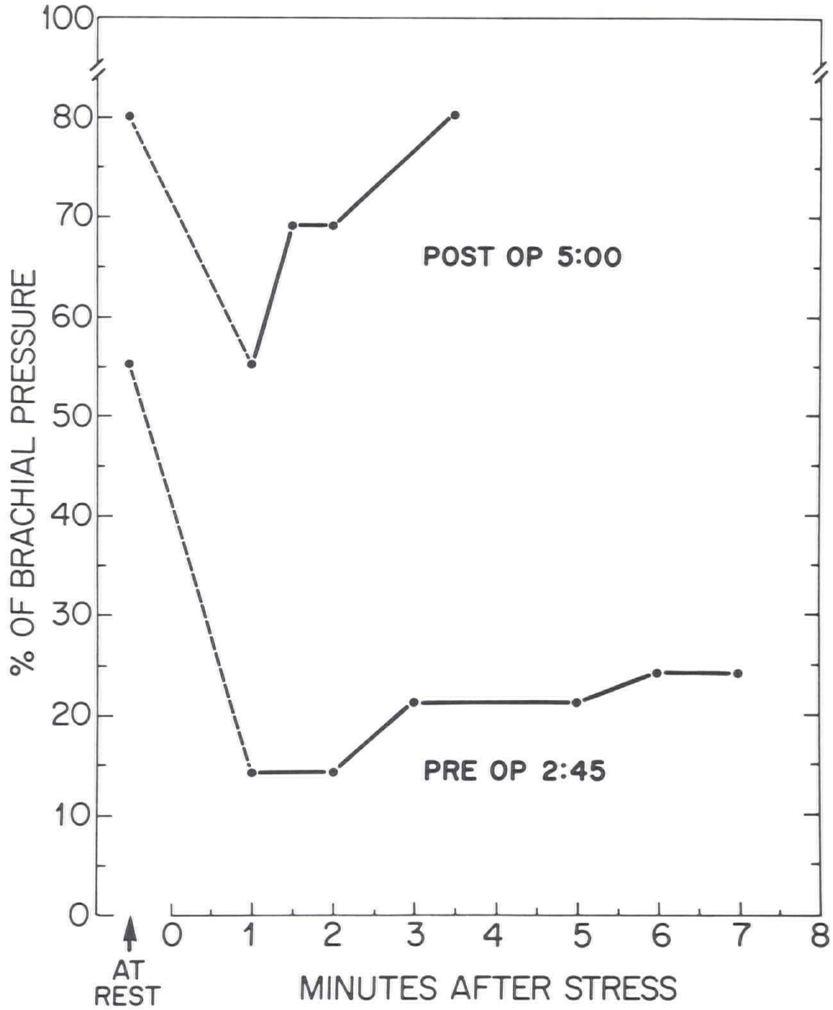

Fig. 1
Stress testing: Changes in ankle pressures after exercise.

pressures are different, the higher value is used). While results can be expressed as absolute values, it is more meaningful to use the ratio of extremity pressure to systemic pressure, often referred to as the ankle / arm index. In normal subjects the ratio obtained at the thigh is somewhat above 1.0 due to artifacts induced to discrepancy between cuff size and thigh size. Below the knee the ratio should be approximately 1.0. With increasing stenosis there is a greater gradient measured and a lower index. A decreased pressure in the thigh indicates occlusive disease at the aorta, iliac, or femoral level. Pressure drops across the knee or between upper and lower calf indicate sites of stenosis between the points measured.

The resting pressure measurements described above are clearly abnormal in patients with severe occlusive disease. However, there is a significant group of patients with complaints of claudication in whom resting pressures are borderline. These patients have lesions which do not interfere with resting flow but which limit the increase required by exercise.If ankle blood pressures are measured following exercise, there is usually a significant drop and a slow return to resting pressure. Both the degree of pressure drop and the duration of recovery correlate well with the degree of proximal stenosis. By contrast, normal subjects show little, if any, decrease in ankle pressures following moderate degrees of exercise. Figure 1 shows the changes in ankle pressure in a patient with severe iliac stenosis. The preoperative values show marked pressure drop with prolonged recovery. After an aortofemoral bypass, the decrease is much less with a return to resting levels in four minutes. (The postoperative curve is abnormal due to an uncorrected superficial femoral artery occlusion.)

