SUMMARY One hundred and eight patients were studied with fluid-filled oculoplethysmography and carotid phonoangiography (OPG-CPA) and by arteriography. Thirty-two patients also had "Doppler evaluation" of supraorbital arterial flow. The OPG-CPA correctly predicted the degree of occlusion in 76% of the involved vessels, including the degree of occlusion of each carotid for each patient (63%). The OPG-CPA identified at least one obstructing carotid lesion in 51 of the 56 (91%) patients with obstructing lesions demonstrated by arteriography. On a per patient basis, which requires that both carotids be correctly assessed, the OPG-CPA had a false negative rate of 9.6% and false positive rate of 50%. The supraorbital artery "Doppler evaluation" had an accuracy rate of 66%, a per patient false negative rate of 50%, and a per patient false positive rate of 12%.

The OPG-CPA and supraorbital artery "Doppler evaluation" are adjunctive tests for evaluating patients with cerebral vascular insufficiency and should not, at present, replace arteriography in symptomatic patients or in certain asymptomatic patients.

SEVERAL NON-INVASIVE TESTS are now available to aid in the screening for and diagnosis of extracranial cerebrovascular disease. Doppler evaluation of supraorbital artery flow patterns, carotid phonoangiography (CPA) in combination with a type of oculoplethysmography (OPG) are the major non-invasive screening tests now used to detect stenotic lesions of the extracranial carotid system.

The authors have tested the thesis that the OPG-CPA and/or the "Doppler evaluation" of the supraorbital arterial flow could help to better select patients for arteriography in evaluation of their carotid artery disease. This report compares the results of OPG-CPA with cerebral arteriography in 108 patients. In order to determine whether the Doppler evaluation of the supraorbital arterial flow could improve the diagnostic accuracy of the non-invasive evaluation, the results of the Doppler evaluation were reviewed in 32 patients who had this test in combination with OPG-CPA and cerebral arteriography.

Materials and Methods

From January 1, 1978, through April 15, 1979, a total of 259 patients had combined OPG-CPA evaluation using the fluid-filled oculoplethysmography device developed by Kartchner and McRae. The patients were referred for evaluation of symptoms suggestive of cerebrovascular insufficiency or for evaluation of an asymptomatic bruit. One hundred and eight of these patients had cerebral arteriography and this group provides the data base for this report.

During arteriography, the 4 major cerebral vessels were examined by an aortic arch injection. Selective catheterizations of the common carotids and/or vertebral arteries were performed when necessary to rule out an intracranial lesion or to delineate a high internal carotid arterial lesion. Indications for arteriography included classic transient focal ischemic attacks (TIAs), generalized local transient ischemic episodes or completed cerebrovascular accidents.

The OPG-CPA examinations were completed without complications. An inadequate study was obtained in less than 1% of the patients (2 of 259 patients) because of their inability to cooperate sufficiently. An incomplete but interpretable study was obtained in an additional 2% of the patients.

All examinations were performed by one technician with special training in the use of the OPG-CPA equipment. The data were evaluated in a blind fashion without the examiner having prior knowledge of the patient's presenting symptoms or clinical findings. The diagnostic criteria developed by Kartchner and McRae were utilized for interpretation of the OPG-CPA. OPG-CPA results were interpreted as demonstrating either absent, unilateral or bilateral hemodynamically significant internal carotid stenosis. For the purpose of this report, no further attempt was
made to sub-classify the extent of hemodynamically significant lesions. Kartchner and McRae have defined and published criteria by which significant stenotic lesions identified by OPG-CPA may be subdivided into mild, moderate or severe categories depending on the delay in the pulse arrival times and the area under the differential curve.\(^4\) \(^5\) When the results of the OPG and the CPA were discordant, the OPG results were accepted as reflecting the most likely state of the carotid lesion except in patients where a holosystolic bruit was noted in the mid and/or high positions by CPA.

