Clinical-Angiographic Correlation of Ophthalmodynamometry in Patients with Suspected Carotid Artery Disease: A Prospective Study

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SUMMARY A prospective, clinical study was performed on patients with suspected carotid artery disease to compare the accuracy of compression and suction ophthalmodynamometry with carotid artery stenosis as determined by arteriography. Results were analyzed with respect to current criteria for classification and determination of "significant" carotid artery disease. Although our results suggest that the best correlation for both procedures with arteriography is a ratio of the corrected intraocular pressure to the systolic brachial blood pressure, these results were not statistically improved over those obtained using uncorrected systolic or diastolic values. Both suction and compression ophthalmodynamometry are equally accurate with levels approaching 80 percent; however, neither test is sensitive enough to be used alone as a screening technique. Arteriography remains the best procedure for the determination of carotid artery disease.

Stroke, Vol 12, No 6, 1981

OPHTHALMODYNAMOMETRY (ODM) is a clinical procedure designed to assess flow in the internal carotid artery by measuring the pressure indirectly in one of its tributaries, the ophthalmic artery. Originally popularized by Bailliart in 1917,[1] this procedure and its variations have been in use for the last 60 years, and numerous reports attest to its usefulness; however, it remains unclear how well any type of ODM correlates with arteriography, currently the most accurate method of diagnosing cerebrovascular occlusive disease. We performed a prospective clinical study to determine the degree of correlation between ODM and arteriography in a group of patients with suspected carotid artery disease.

Methods and Materials

Patients tested were those admitted to the Neurology Service of the Johns Hopkins Hospital for evaluation of suspected carotid artery disease. All patients had complete neurological and neuro-ophthalmological examinations prior to testing.

For this study, 2 different methods of performing ODM were used. Compression ODM was performed using a dial type instrument and a 2-person technique.[2] After adequate dilatation of the pupil, the fundus was visualized by one observer using an indirect ophthalmoscope while the second observer applied the instrument to the sclera and recorded results. Both diastolic and systolic values were recorded. The diastolic value was recorded at the beginning of complete pulsation of one or more of the retinal arteries at the optic disc. The systolic value was recorded when there was complete collapse of the pulsating artery or arteries. Intraocular pressure was measured before the procedure was begun, and brachial blood pressure was measured immediately after the procedure was completed.

Suction ODM was also performed. This technique was performed in an identical manner to compression ODM except that application of pressure to the eye was delivered using a vacuum scleral suction cup. Elevation of applied vacuum pressure was produced with a hand-controlled instrument that also automatically recorded both the diastolic and systolic values obtained during the procedure (Digivac Ophthalmodynamometer, Coburn Optical Industries, Clearwater, FL). Suction ODM was always performed after compression ODM and only after ascertaining that intraocular pressure in each eye had returned to pre-testing values. All tests were performed by the same 2 physicians (GES, NRM) with the patient seated.

The absolute diastolic and systolic values for each test were recorded as were values corrected for intraocular pressure based on a combination of initial intraocular pressure and applied force. For compression ODM, the conversion tables of Bedavanija[3] were used:

$$\text{Tdy} = 0.87 \times g + \text{Tcorr}$$

where Tdy is the corrected ODM value, g is the reading from the ophthalmodynamometer and Tcorr is found from the table:

T	Tcorr
12.0	18.0
14.0	19.0
16.0	19.5
18.0	20.5
20.0	21.5

where T is the intraocular pressure measured by applanation prior to ODM.

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Supported in part by NIH Grant #T32EY07047.

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A conversion table for suction ODM is provided by the manufacturer of the instrument. Thus, for each of the tests, the following values were obtained for each eye: uncorrected diastolic, uncorrected systolic, corrected diastolic and corrected systolic. To minimize the potential effect of variations in blood pressure among patients, each of these values was also divided by 3 combinations of blood pressure: systolic brachial, diastolic brachial and mean physiologic brachial (1/3 of systolic brachial plus 2/3 of diastolic brachial blood pressure). In addition, a mean physiologic ODM value was calculated (1/3 of systolic ODM plus 2/3 of diastolic ODM), and this value was divided by the mean physiologic brachial blood pressure. All values were entered into a PDP 11/45 computer for storage, computation and analysis.