Other techniques

Other types of instrumentation can be used to determine systolic endpoint in the measurement of extremity pressures. The mercury strain gauge consists of a very thin, elastic, mercury-filled tube placed around the extremity distal to the cuff. The slight volume increase produced by systole stretches the tubing to produce a change in the electrical resistance, which is detected and recorded. Photoplethysmography detects the pulsatile subcutaneous flow by the reflection of light off the blood in the cutaneous tissue. These two techniques are somewhat more complicated than the routine Doppler examination since they both require recordings.

Pulse Volume Recorder (PVR)

The Pulse Volume Recorder (PVR) developed by Darling and Raines[2] is a different approach to lower extremity evaluation using a sensitive recording oscillometer attached to a pneumatic cuff. Its most important feature is the standardized calibration which permits different tracings to be compared directly. Recordings are made at the thigh, upper calf, and ankle. Amplitude and pulse contour are the main parameters evaluated. The method provides an accuracy of assessment of arterial stenoses comparable to the pressure measurement techniques described above. The PVR is superior in the case of extemely stiff walled vessels which cannot be collapsed by the pressure cuff. In this situation indirect pressure measurements cannot be made, but the oscillometric recording provides a suitable assessment.

The noninvasive assessment of lower extremity arteries provides a useful clinical adjunct, particularly in the following areas:

1. Quantification. Most important when the patient will be followed by different examiners.
2. Functional evaluation. Stress testing can give objective information to indicate whether complaints are related to arterial insufficiency.
3. Postoperative monitoring for patency of reconstruction.

Extensive work is being done to develop noninvasive techniques for the following: 1) objective determination of level of leg amputations; 2) evaluation of functional significance of iliac stenosis; and 3) evaluation of runoff in cases considered for infrapopliteal bypasses.

Cerebrovascular Examination

Ocular pneumoplethysmography

Ocular pneumoplethysmography was developed by Gee and his associates[3] as a noninvasive method for assessing

