Neurosurgical applications of ocular pneumoplethysmography

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Ocular pneumoplethysmography (OPG), a semiautomated form of suction ophthalmodynamometry, was used to evaluate and follow 15 patients who underwent carotid endarterectomy and two patients in whom gradual carotid artery occlusion was performed for inoperable intracranial aneurysm. Postoperative corrected ophthalmic arterial pressures (COAP's) on the operated side in the carotid endarterectomy patients averaged 12.5 mm Hg higher than before surgery, the standard deviation being 4.9 mm Hg for clinically stable patients. There was no significant change in COAP on the contralateral side. Several problems were encountered in closing down carotid clamps, the most potentially serious being a precipitous fall in COAP with the final adjustment. The current uses of OPG and similar techniques are reviewed, and potential neurosurgical applications are discussed.

KEY WORDS: carotid artery occlusion, carotid endarterectomy, cerebral aneurysm, transient cerebral ischemia, ocular pneumoplethysmography, ophthalmodynamometry

OPHTHALMODYNAMOMETRY is an important and well established means of evaluating cerebrovascular disease. The technique involves the measurement of ophthalmic artery pressure by funduscopic observation of pulsations of the retinal arteries during external compression of the globe. The conventional technique introduced by Bailliart in 1917 has several drawbacks: 1) it requires considerable expertise; 2) it is subject to observer variation; 3) it is difficult to perform on agitated or confused patients; 4) it cannot be performed on patients with dense cataracts; and 5) it is impossible to measure simultaneous ophthalmic arterial pressures (OAP's). For these and other reasons, the conventional technique has enjoyed a few spurts of popularity, but even with the modification of Toole, it remains a clumsy, nonreproducible, and time-consuming procedure for most clinicians.

Most of these problems have been overcome by a relatively recent modification called "ocular pneumoplethysmography" (OPG) which uses suction rather than pressure to raise intraocular pressure. Small cups applied laterally to each globe permit the simultaneous application of graduated intraocular pressure by deforming the globes gently with suction. As the intraocular pressure is automatically and gradually decreased, the emerging ophthalmic artery pulsations are detected by a pressure transducer and printed on a strip chart recorder.

At the outset, some confusing terminology should be clarified. There are actually two OPG techniques. In one, the suction cup and tubing connected to the transducer of the system described above are filled with air before a vacuum is applied. This system, which was devised by Gee, et al., after several years of laboratory investigation, has been called "ocular pneumoplethysmography," "oculopneumoplethysmography," "ophthalmoplethysmography," or "OPG-Gee." Since this technique measures actual OAP, Ackerman has also designated this system "OPG-P." Another commercially available method involves less suction, with either an air- or a fluid-filled conduction system. This technique measures the relative arrival time of the ocular pulse waves. The fluid-filled system, known as "oculoplethysmography," is more popular. This technique was devised by McRae and Kartchner, and has been designated "OPG-Kartchner." Since it measures flow rather than pressure, Ackerman has referred to it as "OPG-F." Despite their similarities, OPG-Gee and OPG-Kartchner do not provide equivalent data; in fact, McRae and Kartchner have emphasized that the pulses...
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FIG. 1. Pre- and postoperative corrected ophthalmic artery pressure (COAP) determinations in 15 patients with carotid endarterectomy. Solid line represents a patent, and broken line a nonpatent, anterior communicating artery.

130
120
110
100
90
80
70
60
50

PRE-OP POST-OP PRE-OP POST-OP

OPERATED SIDE NON-OPERATED SIDE

recorded by their technique "represent volumetric pulsations of the eye that cannot be equated with intraocular, retinal or ophthalmic artery pressures."

Both types of OPG have been used largely by the non-neurosurgical community. Paradoxically, their greatest potential use, particularly that of the Gee technique, lies in their neurosurgical applications. This article describes our experience at the Vascular Laboratory of the Gundersen Clinic, Ltd., in La Crosse, Wisconsin, where only the Gee methodology has been employed.

Clinical Material and Methods

Between December 19, 1978, and May 21, 1980, 337 OPG-Gee* determinations were made in 204 patients with suspected or proven cerebrovascular disease. The data for 17 cases are presented here.

