The Clinical Measurement of Retinal Arterial Pressure

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The determination of retinal diastolic arterial pressure by ophthalmodynamometry is described. In both normal and hypertensive subjects there was an average difference of 20 mm. Hg between retinal and brachial arterial diastolic pressures. The clinical usefulness of this procedure was demonstrated in patients with obstructive lesions in the internal carotid artery.

The importance of the retinal blood vessels in physical diagnosis has always been emphasized. However, it is only in recent years that physicians have appreciated a simple technic for measuring the pressure within these vessels. "Ophthalmodynamometry" is the determination of retinal artery pressure by application of a measured external force to the sclera, combined with ophthalmoscopic visualization of the retinal vessels. In effect, the eyeball is used as a sphygmomanometer, collapsing the retinal artery when increasing intraocular tension exceeds the intravascular pressure.

The ophthalmodynamometer currently in use was designed by Bailliart in 1917, but for many years it was of interest only to ophthalmologists. Increasing recognition of the syndrome of thrombosis of the internal carotid artery and the observation that ophthalmodynamometry is a useful tool in the diagnosis of this disorder has now brought this procedure to the attention of internists, neurologists, and neurosurgeons.

This paper deals with a general evaluation of this measurement. First, the relationship of retinal arterial diastolic pressure to brachial arterial diastolic pressure was explored. Second, the significance of factors that purport to correct for varying intraocular tensions was studied. Finally, the clinical usefulness of this procedure in the study of patients with neurologic vascular disease was confirmed.

Materials and Methods

The subjects examined were 31 healthy adults with normal systemic arterial pressures, 44 adults with varying degrees of systemic arterial hypertension (brachial diastolic pressure above 90 mm. Hg plus retinal vascular changes signifying hypertension), and 37 patients with evidences of neurologic vascular disease. All measurements of blood pressure and intraocular tension were performed by one observer.

In normal subjects and hypertensive patients, the blood pressure was measured on one arm by the auscultatory method with a standard sphygmomanometer. When necessary for careful observation, the pupils were dilated with 0.5 per cent hydroxyamphetamine (Paredrine) solution. The external eye was anesthetized with 0.5 per cent tetraaine. With the subject supine, intraocular tension was then measured bilaterally with the Schiotz tonometer. Diastolic retinal arterial pressure was determined bilaterally. The blood pressure cuff measurement was then repeated on the opposite arm. Retinal vascular alterations were evaluated for hypertension and arteriosclerosis by the criteria of Leishman and Wagener and Keith.

The same procedure was followed in 4 patients while the systemic arterial pressure was continually monitored via an indwelling femoral arterial needle, a strain-gage transducer, and a direct-writing recorder.

In the 37 patients with neurologic disease, retinal diastolic pressure measurements were obtained in the same manner, the same agents being used when necessary for dilatation of the pupils and local anesthesia. Thirteen of these patients had either differences between right and left eyes of over 15 per cent in the retinal diastolic pressure measurements, or clinical states suggestive of internal carotid artery thrombosis. These 13 subsequently had carotid arteriograms.
The Baillart ophthalmodynamometer consists of a spring-loaded plunger within a sliding barrel. The plunger is calibrated to indicate pressure in the range of 20 to 150 Gm. water. The instrument and the technique for its use have been illustrated in recent publications. Calibration were made periodically throughout the present study.

With the patient supine, the slightly convex metal foot plate was applied horizontally to the lateral surface of the sclera at the point of insertion of the lateral rectus muscle. By direct ophthalmoscopy the observer's attention was focused on the arteries overlying the optic disk and simultaneously the ophthalmodynamometer was pressed against the eyeball. When the intraocular tension attained the level of the retinal arterial diastolic pressure, the artery on the disk was noted to pulsate maximally. At this point, a convenient brake was applied to the plunger and the instrument was withdrawn from the eye in order to record the reading reached on the plunger scale.