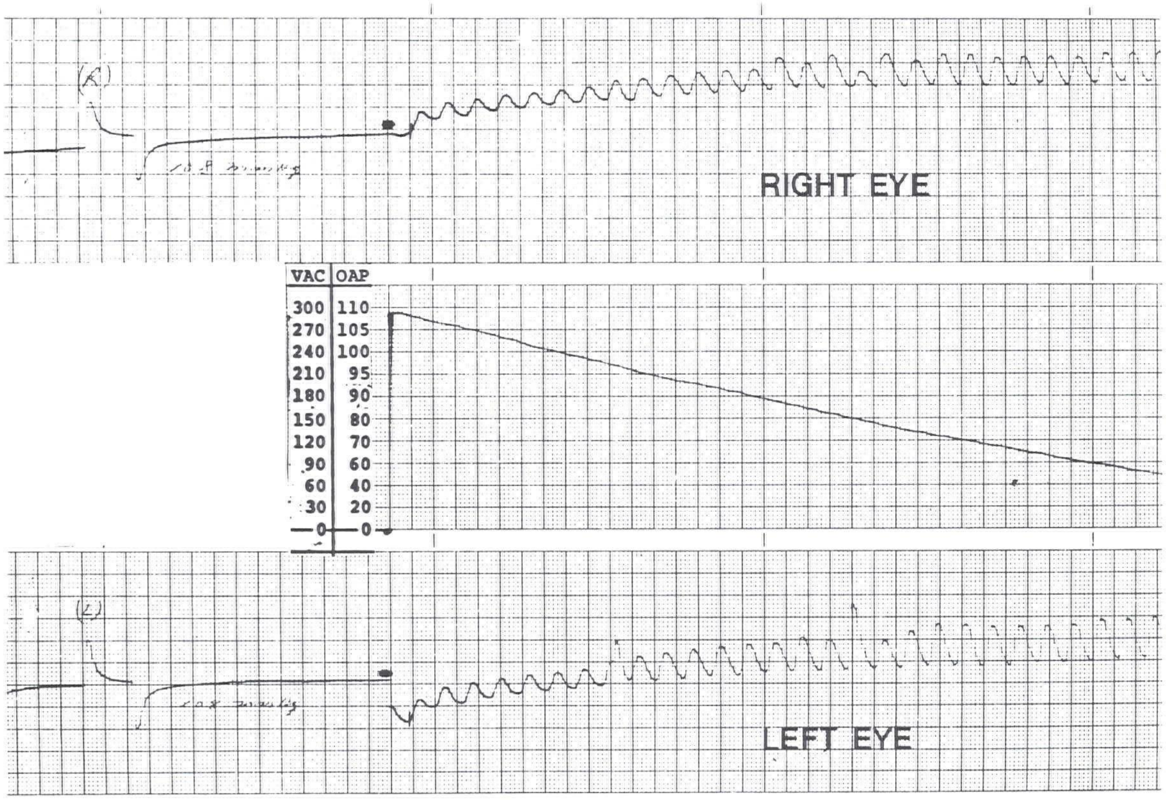

Fig. 2
Ocular pneumoplethysmography: Normal study.

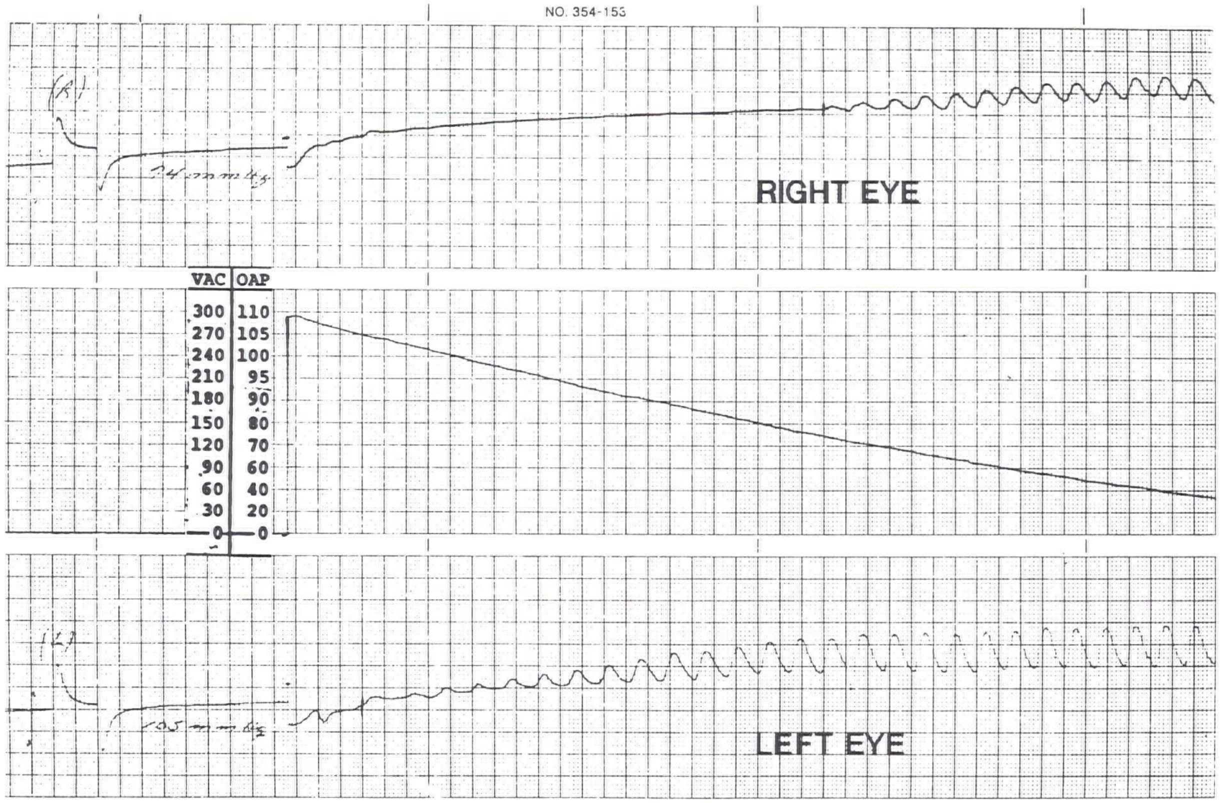

Fig. 3
Ocular pneumoplethysmography: Abnormal study: right internal carotid stenosis.

