Carotid Artery Disease, Carotid Endarterectomy, and Behavior: A Critical Appraisal

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We reviewed the recent literature on the relationship between carotid artery disease, carotid endarterectomy, and behavior. The methodological adequacy of each study and the complexities involved in interpreting behavioral changes in patients with carotid disease are emphasized. Experimental design issues qualify conclusions in all studies. The weight of the evidence suggests that carotid artery disease may result in cognitive impairment, and that carotid endarterectomy is followed by psychometrically determined cognitive improvement in some patients. Although characteristics of the subgroup of patients most likely to improve have been identified in preliminary investigations, the clinical significance of such improvement has not been systematically evaluated. At present, evidence is insufficient to suggest that impaired cognition should serve as an indication for surgery. Carotid endarterectomy is performed to prevent cerebrovascular episodes, and postoperative neurobehavioral improvement should be viewed as a possible additional benefit.

Three decades ago, Fisher (1) postulated a relationship between carotid artery disease and diminished cognitive ability. He suggested that extracranial vascular lesions might be corrected by surgery. Three years later, Eastcott and his colleagues (2) reported the first successful carotid endarterectomy. Subsequently, a dozen studies have appeared that discuss the relationship between cognitive deficits and carotid disease and the potential for endarterectomy to improve cognition. The present paper reviews 12 studies of the relationship between carotid disease, surgical intervention, and behavior. Recent literature, delineating complex interpretations of behavior changes, is emphasized.

Studies that examine psychological consequences of internal carotid artery disease and endarterectomy have addressed at least five questions:

1) What is the incidence, nature, and magnitude of cognitive deficits in patients with significant carotid disease?
2) Can such deficits, when present, be improved by carotid endarterectomy?
3) Are the changes in cognition observed after endarterectomy referable to the cerebral hemisphere on the side of the operated artery?
4) Do these changes correlate with changes in physiological parameters?
5) Is there individual variation in the behavioral sequelae of carotid endarterectomy? and, if so, can the medical and demographic factors related to this variation be precisely identified?

Twelve reports are reviewed. The survey is restricted to published studies from English-speaking countries in which objective neuropsychological procedures were employed. A preliminary description of neuropsychological tests will provide a background for understanding the methodology of each article.

Neuropsychological Procedures

Neuropsychological tests are specialized psychological tests designed to evaluate aspects of behavior affected by cerebral dysfunction. Tests most commonly employed to evaluate the effects of carotid surgery are listed in Table I. Nine of 12 studies used either the Wechsler Adult Intelligence Scale, the Wechsler Memory Scale, a modi-
fication of the Halstead-Reitan Neuropsychological Test Battery, or some combination of these, as the primary assessment devices. Two studies used tests specifically constructed for their projects. One experiment which used only a psychotic reaction profile and clinical evaluation is included because of the unique sample.

The Wechsler Adult Intelligence Scale is the standard, most commonly used test of adult intelligence. It is divided into two sets of subtests: verbal, including information, comprehension, arithmetic, similarities, digit span, and vocabulary subtests; and performance, including digit symbol, picture completion, picture arrangement, object assembly, and block design subtests.

The test provides verbal IQ, performance IQ, and full scale IQ scores; it measures verbal, spatial, numerical, and visual perceptual reasoning abilities and information retrieval. The Wechsler-Bellvue Intelligence Scale is an earlier version of this test.

The Wechsler Memory Scale consists of seven subtests: personal and current information, orientation, mental control, logical memory, visual reproduction, and associate learning. An overall memory quotient (MQ), which is conceptually similar to an IQ score, can be calculated on the basis of the patient's total performance. Attention and concentration, recent memory, and remote memory abilities all contribute to the overall score.

The Halstead-Reitan Neuropsychological Test Battery provides a sensitive index of brain function. Tests include the Trail Making Test, Category Test, Rhythm Test, Speech Perception Test, Aphasia Screening Test, Finger Tapping Test, Tactual Performance Test, and the Perceptual Examination. An overall Impairment Index can be calculated.