(The retinal veins are often noted to pulsate at an intraocular pressure lower than the retinal arterial diastolic pressure. These pulsations can be distinguished by the appearance of the veins themselves and their lack of abruptness as compared to arterial pulses. The retinal arteries may be noted to pulsate slightly, prior to attaining the diastolic pressure. These pulsations can be noted in an estimated one third of all normal subjects by standard direct ophthalmoscopy, and in all patients by specialized ophthalmoscopes. However, this small expansile movement becomes a well defined collapsing pulse when the intraocular tension equals or exceeds the retinal arterial pressure.)

Systolic retinal arterial pressure may be measured by applying pressure to the sclera until visible arterial pulsations cease and the retinal arteries are blanched. This magnitude of intraocular tension causes transient ocular hypotonia, so that accurate measurements can be made at no less than half-hour intervals. Diastolic measurements may be repeated several times in quick succession without significantly affecting the result. Systolic measurements were not made in the present study. It is generally agreed that diastolic measurements proved sharper and more reproducible endpoints.

Further, in hypertensive patients, the systolic pressure in the retinal vessels often exceeds the upper limit of the standard ophthalmodynamometer scale.

The conversion scale of Magitot and Baillart was used to convert the tension applied to the sclera into standard blood pressure units (mm. Hg). This conversion is based on the intraocular tension measurement obtained with the Schiotz tonometer. The necessity for this conversion was evaluated in the present study.

Results

Correction Factors. In 75 subjects with normal intraocular tensions (but with or without arterial hypertension) the uncorrected retinal artery pressure ranged from 24 to 144 mm. When corrected for intraocular pressure by the conversion scale of Magitot and Baillart, the range was from 25 to 140 mm. Hg. The mean uncorrected pressure was 76.4 and the mean corrected pressure 76.8. The difference was not significant.

The normal intraocular tension was taken as a tonometric reading below 24 mm. Hg. The range in the subjects in this series was 10 to 24 mm. Hg. Only 1 subject with normal intraocular pressure showed a retinal artery pressure measurement slightly in excess of the brachial artery pressure (3 mm. Hg). The correction factor in this instance reduced the retinal artery pressure to 2 mm. Hg below brachial artery pressure. (One patient had a tonometric reading of 24.4 mm. Hg. This patient was subsequently found to have glaucoma and is not included in the present series. The uncorrected retinal artery pressure was 73 per cent of the brachial artery pressure. In this case, the correction factor raised the retinal artery measurement to 96 per cent of the brachial artery pressure.)

In view of the generally insignificant effect of correction factors in subjects with normal intraocular tension, the following analyses are confined to uncorrected retinal artery pressure measurements.

Ratio of Retinal Artery to Brachial Artery Pressure. Retinal artery pressure measurements taken in the right and left eye were averaged. In 75 patients with brachial diastolic pressures ranging from 49 to 160 mm. Hg, retinal artery pressures ranged from 24 to 144 Gm. (mm. Hg).

Relationships between brachial and retinal artery pressures are summarized in figure 1. In this figure, data are ranked according to each 10-mm.-Hg increment in retinal artery
pressure between 40 to 129 mm. Hg. Mean differences between retinal and brachial artery pressures are shown with their standard deviations. For example, in the retinal artery pressure range of 60 to 69 mm. Hg (8 cases) the brachial pressure averaged 16.6 mm. Hg higher (S.D. ± 7.0); in the retinal artery pressure range 90 to 99 mm. Hg (6 cases) the brachial artery pressure averaged 19.8 mm. Hg higher (S.D. ± 8.8).

The retinal artery pressure averaged 78 per cent of the brachial artery pressure for the entire group. However, figure 1 reveals that the observations do not fall parallel to the 78 percentile line, but are less in normotensive subjects and greater than 78 per cent in hypertensive patients. Absolute differences between retinal and brachial diastolic pressures averaged 20.4 mm. Hg. Figure 1 reveals this to be a closer correlation between the 2 pressures, since the group of determinations is parallel to the 100 percentile line.

