Fig. 3. Clearance of xenon-133 from a vitreous sample of thickness 0.088 cm.

Table I. Diffusion coefficients (mean ± S.D.)

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Number of measurements</th>
<th>Diffusion coefficient of xenon (×10^-5 cm^2/sec.)</th>
<th>Calculated diffusion coefficient of krypton (×10^-5 cm^2/sec.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sclera</td>
<td>6</td>
<td>1.3 ± 0.3</td>
<td>1.6 ± 0.3</td>
</tr>
<tr>
<td>Choroid</td>
<td>5</td>
<td>0.61 ± 0.14</td>
<td>0.76 ± 0.14</td>
</tr>
<tr>
<td>Retina</td>
<td>5</td>
<td>0.64 ± 0.05</td>
<td>0.80 ± 0.05</td>
</tr>
<tr>
<td>Vitreous</td>
<td>8</td>
<td>0.96 ± 0.12</td>
<td>1.2 ± 0.12</td>
</tr>
</tbody>
</table>

440 seconds (vitreous). These values are at least one order of magnitude greater than those obtained with the empty vessel.

This work was carried out in the Tennent Institute of Ophthalmology, University of Glasgow, and was supported by an M.R.C. Grant No. G971/386/C to Professor W. S. Foulds. Submitted for publication July 12, 1976. Reprint requests: Dr. Ronald Strang, West of Scotland Health Boards, Department of Clinical Physics & Bio-Engineering, 11 W. Graham St., Glasgow G4 9LF, Scotland.

Key words: diffusion coefficient, krypton, xenon, sclera, choroid, retina, vitreous.

REFERENCES

Simultaneous bilateral determination of the systolic pressure of the ophthalmic arteries by ocular pneumoplethysmography. *WILLIAM GEE, *DALE W. OLLER, **LOUIS D. HOMER, and **R. CLIFTON BAILEY.

An ocular pneumoplethysmograph has been developed to measure the systolic pressure of both ophthalmic arteries simultaneously, and with precision. The purpose of this report is to demonstrate the physiologic basis for these measurements.

It has been demonstrated that the application of a variable vacuum to the eye elevates the intraocular pressure in a very precise fashion.1 2 Others have demonstrated that the ocular globe pulsates synchronously with the phasic changes between the systolic and diastolic pressure of the ophthalmic artery.3 4 A pneumatic transducer has been designed to detect these pulsations with much greater ease than was previously appreciated with hydraulic transducers. In addition to the two ocular pulse transducers, a third transducer to measure the degree of vacuum applied to the system is incorporated into the ocular pneumoplethysmograph (Electro-Diagnostic Instruments, Burbank, Calif.) A description of the pneumatic configuration of the three transducers
has been previously reported. Although the instrument has a self-contained three-channel recorder, for the purposes of this report the signals were transmitted to a multichannel recorder.

Methods and materials. In addition to the ocular pneumoplethysmograph, three standard arterial pressure transducers were connected to a multichannel recorder. These three transducers were connected by saline-filled pressure tubing to 18-gauge needles which were introduced into the posterior chamber of each eye of the baboon, and to a flexible cannula inserted into the right carotid artery of the animal. The suction cups of the ocular pneumoplethysmograph were applied to the respective corneas of the baboon. Five adult baboons were studied. Fig. 1 is a line drawing of the experimental configuration.

Results. Fig. 2 is a representative record from one of the baboons. As the vacuum applied to each eyecup by the ocular pneumoplethysmograph was increased from zero to 300 mm. Hg, the intraocular pressure in each eye was elevated from an intrinsic level of 30 mm. Hg to over 120 mm. Hg. As the applied vacuum was allowed to fall, so too did the respective intraocular pressures. The first arrow indicates a point at which the animal blinked both eyes. The second arrow indicates the onset of bilateral ocular pulsations, as detected by the ocular pneumoplethysmograph. This is also the point at which barely detectable pulsatile waves are noted in the respective intraocular pressure tracings. Table I contains the pressure data noted at the onset of ocular pulsations.

Normal blood pressure was observed during most of the determinations in the five animals. Hypotension as low as 55/54 mm. Hg was induced during some determinations. Hypertension as high as 225/130 mm. Hg was induced during other determinations. Extreme hypotension, with its associated low pulse pressure, rendered the ocular globes essentially pulseless. As a result, the ocular pulse transducers of the pneumoplethysmograph recorded only background tremor. However, even at the extremes of blood pressure, relatively small differences in elevation of the intraocular pressure at a given degree of applied vacuum were noted. As might be expected, the elevation of the intraocular pressure tended to be lower than the mean observations in those animals in which the vacuum was applied while the animal was rendered hypotensive. The converse was observed during induced hypertension. The intraocular pressure data from all of the determinations were plotted into 11 groups corresponding to the ten, 30 mm. Hg vacuum increments from zero to 300 mm. Hg. From these data a formula for predicting the intraocular pressure at a given applied vacuum was constructed, as follows:

\[ y = 29.44 + 2.508(x)^{1.428} \]

where \( y \) = the predicted intraocular pressure and \( x \) = the measured vacuum applied to the respective eyecups. The standard error of the prediction is \( \pm 6.6 \) mm. Hg, with normal tables or t tables with 140 degrees of freedom. Fig. 3 is a graphic representation of these calculations, with all figures rounded to the nearest whole number.

