Current Concepts of Cerebrovascular Disease — Stroke

Non-invasive Carotid Evaluation

ROBERT H. ACKERMAN, M.D.

STROKE DUE TO ATHEROMATOUS DISEASE of the carotid artery is preventable by endarterectomy if a causative lesion is identified early enough. Despite its limitations arteriography remains the definitive test for carotid disease. Ideally, arteriography should be done when the risk of stroke is considerably greater than the risk of a complication from the diagnostic procedure. The warning signs of a carotid stroke, however, are often not specific; a bifurcation bruit and/or history suggestive of transient ischemic attacks (TIA) are not always sufficient to justify undertaking arteriography. Additional pathoanatomical and pathophysiological data are required to "rule in" an arteriogram in these situations. Non-invasive laboratory methods of carotid evaluation extend the sensitivity and perceptiveness of the eyes, ears, and fingers and facilitate a neurovascular examination that is more specific for a diagnosis of carotid disease. Because the non-invasive tests permit sequential evaluations, they can also provide important information on the natural history of carotid lesions.

To be effective non-invasive carotid evaluation requires a selected battery of tests.\(^1\) Carotid disease produces anatomical change at the common carotid bifurcation as well as pathophysiological changes both at the bifurcation and in distal circulatory beds. We classify the non-invasive tests as "direct" if they monitor the bifurcation itself and "indirect" if they monitor distal circulatory beds for evidence of carotid disease (table). The direct tests are further divided into those that assess the anatomical status and those that are physiological monitors. The indirect tests are grouped according to whether they monitor the cerebral or orbital circulations, and the tests of the orbital circulation are subclassified into those which monitor the superficial or the deep orbital circulatory beds (table).

Stroke in patients with carotid lesions may be due to thromboemboli arising from ulcerated atheromatous carotid plaques or from impaired distal flow. Symptomatic ulcerated plaques are usually associated with hemodynamically significant lesions, but occasionally, they appear in patients with minimal narrowing of the carotid. A battery of tests permits one to seek evidence of structural change in the absence of a significant physiological disturbance, to monitor the degree and distribution of physiological changes, and to minimize the respective limitations of the tests. For example, tests that visualize the vessel wall depend only on structural changes and typically can detect mild, moderate, or severe disease. Tests that monitor local physiological changes at the bifurcation first can detect evidence of disease when the vessel is moderately stenotic. Such local hemodynamic changes are identifiable before distal hemodynamic alterations. Tests that demonstrate changes in distal circulatory beds become positive only when there is severe bifurcation disease. However, the changes may be so profound that the direct tests monitoring the bifurcation may actually be reduced in value. For example, flow may be too slow to produce audible carotid bruits or detectable carotid Doppler shifts, and calcification may absorb ultrasound waves so that one cannot obtain an image of the carotid. Because the ophthalmic artery is the first major branch of the internal carotid, pressure and flow changes in the orbital circulation are sensitive indices of severe hemodynamic changes at proximal sites such as the bifurcation. Indirect tests of the orbital circulation will be useful when tests monitoring the bifurcation are no longer of value.

A lesion that causes distal hemodynamic change is one reducing lumen area about 80% and diameter about 60% (a residual lumen of 2 to 2.5 mm). The indirect tests are applicable when the residual lumen diameter is 0 to 2.5 mm; the smaller the lumen, the more accurate the result. With virtual or complete occlusion the true-positive rate for the indirect tests may be 90 to 95%. Of the direct tests bruit analysis is most useful when the residual lumen is approximately 0.5 to 3 mm and direct Doppler examination when the residual lumen is approximately 3.5 mm or less. Anatomical changes that do not reduce the lumen to less than 3.5 mm can be monitored most reliably with an imaging system.

Direct Tests

Two types of ultrasound instruments can be used to demonstrate the anatomy of the bifurcation: the
**TABLE. Scheme for Classification of Non-Invasive Tests That Have Been Explored or Proposed**