carotid artery stenosis, based on the indirect measurement of ophthalmic artery pressure. Small plastic suction cups applied to each sclera cause a deformation of the globe with increasing intraocular pressure, proportional to the amount of suction applied. Each cup is connected to a transducer which detects ocular pulsation. When the suction is increased to 300 mm Hg, the arterial pulsation to the eye is obliterated in normotensive patients. The machine automatically decreases the suction over a 30-second interval during which pulse recordings are made from both eyes. The systolic endpoint is defined as the pressure at which pulsation is first detected. The correlation between the amount of suction and the corresponding ophthalmic artery pressure has been determined and a conversion scale developed. The device itself is simple to operate, and in our lab the tests are routinely performed by a nurse.

Figure 2 demonstrates a recording from a normal subject. The right and left eye pulse curves are symmetrical and appear simultaneously at a pressure of 108 mm Hg. Figure 3 shows a typical abnormal recording with a pressure of 108 in the right eye but only 99 in the left eye. While some groups record ophthalmic artery pressures during external compression of the common carotid artery, this has not been a part of our routine testing. A discussion of this added modality is found in the article by Gee.[4]

Early results in applying the Gee test yielded 75-80% accuracy in correct detection of significant, internal carotid stenosis, although other groups using the technique have reported lower accuracy of results. The primary cause for variability in the results has been the difference in criteria of abnormality. After an extensive review of our experience with the technique at UCLA, it was evident that some of the errors resulted from bilateral lesions which produced decreases in both ophthalmic artery pressures. This led to evaluation of the ratio of ophthalmic artery pressure to systemic pressure, which was defined as the higher brachial artery pressure. As a result, we now have three criteria for abnormal records: 1) 5 mm Hg or greater asymmetry between ophthalmic artery pressures; 2) 1-4 mm Hg asymmetry and a ratio of ophthalmic to brachial pressure of less than 66%; 3) no OAP asymmetry but a ratio of less than 60%. With these new criteria, it has been possible to achieve 92% accuracy in correct identification of significant stenosis (more than 60% reduction of lumen diameter on the angiogram).[5]

Oculoplethysmography

A second approach to noninvasive evaluation of the carotid system is Kartchner's oculoplethysmography,[6] which detects the arterial pulse wave at each eye by fluid filled cups