The cerebral arteriograms were reviewed without knowledge of the OPG-CPA results. The degree of luminal diameter narrowing of each internal carotid artery was recorded according to the method of Gross et al.\(^4\) A lesion was considered hemodynamically significant if it compromised greater than 50% of the luminal diameter of the vessel. The presence or absence of an ulcerated plaque was also recorded.

Doppler evaluation of the supraorbital arteries was performed in 32 of these 108 patients according to the technique of Brockenbrough.\(^6\) Blood flow in each supraorbital artery in response to manual occlusion of the ipsilateral superficial temporal artery either increased, remained constant, or diminished. A decrease in supraorbital arterial flow or an absence of flow augmentation in response to ipsilateral superficial temporal artery occlusion was considered indicative of reduced flow in the ipsilateral internal carotid artery. Absence of augmented flow in response to compression of the ipsilateral superficial temporal artery was interpreted as indicative of internal carotid stenosis (50-80%) while reduced flow with compression of the ipsilateral superficial temporal artery was considered indicative of 80-100% stenosis.

Comparisons between the OPG-CPA, supraorbital artery Doppler, and the arteriogram results were made on a "per patient" basis. In order for the non-invasive diagnostic program to be considered correct, it had to be compatible with the arteriographic findings for both internal carotid arteries.

**Results**

**Distribution of Carotid Lesions as Demonstrated by Arteriography**

Fifty-two of the 108 patients (48%) who had arteriograms had less than a 50% reduction of the lumen of either internal carotid artery. Twenty-nine patients (27%) had a greater than 50% reduction of the diameter of only one internal carotid artery and 27 patients (27%) had a greater than 50% reduction of the diameter of both internal carotid arteries. Twenty-one patients had complete occlusion of one internal carotid artery while one patient had total occlusions of both internal carotid arteries. Plaque ulcerations were demonstrated in 16 patients (15%).

**Carotid Lesions Demonstrated by OPG-CPA**

OPG-CPA in 29 of the 108 patients (27%) did not show hemodynamically significant internal carotid stenosis (HSICS). Seventy-nine patients were found by OPG-CPA to have hemodynamically significant internal carotid lesions, 49 patients (45%) unilateral and 30 (28%) bilateral. The OPG and the CPA results agreed in 50 of 108 studies (46%). The CPA results were consistent with the arteriographic findings in 80 of 108 studies (74%), but in only 9% did it predict the extent of the lesion identified by arteriography. OPG correctly predicted the presence or absence of the internal carotid artery stenosis or occlusion demonstrated by arteriography in 68 of 108 patients (63%).

**Angiographic Findings in Patients Without OPG-CPA Recognizable Hemodynamically Significant Internal Carotid Stenosis (HSICS)**

Twenty-two of the 29 patients (76%) in this category had 30% or less stenosis of either carotid artery. Two additional patients had 31% to 50% stenosis of at least one carotid artery. One patient had unilateral carotid stenosis with greater than 50% occlusion and 4 patients had bilateral carotid obstructions with greater than 50% reduction in luminal diameter. Five of the 29 patients (17%) were thus misdiagnosed, i.e., false negatives. Ulcerated plaques were demonstrated in 3 of the patients.

**Arteriographic Findings in Patients With the Diagnosis of Unilateral HSICS by OPG-CPA**

There were 49 patients in this category. Seven had a 30%, or less, reduction of luminal diameter of either carotid. An additional 13 patients had 31% to 50% stenosis in one or both carotids. Thus, 20 of 49 patients (41%) did not have their OPG-CPA lesions confirmed by arteriography. The arteriograms demonstrated ulcerated plaques in 4 of these 20 patients. The OPG-CPA evaluation correctly predicted the presence and site of unilateral HSICS in 25 of the 49 patients (51%), but failed to detect a hemodynamically significant lesion in the contralateral carotid in 4 additional patients. Nine patients with complete internal carotid artery occlusion were among those who were correctly diagnosed as having unilateral significant disease.

