Interpretation of Results of Compression Ophthalmodynamometry

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SUMMARY Retinal artery pressure measurements were correlated with angiograms in 100 patients who underwent these studies for presumed carotid artery occlusive disease. Using 90% stenosis as the level of stenosis required to produce a hemodynamically significant obstruction to flow, we found a false-positive rate of 10% and a false-negative rate of 28%. We conclude that ophthalmodynamometry remains an effective screening tool. Asymmetric retinal artery pressure measurements indicate the high probability of a high-grade stenosis or occlusion of one artery, but negative measurements do not exclude the presence of significant carotid occlusive disease. In this study no patient with the combination of a significantly altered retinal artery pressure and a carotid bruit had an angiogram showing stenosis of 49% or less.

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THOMAS AND PETROHELOS were the first to call attention to the importance of measuring retinal artery pressures in patients with occlusion of the internal carotid artery. They found definite lowering of the ipsilateral retinal artery pressure in 7 of 8 patients with carotid artery lesions and in 8 of 11 similar patients described in the literature. They concluded that the finding of equal retinal artery pressures does not exclude impairment of the internal carotid artery blood flow, but if other reasons for inequality are excluded, unilateral lowering of the retinal artery pressure is strongly suggestive of occlusion in the internal carotid artery. The method of measurement of retinal artery pressures has been well described elsewhere by Hollenhorst and by Smith. Kearns has reviewed the ophthalmic findings in carotid artery disease and has concluded that a unilateral, significantly low retinal artery pressure indicates stenosis of 90% or more and that the pressure is often 50% or less (diastolic and systolic) of the pressure of the normal eye.

However, a significant number of patients with chronic stenosis of the internal carotid artery, even to the point of occlusion, will have equal retinal artery pressures in the two eyes, as a result of the development of collateral circulation to the eye. Kearns observed that normal or equal retinal artery pressures do not rule out stenosis or even occlusion of the internal carotid artery. In the presence of carotid occlusive disease, equal retinal artery pressures would be considered a false-negative finding. In the absence of carotid occlusive disease, asymmetric pressures would be considered a false-positive finding. The possibility that false-positive findings may occur in a number of patients requires further elucidation. The literature contains only a few reports of abnormal retinal artery pressures with normal carotid arteries. It is useful to know the incidence of false-positive findings in patients because all signs and symptoms of carotid occlusive disease are important in making diagnostic and therapeutic considerations. Thus, we undertook an evaluation of retinal artery pressures to identify the incidence of false-positive readings in a group of 100 patients who underwent carotid angiography solely for the evaluation of carotid artery occlusive disease. The retinal artery pressures were correlated with other neuro-ophthalmic and neurovascular findings and with the status of the carotid circulation.

Material and Methods

All carotid angiographic reports for the year 1979 at the Mayo Clinic were reviewed. One hundred one patients were selected with the use of random selection procedures who met all of the following criteria: (1) the carotid angiograms were obtained because of the presence of chronic carotid occlusive disease alone; (2) bilateral retinal artery pressures with systolic and diastolic values were obtained before angiography; (3) the patients had not had carotid endarterectomy or another
cerebral vascular surgical procedure: and (4) the clinicians who ordered the angiogram did not suspect or later diagnose other neurologic illness, and no other vascular defects were discovered on the angiogram.

Several models of ophthalmodynamometers were used in obtaining the retinal artery pressures reported here, including the Baillairg type and the one made by the H. K. Mueller Company (model 427). In every instance, the values were obtained by a member of the staff of the Department of Ophthalmology who had at least several years of experience in the use of the ophthalmodynamometer on a daily basis or by a resident who had at least several months of experience in obtaining retinal artery pressures under the supervision of a staff member. It should be mentioned that in the evaluation of retinal artery pressures, residents are taught to minimize small differences (that is, values of 2 to 4 units on the ophthalmodynamometer scale) and to record them as equal. Estimates of the percentage of stenosis of the internal and common carotid arteries were obtained from the report of the radiologist. In several instances, when the radiologist did not give specific percentages, estimates by the neurosurgeon were used. Estimations were grouped into seven categories because, for the purposes of our study, finer distinctions in the degree of stenosis were not thought to be important. Subsequently, these angiograms were submitted to a radiologist for blind, independent analysis of the extracranial vascular disease. All angiograms were assessed by means of several views to assess the degree of stenosis which was present. One angiogram was excluded from the study because of technical flow problems. Interpretation of 4 of the remaining 100 angiograms was altered by independent review. Angiograms were graded with respect to degree of extracranial arterial (carotid) occlusion and not with respect to ulceration. Ulceration of the carotid artery does occur in carotid occlusive disease and causes symptoms, but this factor was not considered in this study.

