Amplitude of the Ocular Pneumoplethysmography Waveform Is Correlated With Cardiac Output

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Background and Purpose: Ocular pulse amplitude, the amplitude of the ocular pneumoplethysmographic waveform, is altered in several ophthalmologic diseases that disturb ocular blood flow, implying that ocular pulse amplitude may provide an estimate of ocular blood flow. Because ocular blood flow currently cannot be quantified in humans, two experiments were undertaken to evaluate the association of ocular pulse amplitude with total body blood flow.

Methods: In experiment 1, cardiac output was determined by cardiac catheterization in 181 patients who underwent OPG-Gee testing during the same hospitalization. In experiment 2, 110 instances of atrial arrhythmia captured on ocular pneumoplethysmographic tracings were evaluated for transient changes in heart rate (R-R ratio) associated with transient changes in ocular pulse amplitude (ocular pulse amplitude ratio).

Results: In experiment 1, average ocular pulse amplitude in the two eyes (OPAave) was significantly correlated with cardiac output/heart rate (r=0.53; p<0.0001) and cardiac index/heart rate (r=0.43; p<0.0001). In experiment 2, R-R ratio was significantly correlated with ocular pulse amplitude ratio (r=0.85; p<0.001).

Conclusions: These results show that ocular pulse amplitude, a physiological measurement obtained from the globe, is correlated with cardiac output. They imply that ocular pulse amplitude may provide a clinically useful estimate of at least the pulsatile component of ocular blood flow. (Stroke 1993;24:6–9)

Key Words • blood flow velocity • cardiac output • ocular disease

Ocular pneumoplethysmography (OPG) is useful in the noninvasive diagnosis of hemodynamically significant carotid stenosis, but little is known about the relation of OPG testing to ocular hemodynamics. Gee and colleagues documented increased ocular pulse amplitude (OPA), the size of the OPG waveform, in certain patients with carotid-cavernous fistulae; Bosley et al reported that OPA was strikingly reduced in giant cell arteritis, a vasculitis that causes ischemic optic neuropathy, central retinal artery occlusion, and choroidal hypoperfusion. These findings imply that OPA may be associated with ocular blood flow in certain pathological conditions.

Global ocular blood flow cannot be easily measured quantitatively in humans; therefore, in this study a relation was sought between OPA and global body blood flow, or cardiac output (CO). The purposes of this study were as follows: in a group of patients, to compare OPA to an accepted measure of CO; and in individual patients, to evaluate the effect on OPA of transient changes in cardiac ejection volume.

Subjects and Methods

Experiment 1

Hospital records were reviewed from all 181 patients (100 men and 81 women) admitted to Lehigh Valley Hospital Center, Allentown, Pa., during 1987 and 1988 for cardiac catheterization for suspected valvular or septal lesions. Each patient also had OPG testing as part of an ongoing admission survey. No patient was excluded because of possible carotid or ophthalmologic disease or because of technically inadequate OPG studies. CO was measured by the thermal dilution technique, and cardiac index (CI) was calculated by dividing CO by body surface area extracted from height–weight tables.

In both experiments, OPG was performed with the model OPG-3LP machine (Electro-Diagnostic Instruments, Burbank, Calif.) in the recommended fashion. Briefly, small suction cups were placed simultaneously in both eyes over the sclera inferolateral to the cornea. Vacuum (either 300 or 500 mm Hg) was applied, and the intraocular pressure was elevated transiently above ophthalmic artery pressure. As vacuum was gradually

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reduced, the return of blood flow to the eye was detected by volume-calibrated pressure transducers attached to each suction cup assembly. Maximal amplitude of the OPG waveform was typically reached at an estimated intraocular pressure of ≤90 mm Hg, and OPA was measured in this portion of the tracing from both eyes from peak to trough of a representative wave. Average OPA (OPA\textsubscript{AV}) for each tracing was calculated by the formula OPA\textsubscript{AV}=(OPA\textsubscript{L}+OPA\textsubscript{R})/2, where OPA\textsubscript{L} was OPA measured in the tracing from the left eye and OPA\textsubscript{R} that measured from the right eye.