<table>
<thead>
<tr>
<th>NON-INVASIVE</th>
<th>INDIRECT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PALPATION</td>
<td>CEREBRAL CIRCULATION</td>
</tr>
<tr>
<td>BRUIT AUSCULTATION</td>
<td>EEG WITH CAROTID COMPRESS</td>
</tr>
<tr>
<td>BRUIT ANALYSIS (2 TYPES)</td>
<td>RADIOMUCLIDE ANGIOGRAPHY</td>
</tr>
<tr>
<td>DOPPLER EXAMINATION</td>
<td></td>
</tr>
<tr>
<td>ULTRASOUND IMAGING (2 TYPES)</td>
<td></td>
</tr>
<tr>
<td>XEROGRAPHY</td>
<td></td>
</tr>
<tr>
<td>RADIOMUCLIDE ANGIOGRAPHY</td>
<td></td>
</tr>
<tr>
<td>ROORAL CIRCULATION</td>
<td></td>
</tr>
<tr>
<td>EEG WITH CAROTID COMPRESS</td>
<td></td>
</tr>
<tr>
<td>RADIOMUCLIDE ANGIOGRAPHY</td>
<td></td>
</tr>
<tr>
<td>FACIAL PALPATION</td>
<td>ORBITAL CIRCULATION</td>
</tr>
<tr>
<td>THERMOGRAPHY, THERMOMETRY</td>
<td></td>
</tr>
<tr>
<td>DOPPLER ULTRASONOGRAPHY</td>
<td></td>
</tr>
<tr>
<td>OPAKITY PULSE PROPAGATION TIME</td>
<td></td>
</tr>
<tr>
<td>SUPRAORBITAL PHOTOPLETHYSMOGRAPHY</td>
<td></td>
</tr>
<tr>
<td>SUPRAORBITAL FLUORESCEIN TESTING</td>
<td></td>
</tr>
<tr>
<td>DEEP</td>
<td></td>
</tr>
<tr>
<td>OPTHALMODYNAEOMETRY</td>
<td>ARM-TO-RETINA CIRC. TIME</td>
</tr>
<tr>
<td>OCULOPLETHYSMOGRAPHY</td>
<td></td>
</tr>
<tr>
<td>(2 TYPES)</td>
<td>OCULOTONOGRAPHY (INCLUDING CAROTID COMPRESSION TONOGRAPHY)</td>
</tr>
<tr>
<td>OCULAR PULSE WAVE ANALYSIS</td>
<td>OCULARSONOGRAPHY</td>
</tr>
</tbody>
</table>

Doppler imaging device and the B-mode scanner (fig.). The Doppler imaging device uses physiological data to construct profiles of a moving blood column to outline the vessel wall. The B-scanner uses data on tissue composition to construct an anatomical field that includes the carotid artery. The Doppler imaging device registers echoes that are related to flow velocity. The B-scanner registers echoes that are related to variations in acoustical impedance of tissues. The Doppler images take 10 to 20 minutes to construct and are usually static representations of the carotid lumen. The B-scanners provide instantaneous images of the vessel wall in real time; i.e., the vessel can be seen pulsating.

In practice the Doppler imaging systems seem to be most useful for providing a track of the lumen along which to position a Doppler probe for selected data on flow velocity. Direct Doppler examination at the bifurcation can provide valuable velocity waveform and frequency content data to help identify lesions causing proximal (arch) and distal hemodynamic changes as well as local disturbances in flow characteristics.

B-scanners providing high-resolution images (0.5 to 1 mm) can be an important part of a non-invasive battery, but for technical, anatomical, and physical reasons they cannot consistently demonstrate ulcerated plaques, show precise degrees of stenosis, or enable one to discriminate between stenosis and complete occlusion. Interfacing a Doppler device with a high-resolution B-scanner to permit simultaneous direct Doppler examination of flow velocity characteristics would improve the diagnostic effectiveness of a B-scanner, but this marriage is not technically easy.

Electronic methods for analyzing bruits can also provide direct physiological information. Although the two types of bruit analysis in clinical use are both called phonoangiography by their developers, they...
may be classified as direct bruit analysis (Kartchner and McRae method) and spectral bruit analysis (Lees-Duncan-Kistler method). Direct bruit analysis provides a plot of the intensity of the bruit throughout the cardiac cycle while spectral bruit analysis uses frequency data to obtain estimates of residual lumen diameter.

**Indirect Tests**

The indirect tests in most common use today for systematic non-invasive carotid evaluation are periorbital directional Doppler ultrasonography for monitoring the superficial orbital circulation and oculoplethysmography for the deep circulation. The former is used to study the distal branches of the ophthalmic artery as they course over the forehead for evidence of collateral flow from external carotid to internal carotid branches. Two types of oculoplethysmography are available. One determines the relative arrival time of the ocular pulse wave in each eye; the arrival time is delayed when flow is compromised. The other type measures systolic ophthalmic artery pressures. Other indirect tests of the superficial and deep orbital beds have been developed but are in limited use (table). Radionuclide angiography, an indirect test monitoring the cerebral circulation, is not as sensitive as the tests monitoring the orbital circulation.

**Indications for Non-invasive Carotid Evaluation**

With exceptions, non-invasive carotid studies should be used to decide whether to perform arteriography rather than to rule it out. Basically healthy patients with typical transient ischemic attacks or patients with strokes in progress should bypass the non-invasive laboratory and proceed directly to arteriography. At present, these patients include otherwise healthy individuals with typical transient monocular blindness (TMB) or a transient hemispheric attack (THA).