**Arteriographic Findings in Patients With the Diagnosis of Bilateral HSICS by OPG-CPA**

There were 30 patients in this group (13%), 4 with an OPG-CPA diagnosis of bilateral HSICs had 30%, or less, luminal obstruction in either carotid. An additional 4 patients (13%) had 30% to 50% stenosis in one or both carotids. Three patients had unilateral hemodynamically significant lesions. Arteriography did not confirm the presence of bilateral hemodynamically significant internal carotid lesions as determined by OPG-CPA in 11 of the 30 patients (37%). The diagnosis of bilateral hemodynamically significant lesions was confirmed radiologically in 19 patients (63%). Six of these 19 had complete occlusion of one internal carotid artery while one patient had bilateral total internal carotid artery occlusions.
Summary of OPG-CPA Results vs Arteriographic Findings (Table)

OPG-CPA correctly predicted the lesions in both internal carotid arteries in 68 of the 108 patients (63%). The OPG-CPA correctly predicted the presence or absence of at least one hemodynamically significant carotid lesion in 75 patients (69%). Sixty-eight patients were correctly diagnosed, 4 additional patients, diagnosed as having unilateral disease, had bilateral hemodynamically significant carotid lesions on arteriography, and 3 patients who were diagnosed as having bilateral disease had only a unilateral significant lesion.

The overall false negative rate was 17.3% (9 of 52). This includes the 4 patients who had only one of their bilateral hemodynamically significant internal carotid lesions identified by OPG-CPA. The false negative rate, or failure to detect any significant disease, was 9.6% (5 of 56 patients). The false positive rate for the OPG-CPA diagnosis of unilateral and bilateral HSICS was 50% (28 of 56 patients).

Fifty-six patients had hemodynamically significant lesions demonstrated in one or both internal carotid arteries by arteriography. OPG-CPA indicated the presence of at least one corresponding hemodynamically significant internal carotid lesion in 51 of the 56 patients (91%).

Fifty-two patients did not have significant disease in either internal carotid artery on their arteriograms. OPG-CPA correctly predicted the absence of a hemodynamically significant lesion in both internal carotid arteries in only 24 of these patients (46%).

OPG-CPA correctly identified 91% (21 of 23) of the internal carotid artery lesions with greater than 95% stenosis, 83% (35 of 42) of the internal carotid artery lesions with 75–95% stenosis, and 74% (14 of 19) of the internal carotid artery lesions with 50–75% stenosis.

Supraorbital Artery Doppler Examination Results

Supraorbital artery Doppler evaluation did not indicate a significant stenosis in either carotid in 19 of the 32 patients and arteriography confirmed the absence of significant internal carotid stenosis or occlusion in 12 (62%). Six of the 19 patients were found to have unilateral, and one patient bilateral, hemodynamically significant internal carotid lesions.

Doppler examination suggested that 8 of the 32 patients had unilateral significant carotid lesions, and unilateral internal carotid lesions were found at arteriography in 6 of the 8 patients (75%). One of the remaining 2 patients had no significant obstruction in either internal carotid artery while the other had bilateral significant internal carotid lesions.

Five patients were diagnosed as having bilateral carotid artery disease by Doppler examination. On their angiograms one had no significant obstruction, one had only a unilateral internal carotid artery obstruction, and 3 had bilateral internal carotid artery lesions.

The overall accuracy rate of the supraorbital Doppler evaluation was 66% (21 of 32 patients). The false negative rate was 50% (7 of 14 patients), while the false positive rate was 12% (2 of 17 patients).

OPG-CPA and supraorbital artery Doppler examination results were in agreement as to the presence or absence of disease and its location for 22 of the 32 patients. In 17 of these 22 patients (77%) confirmation of these results was possible by arteriography. The results of the OPG-CPA and supraorbital artery Doppler examination disagreed either as regards the existence of significant stenotic disease or location in 10 patients. Three of these 10 patients had the presence and location of their carotid lesions correctly diagnosed by supraorbital artery Doppler examination; 5 had the presence or absence of their disease and its location correctly predicted by OPG-CPA; while neither test correctly predicted the presence or absence of disease in both carotids in the remaining 2 patients.