Analysis of our data required that we define significance for retinal artery pressures and for the degree of stenosis found on angiography. On the basis of our own opinion and that stated by Kearns, we initially defined a positive angiogram (hemodynamically significant carotid lesion) as one with 90% or more stenosis and a negative one as showing less than 90% stenosis. We defined significant retinal artery pressures as follows: (1) a systolic difference between the two sides of more than 15% (difference between systolic retinal artery pressures divided by the larger of the two pressures); (2) a systolic pressure of 40 units or less in both eyes in the absence of systemic hypotension (systolic blood pressure of less than 90 mm Hg); and (3) a diastolic difference between the two sides of more than 50% when the systolic pressures were equal.

The first criterion has been in general use in our clinic to define a significant, asymmetric retinal artery pressure but has not been formally stated. Other authors have suggested that a significant difference is more than 20% or more than 25%. The second criterion is a formalization of the widely held notion that bilateral carotid occlusive disease leads to bilaterally low retinal artery pressures. Low pressures need to be evaluated with regard to the systemic blood pressure. The third criterion is consistent with Kearns, who stated that the retinal artery pressure on the side of 90% stenosis or an occluded internal carotid artery is reduced about 50% or more (diastolic and systolic) as compared with that on the normal side. This allows retinal artery pressures to be considered abnormal in situations in which systolic values cannot be obtained; it applies stricter criteria to the diastolic value because diastolic values are smaller numbers than systolic values and should have larger differences in order to be significant. The third criterion was not used in any of our 100 patients because they had to have bilateral systolic values in order to enter our study. Sensitivity, specificity, and diagnosability were determined as outlined by Gullen and Bearman.

Results

The figure is a plot of the systolic difference between retinal artery pressures on the ordinate and the degree of stenosis on the abscissa. This graph shows the patients grouped together by the degree of maximum stenosis found on their carotid angiograms. These groups were as follows: no stenosis, 1 to 49% stenosis (plotted at 49%), 50 to 69% (plotted at 60%), 70 to 89% (plotted at 80%), 90 to 94% (plotted at 92%), 95 to 99% (plotted at 97%), and total occlusion. With a line drawn at the 15% systolic difference level and with another line drawn at the 90% stenosis level, one can divide the patients into four groups. Those with stenosis of less than 90% and with a retinal artery pressure difference of greater than 15% constitute the false positives. There are six patients in this group. Those with stenosis of 90% and retinal artery pressures of less than 15% constitute a group of false negatives. There are four patients in this group who do not, in fact, represent false negatives. These patients had bilateral carotid disease with bilateral, symmetrically low retinal artery pressures in the absence of systemic hypotension. Thus, there were 12 true false-negative patients.

Table 2 shows the data when the angiograms were separated into three categories of carotid stenosis, that is, a group with stenosis of 90% or more, one with stenosis of 50 to 89%, and one with stenosis of 49% or less. This allowed us to segregate out a group of angiograms that have been considered stenotic to a significant degree by some authors but that we do not consider significant for the purposes of obtaining retinal
artery pressures, namely the 50 to 89% group. Without this middle group, ophthalmodynamometry has a sensitivity of 71.4% and a specificity of 94%. However, one must make inferences from such statistics with caution because, of course, the test is used in practice in patients who have stenosis in the 50 to 89% range. The false-positive results were reflected by 3 of 48 patients with angiograms showing less than 50% stenosis, for a false-positive rate of 6%. What were the characteristics of these three patients? Two of the three had their pressures determined by a senior member of our department. Both of these patients had symptoms of transient ischemic attacks involving the cerebral hemispheres ipsilateral to the side with the low retinal artery pressure. The third patient had one episode of amaurosis fugax and a significantly low retinal artery pressure in this eye; the pressures were said to be equal 3 months later even though there was no intervening surgery. None of the three patients with a false-positive retinal artery pressure had a carotid bruit. None of the three underwent surgery.

In this study of 100 patients, no patient had significantly altered retinal artery pressure and a carotid bruit with a subsequent angiogram showing stenosis of 49% or less. Three patients had positive retinal artery pressures and carotid stenosis estimated to be in the range of 50 to 89% by the radiologists. All three of these patients had carotid bruits on the side of the diminished retinal artery pressure. One patient underwent carotid endarterectomy; the other two had no surgery. Seven patients had negative retinal artery pressures and carotid stenosis in the range of 50 to 89%. Two of these patients had carotid bruits. One underwent carotid endarterectomy. Thus, of the 10 patients with stenosis in the range of 50 to 89%, 2 underwent carotid endarterectomy. The remaining patients were followed with various medical treatments after angiography.