Ocular pneumoplethysmographic measurements were made according to a standard protocol. Except as noted below, each test was conducted by the same technician in the same quiet, secluded room. The purpose of the test and its technique were explained to the patient. The test was presented as a simple, safe, and painless study. The patient's past medical history was reviewed, with special emphasis on evidence of hypertension and ocular disease. Absolute contraindications to OPG-Gee were: 1) a history of retinal hole, tear, or detachment; and 2) ocular injury or surgery within the preceding 6 months. Other contraindications included hypersensitivity to the local anesthetic agent, untreated glaucoma, and a history of vitreous hemorrhage, either spontaneous or secondary to diabetic retinopathy.

The patient was instructed to lie supine on the examining table, and his blood pressure was recorded in each arm by means of a portable Doppler blood flow detector. After inquiring about possible drug allergy, the technician administered local anesthetic drops to each eye, three times over a 10-minute period. The ocular suction cups were applied to the lateral sclera, and the patient was then instructed to look directly ahead at a test object. He was asked not to blink. He was informed that his vision would dim transiently in each eye with a "good test." The OAP's were then measured simultaneously with a maximum vacuum of 300 mm Hg using the OPG-Gee apparatus. If the OAP's could not be measured with this maximum vacuum, the test was repeated using a 500-mm Hg vacuum. At the conclusion of the 10- to 15-second test, blood pressures were again taken in each arm. The higher postexamination systolic value was selected as the reference brachial systolic pressure (BSP). Each OAP was then adjusted to a standard BSP of 140 mm Hg using a nomogram based on Gee's determinations. This was called the "corrected ophthalmic artery pressure" (COAP).

The above protocol was adjusted slightly in the intensive care unit and on the wards where privacy and quiet were not always available. In the operating room during carotid artery surgery, the blood pressure was measured by a direct arterial line.

Results

There were no complications associated with the 337 OPG-Gee determinations performed in the study period. Many patients, usually those undergoing carotid endarterectomy or gradual carotid occlusion, underwent multiple determinations.

Data for 15 consecutive carotid endarterectomy patients who had pre- and postoperative OPG testing are shown in Tables 1 and 2 and Figs. 1 and 2. In every instance but one (Case 13), the COAP's were unchanged or higher postoperatively on the side operated on. Angiographically demonstrated patency of the anterior communicating artery made no appreciable difference, but it should be pointed out that no cross-compression studies were attempted. The COAP changes on the side not operated on were inconsistent.

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*Gee ocular pneumoplethysmography apparatus manufactured by Electro-Diagnostic Instruments, Burbank, California.

†Doppler blood flow detector, Model BF4A, manufactured by Medsonics, Mountain View, California.
FIG 2. Serial pre-, intra-, and postoperative corrected ophthalmic artery pressures (COAP’s) in Case 9. Solid circles represent values on the side of surgery (the left); open circles represent contralateral COAP’s. No intraoperative testing was done until the shunt was already in place. When the internal carotid artery was clamped for shunt removal, the COAP in the left eye fell from 91 to 41 mm Hg. It returned to 92 mm Hg upon completion of the arterial repair. Serial COAP’s in both eyes continued to rise slowly in the immediate postoperative period. ACA = anterior communicating artery.

and unpredictable. Most carotid endarterectomy patients underwent serial postoperative OPG determinations to ensure continued patency of the operated artery (Fig. 2), but no deterioration was noted, either clinically or with OPG.

Two additional patients, who underwent gradual common carotid artery occlusion using a Selverstone or Salibi clamp, were also tested with this technique. The first patient’s course is shown in Fig. 3 (Case 16). With the right common carotid artery completely occluded under general anesthesia, COAP in the right eye dropped from 106 to 50 mm Hg. Clamping of both the right common and external carotid arteries caused COAP in the right eye to fall even further, to 28 mm Hg, indicating a substantial collateral contribution from the right external to internal carotid artery (ICA). A Selverstone clamp was then applied to the right common carotid artery and adjusted to a COAP of about 90% of the resting value, according to the protocol developed by Tindall, et al. The next day the clamp was turned down slightly, but no OPG measurement could be made after turndown because of intense blepharospasm. The next day a reliable measurement was obtained before turndown, but a second determination could not be made because the patient was blinking, despite moderate sedation. Two measurements were possible on the day of clamp removal. Serial OPG determinations for the second patient (Case 17) revealed that no significant change in pressure took place until the final adjustment. In essence, the patient underwent an abrupt common carotid artery occlusion although her Salibi clamp was turned down slowly over a 3-day period.