Discussion

Stroke remains the third leading cause of death in the United States, and is responsible for more than 194,000 deaths per year. Atherosclerosis is responsible for most strokes either by causing luminal narrowing and reduction of cerebral blood flow, or by producing emboli which reduce flow to the brain. The extracranial arteries are involved in the atherosclerotic process in most patients with stroke and are the site of the "critical" lesion in at least 40% of these patients. While approximately 50% of the patients will have had TIA's before a stroke, completed stroke will be the initial evidence of cerebral ischemia in the others. Carotid endarterectomy is believed to reduce significantly the risk of subsequent stroke in patients with extracranial obstructing or ulcerated carotid lesions. The success of carotid endarterectomy in the prevention of stroke has created the need for a reliable and safe method of screening candidates for surgical therapy.

Arteriography remains the most reliable method for identifying occlusive lesions and/or ulcerated plaques in the carotid arteries. Although morbidity and mortality associated with arteriography have decreased with increased experience and improvements in contrast materials and arteriographic procedures, the morbidity and mortality are such that it is undesirable to subject all patients, especially asymptomatic patients, to arteriography. The risks and costs of
arteriography have precluded the utilization of arteriography as the method for "screening" for surgically correctable carotid lesions.

Oculoplethysmography and Doppler evaluation of orbital and supraorbital blood flow are among the non-invasive tests that have been developed to evaluate patients with asymptomatic carotid bruits or with symptoms of transient cerebrovascular insufficiency. The OPG and supraorbital artery Doppler examinations are readily carried out with minimal risks to patients but their diagnostic accuracy has not been uniform. The accuracy in predicting internal carotid artery stenosis with Doppler evaluation of supraorbital artery flow patterns varies from 59% to 95%. The accuracy of combined OPG-CPA in detecting alterations of carotid arterial flow has varied from 57% to 91%. Oculoplethysmography has a reported accuracy rate of 31–94% for the detection of internal carotid artery lesions with greater than 75% diameter narrowing. In this series the CPA agreed with the arteriographic findings in 80 of the patients (74%) (i.e., no bruits in patients with no disease or 95% to 100% stenosis; short duration bruits in patients with 30% to 70% stenosis, and holosystolic bruits in patients with 71% to 95% stenosis). The CPA demonstration of a holosystolic bruit correlated well with the presence of a 70% to 95% stenosis of the internal carotid artery; however, only 9 of 19 patients with 70% to 95% stenosis had holosystolic bruits.

The CPA cannot differentiate between hemodynamically significant stenosis of the external carotid artery and the internal carotid artery. The low diagnostic specificity of the CPA and its inability to detect total or near-total occlusions justifies the continued use of this study only as an aid in the evaluation of the OPG results.

Our overall diagnostic accuracy (63%) of the OPG-CPA is consistent with that reported by Blackshear et al., but is less than that reported by Kartchner and others. Our lower accuracy rate can be explained, in part, by our method for comparison of OPG and CPA results with arteriographic findings on a "per patient" basis rather than with the "per carotid" basis used by other authors. The "per patient" basis reduces overall accuracy rates due to the fact that the OPG-CPA reading must be consistent with the arteriographic findings for both internal carotid arteries in order for the diagnosis to be considered correct. This avoids the problem of artificial inflation of the accuracy rate associated with the "per carotid" method of data analysis where credit is given for a half-correct patient diagnosis. Re-evaluation of our results on a "per carotid" basis reveals an overall accuracy rate of 76% with a false positive rate of 43% and false negative rate of 6.7%, which compares favorably with the 57% accuracy rate of Blackshear et al., and is closer to the 91% accuracy rate of Kartchner.