Descriptive measures identifying the patient sample included age, systolic blood pressure, diastolic blood pressure, heart rate (HR), OPA\textsubscript{AV}, CO, body surface area, and CI. Pearson's correlation coefficients were determined for patient's age, systolic blood pressure, diastolic blood pressure, CO/HR, and CI/HR with OPA\textsubscript{AV}. Multiple regression with stepwise methods was used for determining prediction equations.

Experiment 2

Changes in ventricular rates cause changes in cardiac ejection volume: faster ventricular rates reduced diastolic filling and ejection volume, whereas slower ventricular rates increased ejection volume. For this reason, all 383 OPG tracings obtained in the Wills Eye Hospital Vascular Studies Laboratory between January 1, 1988, and September 1, 1988, were reviewed for instances of atrial arrhythmia captured during the portion of the tracing in which OPA was maximal (estimated intraocular pressure of ≤90 mm Hg). No patient was excluded because of presumed carotid or ophthalmologic disease. An atrial arrhythmia was recognized by an alteration in R-R interval on the OPG electrocardiographic tracing with a P wave preceding an aberrant QRS complex of normal morphology.

Figure 1 illustrates a typical OPG tracing in which normal sinus rhythm established a baseline R-R interval and baseline OPA for each eye before the appearance of an atrial arrhythmia in which an aberrant QRS complex occurring after a short R-R interval was succeeded by another aberrant QRS complex occurring after a long R-R interval (compensatory pause). Each of these aberrant QRS complexes was followed by aberrant OPG waveforms from which the OPA was measured for each eye. Ratios were established for each aberrant QRS complex using the following formulas: R-R ratio=aberrant/baseline R-R interval; and OPA ratio=aberrant OPA\textsubscript{AV}/baseline OPA\textsubscript{AV}. These ratios permitted an assessment within an individual of the effect of relative changes in HR on relative change in OPA.

A total of 110 aberrant QRS complexes were identified in OPG tracings of 26 patients (12 men and 14 women; average age, 66.7 years) that yielded 110 data pairs in which an R-R ratio was linked to an OPA\textsubscript{AV} ratio. Pearson correlation coefficient was obtained between R-R ratios and OPA ratios.

Results

Experiment 1

Table 1 shows normative information for patients and tests included in experiment 1. This older normotensive group had cardiac catheterization and OPG testing no more than 17 days apart. Figure 2 illustrates the significant correlation between OPA\textsubscript{AV} and CO/HR (r=0.53; p<0.0001). Significant correlations were also found between OPA\textsubscript{AV} and CI/HR (r=0.45; p=0.0001) and systolic blood pressure (r=0.42; p=0.001). The stepwise regression equation predicting OPA\textsubscript{AV} was OPA\textsubscript{AV}=6.58−0.118×HR+2.365×CI+0.049×systolic blood pressure (r=0.602; p<0.001). Diastolic blood pressure, age, and body surface area were not correlated with OPA\textsubscript{AV}.

Experiment 2

Figure 3 illustrates the significant correlation between OPA ratio and R-R ratio (r=0.85; p<0.001).