Discussion

General Considerations

In attempting to relate ophthalmic artery pressure to carotid or cerebral blood flow or pressure, Gee relied on the elegant theoretical and experimental studies of Berguer and Hwang, who showed that with increasing arterial stenosis the change in distal pressure was more gradual and less abrupt than the change in flow. Nonetheless, the differences were so slight that for most purposes pressure and flow were affected almost equally and concomitantly. Initially, Gee and his coworkers related ophthalmic artery pressure (OAP) to brachial systolic pressure (BSP) in an
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OAP:BSP ratio. They considered that a determination was abnormal if BSP was 142 mm Hg or less and if either or both OAP:BSP ratios were less than 0.77. This practice proved awkward, and Gee, et al., have since discarded it.10,11

As it was difficult, if not impossible, to relate OAP to carotid or cerebral blood flow or pressure without knowing the concomitant arterial pressure, it was our practice to correct or adjust the OAP to a BSP of 140 mm Hg according to the nomogram determined by Gee, et al.11 In 171 patients, who underwent cerebral angiography and were found to have normal ICA's, the median BSP was 140 mm Hg.11 Thus, an OAP of 115 mm Hg in a patient with a BSP of 162 mm Hg was adjusted to a corrected ophthalmic artery pressure (COAP) of 104 mm Hg. This practice eliminated the need to include concomitant blood pressure measurements in graphs and tables, and it enabled us to make serial comparisons more easily.

One major problem in determining COAP was the variable systolic pressure encountered in patients with pulsus alternans. This condition was seen most frequently in patients with chronic atrial fibrillation in whom the arterial pulse wave varied in both amplitude and regularity. The accuracy of COAP determinations made under such circumstances was questionable; however, gross discrepancies were still readily detected, as were asymmetries of OAP.

The standard deviation in our laboratory for any OPG determination in a clinically stable patient was 4.9 mm Hg. This lack of precision was not due to the OPG apparatus but rather to the technical problems in taking blood pressure. In view of the numerous normal fluctuations in blood pressure, we adopted a rigid...
**TABLE 1**

Pre- and postoperative COA P determinations in 15 carotid endarterectomy patients*

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Side of Operation</th>
<th>Luminal Diameter Stenosis (%)</th>
<th>Patent ACoA</th>
<th>COAP (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Op Side</td>
<td>Nonop Side</td>
<td></td>
<td>Operated Side</td>
</tr>
<tr>
<td></td>
<td>Preop</td>
<td>Postop</td>
<td>Preop</td>
<td>Postop</td>
</tr>
<tr>
<td>1</td>
<td>rt</td>
<td>85</td>
<td>83</td>
<td>+</td>
</tr>
<tr>
<td>2</td>
<td>rt</td>
<td>75</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>3</td>
<td>lt</td>
<td>75</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>4</td>
<td>lt</td>
<td>80</td>
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<td>+</td>
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</tr>
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<td>6</td>
<td>lt</td>
<td>69</td>
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<tr>
<td>15</td>
<td>rt</td>
<td>90</td>
<td>30</td>
<td>+</td>
</tr>
</tbody>
</table>

*COAP = corrected ophthalmic artery pressure; ACoA = anterior communicating artery.

**TABLE 2**

Changes in COA P after carotid endarterectomy*

<table>
<thead>
<tr>
<th>Side &amp; ACoA Patency</th>
<th>COAP Change (mm Hg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>operated side</td>
<td></td>
</tr>
<tr>
<td>ACoA patent</td>
<td>113.0</td>
</tr>
<tr>
<td>ACoA not patent</td>
<td>111.6</td>
</tr>
<tr>
<td>total</td>
<td>112.5</td>
</tr>
<tr>
<td>nonoperated side</td>
<td></td>
</tr>
<tr>
<td>ACoA patent</td>
<td>10.7</td>
</tr>
<tr>
<td>ACoA not patent</td>
<td>10.5</td>
</tr>
<tr>
<td>total</td>
<td>10.3</td>
</tr>
</tbody>
</table>

*COAP = corrected ophthalmic artery pressure; ACoA = anterior communicating artery; I = increase; i = decrease.