The sensitivity of the OPG-CPA examination increased as the severity of stenosis increased. OPG-CPA correctly identified 91% of the carotid internal artery lesions with greater than 95% stenosis while only 74% of internal carotid lesions with 50–75% stenosis were correctly identified. This is in keeping with the reported experience. To improve our accuracy in establishing the correct diagnosis, patients with delays in the right ear pulse tracing, relative to the left, exceeding 10 milliseconds in duration, now have the left ear pulse tracing substituted for the right as the external carotid reference tracing. This reduces the possibility of overlooking hemodynamically significant bilateral carotid lesions when significant right external carotid stenosis is also present. Minor changes in the OPG, previously interpreted as representing hemodynamically significant internal carotid lesions, are now ignored when bruits are not detected by CPA. Failure to identify a carotid bruit by CPA implies the absence of carotid disease or a near total to total carotid artery occlusion. Consequently, patients without carotid bruits by CPA must have severe flow reduction, i.e., marked differential residuals and eye-pulse delays by OPG, before a hemodynamically significant lesion can be diagnosed.

The diagnostic accuracy of the supraorbital Doppler examination in this series was 66% with a 50% false negative rate and 12% false positive rate. The OPG-CPA and supraorbital Doppler examinations gave identical results in 22 of the 32 patients (68.7%). Agreement of the supraorbital Doppler and OPG-CPA evaluations increased the probability that the diagnosis would be confirmed at arteriography. However, 32% of the patients with identical diagnoses by OPG-CPA and supraorbital artery Doppler evaluation failed to have the diagnosis confirmed arteriographically. When the supraorbital artery Doppler and OPG-CPA evaluations were in disagreement, neither test consistently predicted the arteriographic findings. While the finding of diminished supraorbital artery flow, with ipsilateral superficial temporal artery compression, did not improve the overall accuracy of our non-invasive cerebrovascular evaluation, it did help in the identification of patients with high grade stenosis and total occlusions of the internal carotid artery.

The low false negative rate (9.6%) and significant false positive rate (50%) indicate that OPG-CPA is a sensitive but relatively non-specific screening test for the presence of hemodynamically significant internal carotid artery stenosis. The high false negative rate associated with the supraorbital artery Doppler examination makes it less suitable for screening for carotid disease as it will fail to identify a larger number of patients with significant carotid lesions than will the OPG-CPA.

We presently use the OPG and CPA examination to evaluate asymptomatic bruits; to "screen" patients scheduled for major surgery; and as a follow up examination in patients who have undergone carotid endarterectomy. The low false negative rate of 9.6% justifies our present position of delaying arteriography in asymptomatic patients with carotid bruits and a negative OPG-CPA examination until a hemodynamically significant lesion develops on a follow up...
examination or the patient becomes symptomatic. Asymptomatic patients with carotid bruits are studied arteriographically if the OPG-CPA is abnormal in a moderate or severe degree, or if the patient is scheduled for a major surgical procedure where transient hypotension may be anticipated, i.e., major vascular, general surgical or cardiac procedures. OPG-CPA should be performed prior to aortography in patients scheduled for major vascular reconstructive procedures; if indicated by the OPG-CPA results, cerebral arteriography can frequently be performed simultaneously with the aortography.

It must be emphasized that the OPG-CPA examination is, at present, an adjunctive test for the evaluation of cerebrovascular disease and cannot replace arteriography in symptomatic patients. One may delay arteriographic evaluation of patients with asymptomatic carotid bruits if the OPG-CPA evaluation fails to demonstrate evidence of a hemodynamically significant carotid lesion provided the patient returns at frequent intervals for follow up studies, if he remains asymptomatic, or returns promptly when symptoms develop.

References

Use of combined oculoplethysmography, carotid phonoangiography and Doppler in the non-invasive diagnosis of extracranial carotid occlusive disease.

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