Only those patients in whom both fundi could be adequately visualized with an indirect ophthalmoscope and who had satisfactory arteriography during the same hospital admission were included in this study. Most arteriograms were 4-vessel studies performed via a trans-femoral route, and no patient was included unless the arteriogram provided adequate visualization of the aortic arch, both cervical carotid arteries, and the intracranial circulation.

Grading of diameter stenosis was performed in groups of 10%, i.e., 0–10%, 10–20%, etc. to 100%, by an experienced neuro-radiologist unaware of our test results. The grading was made from direct measurement of at least 2 x-ray projections. The percent stenosis used for comparison in this study is the maximum diameter stenosis at any point along the internal carotid artery from its origin at the common carotid artery bifurcation to the ophthalmic artery takeoff. Forty-seven patients had satisfactory arteriography and had both compression and suction ODM.

Results

Several methods have been described for interpreting values obtained during ODM and will be discussed below. In addition, we also explored other methods for interpreting test results for both compression and suction ODM with the hope that one of them might more clearly differentiate among those sides (or patients) with arteriographically-determined, hemodynamically-significant carotid artery disease and those without disease.

Several criteria for classification of results of compression ODM testing have been proposed.[4, 5] These criteria use the figure of greater than 50% stenosis as determined by arteriography as "positive" for hemodynamically-significant disease and include:

1) Positive for ipsilateral carotid artery disease if the uncorrected systolic value is less than or equal to 40 or if the uncorrected diastolic value is less than or equal to 10.

2) Positive for ipsilateral carotid artery disease if there is a 20% or greater difference between sides of either systolic values, diastolic values or both.

3) Positive for ipsilateral carotid artery disease if there is a 20% or greater difference between sides of the ratio systolic ODM/diastolic ODM.

TABLE 1 *Compression ODM Systolic and Diastolic Values Below Absolute Levels*

Patient #1	Right eye:	Systolic	40	95% Stenosis
		Diastolic	10	
	Left eye:	Systolic	40	100% Stenosis
		Diastolic	10	
Patient #2	Left eye:	Diastolic	10	100% Stenosis

Table 1 shows that there were only 5 values (2 systolic, 3 diastolic) from 3 sides of 2 patients that fit criteria 1. Although all sides showed corresponding stenosis of 95–100%, these data represent only 3% of all sides studied and 4% of all patients studied. In addition, since 33 sides of 24 patients had greater than 50% stenosis by arteriography, this method of evaluation identified only 9% of sides and 8% of patients with greater than 50% stenosis.

Applying both criteria 1 and 2 yields the results seen in table 2. Of the 18 patients identified as positive, 15 had greater than 50% stenosis by arteriography. Twenty-nine patients had a difference of less than 20% between sides. Twenty of these patients had less than 50% stenosis by arteriography. The sensitivity of this method is thus 0.63, while the specificity is 0.87, and 74% of patients were correctly identified as having greater or less than 50% stenosis. As expected, when sides rather than patients were considered, the sensitivity of this method diminished to 0.48, while the specificity improved to 0.93.

Application of criteria 3 alone identified 12 patients who were classified "positive." All patients except 2 had already been identified as positive by considering systolic and diastolic values separately, and the 2 additional patients identified by this method had negative arteriograms.

Only one criterion has been proposed in the literature for the classification of suction ODM: positive for ipsilateral carotid artery disease if there is a 12% or greater difference between sides of either systolic value, diastolic value, or both.[6] Applying this criterion to our values yields the results shown in table 3. Eighty-eight percent of patients with greater than 50% stenosis were correctly identified although the specificity was only 0.61.

In an attempt to compare the results of compression and suction ODM, we calculated the sensitivity,

TABLE 2 *Values Showing > 20% Difference Between Sides (Compression ODM)*

	Sides studied Arteriogram*			Patients studied Arteriogram*		
	+	−	Total	+	−	Total
ODM values +	16	4	20	15	3	18
−	17	57	74	9	20	29
	33	61	94	24	23	47
	Sensitivity:		0.48	Sensitivity:		0.63
	Specificity:		0.93	Specificity:		0.87
	Accuracy:		78%	Accuracy:		74%

*A positive arteriogram (+) is defined as greater than or equal to 50% stenosis.