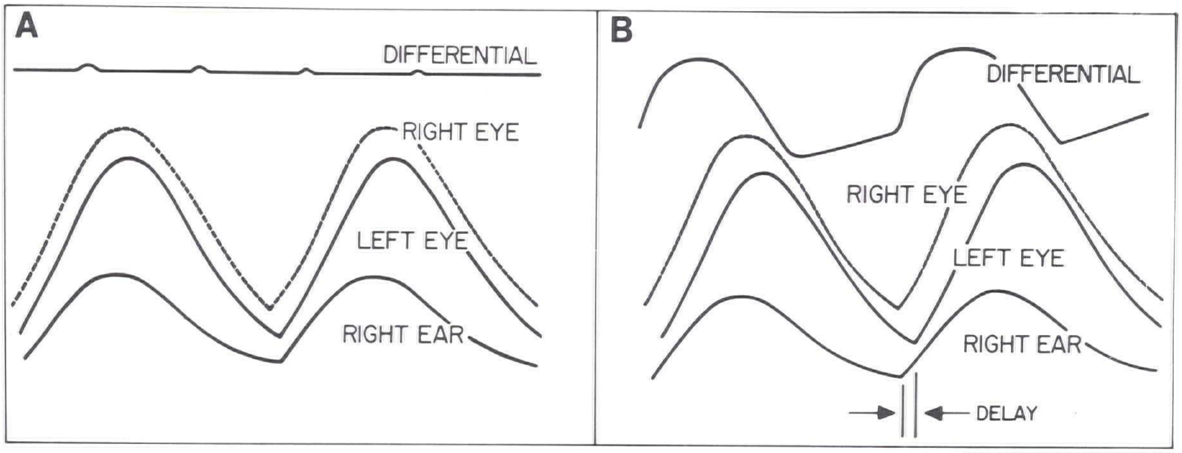

Fig. 4
Oculoplethysmography: A. Normal study; B. Abnormal: left internal carotid stenosis.

attached to sensitive transducers. The recorder gives high speed tracings of the ocular pulse waves, and increased sensitivity is provided by an additional tracing which represents the difference between the signals from the two eyes. Simultaneous evaluation of the external carotid system is obtained from a reading of the pulse recorded at the earlobe by a photoelectric cell sensor. The method is simple, well tolerated by the patient, and can be performed by a technician or nurse.

The technique is based on comparison of the pulse arrival times at the two eyes. In the presence of stenosis there will be