### TABLE I
Neuropsychological Tests

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>WAIS</td>
<td>Wechsler Adult Intelligence Scale</td>
</tr>
<tr>
<td>WB</td>
<td>Wechsler-Bellvue Intelligence Scale</td>
</tr>
<tr>
<td>WMS</td>
<td>Halstead-Reitan Test Battery</td>
</tr>
<tr>
<td>HR</td>
<td>Psychotic Reaction Profile</td>
</tr>
<tr>
<td>PRP</td>
<td>Trail Making Test</td>
</tr>
<tr>
<td>TM</td>
<td>Rorschach</td>
</tr>
<tr>
<td>BVRT</td>
<td>Benton Visual Retention Test</td>
</tr>
<tr>
<td>FTT</td>
<td>Finger Tapping Test</td>
</tr>
<tr>
<td>MMPI</td>
<td>Minnesota Multiphasic Personality Inventory</td>
</tr>
<tr>
<td>STAI TS</td>
<td>State Trait Anxiety Scale</td>
</tr>
<tr>
<td>SB</td>
<td>Special Battery</td>
</tr>
<tr>
<td>BSRM</td>
<td>Buchke Selective Reminding Procedure</td>
</tr>
</tbody>
</table>

### TABLE II
Neuropsychological Studies of Carotid Endarterectomy

<table>
<thead>
<tr>
<th>Group</th>
<th>Study</th>
<th>Sample Size</th>
<th>Control Group</th>
<th>Preoperative Cognitive Status</th>
<th>Postoperative Cognitive Change</th>
<th>Tests</th>
<th>Retest Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bryant, et al 1965</td>
<td>6</td>
<td>No</td>
<td>Psychotic</td>
<td>No</td>
<td>PRP</td>
<td>6 wks.</td>
</tr>
<tr>
<td>2</td>
<td>Williams and McGee 1964</td>
<td>6</td>
<td>No</td>
<td>?</td>
<td>Varied</td>
<td>WB, TM, WMS, ROR</td>
<td>1 mo.</td>
</tr>
<tr>
<td>3</td>
<td>Horne and Royle 1974</td>
<td>14</td>
<td>No</td>
<td>?</td>
<td>Improved</td>
<td>WAIS, WMS, BVRT</td>
<td>“Wide range”</td>
</tr>
<tr>
<td></td>
<td>Perry, et al 1975</td>
<td>20</td>
<td>No</td>
<td>13/20 impaired</td>
<td>Improved</td>
<td>HR</td>
<td>3 mos.</td>
</tr>
<tr>
<td></td>
<td>Drake, et al 1968</td>
<td>64</td>
<td>Yes</td>
<td>Some impaired</td>
<td>Varied</td>
<td>Varied, many</td>
<td>6 and 12 mos.</td>
</tr>
<tr>
<td>5</td>
<td>Kelly, et al 1980</td>
<td>35</td>
<td>Yes</td>
<td>Same as controls</td>
<td>Improved*</td>
<td>WMS, MMPI, STAI TS, SB</td>
<td>1-2 mos.</td>
</tr>
</tbody>
</table>

*Authors attribute cognitive improvement partially to practice effects.

**Authors attribute cognitive improvement solely to practice effects.
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derived by adding performances on tests in the battery most capable of discriminating brain damage. Basic sensory and motor functions as well as higher order reasoning and learning abilities are measured.

Neither the Halstead-Reitan Battery nor the Wechsler Adult Intelligence Scale has an alternate form; thus, repeat testing may be affected by the subject's earlier exposure to the tasks or "practice effects." The Wechsler Memory Scale, on the other hand, has an alternate form which can minimize the effects of practice. Two studies used test batteries especially designed for their projects because they wanted to evaluate a broad range of functions while minimizing practice effects. This goal was achieved either by using alternate forms or by selecting tasks not likely to be affected substantially by practice.

**Carotid Disease and Behavior**

The studies for review have been divided into six groups based primarily on consistencies in method and, to a lesser degree, on chronology. A summary of several key attributes of each study is provided in Table II.

**Group 1**
The first study stands alone in Group 1 (3). Using cerebral angiography, Bryant and his colleagues examined one hundred psychiatric inpatients with chronic psychosis and found seven with significant carotid disease. Six of the seven underwent carotid endarterectomy, and the authors summarily reported (without providing actual data) that no improvement was observed on clinical evaluation or the psychotic reaction profile. They concluded that carotid disease is not a major determinant in the etiology of chronic psychosis, an assertion which has never been challenged. Although the sample size of this study was small, it is the only one that has evaluated chronic psychiatric patients.