The types of patients who might be considered for non-invasive diagnosis can be classified as follows:

1. Patients who have probable TMB or THA but relative medical or other contraindications to arteriography. In this population positive non-invasive tests can help to decide on an arteriogram or accelerate the pace of the cerebrovascular examination.
2. Patients with an evolving stroke who have minor deficits or a previous stroke with good neurological recovery. In this group non-invasive diagnosis can help identify carotid lesions that are sometimes completely unanticipated and determine whether an angiogram should be done. Surgery on a tight stenosis might prevent another stroke.
3. Patients with signs and symptoms that are only equivocal for carotid disease. With a B-mode scanner one can rule out arteriography in this group if all the direct and indirect tests are entirely negative, recognizing however that the battery could miss, for example, a small ulcerative plaque.
4. Patients with asymptomatic bruits. Non-invasive testing can help identify potentially troublesome carotid disease. The non-invasive tests provide more precise means to follow these patients for evidence of progression.
5. Patients with asymptomatic bruits who will be undergoing extensive surgery with possible intraoperative hypotension. If the non-invasive tests indicate hemodynamic change, these patients are candidates for arteriography and repair of a tight stenosis.
6. Patients with central retinal artery occlusion. The incidence of carotid disease is approximately 20% in these patients. Non-invasive testing at the Massachusetts General Hospital has been virtually 100% sensitive and specific in this situation. Negative results of a noninvasive battery can help rule out an arteriogram in this population.

**Discussion**

Neither the direct or indirect tests alone are sufficient for noninvasive diagnosis of carotid disease. A minimum battery might include a physiological monitor at the bifurcation and an indirect test of the superficial and of the deep orbital circulations. A direct anatomical monitor is highly desirable but expensive.

The effectiveness of a battery of 6 tests, including a B-scanner device, has been explored at the Massachusetts General Hospital where a Carotid Evaluation Laboratory has been in routine operation for 6 years. The B-scanner has been an integral part of the battery for two and one-half years, during which time over 2,000 patients (4,000 carotids) have been examined. In 500 consecutive cases with 80 correlative angiograms, the battery was 90% effective in identifying a carotid that had a residual lumen of 2 mm or less. The false-positive rate was 3 to 5% and was often due to an ophthalmic artery lesion. Advanced but not hemodynamically significant disease was frequently identified. In follow up 2 patients with these latter findings progressed to develop evidence of distal hemodynamic change.

With the Carotid Evaluation Laboratory the management of patients with suspected carotid disease has changed at the Massachusetts General Hospital. Three groups of patients are now selected.
for arteriography, primarily on the basis of non-
invasive carotid evaluation: patients with central retinal artery occlusion, stroke patients who demon-
strate good return of function, and patients with asymptomatic bruits who are candidates for major surgery.

Asymptomatic patients with demonstrable bifurca-
tion disease are also managed differently. If a patient with a characteristic bruit has at least moderately severe atheromatous disease by B-scanner, he is followed every 4 to 6 months and is referred for arteriography if the results of the Carotid Evaluation Laboratory battery show obvious progression in the distal hemodynamic effects of the lesion. No patient who has been followed is known to have had a stroke prior to intervention. One patient, however, had his first TIA in the hospital admitting area.

Non-invasive testing may be reducing the cost of evaluating some stroke-prone patients. More stroke-prone patients with asymptomatic bruits, atypical TIAS, and/or relative contraindications to arteriography are being seen as outpatients and are being admitted only if the results of the Carotid Evaluation Laboratory tests are abnormal.

Thus, as a result of the non-invasive battery of tests, stroke-prone patients appear to be better selected for hospital admission and for arteriography.

Non-invasive carotid examination does not replace the bedside neurovascular examination, which should include bruit auscultation over the neck and orbits, facial pulse examination, and, as indicated, ophthalmodynamometry. A non-invasive battery is not a screening procedure but should be used to help resolve questions about carotid disease raised by the clinical history and physical examination.

Eventually, non-invasive alternatives may also include ultrasound characterization of vascular tissues, imaging of tagged platelets at ulcerative plaques, and computer enhancement of intravenous carotid arteriograms. Such a diagnostic armamentarium not only might make non-invasive carotid evaluation more accurate, but also it might help physicians to identify prognostic features of specific carotid lesions, to understand the pathophysiology of cerebral insults in patients with carotid disease, and to follow the response of atheromatous lesions to medical therapy.

References


*A detailed bibliography is contained in references 1 and 2.
Non-invasive carotid evaluation.
R H Ackerman

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