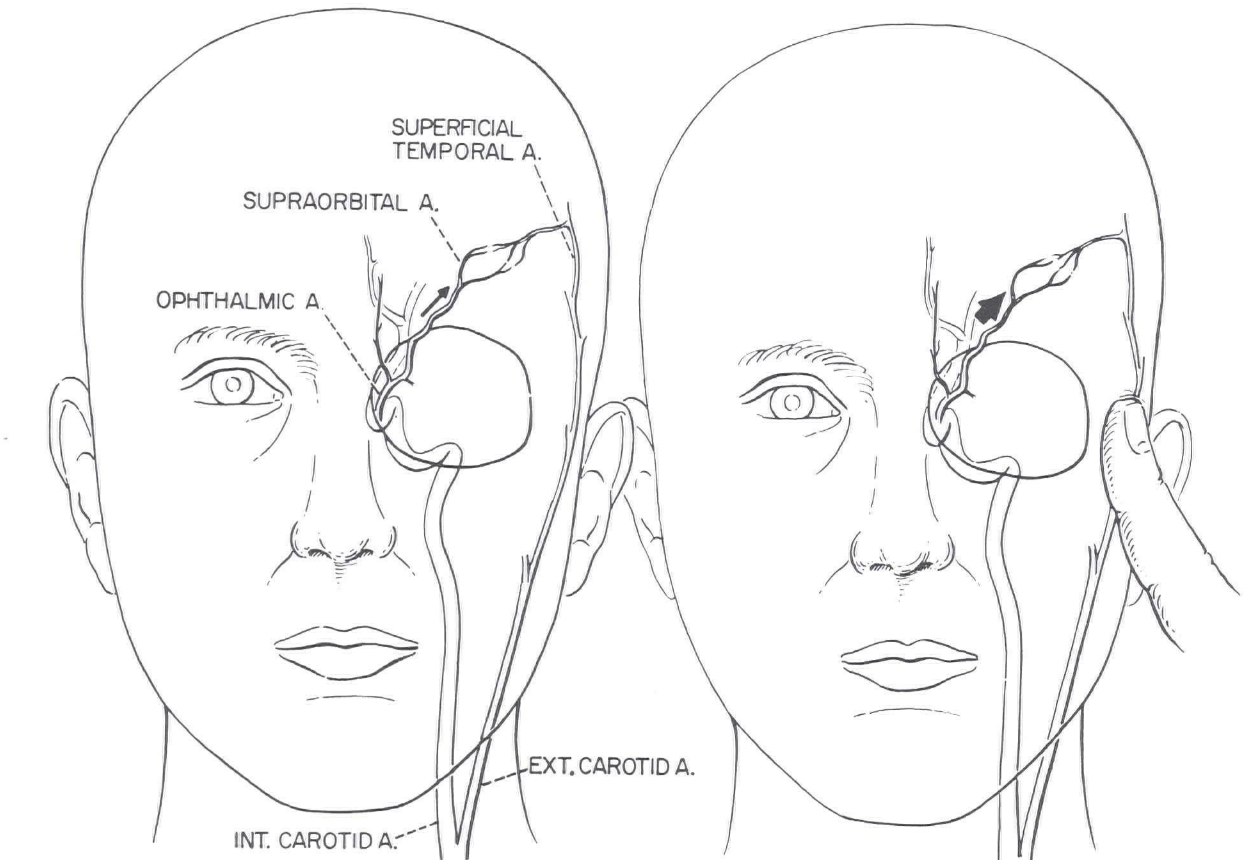

Fig. 5
Doppler Ophthalmic Test: Normal pattern.

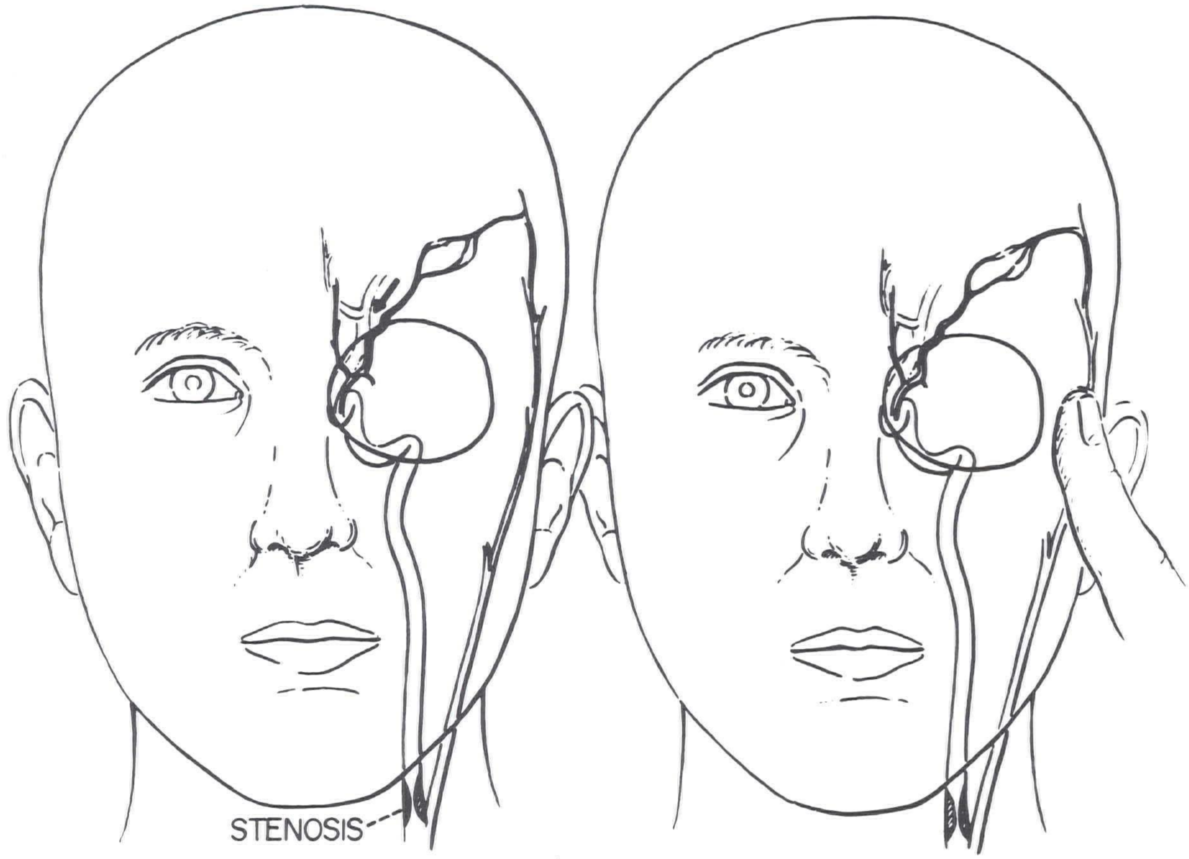

Fig. 6
Doppler Ophthalmic Test: Abnormal pattern.