In an attempt to arrive at closer correlations, the individual observations were divided into 2 groups with a brachial artery pressure of 90 mm. Hg as the dividing line. In individual subjects with brachial artery pressures below 90 mm. Hg, the retinal artery pressure averaged 73 per cent of the brachial artery pressure (S.D. ± 10). In subjects with brachial artery pressures above 90 mm. Hg, the retinal artery pressure averaged 81 per cent of the brachial artery pressure (S.D. ± 9). In the normotensive group, the mean absolute difference between brachial and retinal diastolic pressures was 19.5 mm. Hg (S.D. ± 7).

In the hypertensive group, this difference averaged 21 mm. Hg (S.D. ± 10).
Differences in Retinal Artery Pressure Between Left Eye and Right Eye. In the 75 subjects with average retinal artery diastolic pressures between 24 and 144 mm. Hg, the difference between right eye and left eye ranged between zero and 14 per cent. The mean difference was 2.3 mm. Hg or 3 per cent. In 21 subjects, there was no difference between right and left retinal artery pressure.

Ophthalmodynamometry with Simultaneous Direct Intraarterial Pressure Recordings. The application of the ophthalmodynamometer to the sclera did not significantly alter systemic arterial pressure. Omission of local anesthesia did not alter the tracings. One patient with frequent extrasystoles showed an increased frequency of ectopic beats but no significant change in the continuously monitored femoral arterial pressure.

Study of Patients with Neurologic Vascular Disease. Of 37 patients, 25 had recent sudden onset of hemiparesis. Nine patients had onset of hemiparesis 3 days to 4 years prior to admission. The remaining 3 had recurrent episodes of syncope, blurred vision and aphasia from 1 week to 1 year prior to admission.

Seven of the 37 patients showed a difference of more than 15 per cent between left and right retinal artery diastolic pressures. These differences ranged between 17 and 36 per cent (mean 25 per cent). (In the remaining 30 patients, differences between left and right retinal artery pressures ranged from zero to 14, mean 4 per cent.)

Thirteen of these patients had carotid arteriograms or angiograms including the 7 with retinal diastolic pressure differences of more than 15 per cent. Six arteriograms were entirely negative. These were in the patients with retinal artery diastolic pressure differences of less than 15 per cent.

Among the 7 positive x-ray studies 5 carotid arteriograms showed occlusion (3) or marked narrowing (2) of the internal carotid artery on the side of the lower retinal artery pressure. One patient showed a narrow aortic root and ascending arch with no filling of the innominate artery. The left carotid and subclavian arteries appeared relatively normal.

The diagnosis of pulseless disease was made. The seventh patient showed normal internal carotid arteries. However, the right anterior cerebral artery was displaced to the left. Marked vascularity was noted in the region of the middle cerebral artery, suggestive of a large tumor in this region. The tumor was demonstrated at craniotomy. In this instance no explanation was evident for the discrepancy between right and left retinal arterial pressures.

The following is a brief description of one of the cases of proven internal carotid artery thrombosis. It demonstrates a relationship of the clinical status to differences between right and left retinal arterial pressure measurements.

A. G. was a 42-year-old man with sudden onset of left-sided headache, right hemiparesis, aphasia, and confusion. His blood pressure was 150/100 and a left Horner's syndrome was demonstrated. Ophthalmodynamometry shortly following admission to the hospital revealed retinal artery pressures of 90 mm. Hg right eye, 75 mm. Hg left eye (15 per cent difference). In the 18 hours following admission there was resolution of the Horner's syndrome and improvement in hemiparesis and aphasia. With a brachial blood pressure of 120/90, retinal artery pressures were 63 mm. Hg right eye, 62 mm. Hg left eye (no difference). Over the next several days, his neurologic status again deteriorated with return of the Horner's syndrome and worsening of right hemiparesis and aphasia. On the ninth day there was a 13 per cent difference in retinal artery pressures. At that time a left carotid arteriogram showed complete thrombosis of the left internal carotid artery 3 cm. above the bifurcation of the common carotid artery.