TABLE 3 *Values Showing ≥ 12% Difference Between Sides (Suction ODM)*

		Arteriogram*		
		+	−	Total
ODM Values	+	21	9	30
	−	3	14	17
		24	23	47
		Sensitivity:		0.88
		Specificity:		0.61
		Accuracy:		74%

*A positive arteriogram (+) is defined as greater than or equal to 50% stenosis.

specificity and accuracy of compression and suction ODM for differences between systolic values, diastolic values or both from 10% to 20%. Figures 1 and 2 show the results of these calculations for compression and suction ODM respectively. The figures show that the highest sensitivities are obtained with each test when lower differences are considered a positive result. As the percent difference increases, sensitivity lowers as specificity improves.

In addition, we performed a similar evaluation of changes in sensitivity, specificity and accuracy when 70% (or greater) angiographically determined stenosis was considered positive for carotid artery disease. For compression ODM, sensitivity was relatively high (0.850) and constant for all percent differences between sides from 10% to 20%, reflecting the fact that there were no angiographically-positive patients with values between 10% and 20%. Specificity gradually increased to a relatively high value (0.830) (fig. 3). For suction ODM, low percent differences between sides gave sensitivities of 0.950 to 1.000 with relatively low specificities (0.519 to 0.630) while higher percent differences resulted in lower sensitivities and higher specificities (fig. 4).

The accuracy of these tests is an average of sensitivity and specificity weighted by the proportion of the screened population with and without angiographically-determined stenosis. Twenty-four of 47 patients (51%) had at least 50% stenosis and 20 of 47 patients (43%) had at least 70% stenosis. Thus, accuracy for our population fell approximately midway between sensitivity and specificity for all tests.

In order to determine if the sensitivity of either type of ODM could be improved by taking systemic blood pressure into account, a linear regression was per-

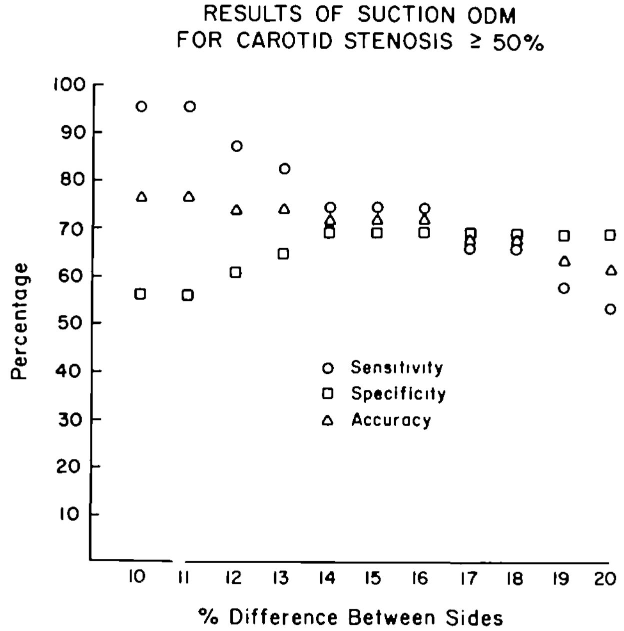

FIGURE 2. *Results of suction ODM for carotid artery stenosis greater than or equal to 50%.*

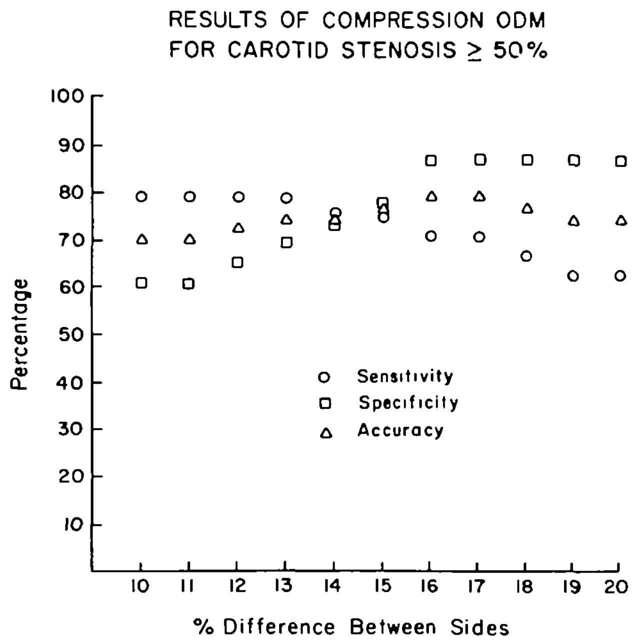

FIGURE 1. *Results of compression ODM for carotid artery stenosis greater than or equal to 50%.*