On the basis of these observations, it is reasoned that by knowing the degree of vacuum applied to the eye, one can infer the intraocular pressure. Furthermore, from a knowledge of the intraocular pressure at which eye pulsations commence, the systolic pressure of the respective ophthalmic arteries can be inferred.

Comments. We have applied this experimental technique to adult New Zealand white rabbits, also. Although the method cannot be applied to human beings, others have determined the variation of intraocular pressure in man, by tonometry, when increments of vacuum are applied to the eye. In all of these experimental and clinical situations the same-sized eyecup was used,

Table I. Pressure data at the onset of ocular pulsations

<table>
<thead>
<tr>
<th>Vacuum</th>
<th>Pressure</th>
</tr>
</thead>
<tbody>
<tr>
<td>240 mm. Hg</td>
<td>Right intraocular pressure</td>
</tr>
<tr>
<td>112 mm. Hg</td>
<td>Left intraocular pressure</td>
</tr>
<tr>
<td>105 mm. Hg</td>
<td>Right carotid systolic pressure</td>
</tr>
</tbody>
</table>

where \( y \) = the predicted intraocular pressure and \( x \) = the measured vacuum applied to the respective eyecups. The standard error of the prediction is \( \pm 6.6 \) mm. Hg, with normal tables or t tables with 140 degrees of freedom. Fig. 3 is a graphic representation of these calculations, with all figures rounded to the nearest whole number.

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Fig. 2. Representative ocular pneumoplethysmograph from one baboon. This record was obtained at a paper speed of 10 mm. per second.

which has an internal diameter of 12 mm. and an external diameter of 14 mm. The transverse diameters of the human, baboon, and New Zealand white rabbit eyes are 24, 22, and 20 mm., respectively. The application of 300 mm. Hg vacuum via the standard eyecup to the eyes of each species results in a maximum elevation of the intraocular pressures of 110, 128, and 154 mm. Hg, respectively. The intrinsic intraocular pressures were 25, 30, and 20 mm. Hg, respectively. Therefore, the intraocular pressures generated by the vacuum application do not seem to be related to the intrinsic intraocular pressures, but the differences in magnitude among the three species appears to be inversely related to the size of the respective eyes. Proportionate to the surface areas of the respective eyes, a vacuum of 300 mm. Hg applied via an eyecup of 12 mm. internal diameter exerts the greatest force on the rabbit eye, a lesser force on the baboon eye, and the least force on the human eye. For this reason, care must be taken in comparing experimental data when this technique is applied to various species.

For the purposes for which the ocular pneumoplethysmograph was originally designed, there is no need to elevate the intraocular pressure above 110 mm. Hg in human beings. In our clinical application of the instrument, it has been used, in conjunction with proximal common carotid artery compression, to determine the collateral hemispheric blood pressure. It is uncommon for this figure to exceed 110 mm. Hg in man. The non-invasive determination of the collateral hemispheric blood pressure is considered absolutely essential to the management of certain brachiocephalic arterial lesions. All of our experimental and clinical work with the ocular pneumoplethysmograph thus far has been done with a maximum vacuum of 300 mm. Hg. Our clinical experience has revealed that many of the patients whom we encounter are hypertensive. In these hypertensive patients the ophthalmic systolic blood pressure
Fig. 3. The graph represents the cumulative data from the five baboons and relates degree of intraocular pressure elevation to degree of vacuum applied to the sclera. All numbers represent millimeters of mercury and, as noted in the text, are rounded to the nearest whole number. Therefore, the standard error of the mean of each intraocular pressure prediction is ± 9 mm. Hg.

frequently exceeds 110 mm. Hg. Consideration has been given to modification of the instrument to permit a maximum of 400 mm. Hg vacuum. This would allow the measurement of ophthalmic systolic blood pressures in human subjects up to the 125 to 130 mm. Hg range. Vacuums as high as 500 mm. Hg are routinely used in suction ophthalmodynamometry.² The ability to measure ophthalmic systolic blood pressures in the 125 to 130 mm. Hg range, coupled with our current work in determining pulse propagation times, should result in an instrument applicable for mass screening of subclinical carotid stenoses.

The data in this report are presented to substantiate the accuracy with which the systolic pressure in both ophthalmic arteries can be measured simultaneously, by the use of an ocular pneumoplethysmograph. The ability to make these determinations noninvasively is assuming increasing importance in the diagnosis, prognosis, and management of many brachiocephalic arterial lesions.

From the *Department of Surgery, National Naval Medical Center, and **Naval Medical Research Institute, Bethesda, Md. Opinions contained herein are those of the authors, and they do not necessarily reflect official views of the Navy Department or the naval service at large. The animals involved in this study were maintained in accordance with the Guide for Laboratory Animals Facilities and Care as published by the National Academy of Sciences—National Research Council. This study was supported in part by CICC 4-06-430. Submitted for publication May 25, 1976. Reprint requests: William Gee, M.D., National Naval Medical Center, Bethesda, Md. 20014.

REFERENCES