Patients in all other studies presented with neurologic rather than psychiatric symptoms.

**Group 2**
The study by Williams and McGee (4) was the first to use formal neuropsychological testing. Both this pioneering study and later studies by Goldstein, et al (5) and Matarazzo, et al (6) evaluated a small group of patients before and after surgery. None included a formal control group or samples of carotid surgery patients specified as neurologically homogeneous before surgery; i.e., they failed to discriminate between patients with completed stroke and those with transient ischemic attacks at the time of surgery.

Only Williams and McGee commented specifically on preoperative cognitive deficits, but their statement was based on qualitative rather than quantitative inspection of data. They reported data on preoperative-postoperative changes descriptively and indicated that roughly equal numbers of patients improved, deteriorated, or remained the same: the outcome was variable, but patients with bilateral disease seemed to show greatest improvement.

The other two studies reported postoperative improvement on several neuropsychological measures. Gains in the Goldstein, et al group included a 7.33 point increase in the Full Scale IQ and improvement on most parameters of the Reitan battery, including an average of 35 fewer errors on the Category Test, a measure of abstract reasoning. Gains on the Matarazzo, et al study, which used a similar battery, were much less dramatic: a 3.6 point increase in Full Scale IQ, 6.14 fewer errors on the Category Test. However, Goldstein, et al attributed some and Matarazzo, et al attributed all observed improvement to practice. This contention is difficult to evaluate because the former study had no controls, and the latter used only "crude comparison groups" quite dissimilar to the group of carotid patients. In addition, some gains found by Goldstein, et al are greater than clinicians would ordinarily attribute to practice. These suggest, however, that reversal of cognitive impairment after carotid endarterectomy is at least possible in some instances.

**Group 3**
Group 3 contains studies by Horne and Royle (7) and Perry, et al (8). These investigations included a combination of patients with both completed strokes and transient ischemic attacks before surgery; they also failed to use a control group. While interpretation of these results is clouded, each provides data of interest. Horne and Royle did not address the issue of preoperative cognitive impairment. Although they commented that patients with more severe atheromata performed more poorly on several tasks, they provided no supporting data. Perry's group found that 13 of 20 patients had abnormal Halstead-Reitan Impairment Index scores before surgery, suggesting cognitive deficit.

However, the inference of preoperative impairment must be viewed cautiously considering the sample's advanced age and unknown level of education.

Both studies reported some improvement in cognition postoperatively: Horne and Royle reported an increase of 6.4 points in the Performance IQ (7), and Perry, et al observed improved scores on the HR Impairment Index, Categories Test, and Tactual Performance Test (8). Again, with no group to control for effects of practice, results
are of limited value. Horne and Royle (7) also reported that they found no relationship between severity of vascular disease (measured by angiography) and degree of postoperative cognitive improvement, although their methods for making this determination were not fully described. Similarly, Perry's group (8) reported no relationship between changes in carotid blood flow immediately after surgery and cognitive changes three months after surgery.

Group 4
Each of the three studies in Group 4 included a control group and addressed a different, previously unanswered question. As with preceding studies, however, carotid endarterectomy samples were either neurologically heterogeneous before surgery, or the authors failed to specify the sample as such. Haynes, et al (9) did not compare carotid and control groups preoperatively. Duke, et al (10) used only cerebrovascular disease controls and therefore could not address the issue of preoperative impairment.

Drake, et al (11) distinguished between unilateral and bilateral carotid disease patients. After rating objective test data subjectively (and not providing any raw data), they judged "some degree of intellectual loss" in 70% of the unilateral and 89% of bilateral carotid disease patients but in only 30% of age-matched medical controls without vascular disease. The sample was neurologically heterogeneous before surgery and included at least some patients with completed stroke.

The three studies have disparate interpretations about postoperative change. Duke and his colleagues reported that cognitive improvement occurred in patients after carotid endarterectomy with several IQ measures used in the follow-up testing (Full Scale IQ increase of 6.4 points). However, one of two nonoperated cerebrovascular disease groups were similarly improved, and the changes were attributed to practice. It is important that the control group not showing follow-up improvement (patients with carotid disease who did not have surgery) was more similar to the carotid endarterectomy group in terms of type of disease and length of follow-up interval than was the group which did improve (patients with small vessel cerebrovascular disease). Attributing the change solely to practice may not, therefore, be tenable.