Table 1. Normative Data for Patients and Tests in Experiment 1

<table>
<thead>
<tr>
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<th>Mean±SEM</th>
<th>95% confidence interval</th>
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<tbody>
<tr>
<td>Age (years)</td>
<td>65.6±0.82</td>
<td>63.97−67.20</td>
</tr>
<tr>
<td>No. days between studies</td>
<td>3.1±0.23</td>
<td>2.6−3.5</td>
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<tr>
<td>Blood pressure (mm Hg)</td>
<td></td>
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<tr>
<td>Systolic</td>
<td>127.9±1.77</td>
<td>124.4−131.4</td>
</tr>
<tr>
<td>Diastolic</td>
<td>71.6±1.04</td>
<td>69.5−73.6</td>
</tr>
<tr>
<td>Heart rate (bpm)</td>
<td>77.1±1.13</td>
<td>74.9−79.4</td>
</tr>
<tr>
<td>OPA\textsubscript{AV} (mm)</td>
<td>10.4±0.35</td>
<td>9.74−11.12</td>
</tr>
<tr>
<td>Cardiac output (l/min)</td>
<td>4.93±0.091</td>
<td>4.74−5.12</td>
</tr>
<tr>
<td>Body surface area (m²)</td>
<td>1.87±0.02</td>
<td>1.83−1.91</td>
</tr>
<tr>
<td>Cardiac index (l/min per m²)</td>
<td>2.64±0.048</td>
<td>2.54−2.73</td>
</tr>
</tbody>
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bpm, Beats per minute; OPA\textsubscript{AV}, average ocular pulse amplitude.
Discussion

A test that accurately estimates human ocular blood flow in vivo would be valuable in the diagnosis and quantification of ophthalmologic disorders known to be vascular in origin and in the investigation of ophthalmologic disorders that may have abnormalities of blood flow as part of their pathophysiology. Unfortunately, techniques currently used to evaluate ocular blood flow are nonquantitative (e.g., fluorescein angiography), technically difficult (e.g., laser photoveloecimetry), inappropriate for humans (e.g., radioactive microspheres), or unproven (e.g., measurement of pulsatile changes in intraocular pressure). OPG testing is safe, reproducible, technically straightforward, and widely used for the evaluation of carotid disease. OPA, the amplitude of OPG waveforms, is altered appropriately in certain ophthalmologic disorders causing increased and decreased ocular blood flow, but the relation of OPA to ocular blood flow in the absence of ocular disease has been unclear.

In this study we compared two different measures of CO to OPA on the assumption that a significant correlation would imply that OPA provides an estimate of the ocular portion of total body blood flow. Experiment 1 demonstrated a significant correlation in a group of patients between CO (and CI) by the thermal dilution technique and OPA. Experiment 2 documented a strong correlation in individual patients between transient changes in HR and associated changes in OPA.

In experiment 1, CO/HR accounted for only 28% (Pearson R²) of the variation in OPA. Cardiac catheterization and OPG were not performed at the same time, and the strength of this correlation will also be affected by the experimental error inherent in both tests. In addition, CO is not the only determinant of ocular blood flow. Systolic blood pressure was also correlated with OPA in this study, and Gee reported significant changes in OPA due to hemodynamic carotid disease. Certain ophthalmologic disorders influence OPA, and undetermined factors related to a particular individual (such as choroidal anatomy, nonpulsatile [diastolic] ocular blood flow, and scleral rigidity) might affect either global ocular blood flow or OPA (independent of ocular blood flow).

Experiment 2 was not influenced by many of these undetermined factors because the effects of transient changes in the duration of diastole were compared with baseline HR and OPA values established in the same OPG tracing. Cardiac ejection volume is greatly influenced by the duration of diastole, and cardiac ejection volume will affect the volume of blood arriving at the eyes and other organs after each systole. This estimation of total body blood flow is considerably different from that in experiment 1 because it focuses on changes in blood flow between individual systoles within an individual patient. Transient changes in R-R interval (with attendant transient changes in CO and blood pressure) accounted for 72% (Pearson R²) of the variation in OPA, demonstrating that changes in the duration of diastole in a particular individual have a significant effect on the amplitude of the OPG waveform. The strength of this correlation implies that OPA may be quite predictive of at least the pulsatile (systolic) portion of ocular blood flow during a single cardiac cycle.

The present study leaves in doubt the exact quantification of ocular blood flow from OPA because it does not evaluate the possible contribution of nonpulsatile (diastolic) blood flow and because it offers no method of converting OPA and HR information to ocular blood flow in milliliters per minute. Nevertheless, OPA may be the best estimate now available of pulsatile ocular blood flow, and the use of appropriate control groups in clinical studies may reduce uncertainties regarding quantification.

References
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