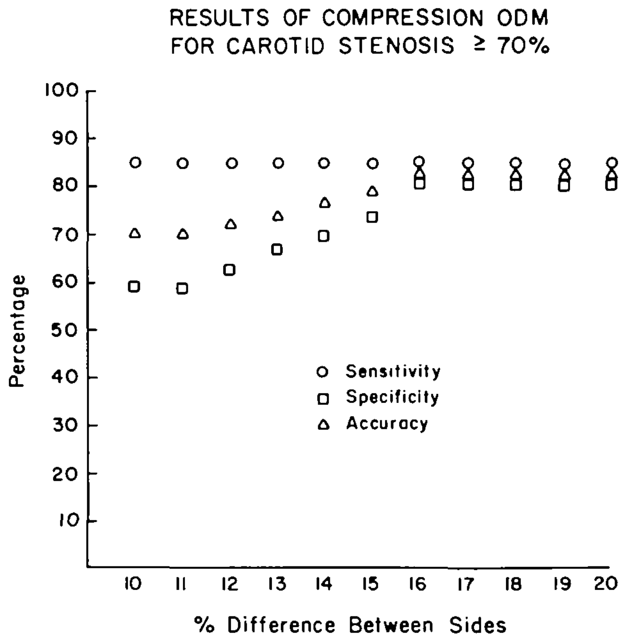

FIGURE 3. *Results of compression ODM for carotid artery stenosis greater than or equal to 70%.*

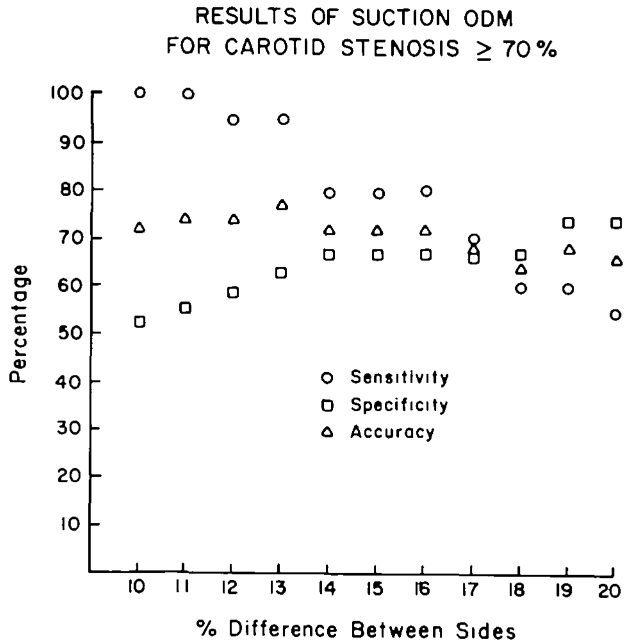

FIGURE 4. *Results of suction ODM for carotid artery stenosis greater than or equal to 70%.*

formed for each of the calculated ratios of corrected and uncorrected systolic, diastolic and mean ODM values to systolic, diastolic and mean physiologic blood pressure against percent stenosis as determined by arteriography. For both compression and suction ODM, the best correlation was obtained using the corrected systolic value divided by systolic brachial blood pressure (SYS ODM/SYS BP). However, this method of analysis did not improve sensitivity or specificity over that obtained by considering the ODM values alone.

Finally, if symmetrical, significant stenosis is defined as bilateral stenosis of greater than or equal to 50% but with a difference between sides of less than or equal to 15%, there were 6 patients who fell into this category. Despite the fact that on theoretical grounds, a test that involves comparison between sides should not be able to identify symmetrical degrees of stenosis no matter how severe, both compression and suction ODM identified the majority of these patients (compression, 5 of 6; suction, 4 of 6) for all criteria from 10 to 20%.