a delay in the systolic peak on the affected side. With lesser degree of stenosis, the difference in tracings from each eye will be too small to detect by comparing the two tracings, but the differential signal will reflect an abnormality. With more than 70% reduction in lumen diameter, the delay is sufficient to produce a visible difference between the two ocular pulse curves (Figure 4). In the case of bilateral severe lesions there may be no significant difference in pulse arrival times, but there would be a delay in reference to the ear lobe tracing. Kartchner has demonstrated that with experience in interpreting the tracings it is possible to achieve 90% accuracy in correct identification of significant carotid stenosis.

Doppler ophthalmic test

The Doppler ophthalmic artery examination developed by Brockenbrough[7] is based on the fact that the ophthalmic artery serves as a collateral in the presence of major internal carotid stenosis. With the patient supine, the Doppler probe is placed over the supraorbital artery and positioned for an optimal signal. The ipsilateral superficial temporal artery is compressed and the change in signal noted. In the normal patient there is flow to the forehead from both the supraorbital and temporal branches, and with compression the supraorbital flow will remain the same or increase moderately (Figure 5). However, in the presence of reduced internal carotid artery pressure there will be collateral flow from the superficial temporal to the ophthalmic and into the distal internal carotid. In this case, the compression maneuver obliterates the collateral path and causes decrease or stoppage of the supraorbital flow, which can be detected with the Doppler meter (Figure 6).

Because the ipsilateral supraorbital artery is a major collateral in a large portion of carotid stenoses, many investigators limit the examination to superficial temporal artery compression. However, more recent studies have shown that the major collateral to the ophthalmic can come from infraorbital or facial arteries. Barnes[8] reported only 64% accuracy when the exam was limited to superficial temporal compression, but 98% accuracy when sequential compression of the temporal, infraorbital, facial, and common carotid was performed. Probe position is very critical. Proper performance of the test requires considerable experience, and the accuracy depends primarily on the skill of the person performing the test.

The three noninvasive techniques for cerebrovascular evaluation measure different changes produced by major car-

NONINVASIVE CEREBROVASCULAR EXAMINATION

Technique	Parameter Measured	Limitations	Test Administration	Equipment Cost
Ocular pneumoplethysmograph (Gee)	Ophthalmic art. pressure	Cannot use with BP 160.	Simple	$6800
Oculoplethysmography (Kartchner)	Systolic peak arrival time	At least one carotid branch must be normal.	Simple	$6700
Doppler exam	Collateral flow pattern	Accuracy highly dependent on skill of person performing test	Complex testing routine required for maximal accuracy	$850

otid stenosis or occlusion. The accompanying table compares the features of the systems. The major limitation of all three is that they identify only significant stenosis, but are of no help in identifying lesser obstructions which may be the source of platelet emboli. However, the noninvasive methods are not primarily intended for evaluation of symptomatic patients, who, under most circumstances, are candidates for surgery and should have angiography. The primary uses for the noninvasive studies are: 1) evaluation of the asymptomatic bruit; 2) screening of high risk groups; and 3) postoperative follow-up.

Discussion

The noninvasive techniques reviewed provide quantitative measurements which extend and supplement the physical examination. However, a major problem is the ever-increasing number of special diagnostic techniques being developed. Frequency analysis of vascular murmurs, on-line computer analysis of flow curves, and whole limb electromagnetic flow meters offer examples of the advancing complexity and sophistication (and, of course, escalating cost) resulting from the technological explosion. It becomes ever more important to put new tests in proper perspective. What information does a given test provide and what is the reliability? How significant is that information to patient management? What is the real cost of the test and does the information gained justify the cost? Certain techniques may yield elegant results but add little or nothing to management. Another trap is having several different tests which provide the same information. The question is no longer whether noninvasive tests are suited for the clinical setting but which tests should be used in a given situation.

Summary

The listed methods of evaluation provide valuable physiological data. They do not replace angiography but permit more careful selection of patients. Because the noninvasive techniques are simple and acceptable to patients, they are particularly well suited for screening and repeated follow-up testing.

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