Drake and his co-workers reported that cognitive improvement followed surgery in a group of private patients. The observed changes were compared (again, using subjective ratings of the objective data) to those occurring in nonoperated control patients who had surgically inaccessible cerebrovascular disease. Therefore, natural recovery cannot readily explain the improvement. In a group of surgically treated patients from a Veterans Administration hospital (i.e., lower socioeconomic status and disease of longer duration), no such improvement took place. This was the first study to identify factors related to individual variation in response to surgery.

The Haynes group found that significant postoperative cognitive improvement followed carotid surgery (4.8 and 12.0 point increases in Verbal-Comprehension and Perceptual-Organization IQ scores, respectively, and significant improvement in mental speed on TM); but no change occurred in control patients who were undergoing surgery not involving the nervous system. These investigators, the first to systematically employ personality measures, found that both carotid surgery and control patients showed reduced state anxiety during follow-up, which ruled out decreased anxiety to explain observed intellectual changes.

Thus, the findings in all three studies indicate that improved mental function followed surgery. The improvement cannot be accounted for solely on the basis of either practice (all three studies), reduced preoperative anxiety (Haynes, et al) or natural history of disease (Drake, et al). However, none of the studies used the ideal control group, i.e., patients with surgically accessible carotid disease randomly assigned to a nonoperated group. Also, each study had inadequacies in methods of data reporting. Duke's group attempted without success to relate the nature of the cognitive improvement to the laterality of the endarterectomy.

Group 5
In Group 5 are two recent studies which not only employed control groups, but also studied carotid surgery patients who were neurologically similar before surgery. Kelly, et al (12) restricted their carotid surgery sample to patients with a history of transient ischemic attacks and excluded stroke patients. The control group consisted of patients hospitalized for peripheral vascular surgery, primarily involving the lower extremities. Although these patients were not healthy control subjects, they did not manifest signs or symptoms of cerebrovascular disease. Preoperatively, the carotid surgery group tended to perform less well than controls on several cognitive measures, but no statistically significant differences were found. Postoperatively, the carotid patients improved on several of the 12 cognitive measures on which controls did not improve: the Wechsler Memory Scale Memory Quotient increased by 9.7 points and verbal fluency on the Controlled Word Association Test also increased.
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Postoperatively, both groups showed reduced state anxiety. More important, Kelly, et al identified a subgroup whose cognition significantly improved postoperatively on a portion of their battery. This subgroup was significantly younger, better educated, and had lower blood pressure when admitted than those patients who did not improve. A trend in the data toward statistical significance suggested that the improved group had a lower incidence of generalized vascular disease.

Borenstein and his colleagues (13) studied carotid surgery patients with both completed stroke and with transient ischemic attacks, but they differentiated between them in data analysis. Two control groups were used: a “noncerebral surgery” group and a mixed, nonoperated cerebrovascular disease group. While use of two control groups is laudable, they did not describe the nature of preoperative neuropsychological deficits in their sample. Postoperatively, the carotid endarterectomy patients improved significantly on more neuropsychological measures than did the controls, but the particular tests were not delineated. Right carotid endarterectomy patients showed significantly greater improvement than either left or bilateral endarterectomy patients or controls on a number of “selected” variables. The rationale for selecting only a certain number of measures to compare the groups is not clear. Carotid endarterectomy patients with stroke showed significantly more improvement than did those with transient ischemic attacks or the vascular disease controls. Borenstein, et al conclude that the improvement in endarterectomy patients with stroke cannot be attributed to spontaneous recovery because the improvement was significantly greater than that shown by nonoperated cerebrovascular disease controls. Somewhat surprisingly, they found that patients with right (but not left) carotid endarterectomy evidenced a relationship between the side of surgery and the nature of the cognitive improvement observed. Again, however, the specific measures selected for this comparison were not identified.

These two studies suggest that mental improvement greater than that to be expected on the basis of practice (Kelly, et al) or spontaneous recovery (Borenstein, et al) can sometimes occur.