Discussion

Several authors have discussed the special anatomic and physiologic features of the retinal circulation with reference to ophthalmodynamometry. Turk has emphasized that retinal vessels behave more like rigid tubes than other vessels because of the high tissue (intraocular) pressures (20 to 25 mm. Hg) to which they are subjected. Duke-Elder and others have suggested that the ophthalmodynamometer measures the lateral pressure of the ophthalmic artery, and not of
the vessels viewed on the retina. When these latter vessels are compressed, the blood contained in them is immobilized. The pressure within them then is the lateral pressure of the most proximal arterial branching.

Koch\textsuperscript{10} and Duke-Elder\textsuperscript{2} listed values for retinal diastolic pressure in normal persons obtained by many authors. Results varied widely. Values obtained in the present series of normotensive subjects (mean 53 mm. Hg) are higher than those obtained by most earlier authors. These discrepancies may result from differences in endpoints, technics, and instruments. In the past 5 years, Bailliart's ophthalmodynamometer has been used almost exclusively. Therefore, more uniformity in measurements by different observers may now be expected. When low diastolic retinal artery pressures were found, Svein and Hollenhorst discovered that these could be elevated by placing the patients supine.\textsuperscript{20} This observation has been verified by other authors cited by Koch.\textsuperscript{10} (Seven patients in the present series were studied for this effect; sitting pressures averaged 5 mm. Hg lower than those obtained in the supine position.)

The reproducibility of retinal artery pressure measurement was studied by Streiff.\textsuperscript{12} With 2 observers working consecutively in 800 patients, the mean error obtained was 2.5 mm. Hg (maximum 7.4 mm. Hg). This accuracy was found to be better than the tonometer.

Measurements published by authors in the past have relied upon the conversion chart of Bailliart and Magitot in converting units from Gm. to mm. Hg. The chart is based upon experiments in anesthetized cats. Furthermore, the gradations are not suitable for precise conversion. The present study indicates that in the range of accuracy of the ophthalmodynamometer, conversion factors are unnecessary in subjects with normal intracocular tensions. The diastolic retinal pressure can be read directly from the instrument.

Bailliart\textsuperscript{1, 2} and Koch\textsuperscript{10} also noted a progressive increase in the retinal diastolic pressure and in its ratio to brachial diastolic pressure in hypertensive patients. A reason for this changing ratio becomes evident from the observation that absolute differences (mm. Hg) between brachial and retinal arterial pressures are similar in both normotensive and hypertensive groups. Vascular resistance is proportional to a pressure gradient divided by blood flow. If one assumes a relative uniformity of blood flow to the eye in all patients, as well as relative uniformity of resistance between the aorta and the eye (composed largely of intraocular pressure), then there must be a relatively uniform pressure gradient from aorta to eye. This gradient is independent of the absolute level of the blood pressure. Therefore, the relationship between brachial and retinal arterial pressures can most accurately be expressed as a difference of approximately 20 mm. Hg. It is less meaningful to express retinal artery pressure as 78 per cent of brachial artery pressure.

The changes in retinal arterial pressures that occur in unilateral obstruction of the internal carotid artery have been described.\textsuperscript{18-22} In occlusion of this artery, the decrease of pressure in its various accessible distal branches is proportionate. A significant decrease of retinal artery pressure constitutes a reliable guide to occlusion of the ipsilateral internal carotid artery proximal to the ophthalmic artery.