from shallow ulcerations that do not significantly affect flow. It has also been shown that even arteriography of excellent quality cannot consistently identify active ulcer craters. Since most transient ischemic attacks (TIA's) are secondary to cerebral embolization in patients with an otherwise satisfactory regional cerebral blood flow, the real value of all noninvasive testing has been questioned. Fortunately, there is a high correlation between embolization and stenosis, and many patients with TIA's who are symptomatic from embolization are also found to have significantly impaired carotid flow secondary to the stenotic ulcerated plaque. According to the current Mayo Clinic protocol for the management of TIA's, ulcerated plaques that do not significantly impair flow through the ICA are usually treated medically, whereas those lesions with greater than 50% stenosis are treated by endarterectomy.

The COAP's either remained the same or increased in the ipsilateral eye after carotid endarterectomy (Tables 1 and 2, and Fig. 1). Some increases were dramatic, as, for instance, a jump from 68 to 92 mm Hg in a patient with a 90% luminal diameter stenosis on the side operated on, and a complete occlusion on the other (Fig. 2). There was no consistent trend for the contralateral COAP; it might increase, decrease, or remain the same, but whatever the change, it was not as pronounced as on the operated side. The greatest fluctuations in the contralateral eye were seen in patients whose anterior communicating arteries were found to be patent on routine cerebral angiography. Kobayashi, et al., used ophthalmodynamometry to evaluate their patients before and after carotid endarterectomy. They found the retinal arterial pressure (a term that is synonymous with OAP) had a high correlation with the degree of stenosis of the ipsi-
lateral carotid artery when that stenosis was severe. Asymmetry in retinal arterial pressure was found to be greatest when the stenosis was more marked on one side, but both values tended to be decreased when the stenosis was severe bilaterally. Postoperatively, these patients usually had an increased retinal arterial pressure on the side operated on as well as on the contralateral side. The authors believed that the ipsilateral pressure should be normal after carotid endarterectomy and that a subnormal postoperative value demanded immediate investigation.

In recent years, the safety of carotid endarterectomy has come under sharp attack, and there has been increased emphasis on intraoperative monitoring in operations performed under general anesthesia. Current popular techniques include the measurement of carotid stump or back pressure, electroencephalography, OPG-Gee, OPG-Kartchner, and supraorbital photoplethysmography.

The OPG-Kartchner system, in which the vacuum applied to each globe is only 50 to 70 mm Hg, can be employed continuously. Pearce, et al., described an incident in which the pulse delay in the ipsilateral eye rose abruptly to 60 msec from a normal baseline value at the time a shunt was inserted. The shunt was then moved a slight distance proximally, and the pulse delay readings returned instantly to less than 10 msec. They concluded that the distal end of the shunt had impinged upon the wall of the ICA above the arteriography and out of the surgeon’s view. In contrast, the Gee system, because of its higher suction requirement, can be used only intermittently during carotid artery surgery, but it has the advantage of measuring actual OAP’s. Sometimes the values observed toward the end of our procedures were inexplicably low, and on one occasion the suture line was reopened to make sure that a distal thrombus was not responsible for this finding. Gee also noted this phenomenon, and pointed out that the OAP usually returned to a resting value several days after surgery. He attributed these events to arterial spasm provoked by the operation.

Carotid Artery Kinking

Stanton, et al., used the OPG-Kartchner apparatus to assess the role of kinking of the ICA in cerebral ischemia. They documented ICA kinking on the angiograms of 26 patients with some form of cerebrovascular symptomatology. Testing was performed with the patient’s head and neck in a neutral position, followed by extreme right and left rotation and then flexion and extension. Sixteen patients underwent angioplasty. Electromagnetic flow measurements during surgery showed a 30% to 80% reduction in flow during similar intraoperative positioning for 14 of the 16 patients. All 14 patients with abnormal intraoperative flow measurements also had abnormal preoperative OPG testing. No such abnormalities were noted after surgical correction. The authors concluded that positional OPG testing may be helpful in detecting hemodynamically significant kinking; however, it should be pointed out that the vast majority of patients who underwent surgery presented with vertebrobasilar and not carotid artery symptoms.