Group 6

A recent study by Owens, et al (14), although it did not employ a control group or address directly the issue of preoperative deficits, is still of substantial importance. This is the first study to consistently use radiographs in pre- and postoperative assessment. They studied carotid surgery patients presurgically and three to ten days and three months postoperatively with psychometric and neurological measures. The authors found several patients had postoperative strokes which could not be detected clinically but could be demonstrated by radiological studies. The group with postoperative stroke showed deterioration in early follow-up psychometric studies, while patients with apparently normal brains and flow-restrictive stenosis showed immediate postoperative improvement. These preoperative-postoperative changes were not evaluated statistically. Over the three-month interval, patients with postoperative infarctions improved, whereas those with flow-restrictive stenosis showed no further improvement than that observed shortly after surgery. In a subgroup of the patients with flow-restrictive stenosis, preoperative-postoperative flow measures demonstrated a mean increase of 110cc/minute through the operated artery. Although postoperative improvement in manual dexterity was lateralized as expected, postoperative changes in higher order function were not. Not only does the study lack statistical analyses for many comparisons, but many interesting comparisons were not reported at all. The authors rightly emphasize that the role of small strokes and of blood flow changes in interpretation of results has heretofore been poorly studied.

Overview

In each study, methodological issues qualify conclusions. For instance, only the studies of Perry, et al and Kelly, et al specify their samples as consecutive, and only Kelly, et al specifically state that they eliminate patients with other known neurological psychiatric diseases from their sample. Many studies fail to describe severity and laterality of carotid disease, presence and nature of concomitant serious vascular and other medical illnesses, demographic characteristics of the sample, or details of the surgical technique. Few studies attempted to correlate behavioral data with physiological parameters. Several studies used inconsistent preoperative-postoperative testing intervals or did not test all patients fully.

Methodological inadequacies aside, it is difficult to compare studies because they differ in such factors as the tests employed, variations in medical and demographic characteristics in the samples, and between study differences in test-retest intervals. In an earlier review, Asken and Hobson (15) discussed some of these issues.

Even with this wide variation, it is reasonable to conclude that carotid artery disease may be associated with cognitive impairment, and uncomplicated carotid endarterectomy is followed by improvement in some patients. All of the 11 studies of neurological patients reviewed suggested cognitive improvement in at least some of their patients. Postoperative improvement was greater than
could be accounted for by practice or reduction in preoperative anxiety. Despite flaws in data reporting and methodological weaknesses, studies by Drake, et al and Borenstein, et al further suggest that postoperative cognitive improvement is greater than would be expected by the natural history of disease. The studies by Drake, et al and Kelly, et al provide the distinctive if preliminary finding that certain patients are more likely than others to benefit cognitively from surgery.

There are at least two physiological mechanisms whereby patients may show improved cognition following carotid endarterectomy. First, surgery may arrest the propagation of clinically occult microemboli. Embolization of small thrombi from the carotid artery to the brain may recur in steady succession with the reduced blood flow in small vessels causing frequent but transient cognitive changes. Such a situation could be reversed if the source of embolization was removed. Nevertheless, at present there is no evidence to support or refute this model as the physiological basis for cognitive recovery.

A second possibility is that surgery results in increased cerebral blood flow, an explanation which has indirect support. Herrschaft and his colleagues (16) studied 49 patients by the intracarotid Xenon method before and four to six weeks after endarterectomy. All patients suffered from slight to moderate neurological defects. Preoperative flows were judged low compared to normal values. In two groups of patients, those with severe unilateral stenosis and those with kinking, mean postoperative increases were 33% and 26%, respectively. They observed no change in five patients without surgery. Nine patients with stenosis on one side and occlusion on the other showed no change. There was much individual variation among the patients, but neither neurobehavioral data nor neurological follow-up information were reported. Some neuropsychological studies reviewed here also reported individual variation in response to surgery. In future studies that employ both blood flow and neuropsychological techniques, correlating test results should contribute to understanding the mechanisms of recovery.

A very recent study (17) published after our symposium provides further support for the “increased hemodynamic flow” model for cognitive improvement. Twelve patients with 75% or greater stenosis of both carotid arteries (termed “low flow-endangered brain” syndrome) were studied before and after endarterectomy. Patients undergoing endarterectomy for ulcerative but hemodynamically insignificant lesions served as controls. A special battery of tests showed that improvement in cognitive ability (on the BSRM and TM) was significantly greater in patients with the low flow-endangered brains than in control subjects with ulcerative lesions. No blood flow studies were done. Citing experimental neurophysiological studies (18) which indicate that reduced cerebral blood flow can cause potentially reversible neurological dysfunction, the authors attributed the improvement in their low-flow, endangered brain group to restoration of blood flow. Certainly, studies combining blood flow and neuropsychological technology promise to add considerably to our understanding.