What happened to the 42 patients who had carotid stenosis of 90% or more? Ten patients did not have surgery; various reasons for this are cited, including refusal of surgery, change in neurologic status, and a subsequent change in the decision regarding the patient’s surgical candidacy for medical reasons. Twenty-five patients had some type of carotid endarterectomy, and seven other patients underwent superior temporal artery-to-middle cerebral artery bypass procedures. Thus, of the 42 patients with angiographic evidence of stenosis of 90% or more who were regarded as surgical candidates, 76% underwent surgical procedures.

This study afforded an opportunity to make certain additional observations regarding retinal artery pressures. Of the 30 patients who had significant pressures and positive angiograms, 8 did not undergo surgery, 16 underwent carotid endarterectomy, and 6 had vascular bypass procedures. Twelve of the patients who underwent carotid endarterectomy had both preoperative and postoperative assessment of the retinal artery pressures.

The interpretation of angiograms is divided into three groups of estimated stenosis: Nonsignificant, Significant, and Positive. The results of retinal artery pressures when angiograms are divided into these groups are shown in Table 2.

Table 1: Results of Retinal Artery Pressures on the Basis of Criteria Recommended

<table>
<thead>
<tr>
<th>Retinal artery pressure</th>
<th>Interpretation of angiogram</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonsignificant</td>
<td>Negative 52, Positive 12*</td>
</tr>
<tr>
<td>Significant</td>
<td>6†, 30</td>
</tr>
</tbody>
</table>

*False negative (12 of 42 = 0.286).
†False positive (6 of 58 = 0.103).

Table 2: Results of Retinal Artery Pressures When Angiograms Are Divided Into Three Groups of Estimated Stenosis

<table>
<thead>
<tr>
<th>Degree of stenosis on angiogram</th>
<th>Less than 50%</th>
<th>50 to 89%</th>
<th>90% or more</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nonsignificant</td>
<td>45</td>
<td>7</td>
<td>12*</td>
</tr>
<tr>
<td>Significant</td>
<td>3†</td>
<td>3</td>
<td>30</td>
</tr>
</tbody>
</table>

*False negative.
†False positive.
pressures; all of these patients had normalization of the abnormally low retinal artery pressure after their endarterectomy. In the seven patients who had a bypass operation, three did not have postoperative assessment of retinal artery pressures. In the four who did have postoperative retinal artery pressures assessed, none had normalization. All continued to have significantly decreased retinal artery pressures on the affected side.

We reviewed the clinician's narrative notes and reports in an endeavor to determine how the information from the measurement of retinal artery pressures was used. No patient in our series had angiography ordered for unequal or significantly asymmetric pressures alone. Other stigmata of cerebrovascular disease were always present when angiography was ordered.

Four of the patients in our series had venous stasis retinopathy. In two instances, the artery on the side of the retinopathy was occluded, as determined by angiography, and in two instances the artery was thought to show more than 95% stenosis on angiography. In every instance, the retinal artery pressures were significantly decreased on the side of the venous stasis retinopathy. Three of the four patients had a history of amaurosis fugax in the eye affected by the retinopathy. None of these patients had diabetes. One underwent endarterectomy and two underwent superior temporal artery-to-middle cerebral artery bypass procedures.

Discussion

On the basis of the criteria listed for significant asymmetry of the retinal artery pressures and considering an angiogram to be hemodynamically negative if it shows less than 90% stenosis, our data suggest a false-positive rate of 10% and a false-negative rate of 28%. Whether an angiogram of 50 to 89% stenosis should be considered hemodynamically negative or positive with regard to ophthalmodynamometry may be a controversial point. Because no patients with stenosis of 49% or less underwent endarterectomy, it seems reasonable to conclude that stenosis of 49% or less is often not significant from a surgical perspective unless there is gross ulceration. We have already pointed out that Kearns and colleagues have reviewed the literature and has expressed the belief that at least 90% stenosis must be present before the lumen of a carotid vessel can be considered sufficiently narrow to reflect significant lowering of the retinal artery pressure. Kobayashi and associates11 studied 45 patients who had angiography and surgery for one or both carotid arteries. They found that a stenosis of 80% diameter was associated with a meaningful decrease in retinal artery pressure. We chose a 90% reduction in diameter in order to utilize conservative criteria. We believe that the actual percentage of stenosis which is useful for retinal artery pressures may be as low as 80%, as suggested by Kobayashi et al. In our series, of the three patients with positive retinal artery pressures and with stenosis in the 50 to 89% range, one underwent carotid endarterectomy and the two others were followed without surgery. Of the seven patients with negative pressures, one underwent carotid endarterectomy and six were followed. Stenosis in the range of 50 to 89% is difficult to call either negative or positive. Moreover, we are skeptical of the accuracy of measuring stenosis on angiograms in fine gradations. It is probably best to regard stenosis in the 50 to 89% range as having uncertain significance with respect to retinal artery pressures.