Extracranial-Intracranial Bypass

In contrast to their results with carotid endarterectomy, Kearns, et al., found that retinal arterial pressures did not return to normal following a successful superficial temporal artery-middle cerebral artery bypass. Their procedures were performed for venous stasis retinopathy and/or ischemic orbital pain secondary to carotid occlusive disease. Of 24 patients who underwent extracranial-intracranial bypass for non-ocular manifestations of carotid occlusive disease in the series of Gee, et al., 17 demonstrated improvement on postoperative OPG testing. Improvement was unilateral in four patients, definitely bilateral in eight, and possibly bilateral in five.

Gradual Carotid Artery Occlusion

Although gradual occlusion of the internal or common carotid artery used to be a popular means of treating certain intracranial aneurysms, the procedure has lost much of its appeal because of the increasing success of direct operative intervention. Unfortunately, some aneurysms are still not amenable to direct attack, and gradual carotid artery occlusion may be the treatment of choice. Tindall, et al., devised a protocol for safe occlusion of the common carotid artery based upon the gradual reduction of retinal artery pressures measured by ophthalmodynamometry. This protocol was attempted for our first aneurysm patient, but it could not be followed with the patient awake, even when she was moderately sedated, because of intense blepharospasm. Kindt also attempted to make carotid occlusion a less hazardous process by designing a clamp in which the luminal area rather than the diameter of the vessel was decreased in a linear fashion. The results of OPG testing in our second patient support Kindt’s argument.

Carotid Ligation for Extracranial Aneurysms

Oller, et al., used OPG in the evaluation and treatment of four patients with aneurysms of the extracranial portion of the ICA. Before ligation of that vessel, the authors demonstrated back pressure in the ICA by performing OPG during ipsilateral common carotid compression. They also determined the continuing adequacy of collateral flow with serial postoperative OPG measurements.

Subtotal Carotid Occlusion for Intracranial Aneurysms

Mullan advocated subtotal occlusion of the common carotid artery as part of his preoperative protocol for ruptured intracranial aneurysms. Following

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diagnostic angiography, 16 patients underwent the application of a common carotid artery clamp low in the neck. The artery was totally occluded, then the clamp was slowly released until the carotid pulsation could be manually palpated in the area of the carotid bifurcation. In five cases, direct pressure measurements were made by catheterizing the superficial temporal artery down to the region of the bifurcation. In two patients, retinal arterial pressures were determined by ophthalmodynamometry.

Mullan’s intent was to prevent rupture of the aneurysm by reducing blood pressure distal to the clamp, and at the same time maintaining flow through the common carotid artery so as to prevent the formation of a thrombus above the clamp. The clamp was removed after definitive surgery on the aneurysm. One clamp was not removed in a patient with multiple aneurysms. Mullan also pointed out that with some clamps there was a tendency toward spontaneous opening in the first few days, and that it was necessary to check each clamp twice daily. Unhappily, this is a common problem with carotid artery clamps, and since there is no accurate way of knowing how far a clamp has yet to be turned down or how much it has loosened, OPG-Gee would seem to offer the most exact means of regulating ICA pressure and flow.

Head and Neck Trauma

One of the few advantages of cerebral angiography over computerized tomography (CT) for evaluation of head trauma is that the former supplies vascular details that can only be inferred by the latter. A case in point is traumatic ICA thrombosis secondary to nonpenetrating injury of the neck. The CT scan may show a large low-density area with sharp margins corresponding to the distribution of the ICA, but such change can also be due to direct brain injury. If, as originally suggested by Schneider and Lemmen, the retinal arterial pressures (OAP’s or COAP’s) are disparate, the diagnosis is supported. If the values are the same, the lesion is due to either a direct brain injury or arterial injury distal to the origin of the ophthalmic artery. Thus, OPG may obviate the need for arteriography.

Other Applications

The OPG-Gee technique has also proved helpful for problems unassociated with cerebrovascular disease. The distinction between central retinal artery and venous occlusion is generally considered to be straightforward, but this is not always true. The OPG-Gee procedure confirmed the diagnosis of a central retinal artery occlusion for one patient in our series. Nolph, et al., have also used it to determine whether patients with head and neck cancer could tolerate resection of the involved artery.

Conclusions

Ocular pneumoplethysmography is a safe, simple, painless, accurate, and reproducible way of evaluating and treating patients with a variety of disorders of the head and neck. Its greatest application lies in cases of cerebrovascular disease, especially carotid artery stenosis.

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