Another pragmatic issue surfaces on reviewing this literature. If carotid endarterectomy can effect improvement in neuropsychological tests, is there parallel change in the day-to-day life of patients? Some writers (7) provide anecdotal reports of dramatic improvement on testing or in daily living competencies. In one patient, verbal IQ increased from 54 to 91 after surgery. The condition of a mental hospital patient so improved postoperatively that she was transferred to a less rigidly supervised ward and was being considered for discharge. Although objective, systematic studies of such phenomena are lacking, stories appear from time to time in the popular press (19) suggesting that “senility may be reversible” by carotid endarterectomy. Available data are insufficient to show that carotid endarterectomy results in clinically significant (vs statistically significant) improvement in mentation. Accordingly, the primary indication for carotid artery surgery is to prevent cerebrovascular episodes, not to improve cognition.

**Future Research**

Adherence to the following guidelines for future investigations should yield reliable information about the anticipated results from carotid artery surgery.

First, patients should be carefully characterized as to neurological status (stroke vs transient ischemic attack vs asymptomatic), type (hemodynamically significant lesion vs ulcerating plaques), and laterality of the carotid disease. The character, intensity, and duration of cerebrovascular symptoms and the degree of preoperative deficits must be documented. The presence of associated conditions such as hypertension, cardiac or pulmonary disease, and the use of medications which might influence neuropsychological test performance must be recorded. Emotional status and pertinent demographic data are needed for every patient. Investigators should select one or two design strategies which encompass these variables. One possible approach would restrict the study to a homogenous group of patients. Another would utilize a broader sample of patients and multivariate testing methods to define the various factors which affect the cognitive changes observed after surgery.
Appropriate controls for practice effects, anxiety, and the natural history of recovery from a cerebrovascular event are critical for research design. An ideal study which randomly assigned patients to surgical or nonsurgical treatment groups would provide control for the natural history of the disease without surgery. Practical difficulties for such a study arise when patients are referred specifically for carotid endarterectomy. However, with promising alternative medical treatment, a controlled, randomized investigation seems justified. In addition, a group of patients who are undergoing a surgical procedure not affecting the cerebral circulation would control for the effects of practice and preoperative anxiety. Finally, a healthy control group would help to establish the nature of subtle preoperative cognitive deficits in the carotid disease group and provide additional information about effects of practice. Patients in all control groups should be similar to endarterectomy patients in age and education.

To evaluate cognitive function, tests with alternate forms or which minimize practice effects will reduce ambiguity in interpretation. Test batteries which emphasize abstract reasoning abilities, mental flexibility and speed, and recent memory are well suited for detecting subtle changes in cognition.

Regional cerebral blood flow assessments should be included in study protocols. Previous attempts to relate cognitive changes to carotid blood flow measures or carotid angiography have not succeeded. The complexity of the cerebral circulation, the presence of intracranial arteriosclerotic disease, and the development of collateral flow patterns complicate these correlations. Regional cerebral blood flow studies provide more reliable information because they measure changes in cerebral rather than extracranial circulation. Other neuroradiological methods should be used to document the presence of either pre- or postoperative stroke.

Finally, future studies should address the clinical significance of the findings. Modest but consistent changes on neuropsychological tests can be statistically significant, but these have limited practical importance for the patient’s quality of life. The duration of desirable postoperative cognitive changes is pertinent. Adding measures of quality of daily life (20) to neuropsychological batteries would clarify the implications of the changes demonstrated by objective neurobehavioral tests. Description of changes in living or occupational status as a result of surgery should be correlated with serial, long-term follow-up studies of mental function.

If the results of any study of the behavioral consequences of carotid endarterectomy are to have clinical relevance, neuropsychological research must be aware of the technical improvements in surgery (21,22) and the promising alternative medical therapies (23). Greater attention must be given to identifying the type of patient most likely to benefit cognitively from surgery. More stringent research designs and identification of the medical, demographic, physiological, and emotional factors related to an individual’s response to surgery will result in greater practical and theoretical understanding.

References