Discussion

The technique and instrumentation for ODM were originally developed by Bajardi around 1906. Although this work was never published, Rubino reported his own results using the Bajardi instrument in 1911.[7] Three years later, Henderson, apparently independently, re-invented the same technique but used a modified Geneva lens gauge to record the applied force.[8] In 1917, Bailliart published his report on the procedure using an instrument almost identical to that of Bajardi.[1] Later, with Magitot, Bailliart developed a calibration chart to convert his instrument readings into intraocular pressure.[9] ODM was not applied to the diagnosis of carotid artery disease until Baurmann made the original observation in 1936 that ipsilateral ODM values are decreased when the carotid artery is compressed.[10]

Over the last 60 years, there have been a number of minor modifications in instrumentation, but the only fundamental modification was Kukan's introduction, in 1936, of the use of an applied vacuum to create suction and thus to raise intraocular pressure.[11] Linksz later developed an improved version of this instrument making it possible for a single observer simultaneously to elevate intraocular pressure and view the ocular fundus.[12] In 1969, Galin and co-workers reported on a similar instrument that allowed the pressure to be elevated with a control attached to the ophthalmoscope and also allowed the pressure applied at systole and diastole to be recorded on the instrument while observing the fundus.[13]

There are several theoretical advantages of suction ODM over compression ODM. Suction ODM distorts the eye less than compression ODM since the eye is not pushed into the orbit during the test. This theoretically avoids the possibility of kinking or closing off blood vessels in the orbit. In addition, the instrument cannot inadvertently slip off the sclera at higher pressures as can occur during compression ophthalmodynamometry. Finally, because the eye is not pushed into the orbit, patients are able to fixate a target more easily during the entire procedure.

Theoretically, ODM measures the pressure in the ophthalmic artery which also represents the pressure in the internal carotid artery. It can be demonstrated that in humans with cervical carotid artery occlusion, the fall in pressure is the same in all branches of the internal carotid artery down to 0.4 mm. in diameter.[14] Unfortunately, presumably on the basis of development of collateral circulation, the maximum pressure drop after an acute, complete occlusion of the cervical carotid artery is only about 50%.[15] This reduction is probably much less for a slowly progressive stenotic lesion that allows for development of collateral circulation over a long period of time.

It has also been demonstrated that a stenosis of less than 50% in diameter of the carotid artery will not produce any pressure drop, and that a hemodynamically significant reduction in pressure is not apparent until a stenosis of 60–80%.[16] On theoretical grounds, therefore, no non-invasive test that relies on measuring pressure changes distal to the obstructed carotid artery should be effective for lesions producing less than 50% reduction in diameter, despite the fact that such lesions can produce both transient and permanent neurological dysfunction.

Non-invasive tests for the detection of carotid artery disease must be effective as screening procedures. They must have a high sensitivity — the ability to identify disease that is present — as well as a specificity — the ability to identify correctly patients with no disease — that results in a minimum of patients with no disease being subjected to the potential risks of angiography. Realizing the limitations of current non-invasive techniques for the detection of carotid artery disease, our study nevertheless agrees with that of Zaret and co-workers[6] that when specific criteria are used to define "significant" carotid artery disease (greater than 50% angiographically-determined stenosis) and a "positive" test (10–20% difference between sides of systolic or diastolic values), the sensitivity and specificity of ODM allow it to be used with relative confidence as a screening procedure.

In deciding to perform this test, the individual physician must also decide which criteria to use in establishing significant carotid artery disease and positive test results. In high risk populations, it might be wiser to use lower percent differences between sides. This will result in a relatively high sensitivity; however, in such a setting, one must accept the fact that a certain percentage of patients considered positive by ODM criteria will have less than 50% stenosis. Of course, how many of these patients will still have some degree of carotid artery disease is unclear, and we have not addressed this question in this study.

The physician examining a low risk population might wish arbitrarily to adopt a somewhat different set of criteria. This will produce a test with reasonable sensitivity and a higher specificity.

Although suction ODM has some technical advantages over compression ODM, the values for the 2 tests are similar when the same criteria for a positive test are used.

Finally, we would emphasize that in view of the propensity for hemodynamically-insignificant lesions to produce significant neurological dysfunction, it is our belief that arteriography remains the most reliable test of carotid artery disease, and that patients with symptoms suggestive of transient ischemia should have arteriography if they are considered candidates for surgical intervention whether or not ODM predicts "significant" carotid artery disease.

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Stroke
JOURNAL OF THE AMERICAN HEART ASSOCIATION

American Heart Association
American Stroke Association

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Stroke. 1981;12:770-774
doi: 10.1161/01.STR.12.6.770
Stroke is published by the American Heart Association, 7272 Greenville Avenue, Dallas, TX 75231

Print ISSN: 0039-2499. Online ISSN: 1524-4628