Thomas and Petrohelos\textsuperscript{19} found a reported range of difference in bilateral retinal diastolic pressures of 0 to 14 per cent in approximately 250 subjects without evidence of carotid artery obstruction. Their own average difference between the 2 eyes in 50 normal subjects was 2.7 per cent. They found in the literature 8 cases of internal carotid artery thrombosis with bilateral pressures recorded. These authors added 5 patients and found significant ipsilateral pressure reductions of greater than 15 per cent in all cases. Subsequent authors have confirmed this.\textsuperscript{20-22} It is generally agreed that differences from 0 to 14 per cent may be normal, but differences greater than this almost always denote compromised flow through an internal carotid artery. However, the finding of retinal arterial pressure differences in the normal range does not exclude impairment of the internal
carotid blood flow. Borderline difference (10 to 14 per cent), if consistent, warrant an arteriogram when there are neurologic signs.

Differences greater than 15 per cent are said always to occur in the acute phase of obstruction, but patients have shown gradually increasing pressures in the ipsilateral eye as collateral flow develops. In these instances digital pressure over the normal carotid artery lowers the pressure in the opposite eye to its previous level.\textsuperscript{18, 19}

Several authors have suggested the clinical usefulness of this technic in selecting patients for carotid ligation and in evaluating the efficiency of the ligation.\textsuperscript{18–20}

**Summary**

The use of the ophthalmodynamometer as a measure of retinal arterial pressure has been evaluated in 75 subjects with or without systemic hypertension, and 37 subjects with neurologic vascular disease. Direct intraarterial pressure recordings showed no significant alteration of systemic arterial pressure during use of the ophthalmodynamometer.

Correction factors (for conversion to mm Hg) based on intraocular tension were found unnecessary in subjects with normal intraocular tension. The mean normal retinal diastolic arterial pressure was 53.1 mm Hg and the retinal diastolic to brachial diastolic pressure ratio was 73 per cent (S.D. \( \pm 10 \)). This ratio was increased in hypertensive patients (81 per cent \( \pm 9 \) in patients with brachial diastolic pressure exceeding 90 mm Hg).

For the whole range of brachial arterial pressures there was an average difference of 20.4 mm Hg between retinal and brachial diastolic pressures. There was no significant alteration in this figure when hypertensive patients were compared with normotensive subjects.

The normal range of difference between eyes was 0 to 14 per cent (mean 2.3 mm Hg). Differences greater than 15 per cent indicated compromised blood flow through the internal carotid artery on the side of the lower pressure. Seven patients with differences greater than 15 per cent were studied and 6 were found to have obstructing lesions of the internal carotid artery.

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**Summario in Interlingua**

Le utilitate del ophthalmodynamometro in le mesuration del pression retino-arterial esseva evaluate in 75 subjectos con o sin hypertension systemic e 37 subjectos con morbo vascular neurologic. Directe registrationes del pression intra-arterial monstrava nullo significative alteration del pression arterial systemic durante le uso del ophthalmodynamometro.

In subjectos con normal tensiones intraocular, le introduction de factores de correction super le base del tension intra-ocular (pro le conversion in mm de Hg) se revelava como superflue. Le normal valor medie del diastolic pression retino-arterial esseva 53, 1 mm de Hg, e le proportion inter le pression diastolic retinal e le pression diastolic brachial esseva 73 pro cento (con un deviation standard de \( \pm 10 \)). Iste proportion esseva augmentate in patientes hypertensive. Illo amontava a 81 pro cento (\( \pm 9 \)) in patientes in qui le pression diastolic brachial excedeva 90 mm de Hg. Pro le complete scala de presiones brachio-arterial, le differentia medie inter le diastolic pressiones retinal e brachial amontava a 20.4 mm de Hg. Nulle significative alteration de iste valor esseva constatate in comparar patientes hypertensive con subjectos normotensive.

Le scala del differentias normal inter le duo oculos esseva 0 a 14 pro cento (valor medie 2.3 mm de Hg). Differentias de plus que 15 cento indicava un compromiss del fluxo de sanguine via le interne arteria carotic al latere del pression inferior. Esseva studiate 7 patientes con differentias inter le oculos lesions obstructive del interne arteria carotic amontante a plus que 15 pro cento. In 6, lesions obstructive del interne arteria carotic esseva constatate,
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