Some recent reviews of the value of ophthalmodynamometry have ignored the notion that the pressure in a vessel does not drop until a relatively high degree of stenosis is present. Sanborn and associates12 compared several types of ophthalmodynamometry with other means of detection of carotid stenosis. These workers studied all stenotic lesions more than 50% in diameter, and they concluded that compression ophthalmodynamometry had a false-positive rate of 26% and a false-negative rate of 20%. They also concluded that compression ophthalmodynamometry and suction ophthalmodynamometry were superior to oculoplethysmography, modified oculopneumoplethysmography, and Doppler flow studies. Batko and Appen13 reported a false-negative rate and a 19% false-positive rate for ophthalmodynamometry in 36 patients who underwent ophthalmic examinations before carotid angiography. These workers considered the angiograms to be positive if more than 50% stenosis was present. Some other noninvasive tests may be more sensitive in detecting lesser degrees of stenosis. Oculocerebrovascularometry may be useful for detecting stenosis of as little as 10% but with a false-positive rate of 40%.14

We believe that false-positive results occur with this test, for the most part because of observer error and inaccuracies in the proper positioning of the ophthalmodynamometer. We think that it is unlikely that the patients found to have false-positive values had angiographically undetected stenosis. Transient vascular disturbances causing impaired blood flow to the central retinal artery remain a potential cause for false-positive results.

Although uniformly obtained systolic values may be uncomfortable for the patient, we believe that they are important. A larger difference is likely to exist among greater numbers, and thus systolic numbers for retinal artery pressures are more likely to reflect differences with less error. Although we recognize the subjectivity in the determination of end points in ophthalmodynamometry, we are inclined to believe that large differences — those that are significant — are relatively easy to detect. The end points for diastole and systole may vary from examiner to examiner, but examiners are likely to use the same end points for both eyes. It is unlikely that obtaining systolic values will harm the patient. In his paper on ophthalmodynamometric technique, Smith15 discussed an experiment showing that scleral depression as routinely used in visualizing the peripheral fundus elevates intraocular pressure more than does the use of the common ophthalmodynamometer at its maximum limit of 150 units.

The term "venous stasis retinopathy" was used by Kearns and Holllenhorst14 in 1963 to emphasize the
appearance of the retinal venous circulation in carotid artery occlusive disease. They found retinopathy in 5% of their patients who had unilateral stenosis or occlusion of the internal carotid artery. The finding of venous stasis retinopathy in 4 of 42 patients with angiographically proven stenosis of 90% or more in our study suggests a somewhat higher incidence of about 10%. This may, in part, be due to our sample size, or it may be due to an enhanced awareness regarding this condition.

Many attempts have been made to develop a combination of noninvasive tests that can be relied upon to indicate the presence of underlying carotid vascular disease and indicate the need for proceeding with angiography. The use of the ophthalmodynamometer is particularly appealing because the instrument is compact and relatively inexpensive; the test requires only a few minutes and can be done at the bedside. We note with interest that in no instance in our study was there significant asymmetry of the retinal artery pressure and the presence of carotid bruit without subsequent angiographic demonstration of 50% or more stenosis. We believe that patients with abnormal retinal artery pressures and a carotid bruit should have angiography if their clinical condition justifies and permits the study and if the morbidity of carotid endarterectomy at the institution is acceptable.

Conclusion

We wish to call attention to the dictum that stenosis of approximately 90% must be present before retinal artery pressures can be relied upon to show a significant difference because we believe that this matter has been a major source for misinterpretation of this test in the past. In the presence of a high degree of carotid artery stenosis, and applying rigid criteria for the determination of significant asymmetry of the retinal artery pressures, ophthalmodynamometry by the usual compressive technique remains an effective tool. With the criteria that we have outlined, the false-positive rate was 10% and the false-negative rate was 28% in a population in which angiography had been ordered because of the suspicion of cerebrovascular disease.

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